Neotropical mangroves: conservation and sustainable use in a scenario of global climate changes

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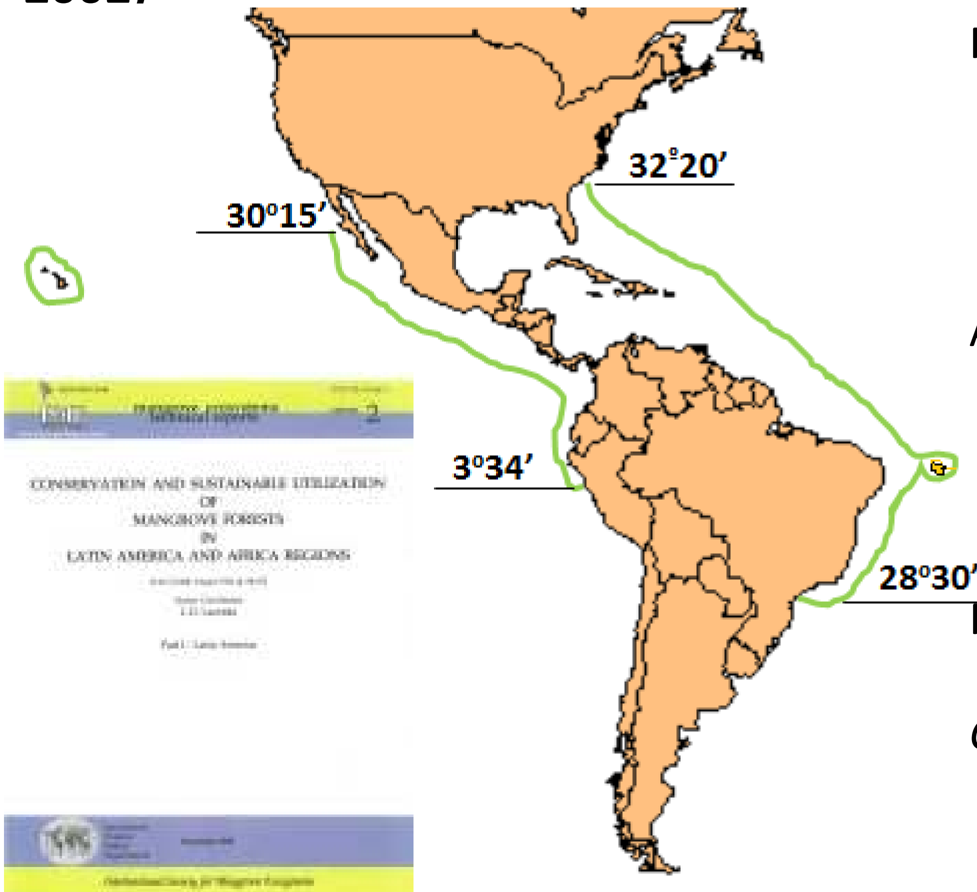
ISME

International Society for Mangrove Ecosystems

Latitudinal distribution and composition of Neotropical mangroves (Lacerda, 1993, 2002)



Rhizophoracea	1. *R. mangle*
	2. *R. harrisonii*
	3. *R. racemosa*
	4. *R. samoensis*
Avicenniaceae	5. *A. germinans*
	6. *A. schaueriana*
	7. *A. bicolor*
	8. *A. tonduzii*
Pelliciceriaceae	9. *P. rhizophorae*
Combretaceae	10. *Laguncularia racemosa*
	11. *Conocarpus erecta*

Mangrove area in Latin America and the Caribbean (~26% of the world's mangroves)

Atlantic Coast	2.14×10^6 ha
Pacific Coast	1.54×10^6 ha
Caribbean Islands	0.76×10^6 ha
Total	$4.06\ (3.58 – 4.54) \times 10^6$ ha

Summary of drivers, pressures and impacts on mangroves of Latin America and the Caribbean regions acting from the 1970's to the 1990's *

Drivers	Major Pressures	Major Impacts	Response	Observations
Urbanization	Solid waste disposal; area conversion; wastewaters disposal	Contamination of the biota; eutrophication; mangrove eradication	Coastal Zone Management Plans; improving wastes treatment Integrating green & grey architecture, reforestation	**Major** Widespread through the region
Industrialization	Effluents disposal Oil spills	Contamination of the biota; tree and fauna mortality	Stronger regulations; improving wastes treatment; changing technologies; banning tank washing; improving preparedness	**Major** Restricted to most industrialized nations, Brazil and Colombia, in particular.
Damming	Sediment and salt balance; nutrient fluxes	Erosion of coastal forests; burying basin forests; increasing soil and pore water salinity	Watershed committees including coastal communities' representatives.	**Major** Particularly important along semiarid regions.
Agriculture	Nutrient fluxes; chemical effluents, land reclamation	Eutrophication; contamination of the biota; deforestation	Watershed communities regulating land uses, restriction on agrochemicals use.	**Intermediate**
Forestry	Wood and wood products exploitation	Deforestation	Restraining mangrove wood use; Extractive reserves; reforestation community-based management.	**Intermediate** Particular in Central America and Venezuela
Tourism	Waste disposal; forest conversion	Localized eutrophication and deforestation.	Tourism environmental regulations; Eco-tourism.	**Intermediate** Particularly in Caribbean nations
Fisheries	Fisheries products	Overfishing and decreasing stocks	Community -based management; establishing fishing seasons (defesos)	**Minor** Particularly successful for mangrove crabs and species reproducing in mangroves.
Salt production	Conversion	Deforestation	Abandoning ponds	**Minor** In semiarid regions
Aquaculture	Conversion; Nutrient fluxes	Deforestation; eutrophication	Initial regulation laws, public awareness.	**Minor** Mostly restricted to Ecuador, the 2nd world shrimp producer in 1991; and to a lesser extent in Central America

* ITTO-ISME Project PD114/90 (F) Conservation and Sustainable Utilization of Mangrove Forests in Latin America and Africa Regions

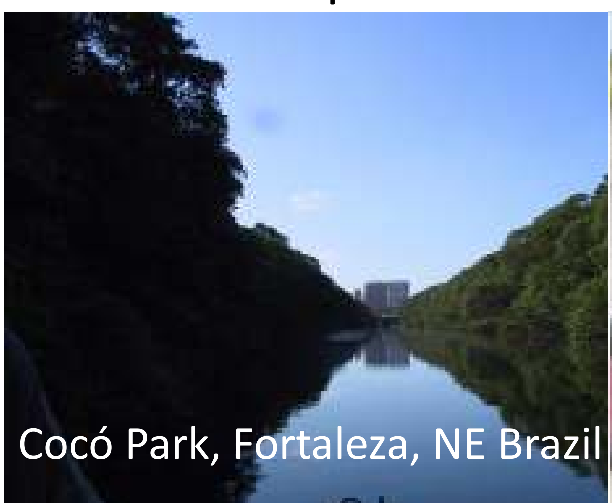
Impacts and response

Urbanization

Intensive and extensive destruction of mangrove areas, solid waste disposal, contamination of biological resources.

Incorporating mangrove in urban structure (green architecture); aesthetics and protection

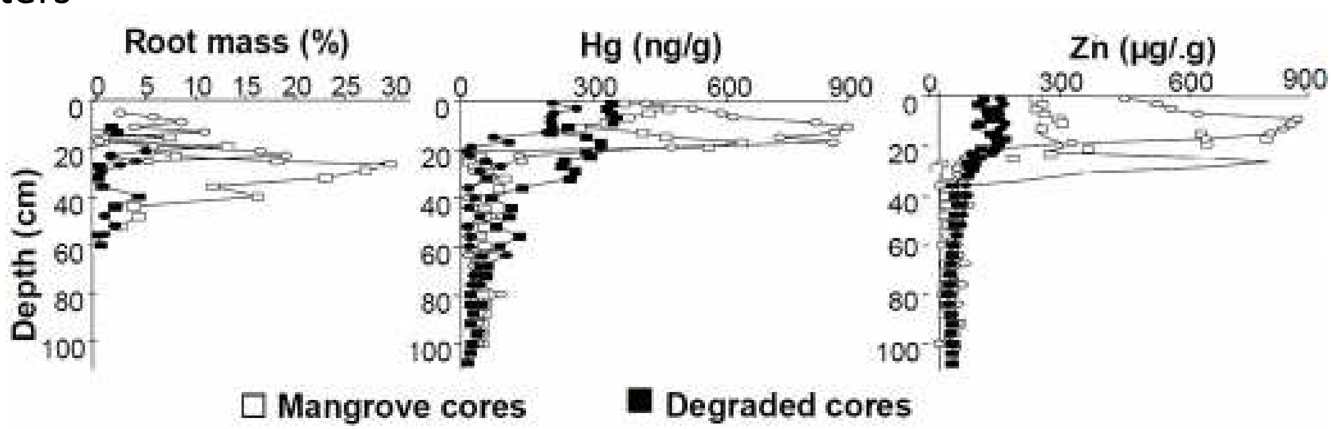
2015



Urbanization

The Jardim Gramacho Landfill in SE Brazil: about 14,000 t of solid wastes per day. The largest in South America.

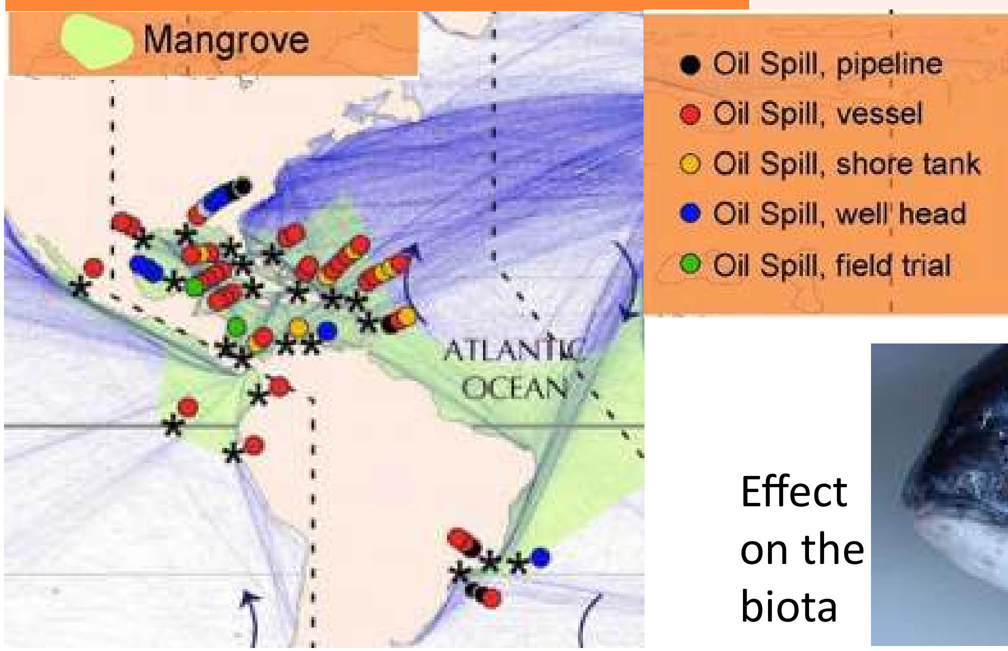
Rehabilitation and using mangrove as filters to protect adjacent coastal areas. Mangrove rhizosphere actually trap metals from ground water leaching, avoiding contamination of adjacent coastal waters



Reported oil spill incidents with actual impacts on mangrove habitats between 1970 and 1999 and between 2000 and 2016 in Latin America and the Caribbean; and global amount of oil involved, adapted from Duke (2016).

Industrialization

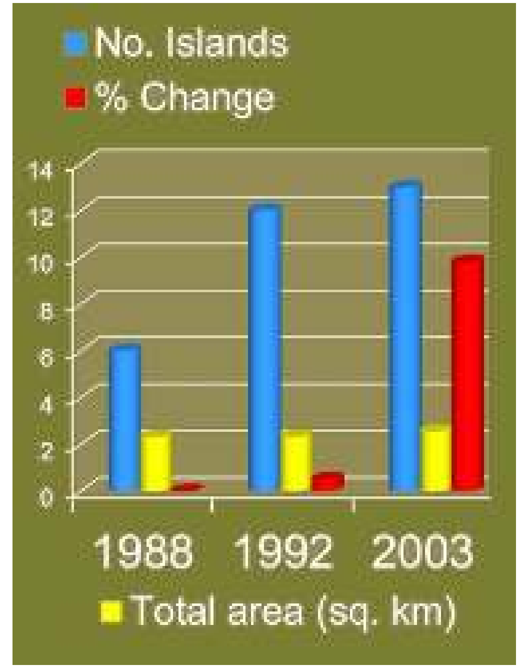
Category	1970-1999	2000-2016
Number of incidents	71 (2.4 yr^{-1})	69 (4.3 yr^{-1})
Total area of dead mangroves (ha)	100 (3.3 yr^{-1})	13 (0.8 yr^{-1})
Global amount spilled (t/spill)	30,990 – 60,187 (1,520 yr^{-1})	6,664 – 15,832 (703 yr^{-1})
Global area affected, oiled (ha)	24,419 (814 yr^{-1})	3,627 (227 yr^{-1})



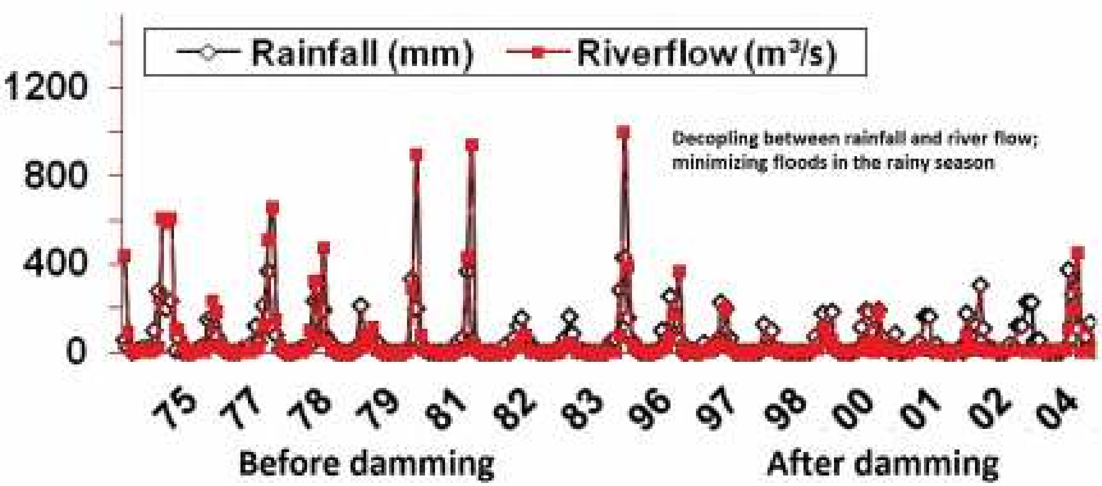
Oils spills in Latin American and Caribbean mangrove forests, showing hot spots in the Caribbean and SE Brazil. Modified from Duke (2016)

Effect on the biota

Damming

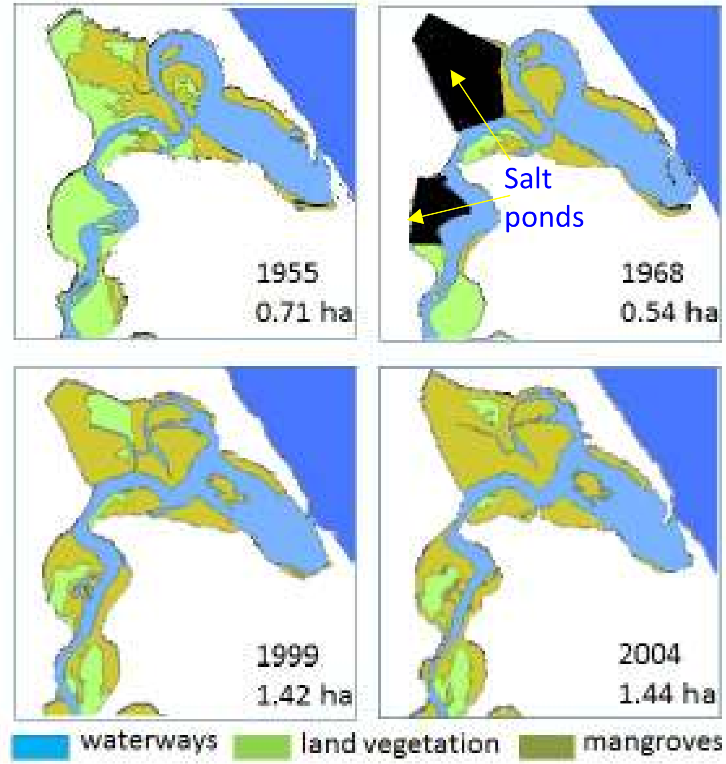


Siltation of estuaries and colonization by mangroves. Erosion of fringe mangroves due to reducing sediment supply to the coast and sea level rise in northeastern Brazil



Salt production

Salt production and mangroves. A significant area of natural mangrove rehabilitation derived from abandoned slat pods. An example is the Pacoti River Estuary, NE Brazil.



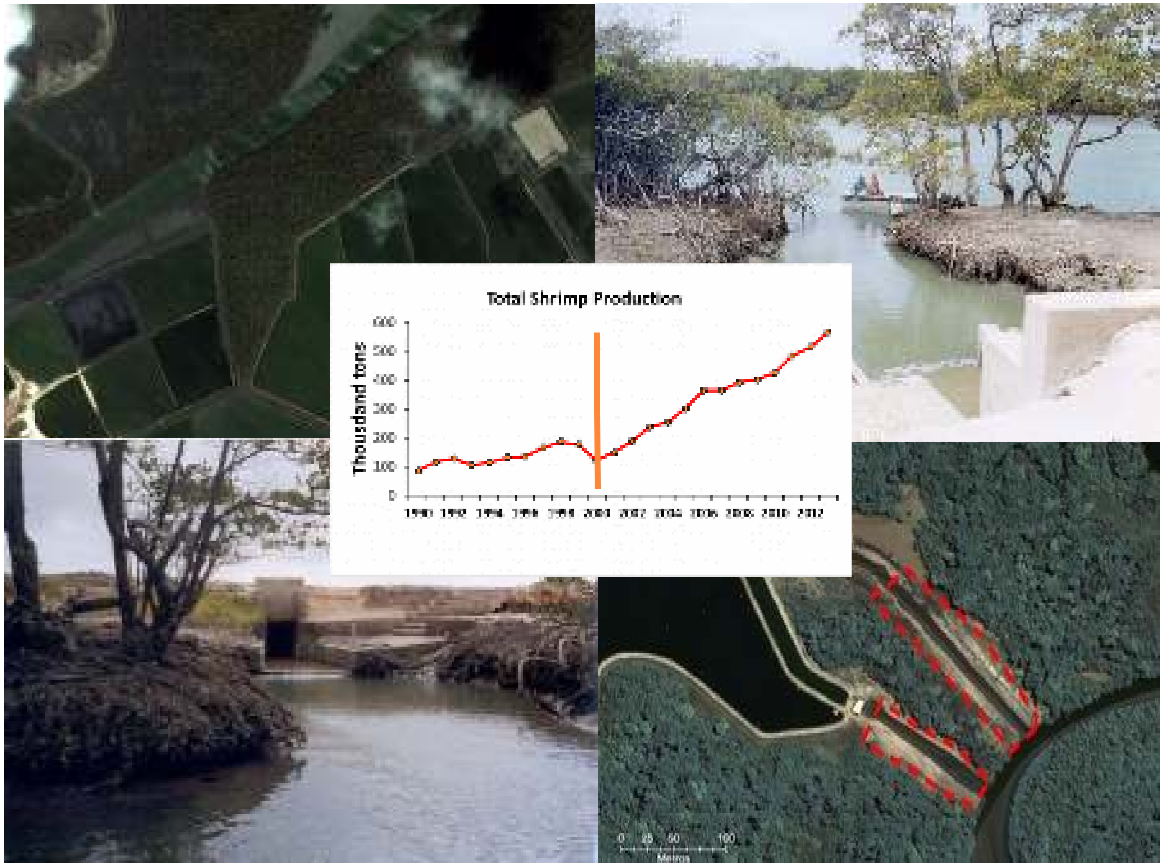
km^2

Year	1958	1968	1999	2004
Mangrove area	0.71	0.54	1.42	1.44
Salt ponds	0.00	0.69	0.00	0.00

Agriculture

Eutrophication and siltation of estuaries

Shrimp aquaculture

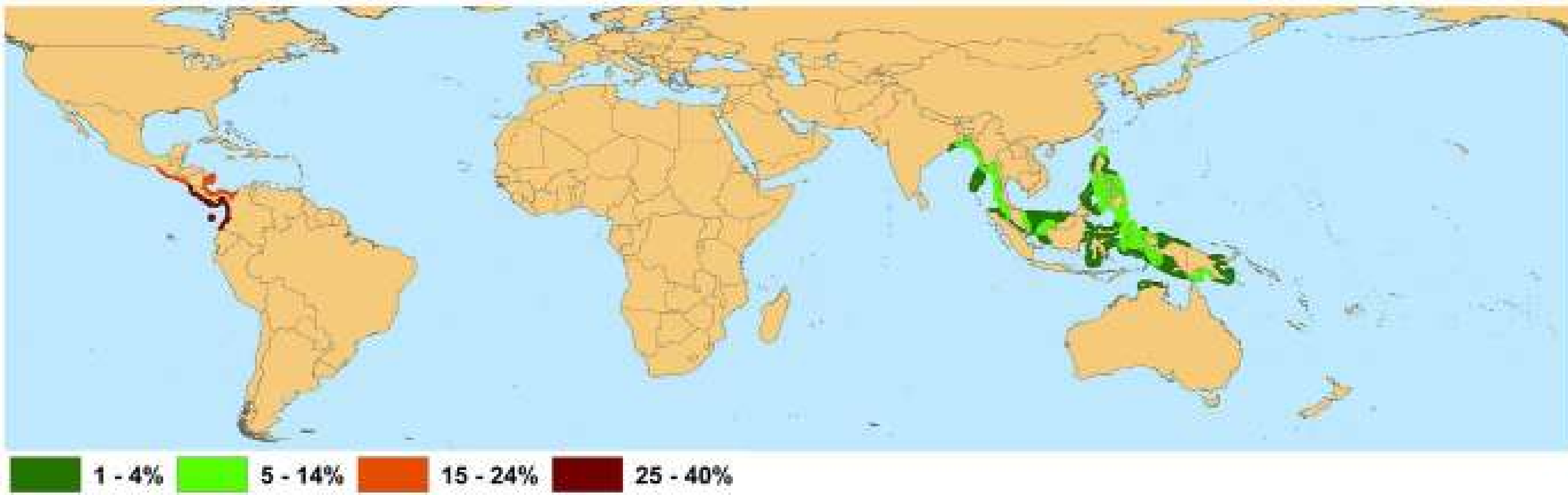


- Eutrophication due to excess nutrient release;
- Erosion at extrusion canals and siltation of estuaries due to large amount of suspended solids in effluents.
- Although limited in area in the 1980's and 1990's, emission factors from shrimp aquaculture are higher than from all other sources of nutrients and metals to LA & C estuaries. Also, effluents are released directly into the estuarine environment

Temporal trends of the 1970's-1990's drivers and impacts and response effectiveness on mangroves of Latin America and the Caribbean regions in the 21th century (Lacerda et al., 2002; Ferreira & Lacerda, 2012).

Drivers	Major Impacts	Temporal trend	Effectiveness of the response
Urbanization	Contamination of the biota	**Increasing**	Establishing Coastal Zone Management Plans (e.g. in Mexico and Brazil), but only partially able to control urban growth, in particular during economic crisis; Improving wastes treatment, but still restricted to a few metropolitan areas
	Eutrophication	**Increasing**	
	Deforestation	Stable	
Industrialization	Contamination of the biota	Decreasing	Stronger regulations applied through the region, in particular to oil and persistent pollutants; improving wastes treatment and changing technological procedures; reduced emissions from point sources. Contamination persist, but from diffuse sources.
	Tree and fauna mortality	Decreasing	
Damming	Erosion of coastal forests	**Increasing in semiarid coasts**; stable elsewhere	Coastal communities are still underrepresented in basin management committees, even when community based management is enforced, it has small impact on the decision making process.
	Burying basin forests		
	Saline intrusion		
Agriculture	Eutrophication	**Increasing**	A shift to intensive agriculture diminish the impact of responses, by increasing nutrient emissions. However, stronger legislation decreased land conversion, and agrochemicals' use.
	Contamination of the biota	Decreasing	
	Deforestation	Decreasing	
Forestry	Deforestation	Decreasing	Protection of forests and creation of extractive reserves and community - based management largely decreased deforestation
Tourism	Localized eutrophication	Decreasing	Reduction of impacts occurred throughout the region do to responses involving a better understanding of the role of preserved mangrove areas for the activity proper, such as ecotourism
	Deforestation		
Fisheries	Overfishing	Decreasing	Sustainable use of mangrove fisheries was achieved in most countries, including recovery of overexploited stocks
	Decreasing biodiversity		
Salt production	Deforestation	Decreasing	Market aspects largely reduced the activity in mangrove areas, abandoned ponds naturally regenerated
Aquaculture	Deforestation	**Increasing**	Existing regulation were not sufficiently enforced to hamper the impacts on mangroves. Recent finding on pollutants emissions from the activity increased its potential as a pollution source
	Eutrophication		
	Contamination of the biota		

Neotropical mangroves in the 21st Century



Globally, in 2010, the highest proportion of threatened mangrove species is found along the **Atlantic and Pacific coasts of Central America**. Four out of the 10 (40%) mangrove species present along the Pacific coasts of Costa Rica, Panama and Colombia are listed in one of the three threatened categories, and a fifth species *Rhizophora samoensis* is listed as **Near Threatened**. Three of these species, *Avicennia bicolor*, *Mora oleifera* and *Tabebuia palustris* all listed as **Vulnerable**, are rare or uncommon species only known from the Pacific coast of Central America (Polidoro et al., 2010).

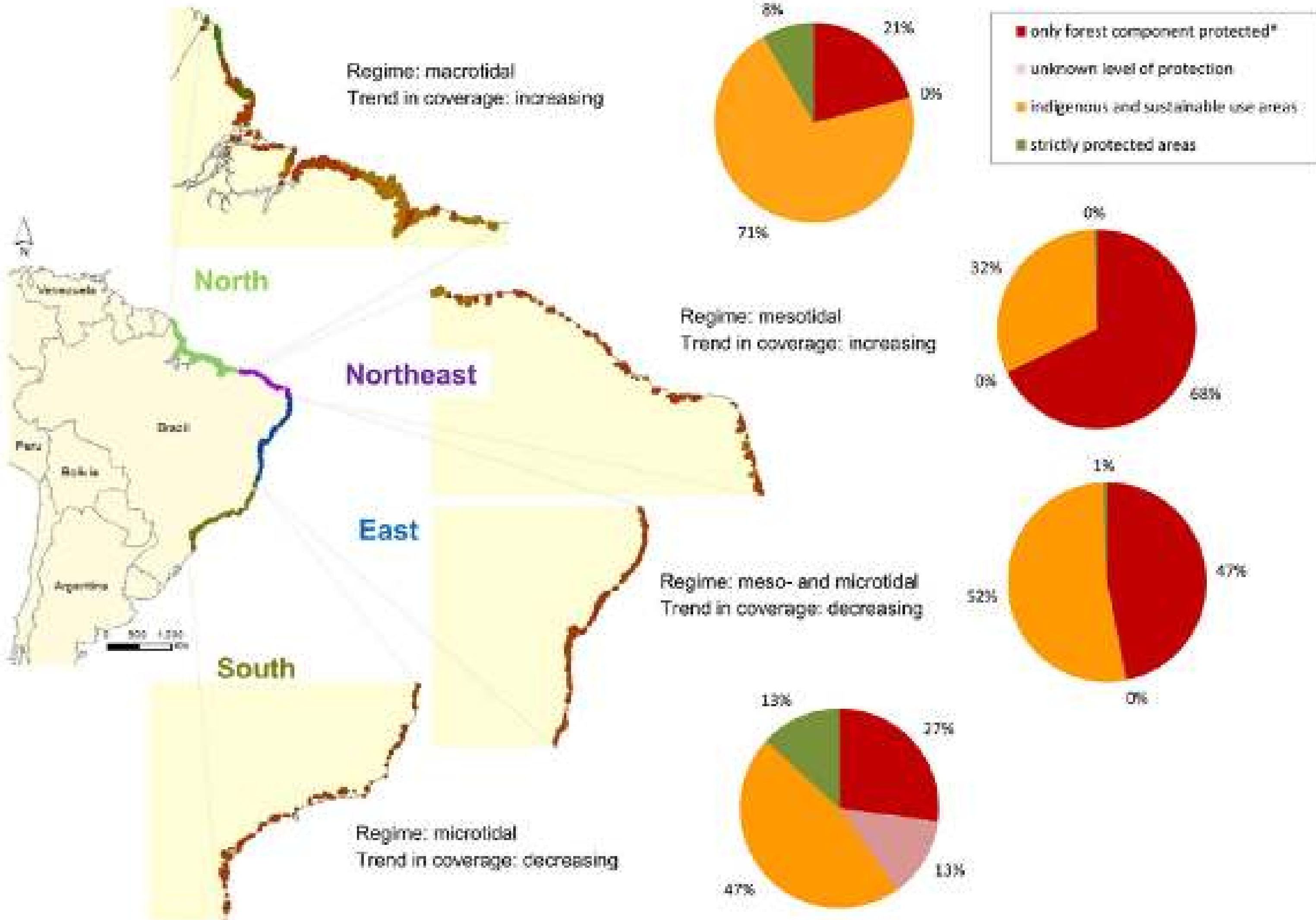


FIGURE 1 | Brazilian mangroves and formal protection level for each proposed macro-unit. Based on Kroppers et al. (1999), Godoy and Lacerda (2015). The mangrove distribution data derive from Giri et al. (2011), and the protected area data from (IUCN UNEP-WCMC., 2017). "Unknown protection" was assigned to categories whose level of protection was not declared in the UNEP-WCMC dataset. *"only forest component protected" refers to mangrove areas that are not inside a protected area or indigenous area, but are, like all forest components of mangroves in Brazil, protected under the Forest Code (BRASIL, 2012) as "permanent protection areas." Considering the states in Brazil, the division goes as follows: AP, PA, and MA (North); PI, CE, and RN (Northeast); PB, PE, AL, SE, and BA (East); ES, RJ, SP, PR, and SC (Southeast).

Major constrains to the societal responses: What bottlenecks?

- ✓ **Lacking the inclusion of a already real and present climate change scenario, making some legislation towards mangrove protection, weak.**

e.g. a new forest code in Brazil, protecting forests, but excluding salt flats, which decrease mangrove resilience to rising sea level.

- ✓ **Community-based management unable to cope with large capital investments.**

e.g. Harbor development and shrimp farming

- ✓ **Extractive reserves seldom with economic planning to augment product value or finding new markets.**

e.g. organic honey production, most traditional fisheries

- ✓ **Global climate change and increasing water demand along watersheds results in expanding river damming with environmental impact assessment derived for upstream systems and not including the coastal zones and their mangroves.**

e.g. Most LA&C coasts under semiarid climate

Preliminary* summary of drivers, pressures and impacts on mangroves of Latin America and the Caribbean regions acting in the 21th century*

Drivers	Major Pressures	Major Impacts	Response constrains	Observations/Trends
Aquaculture	Conversion; Nutrient emissions Sediment emissions Heavy metal emissions	Deforestation; eutrophication; Pollution siltation	Initial regulation laws did not take into consideration climate change. Public awareness insufficient or poorly distributed. Community-based management weak relative to capital pressures	**Major/Increasing** Widespread through LA&C continental margins; increasing up to 40% per year. Legally releasing new areas for pond construction; highest emission factors for nutrients and metals
Damming	Sediment and salt balance; nutrient fluxes	Erosion of coastal forests; burying basin forests; increasing soil and pore water salinity	Watershed committees including coastal communities' representatives fail to consider downstream, coastal impacts.	**Major/Increasing** Particularly important along semiarid regions.
Climate change	Sediment and salt balance; Remobilization of pollutants Frequency of extreme events	Erosion of coastal forests; burying basin forests; increasing soil and pore water salinity Contamination of biological resources Mangrove migration	No specific societal response so ever. Adaptation depends on local environmental setting and permitted adjacent human activities. Conservation laws do not include climate change as a variable.	**Major/Increasing** Atmospheric CO_2 increased from 390 ppm, in 1995, to 407 ppm in 2017. Notwithstanding the Kyoto protocol, emissions are on the rising. Unknown resistance / resilience threshold for mangroves
Replanting and Rehabilitation (+)	Augmenting mangrove area;	Augmenting carbon sequestrations, natural resources availability, natural protection reduces erosion	Community-based; small relevance to government; lack of monitoring; environmental conditions resulted from the past activity	**Major/Increasing** Rehabilitation policy not regulated at country level. Natural regeneration treated unattained. Planting on seagrass beds
Urbanization	Solid waste disposal; area conversion; wastewaters disposal	Contamination of the biota; eutrophication; mangrove eradication	Economic crisis and impoverishment of the population	**Intermediate/Stable** Widespread through the region, changing with economic growth and crisis
Agriculture	Nutrient fluxes; chemical effluents, land reclamation	Eutrophication; contamination of the biota; deforestation	Watershed committees failed to advance on the coastal zone., illegal commercialization of agrotoxics	**Intermediate/Stable** Major impacts are from intensive irrigated agriculture

** Fisheries, tourism, salt production and industrialization, are, today, considered of minor significance (??) and either decreasing or stable in importance (??), although, very site-specific. Urgent regional assessment needed, extension and gravity vary enormously locally.*

Notwithstanding the international media; official and scientifically mangroves from LA&C are quite forgotten!

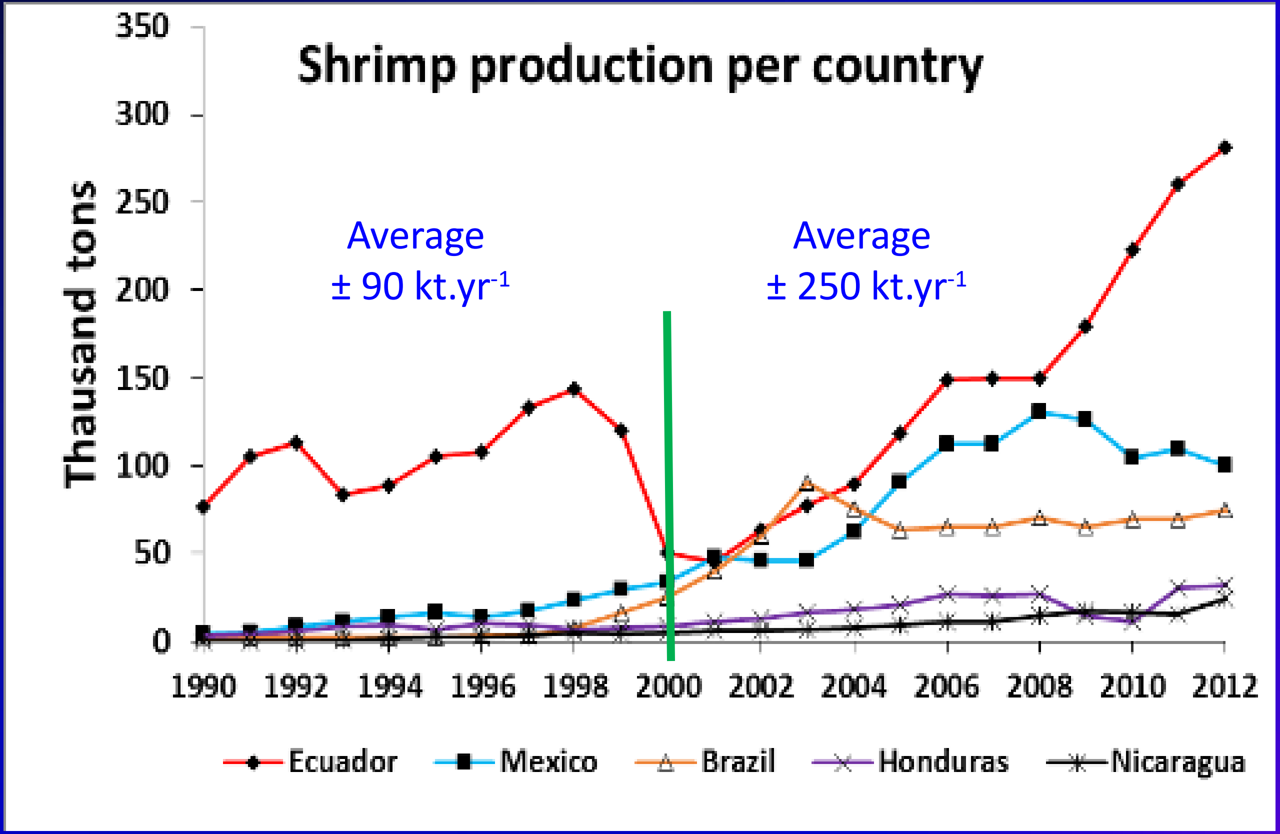
Table 7. Comparison of major drivers affecting Latin American and Caribbean mangroves between the end of last century, the beginning of this century and the most recent regional assessment by UNEP (2014).

			End of last century	Beginning of this century		UNEP (2104)
Drivers	Main pressures	Main impacts	Importance	Importance	Current trend	Importance and trend
Aquaculture, mostly shrimp farming	Conversion; nutrient emissions; sediment emissions; heavy metal emissions	Deforestation; eutrophication; pollution; siltation	Minor: Restricted to Ecuador and Central America	Major: Widespread through LA&C; increasing up to 40% per year; highest emission factors for N, P, Cu and Hg	Increasing	High / Increasing
Damming	Sediment and salt balance; nutrient fluxes	Erosion of fringe forests; burying basin forests; increasing soil and pore water salinity	Major: Particularly along semiarid regions	Major: Particularly along semiarid regions, but maximized by global warming	Increasing	Not mentioned
Climate change	Sediment and salt balance; remobilization of pollutants; frequency of extreme events	Erosion of fringe forests; burying basin forests; increasing soil and pore water salinity; contamination of biota; mangrove migration	Minor: Probably already affecting mangroves, but no actual data existed by then	Major: Despite international agreements, GHG emissions are rising. Unknown resistance / resilience threshold for mangroves	Increasing	No agreement / Increasing
Replanting and rehabilitation	Increasing mangrove area	Increasing carbon sequestration and natural resources availability and protection; reducing erosion	Minor: Small scale initiatives at the local level	Major: National scale programs, widespread initiatives at local levels, increasing public awareness, in need of long term assessments and monitoring	Increasing	Not mentioned

Urbanization	Solid waste and wastewater disposal; conversion	Contamination of the biota; eutrophication; mangrove eradication	Major: Widespread through the region	Intermediate: widespread through LA&C, changing with economic growth and/or crisis	Stable	Medium / increasing *Includes tourism and coastal engineering works
Agriculture	Nutrient fluxes; chemical effluents; land reclamation	Eutrophication; contamination of the biota; deforestation	Intermediate: Large scale mechanized agriculture far from the coast	Intermediate: Despite increasing intensive agriculture and thus nutrient and sediment emissions, stronger legislation decreased land conversion and pesticide use***	Stable	Not mentioned
Industrialization	Solid waste & wastewaters disposal; conversion.	Contamination; eutrophication; mangrove eradication	Major: Widespread through the region	Intermediate: Decreasing emissions from point sources, but small effect on diffuse sources.	Decreasing	Medium / Increasing *Concerns pollution
Salt production	Conversion	Deforestation	Minor: Mostly artisanal in a local scale	Minor: Economic constrain hamper the activity and abandoned ponds witness rehabilitation	Decreasing	Not mentioned
Fisheries	Fisheries products	Overfishing and decreasing stocks	Minor: Mostly affecting crabs and species reproducing in mangroves.	Minor: Very restricted to the local scale	Decreasing	Not mentioned
Forestry	Wood and wood products	Deforestation	Intermediate Mainly in Central America and Venezuela	Minor: Restricted to Central America	Decreasing	Medium / Stable
Tourism	Waste disposal; forest conversion	Localized eutrophication and deforestation.	Intermediate Particularly in Caribbean nations	Minor: Restricted to the local scale and under stronger regulation	Decreasing	Not mentioned

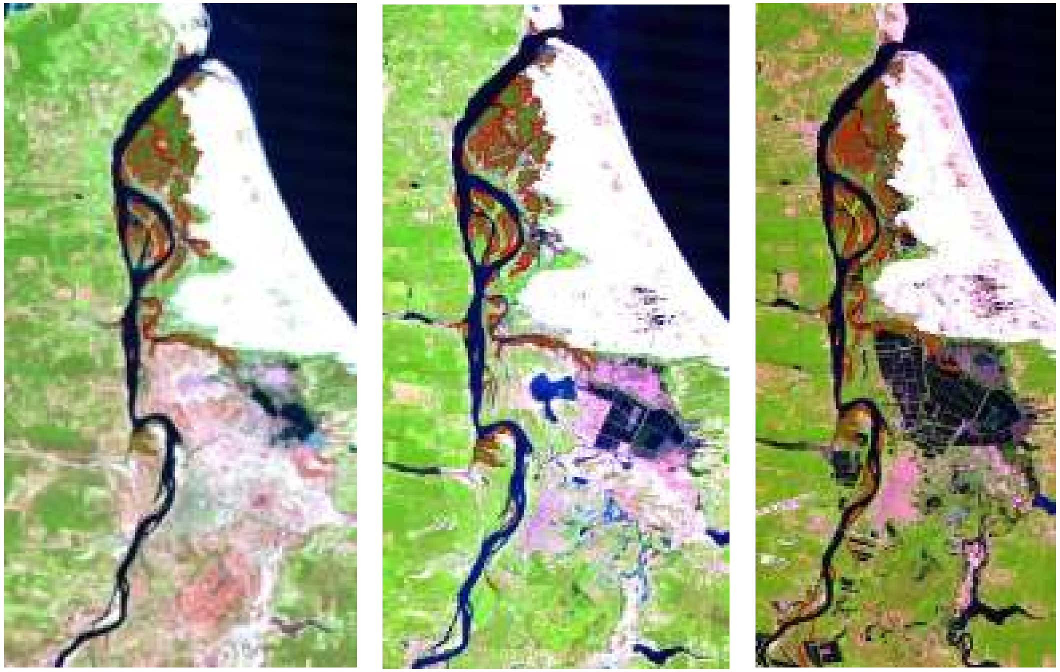
Aquaculture

Shrimp aquaculture in Latin America and the Caribbean (FAO, 2015)



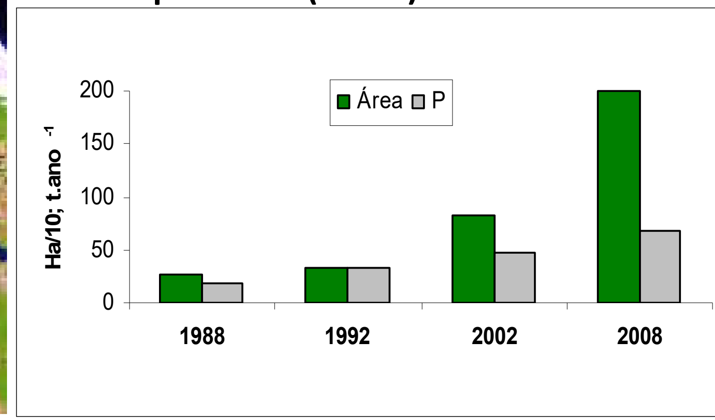
Expanding shrimp aquaculture in northeastern Brazil, the Jaguaribe Estuary.

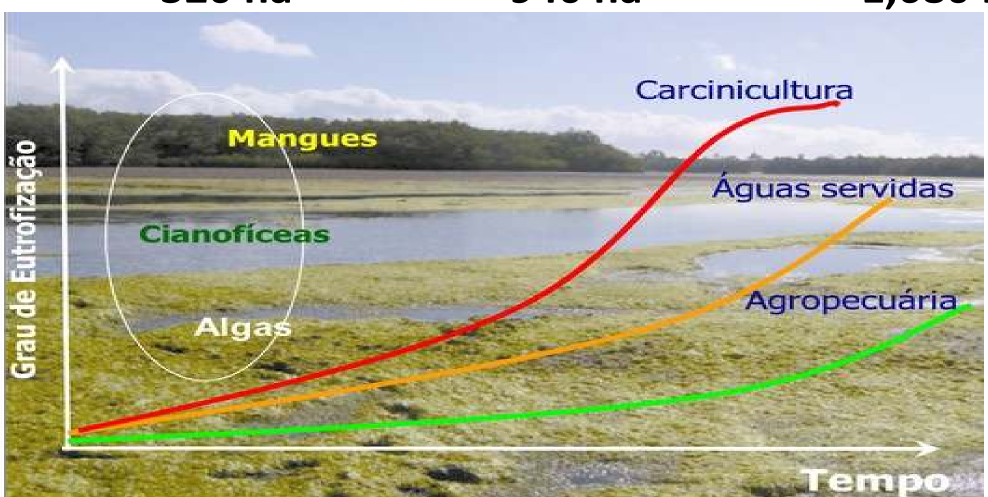
1993 1999 2010



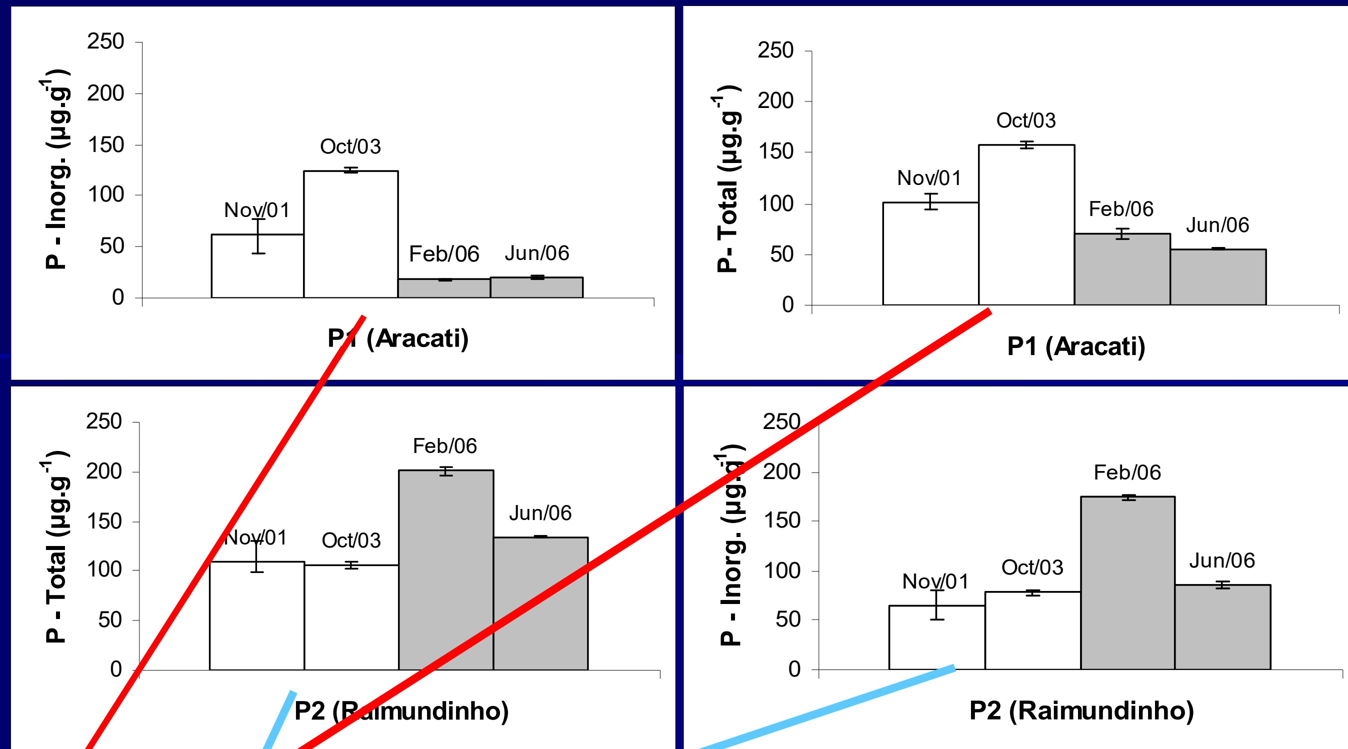
320 ha 940 ha 1,680 ha

Pond area and phosphorus emission to the Jaguaribe Estuary (upper) and fast eutrophication (lower)

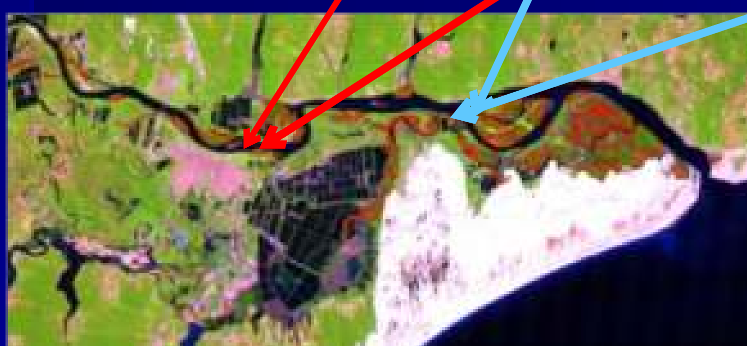




Shifting eutrophication sources



(c.f. Marins *et al*., 2008)



P1- downstream urban areas
P2- downstream shrimp farms

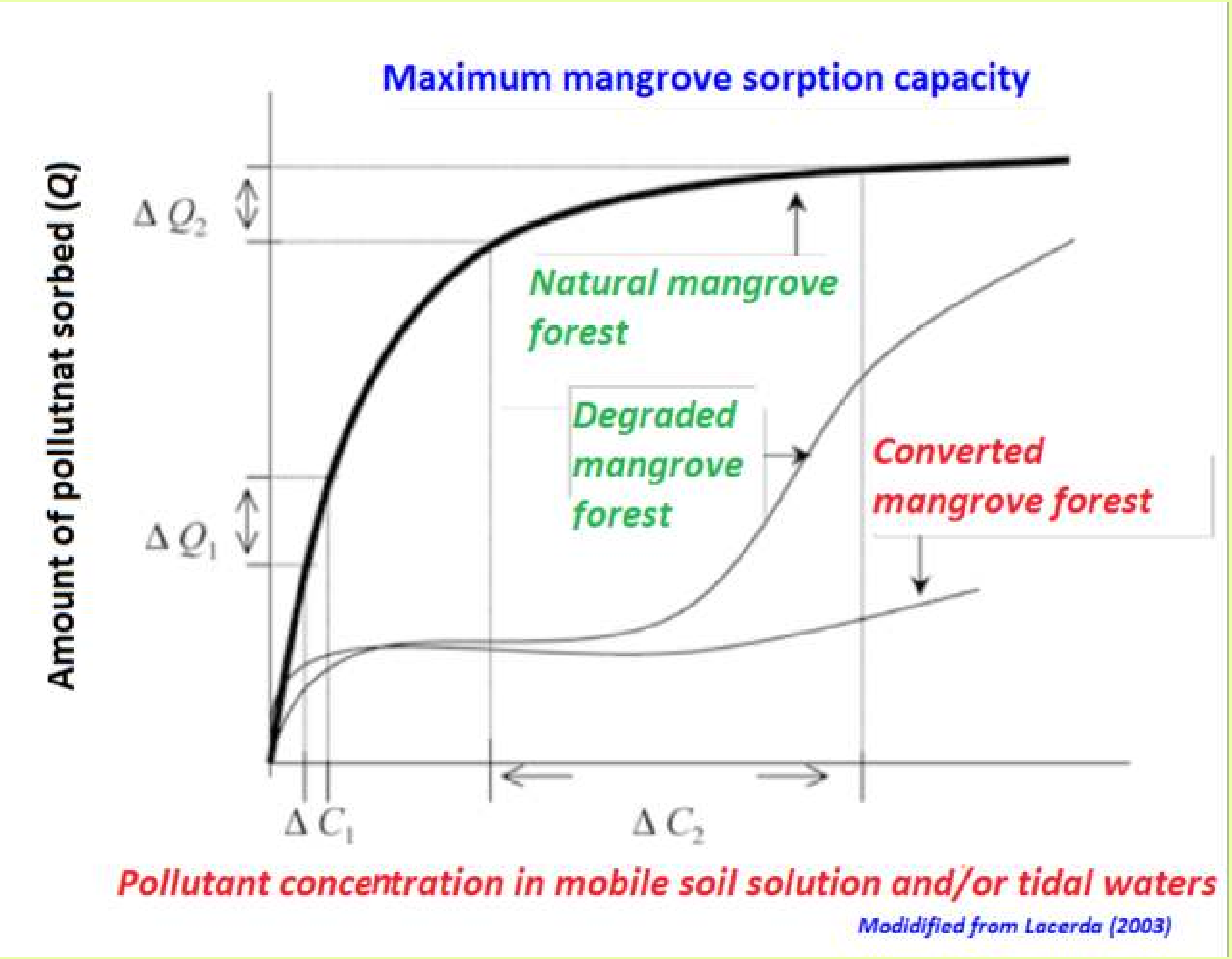
Year	Waste waters	Shrimp farming
2001	42.5	21.9
2008	45.6	60.9

Emission factors for Nitrogen, Phosphorus, Cooper, Zinc and Mercury from anthropogenic and natural sources, compared to shrimp farming.

Shrimp aquaculture

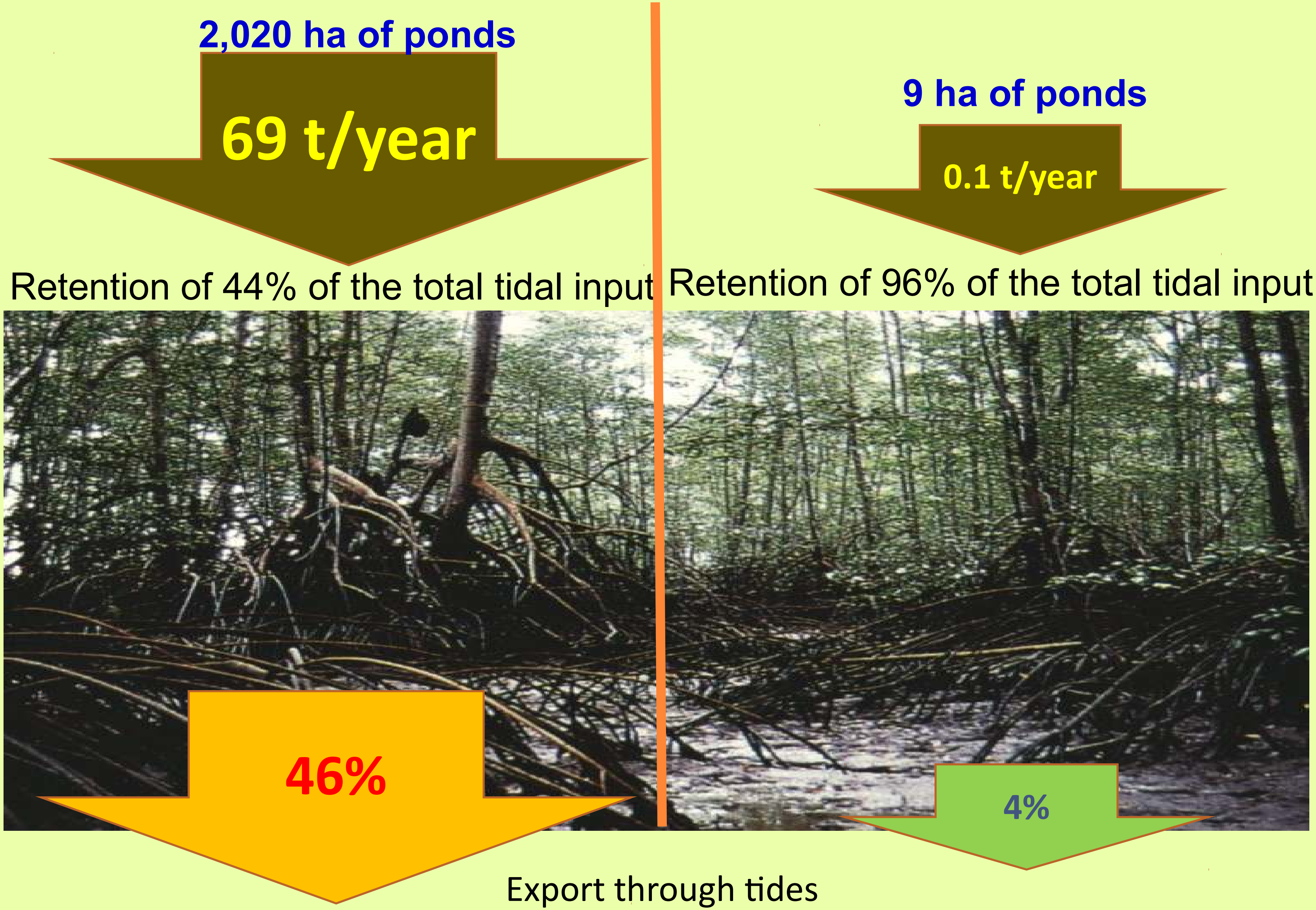
Sources	Emission factors N e P (t/km²/ano); Cu, Hg e Zn (kg/km²/ano)		Substances present in effluent		
Natural sources	N = 0.05 – 0.9 P = 0.01 – 0.06	Cu = 2.0 – 2.6 Zn = 5.0 – 6.5 Hg = <0.001	Mostly associated with particulate matter		Receiving body
Agriculture	N = 0.05 – 2,65 P = 0.12 – 0.56	Cu = 0.7 – 13.5 Zn = 0.04 – 0.13 Hg = 0.02	Nitrate, Ammonia Phosphate	Cu^{2+}, Zn^{2+}, Part. 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	Part. 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, P-particulate	Cu^{2+}, Zn^{2+}, Hg^{2+}, Part. Cu and Zn	Soil, water ways 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	Forms of N and P unknown	Cu^{2+}, Zn^{2+}, Hg^{2+}, Part. 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	Part. Cu, Zn and Hg	Water ways and estuaries

* (Lacerda et al., 2006; 2008; 2011; León-Canhedo et al., 2017)



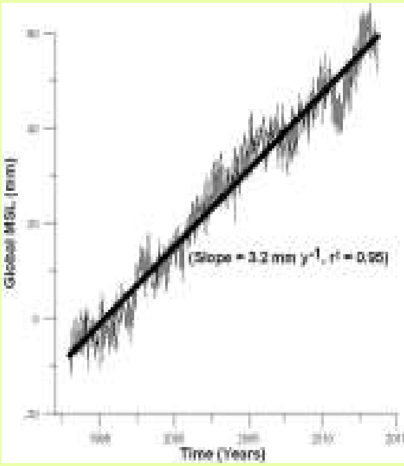
Maximum mangrove sorption capacity
Amount of pollutnat sorbed (Q)
Δ Q2
Δ Q1
Natural mangrove forest
Degraded mangrove forest
Converted mangrove forest
Δ C1
Δ C2
Pollutant concentration in mobile soil solution and/or tidal waters
Modidified from Lacerda (2003)

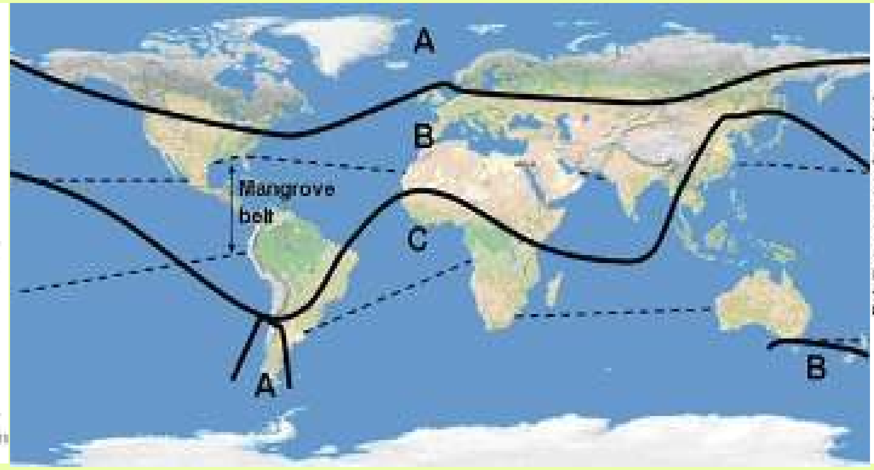
Some technical people suggest mangroves as filters for aquaculture effluents, however, most mangroves are far from pristine. e.g. Phosphorus balance in two mangrove forests in NE Brazil, receiving effluents from shrimp aquaculture

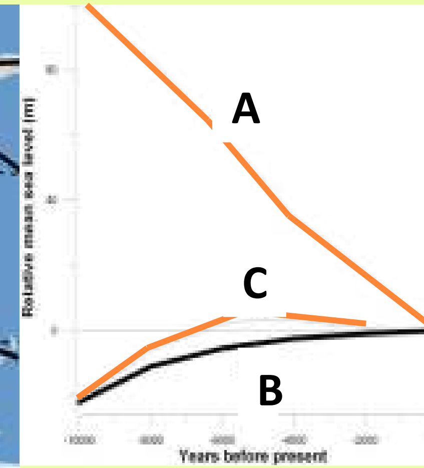


Mangrove and sea level rise (adapted from Jennerjahn (2017)

Climate change





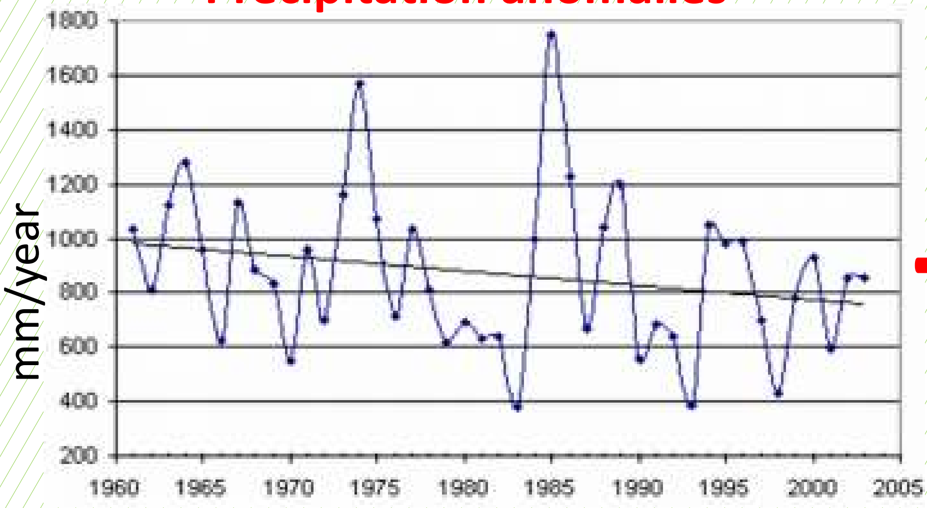


	RCP2.6 ΔT (°C)	RCP4.5 ΔT (°C)	RCP6.0 ΔT (°C)	RCP8.5 ΔT (°C)
Global	1.0±0.4	1.8±0.5	2.2±0.5	3.7±0.7
Land	1.2±0.6	2.4±0.6	3.0±0.7	4.8±0.9
Tropics	0.9±0.3	1.6±0.4	2.0±0.4	3.3±0.6
Ocean	0.8±0.4	1.5±0.4	1.9±0.4	3.1±0.6

Surface air temperature increase between the period 1986-2005 and the period 2081-2100 according to the four IPCC scenarios.

A positive feed back occurs between damming and climate change, particularly under dry climates.

Precipitation anomalies



Evolution Trend (1961 – 2008) in annual precipitation over Ceará. (5,3 mm.yr^{-1} reduction)

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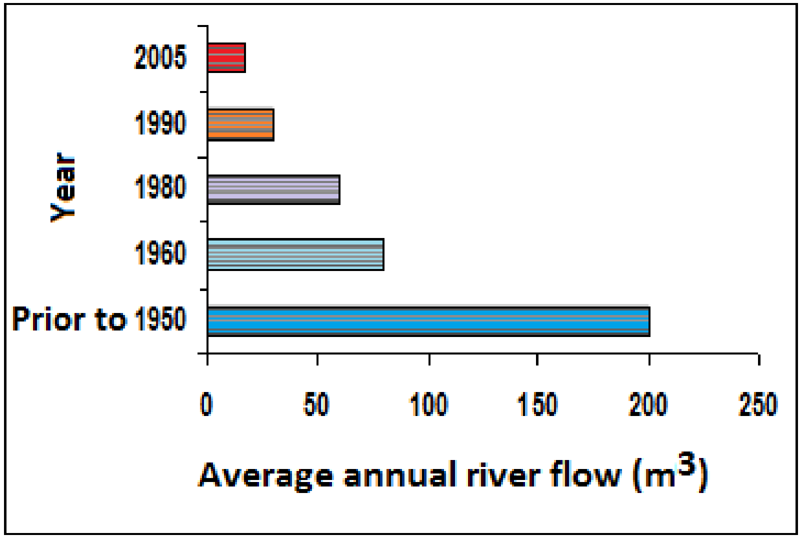
Fluvial flux decrease



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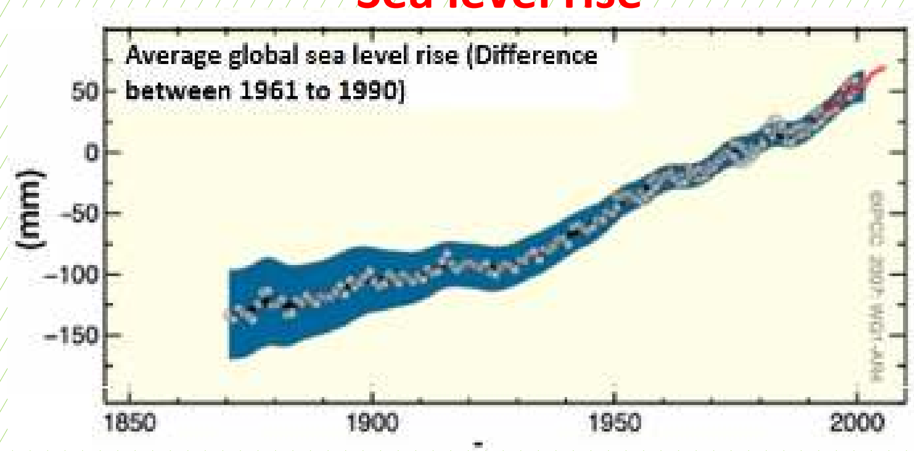
Sea level rise



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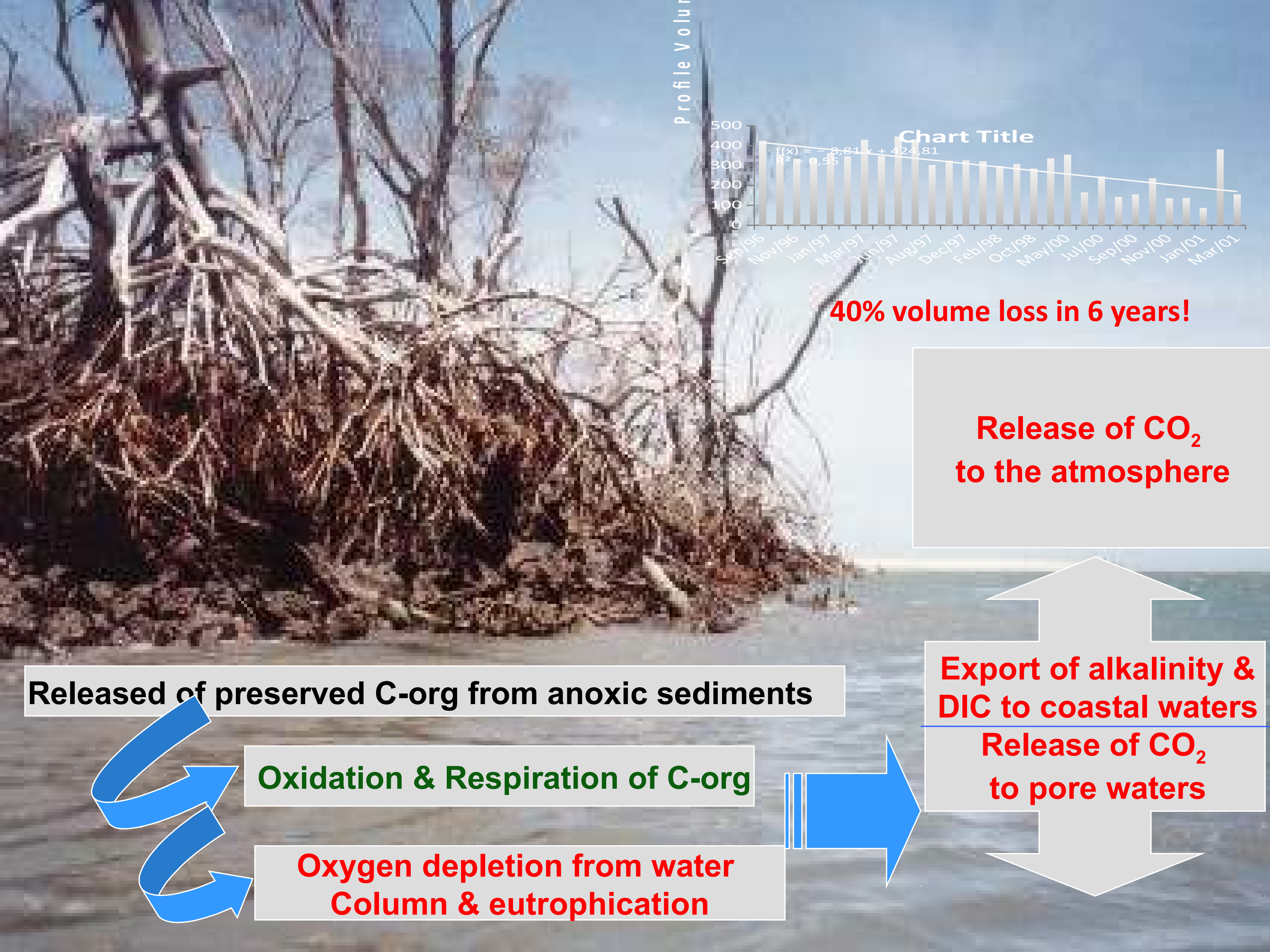


Chart Title
f(x) = − 8,81 x + 424,81
R² = 0,55
500
400
300
200
100
0
Sep/96
Nov/96
Jan/97
Mar/97
Jun/97
Aug/97
Dec/97
Feb/98
Oct/98
May/00
Jul/00
Sep/00
Nov/00
Jan/01
Mar/01
40% volume loss in 6 years!
Release of CO2 to the atmosphere
Released of preserved C-org from anoxic sediments
Oxidation & Respiration of C-org
Oxygen depletion from water Column & eutrophication
Export of alkalinity & DIC to coastal waters
Release of CO2 to pore waters

Carbon balance under diferent environmental scenarios

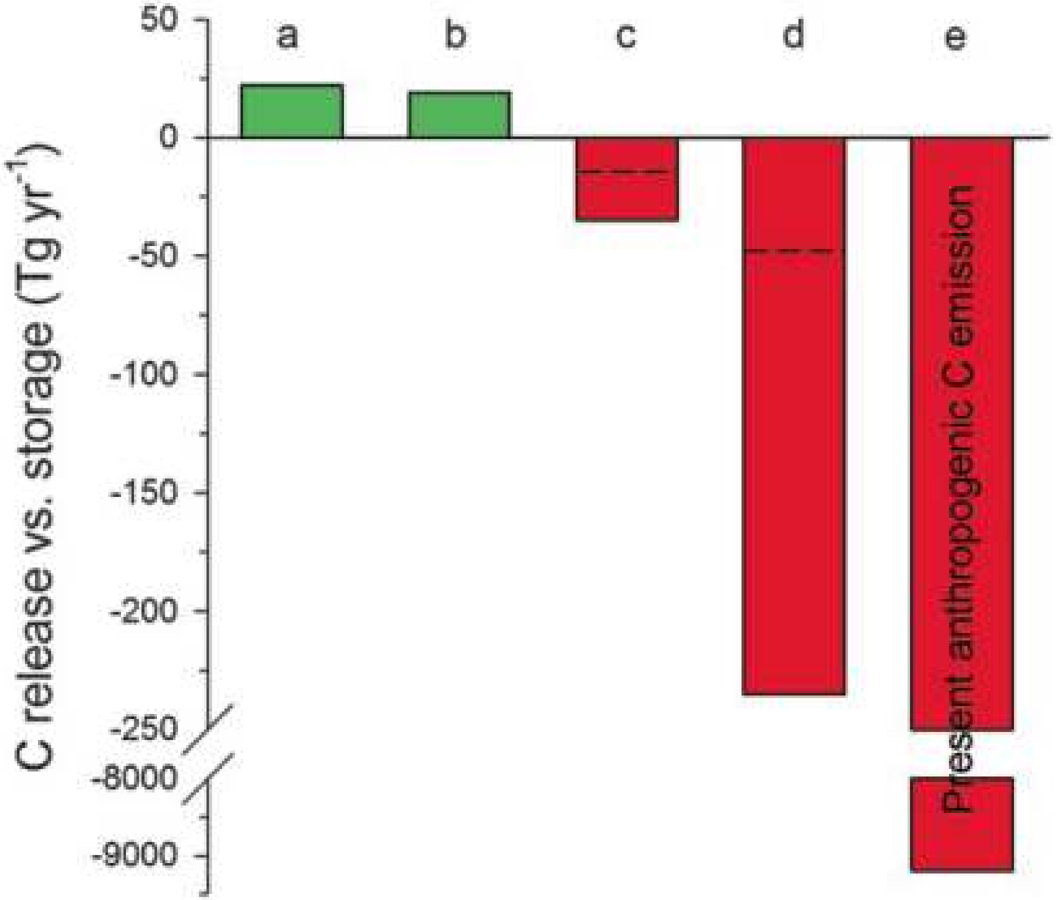
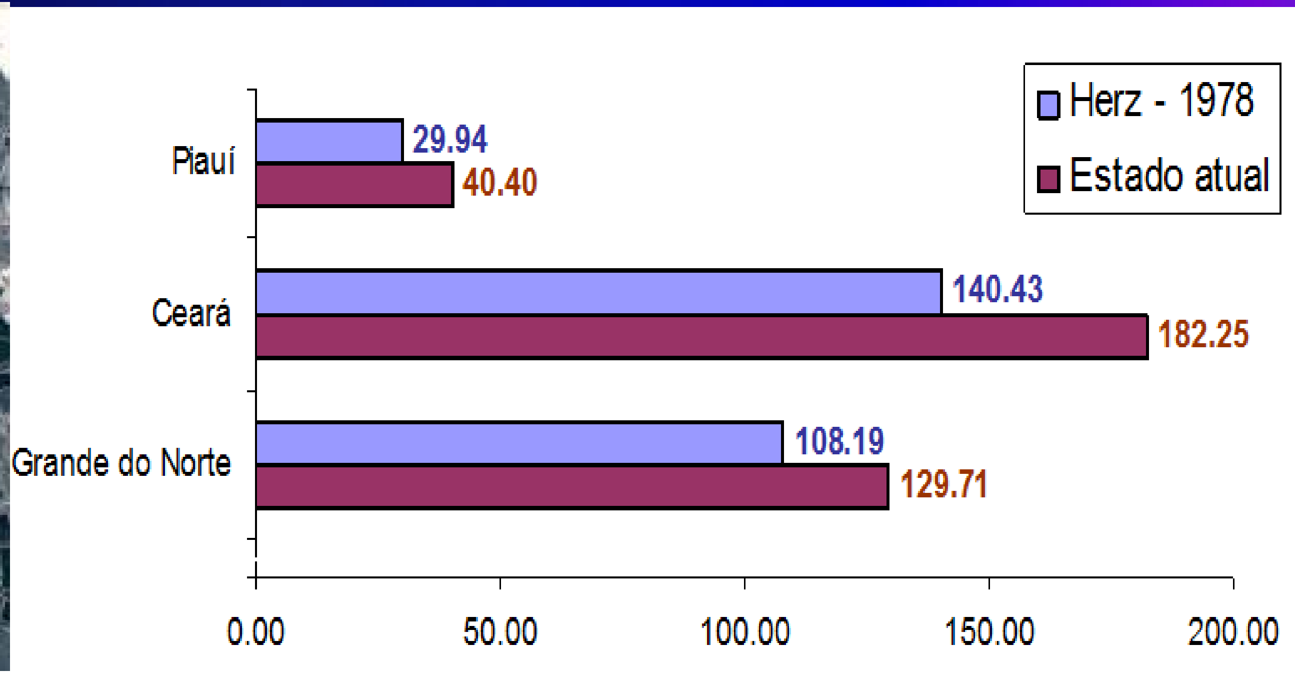


Fig. 7.4 Annual mangrove carbon storage (*green*) and release (*red*) today (*a*) and under 10–15% loss (*b* and *c*) and total loss scenarios (*d*) until the year 2100 compared to the present-day (i.e., 2012) anthropogenic carbon emissions (*e*). *Dashed lines* denote the lower limit of carbon release from mangroves as reported in the text (Data sources: Ciais et al. (2013), Donato et al. (2011) and data sources in the text. Note the break in the *Y*-axis)

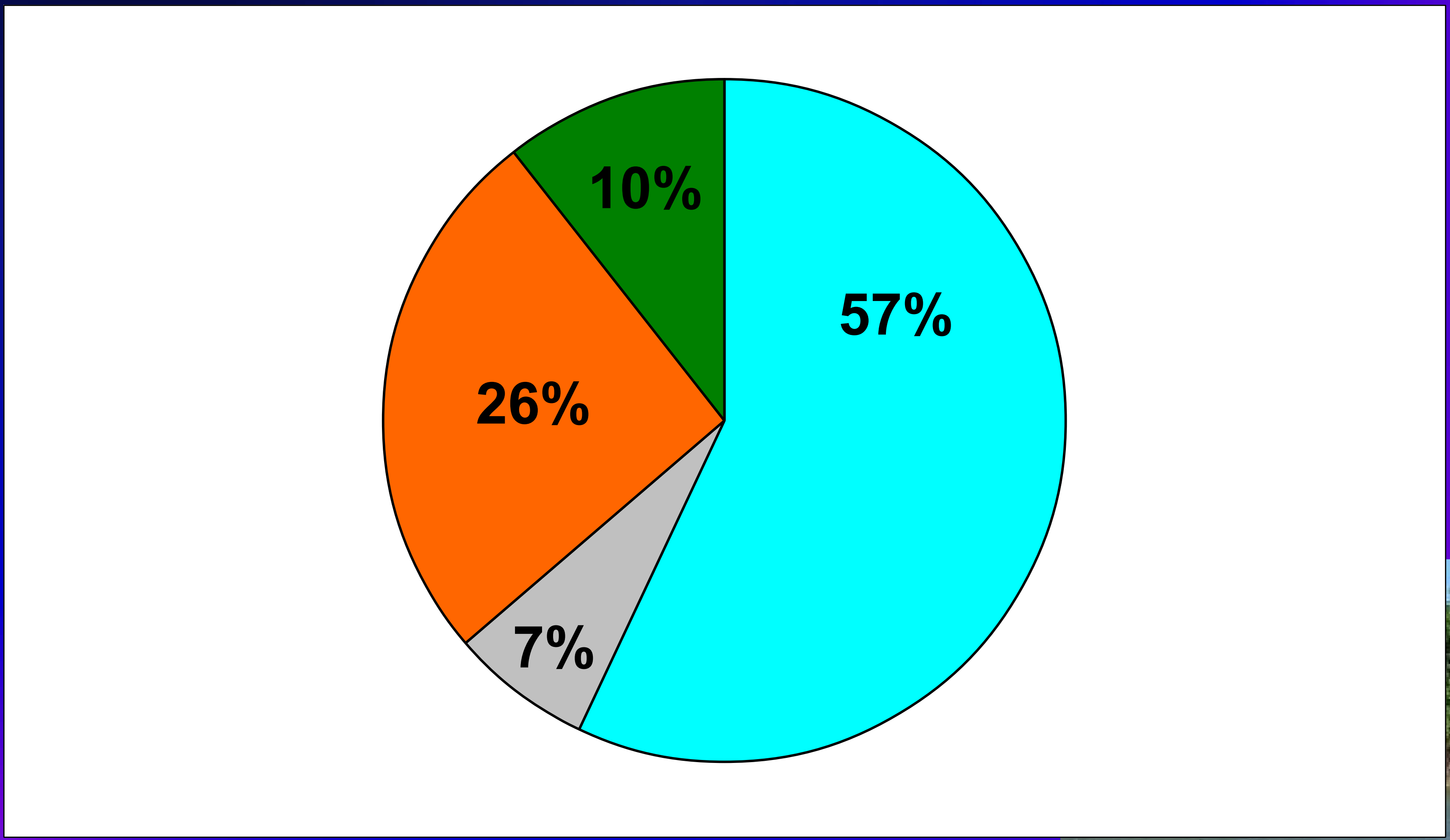
Changes in mangrove extension in 27 estuaries along the semiarid coast of Brazil (Maia et al., 2006), Mangrove Atlas of NE Brazil.

www.insitutomilenioestuarios.com.br



Parameter	km^2	%	
Total mangrove area in 1978	278		
Total mangrove area in 2004	352		
Increase (uncertainty)	74	21%	(± 8%)

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



Some conclusions and gaps

- Drivers of impacts on mangroves have changed drastically, this has reduced the effectiveness of some important societal responses towards conservation and sustainable management .

- It is clear that rehabilitation strategies and conservation and management legislation and practices of existing forests shall take into consideration not only local anthropogenic drivers but the climate change scenario. However…

- How global climate change interacts with local anthropogenic drivers?

- Does and how typology influences the impacts onto and the response of mangrove forests to climate change?

- How major anthropogenic drivers presently affecting mangroves may maximize or minimize impacts from climate change?

Acknowledgements

The International Tropical Timbre Organization provided full financial support for the author's participation. Special thanks are due to Dr. Hwan-ok Ma, for the help in organizing this presentation.

The International Society for Mangrove Ecosystems, and in particular, Prof. Shigeyuki Baba for supporting my application to participate in the meeting and support for the many projects coordinated together within ISME's framework.

Sincere thanks to the Ministry of Environment and Forestry of Indonesia for hosting the conference and kindly welcome me to your beautiful country.

Neotropical mangroves: conservation and sustainable use in a scenario of global climate changes

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International Society for Mangrove Ecosystems

Latitudinal distribution and composition of Neotropical mangroves (Lacerda, 1993, 2002)

Rhizophoracea	1. *R. mangle*
	2. *R. harrisonii*
	3. *R. racemosa*
	4. *R. samoensis*
Avicenniaceae	5. *A. germinans*
	6. *A. schaueriana*
	7. *A. bicolor*
	8. *A. tonduzii*
Pelliciceriaceae	9. *P. rhizophorae*
Combretaceae	10. *Laguncularia racemosa*
	11. *Conocarpus erecta*

Mangrove area in Latin America and the Caribbean (~26% of the world's mangroves)	
Atlantic Coast	2.14 x 10^6 ha
Pacific Coast	1.54 x 10^6 ha
Caribbean Islands	0.76 x 10^6 ha
Total	4.06 (3.58 – 4.54) x 10^6 ha

Summary of drivers, pressures and impacts on mangroves of Latin America and the Caribbean regions acting from the 1970's to the 1990's *

Drivers	Major Pressures	Major Impacts	Response	Observations
Urbanization	Solid waste disposal; area conversion; wastewaters disposal	Contamination of the biota; eutrophication; mangrove eradication	Coastal Zone Management Plans; improving wastes treatment Integrating green & grey architecture, reforestation	**Major** Widespread through the region
Industrialization	Effluents disposal Oil spills	Contamination of the biota; tree and fauna mortality	Stronger regulations; improving wastes treatment; changing technologies; banning tank washing; improving preparedness	**Major** Restricted to most industrialized nations, Brazil and Colombia, in particular.
Damming	Sediment and salt balance; nutrient fluxes	Erosion of coastal forests; burying basin forests; increasing soil and pore water salinity	Watershed committees including coastal communities' representatives.	**Major** Particularly important along semiarid regions.
Agriculture	Nutrient fluxes; chemical effluents, land reclamation	Eutrophication; contamination of the biota; deforestation	Watershed communities regulating land uses, restriction on agrochemicals use.	**Intermediate**
Forestry	Wood and wood products exploitation	Deforestation	Restraining mangrove wood use; Extractive reserves; reforestation community-based management.	**Intermediate** Particular in Central America and Venezuela
Tourism	Waste disposal; forest conversion	Localized eutrophication and deforestation.	Tourism environmental regulations; Eco-tourism.	**Intermediate** Particularly in Caribbean nations
Fisheries	Fisheries products	Overfishing and decreasing stocks	Community -based management; establishing fishing seasons (defesos)	**Minor** Particularly successful for mangrove crabs and species reproducing in mangroves.
Salt production	Conversion	Deforestation	Abandoning ponds	**Minor** In semiarid regions
Aquaculture	Conversion; Nutrient fluxes	Deforestation; eutrophication	Initial regulation laws, public awareness.	**Minor** Mostly restricted to Ecuador, the 2nd world shrimp producer in 1991; and to a lesser extent in Central America

* ITTO-ISME Project PD114/90 (F) Conservation and Sustainable Utilization of Mangrove Forests in Latin America and Africa Regions

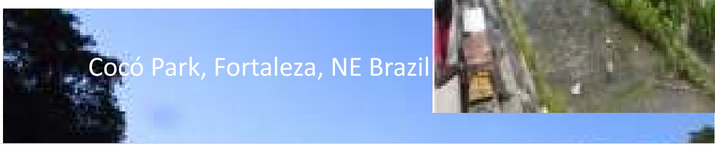
Impacts and response

Urbanization

Intensive and extensive destruction of mangrove areas, solid waste disposal, contamination of biological resources.

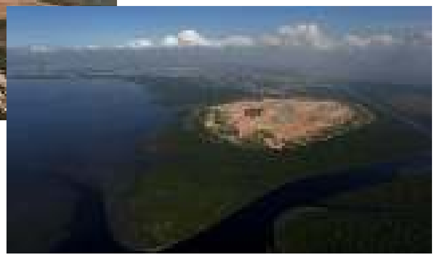
Incorporating mangrove in urban structure (green architecture); aesthetics and protection

2015

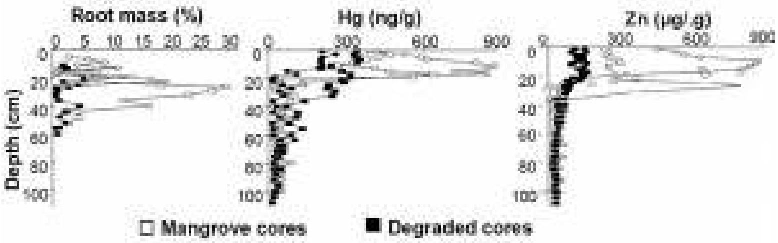


Urbanization

The Jardim Gramacho Landfill in SE Brazil: about 14,000 t of solid wastes per day. The largest in South America.



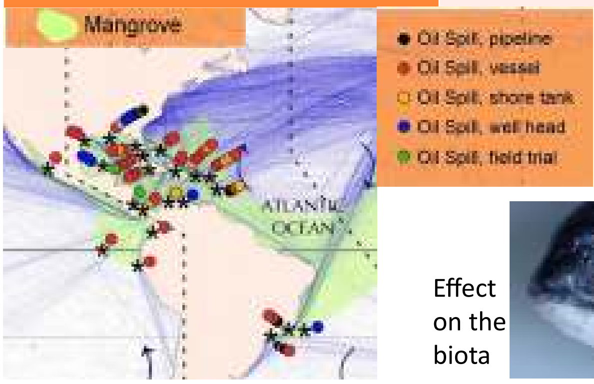
Rehabilitation and using mangrove as filters to protect adjacent coastal areas. Mangrove rhizosphere actually trap metals from ground water leaching, avoiding contamination of adjacent coastal waters



Industrialization

Reported oil spill incidents with actual impacts on mangrove habitats between 1970 and 1999 and between 2000 and 2016 in Latin America and the Caribbean; and global amount of oil involved, adapted from Duke (2016).

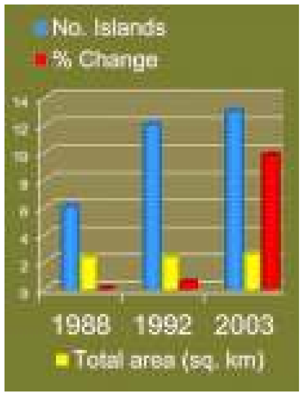
Category	1970-1999	2000-2016
Number of incidents	71 (2.4 yr^{-1})	69 (4.3 yr^{-1})
Total area of dead mangroves (ha)	100 (3.3 yr^{-1})	13 (0.8 yr^{-1})
Global amount spilled (t/spill)	30,990 – 60,187 (1,520 yr^{-1})	6,664 – 15,832 (703 yr^{-1})
Global area affected, oiled (ha)	24,419 (814 yr^{-1})	3,627 (227 yr^{-1})



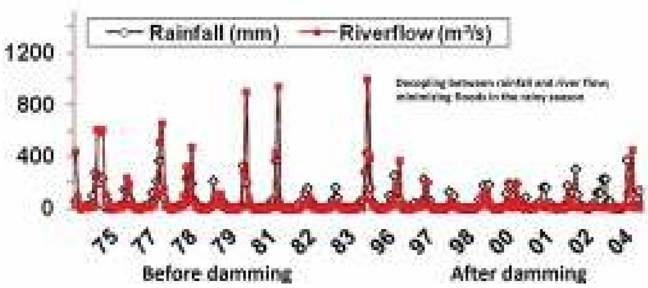
Oils spills in Latin American and Caribbean mangrove forests, showing hot spots in the Caribbean and SE Brazil. Modified from Duke (2016)

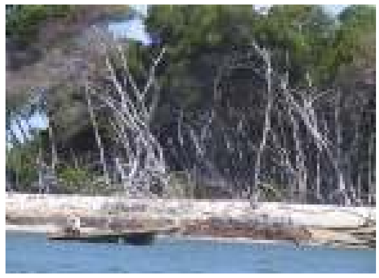
Effect on the biota

Damming



Siltation of estuaries and colonization by mangroves. Erosion of fringe mangroves due to reducing sediment supply to the coast and sea level rise in northeastern Brazil



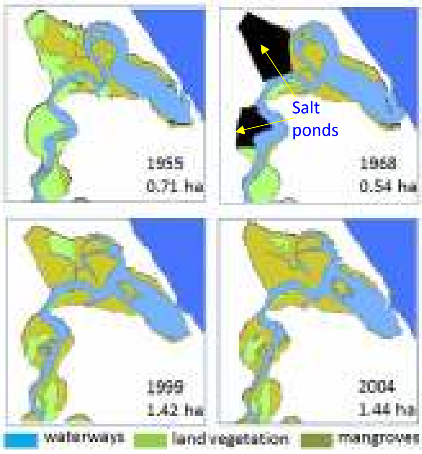


Salt production

Salt production and mangroves. A significant area of natural mangrove rehabilitation derived from abandoned slat pods. An example is the Pacoti River Estuary, NE Brazil.

km²

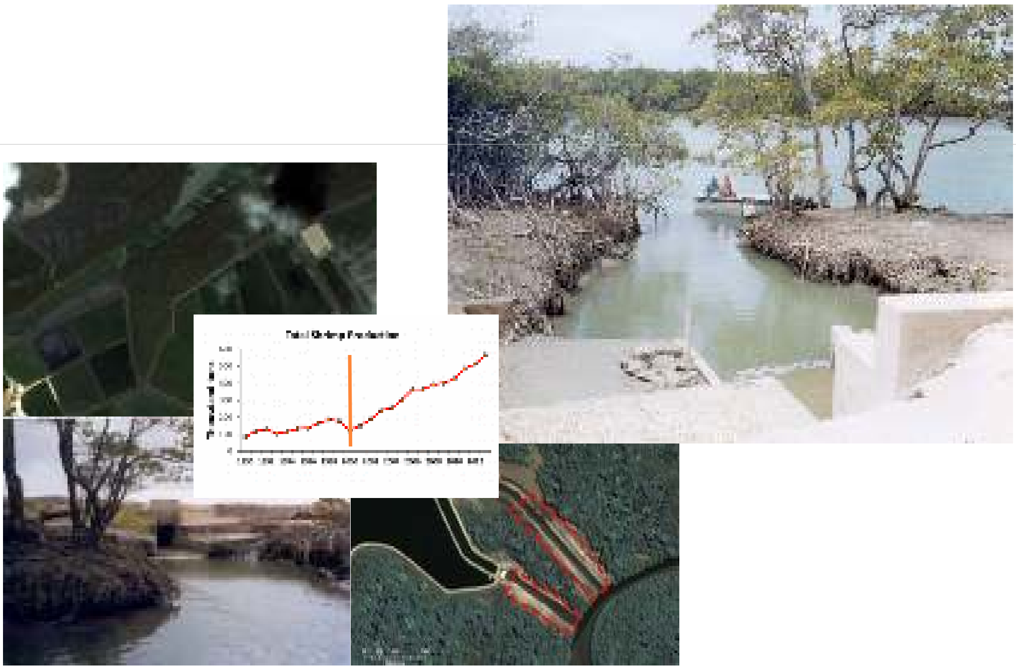
Year	1958	1968	1999	2004
Mangrove area	0.71	0.54	1.42	1.44
Salt ponds	0.00	0.69	0.00	0.00



Agriculture

Eutrophication and siltation of estuaries

Shrimp aquaculture

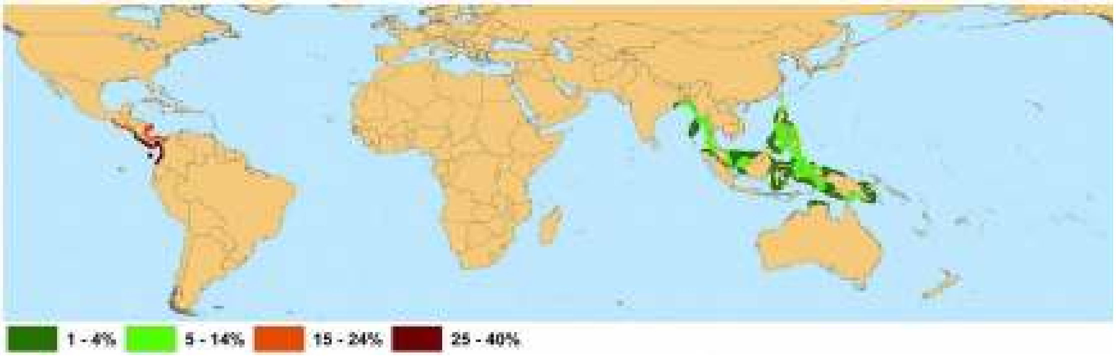


- Eutrophication due to excess nutrient release;
- Erosion at extrusion canals and siltation of estuaries due to large amount of suspended solids in effluents.
- Although limited in area in the 1980’s and 1990’s, emission factors from shrimp aquaculture are higher than from all other sources of nutrients and metals to LA & C estuaries. Also, effluents are released directly into the estuarine environment

Temporal trends of the 1970's-1990's drivers and impacts and response effectiveness on mangroves of Latin America and the Caribbean regions in the 21th century (Lacerda et al., 2002; Ferreira & Lacerda, 2012).

Drivers	Major Impacts	Temporal trend	Effectiveness of the response
Urbanization	Contamination of the biota	Increasing	Establishing Coastal Zone Management Plans (e.g. in Mexico and Brazil), but only partially able to control urban growth, in particular during economic crisis;
	Eutrophication	Increasing	
	Deforestation	Stable	Improving wastes treatment, but still restricted to a few metropolitan areas
Industrialization	Contamination of the biota	Decreasing	Stronger regulations applied through the region, in particular to oil and persistent pollutants; improving wastes treatment and changing technological procedures; reduced emissions from point sources. Contamination persist, but from diffuse sources.
	Tree and fauna mortality	Decreasing	
Damming	Erosion of coastal forests	Increasing in semiarid coasts; stable elsewhere	Coastal communities are still underrepresented in basin management committees, even when community based management is enforced, it has small impact on the decision making process.
	Burying basin forests		
	Saline intrusion		
Agriculture	Eutrophication	Increasing	A shift to intensive agriculture diminish the impact of responses, by increasing nutrient emissions. However, stronger legislation decreased land conversion, and agrochemicals' use.
	Contamination of the biota	Decreasing	
	Deforestation	Decreasing	
Forestry	Deforestation	Decreasing	Protection of forests and creation of extractive reserves and community -based management largely decreased deforestation
Tourism	Localized eutrophication	Decreasing	Reduction of impacts occurred throughout the region do to responses involving a better understanding of the role of preserved mangrove areas for the activity proper, such as ecotourism
	Deforestation		
Fisheries	Overfishing	Decreasing	Sustainable use of mangrove fisheries was achieved in most countries, including recovery of overexploited stocks
	Decreasing biodiversity		
Salt production	Deforestation	Decreasing	Market aspects largely reduced the activity in mangrove areas, abandoned ponds naturally regenerated
Aquaculture	Deforestation	Increasing	Existing regulation were not sufficiently enforced to hamper the impacts on mangroves. Recent finding on pollutants emissions from the activity increased its potential as a pollution source
	Eutrophication		
	Contamination of the biota		

Neotropical mangroves in the 21st Century



Globally, in 2010, the highest proportion of threatened mangrove species is found along the **Atlantic and Pacific coasts of Central America**. Four out of the 10 (40%) mangrove species present along the Pacific coasts of Costa Rica, Panama and Colombia are listed in one of the three threatened categories, and a fifth species *Rhizophora samoensis* is listed as **Near Threatened**. Three of these species, *Avicennia bicolor*, *Mora oleifera* and *Tabebuia palustris* all listed as **Vulnerable**, are rare or uncommon species only known from the Pacific coast of Central America (Polidoro et al., 2010).

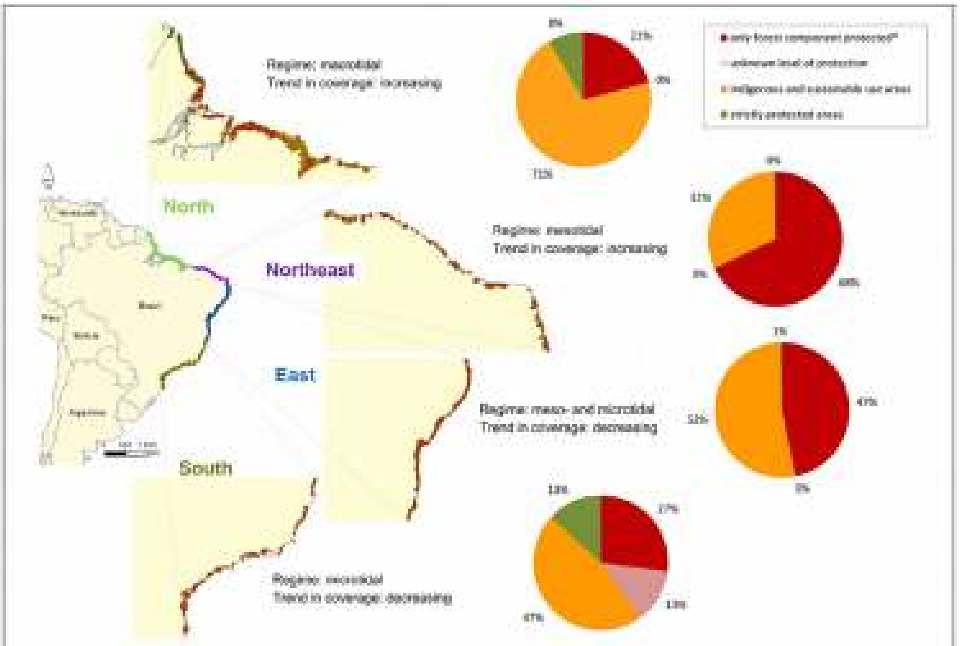


FIGURE 1 | Brazilian mangroves and formal protection level for each proposed macro-unit. Based on Knoppers et al. (1999), Godoy and Lacerda (2015). The mangrove distribution data derive from Giri et al. (2011), and the protected area data from (IUCN/UNEP-WCMC, 2017). "Unknown protection" was assigned to categories whose level of protection was not declared in the UNEP-WCMC dataset. *"only forest component protected" refers to mangrove areas that are not inside a protected area or indigenous area, but are, like all forest components of mangroves in Brazil, protected under the Forest Code (BRASIL, 2012) as "permanent protection areas." Considering the states in Brazil, the division goes as follows: AP, PA, and MA (North); PI, CE, and RN (Northeast); PB, PE, AL, SE, and BA (East); ES, RJ, SP, PR, and SC (Southeast).

Major constrains to the societal responses: What bottlenecks?

- ✓ **Lacking the inclusion of a already real and present climate change scenario, making some legislation towards mangrove protection, weak.**

e.g. a new forest code in Brazil, protecting forests, but excluding salt flats, which decrease mangrove resilience to rising sea level.

- ✓ **Community-based management unable to cope with large capital investments.**

e.g. Harbor development and shrimp farming

- ✓ **Extractive reserves seldom with economic planning to augment product value or finding new markets.**

e.g. organic honey production, most traditional fisheries

- ✓ **Global climate change and increasing water demand along watersheds results in expanding river damming with environmental impact assessment derived for upstream systems and not including the coastal zones and their mangroves.**

e.g. Most LA&C coasts under semiarid climate

Preliminary* summary of drivers, pressures and impacts on mangroves of Latin America and the Caribbean regions acting in the 21th century*

Drivers	Major Pressures	Major Impacts	Response constrains	Observations/Trends
Aquaculture	Conversion; Nutrient emissions Sediment emissions Heavy metal emissions	Deforestation; eutrophication; Pollution siltation	Initial regulation laws did not take into consideration climate change. Public awareness insufficient or poorly distributed. Community-based management weak relative to capital pressures	**Major/Increasing** Widespread through LA&C continental margins; increasing up to 40% per year. Legally releasing new areas for pond construction; highest emission factors for nutrients and metals
Damming	Sediment and salt balance; nutrient fluxes	Erosion of coastal forests; burying basin forests; increasing soil and pore water salinity	Watershed committees including coastal communities' representatives fail to consider downstream, coastal impacts.	**Major/Increasing** Particularly important along semiarid regions.
Climate change	Sediment and salt balance; Remobilization of pollutants Frequency of extreme events	Erosion of coastal forests; burying basin forests; increasing soil and pore water salinity Contamination of biological resources Mangrove migration	No specific societal response so ever. Adaptation depends on local environmental setting and permitted adjacent human activities. Conservation laws do not include climate change as a variable.	**Major/Increasing** Atmospheric CO_2 increased from 390 ppm, in 1995, to 407 ppm in 2017. Notwithstanding the Kyoto protocol, emissions are on the rising. Unknown resistance / resilience threshold for mangroves
Replanting and Rehabilitation (+)	Augmenting mangrove area;	Augmenting carbon sequestrations, natural resources availability, natural protection reduces erosion	Community-based; small relevance to government; lack of monitoring; environmental conditions resulted from the past activity	**Major/Increasing** Rehabilitation policy not regulated at country level. Natural regeneration treated unattained. Planting on seagrass beds
Urbanization	Solid waste disposal; area conversion; wastewaters disposal	Contamination of the biota; eutrophication; mangrove eradication	Economic crisis and impoverishment of the population	**Intermediate/Stable** Widespread through the region, changing with economic growth and crisis
Agriculture	Nutrient fluxes; chemical effluents, land reclamation	Eutrophication; contamination of the biota; deforestation	Watershed committees failed to advance on the coastal zone., illegal commercialization of agrotoxics	**Intermediate/Stable** Major impacts are from intensive irrigated agriculture

** Fisheries, tourism, salt production and industrialization, are, today, considered of minor significance (??) and either decreasing or stable in importance (??), although, very site-specific. Urgent regional assessment needed, extension and gravity vary enormously locally.*

Notwithstanding the international media; official and scientifically mangroves from LA&C are quite forgotten!

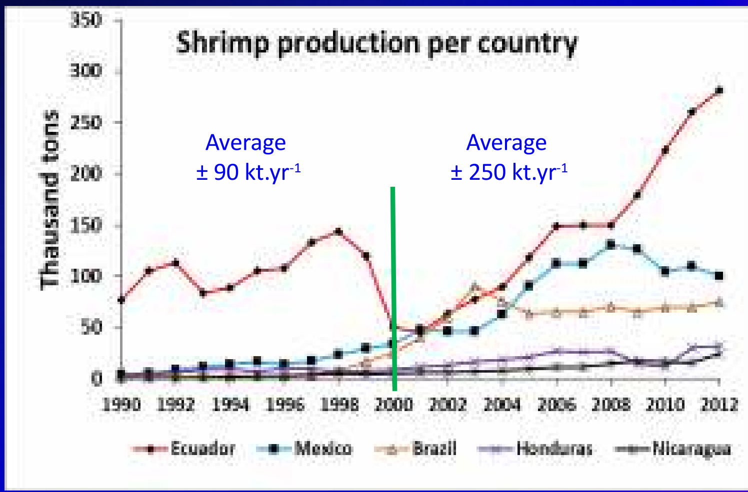
Table 7. Comparison of major drivers affecting Latin American and Caribbean mangroves between the end of last century, the beginning of this century and the most recent regional assessment by UNEP (2014).

			End of last century	Beginning of this century		UNEP (2104)
Drivers	Main pressures	Main impacts	Importance	Importance	Current trend	Importance and trend
Aquaculture, mostly shrimp farming	Conversion; nutrient emissions; sediment emissions; heavy metal emissions	Deforestation; eutrophication; pollution; siltation	Minor: Restricted to Ecuador and Central America	Major: Widespread through LA&C; increasing up to 40% per year; highest emission factors for N, P, Cu and Hg	Increasing	High / Increasing
Damming	Sediment and salt balance; nutrient fluxes	Erosion of fringe forests; burying basin forests; increasing soil and pore water salinity	Major: Particularly along semiarid regions	Major: Particularly along semiarid regions, but maximized by global warming	Increasing	Not mentioned
Climate change	Sediment and salt balance; remobilization of pollutants; frequency of extreme events	Erosion of fringe forests; burying basin forests; increasing soil and pore water salinity; contamination of biota; mangrove migration	Minor: Probably already affecting mangroves, but no actual data existed by then	Major: Despite international agreements, GHG emissions are rising. Unknown resistance / resilience threshold for mangroves	Increasing	No agreement / Increasing
Replanting and rehabilitation	Increasing mangrove area	Increasing carbon sequestration and natural resources availability and protection; reducing erosion	Minor: Small scale initiatives at the local level	Major: National scale programs, widespread initiatives at local levels, increasing public awareness, in need of long term assessments and monitoring	Increasing	Not mentioned

Urbanization	Solid waste and wastewater disposal; conversion	Contamination of the biota; eutrophication; mangrove eradication	Major: Widespread through the region	Intermediate: widespread through LA&C, changing with economic growth and/or crisis	Stable	Medium / increasing *Includes tourism and coastal engineering works
Agriculture	Nutrient fluxes; chemical effluents; land reclamation	Eutrophication; contamination of the biota; deforestation	Intermediate: Large scale mechanized agriculture far from the coast	Intermediate: Despite increasing intensive agriculture and thus nutrient and sediment emissions, stronger legislation decreased land conversion and pesticide use***	Stable	Not mentioned
Industrialization	Solid waste & wastewaters disposal; conversion.	Contamination; eutrophication; mangrove eradication	Major: Widespread through the region	Intermediate: Decreasing emissions from point sources, but small effect on diffuse sources.	Decreasing	Medium / Increasing *Concerns pollution
Salt production	Conversion	Deforestation	Minor: Mostly artisanal in a local scale	Minor: Economic constrain hamper the activity and abandoned ponds witness rehabilitation	Decreasing	Not mentioned
Fisheries	Fisheries products	Overfishing and decreasing stocks	Minor: Mostly affecting crabs and species reproducing in mangroves.	Minor: Very restricted to the local scale	Decreasing	Not mentioned
Forestry	Wood and wood products	Deforestation	Intermediate Mainly in Central America and Venezuela	Minor: Restricted to Central America	Decreasing	Medium / Stable
Tourism	Waste disposal; forest conversion	Localized eutrophication and deforestation.	Intermediate Particularly in Caribbean nations	Minor: Restricted to the local scale and under stronger regulation	Decreasing	Not mentioned

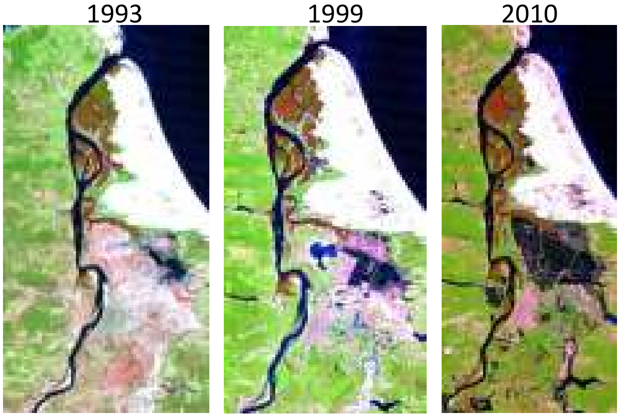
Aquaculture

Shrimp aquaculture in Latin America and the Caribbean (FAO, 2015)



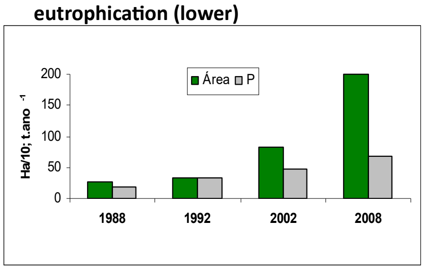
Expanding shrimp aquaculture in northeastern Brazil, the Jaguaribe Estuary.

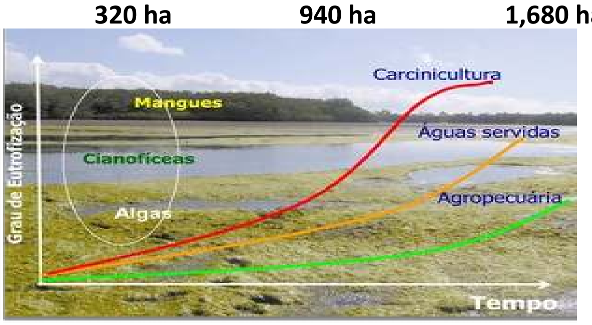
1993 1999 2010



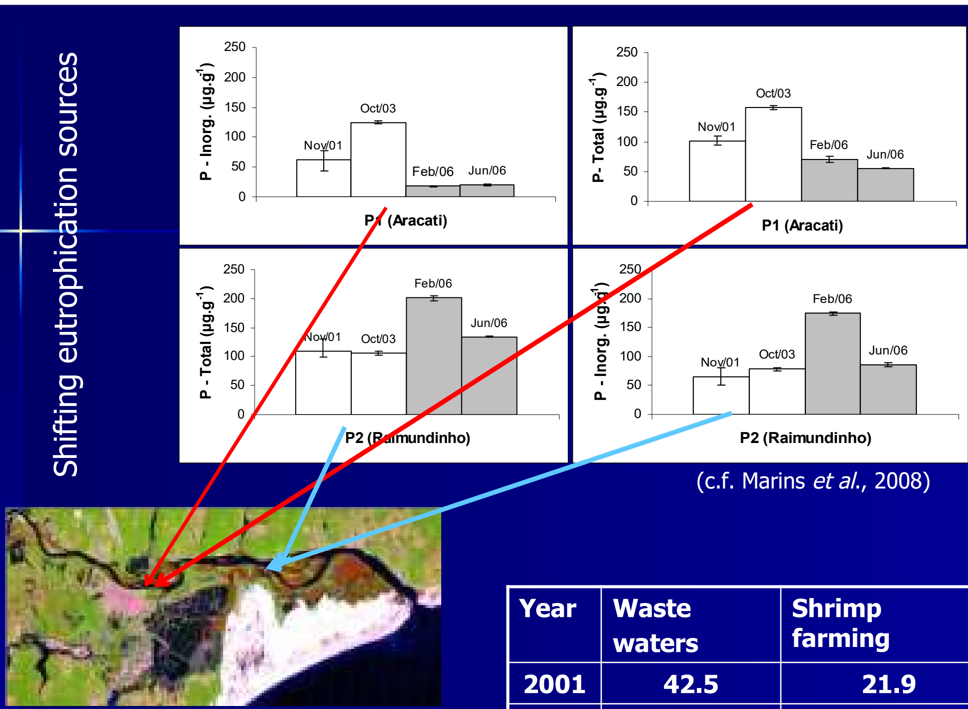
320 ha 940 ha 1,680 ha

Pond area and phosphorus emission to the Jaguaribe Estuary (upper) and fast eutrophication (lower)





Shifting eutrophication sources



(c.f. Marins *et al.*, 2008)

Year	Waste waters	Shrimp farming
2001	42.5	21.9
2008	45.6	60.9

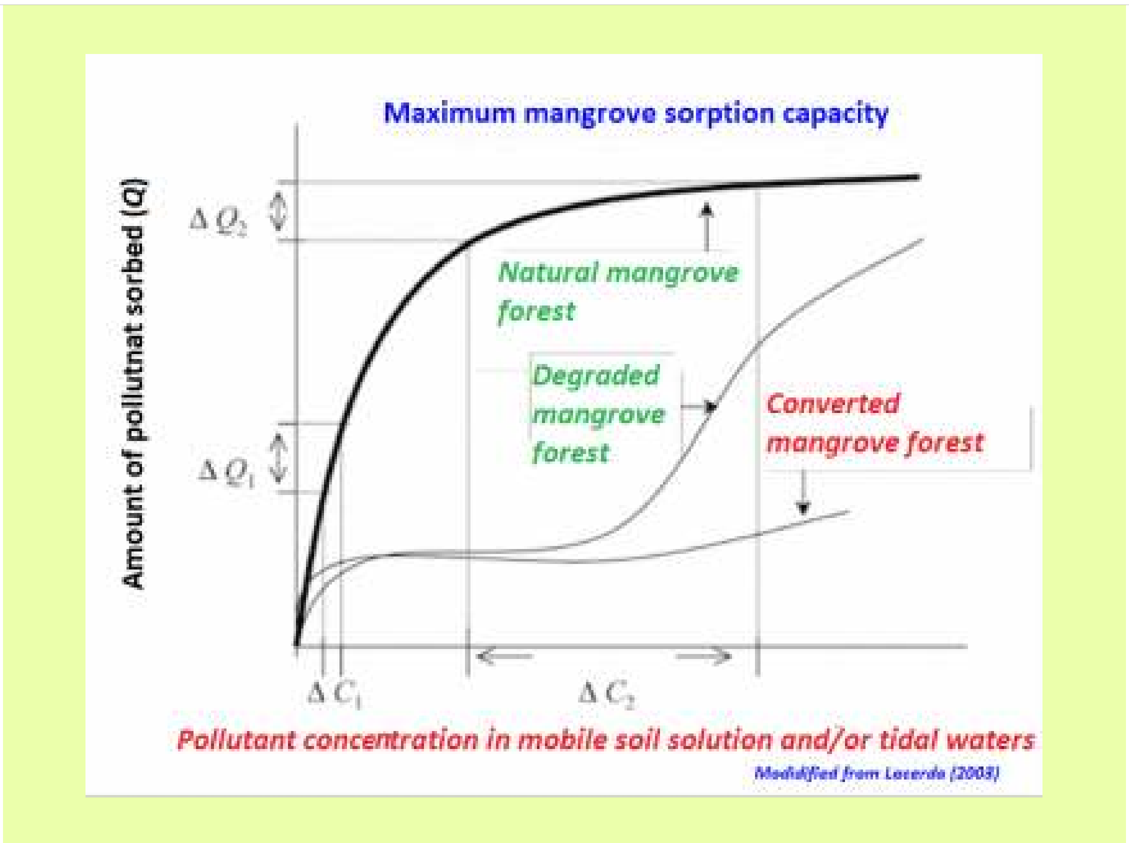
P1- downstream urban areas
P2- downstream shrimp farms

Shrimp aquaculture

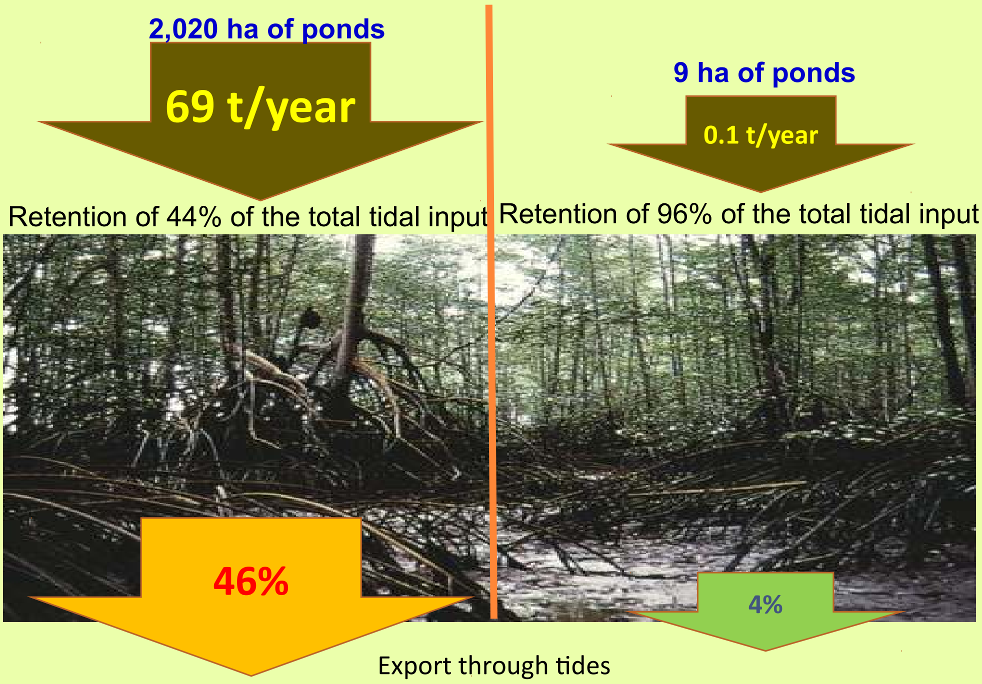
Emission factors for Nitrogen, Phosphorus, Cooper, Zinc and Mercury from anthropogenic and natural sources, compared to shrimp farming.

Sources	Emission factors N e P (t/km²/ano); Cu, Hg e Zn (kg/km²/ano)		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+}, Part. 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	Part. 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, P-particulate	Cu^{2+}, Zn^{2+}, Hg^{2+}, Part. Cu and Zn	Soil, water ways 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	Forms of N and P unknown	Cu^{2+}, Zn^{2+}, Hg^{2+}, Part. 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	Part. Cu, Zn and Hg	Water ways and estuaries

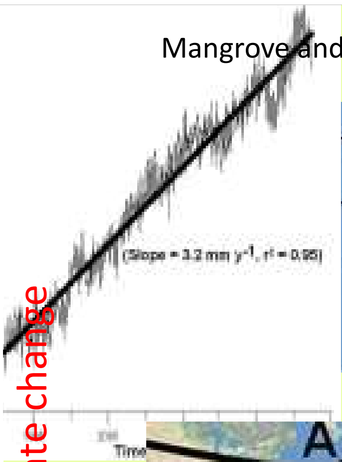
* (Lacerda et al., 2006; 2008; 2011; León-Canhedo et al., 2017)


Maximum mangrove sorption capacity
Amount of pollutnat sorbed (Q)
Δ Q2
Δ Q1
Natural mangrove forest
Degraded mangrove forest
Converted mangrove forest
Δ C1
Δ C2
Pollutant concentration in mobile soil solution and/or tidal waters
Modidified from Lacerda (2003)

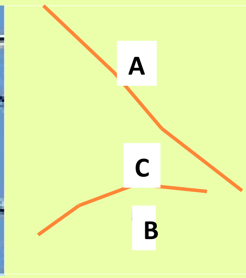
Some technical people suggest mangroves as filters for aquaculture effluents, however, most mangroves are far from pristine. e.g. Phosphorus balance in two mangrove forests in NE Brazil, receiving effluents from shrimp aquaculture



Mangrove and sea level rise (adapted from Jennerjahn (2017)



Climate change

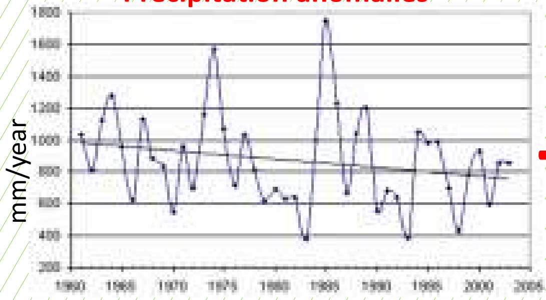


	RCP2.6 ΔT (°C)	RCP4.5 ΔT (°C)	RCP6.0 ΔT (°C)	RCP8.5 ΔT (°C)
Global	1.0±0.4	1.8±0.5	2.2±0.5	3.7±0.7
Land	1.2±0.6	2.4±0.6	3.0±0.7	4.8±0.9
Tropics	0.9±0.3	1.6±0.4	2.0±0.4	3.3±0.6
Ocean	0.8±0.4	1.5±0.4	1.9±0.4	3.1±0.6

Surface air temperature increase between the period 1986-2005 and the period 2081-2100 according to the four IPCC scenarios.

A positive feed back occurs between damming and climate change, particularly under dry climates.

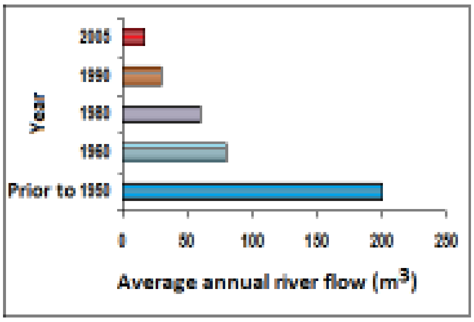
Precipitation anomalies



Evolution Trend (1961 – 2008) in annual precipitation over Ceará. (5,3 $mm.yr^{-1}$ reduction)

+

Fluvial flux decrease



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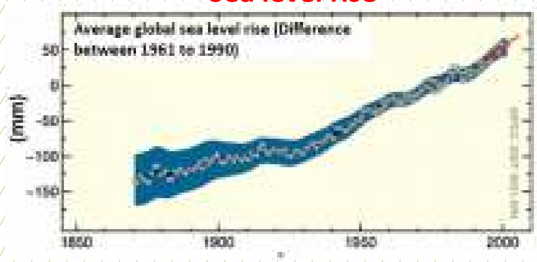
Sea level rise



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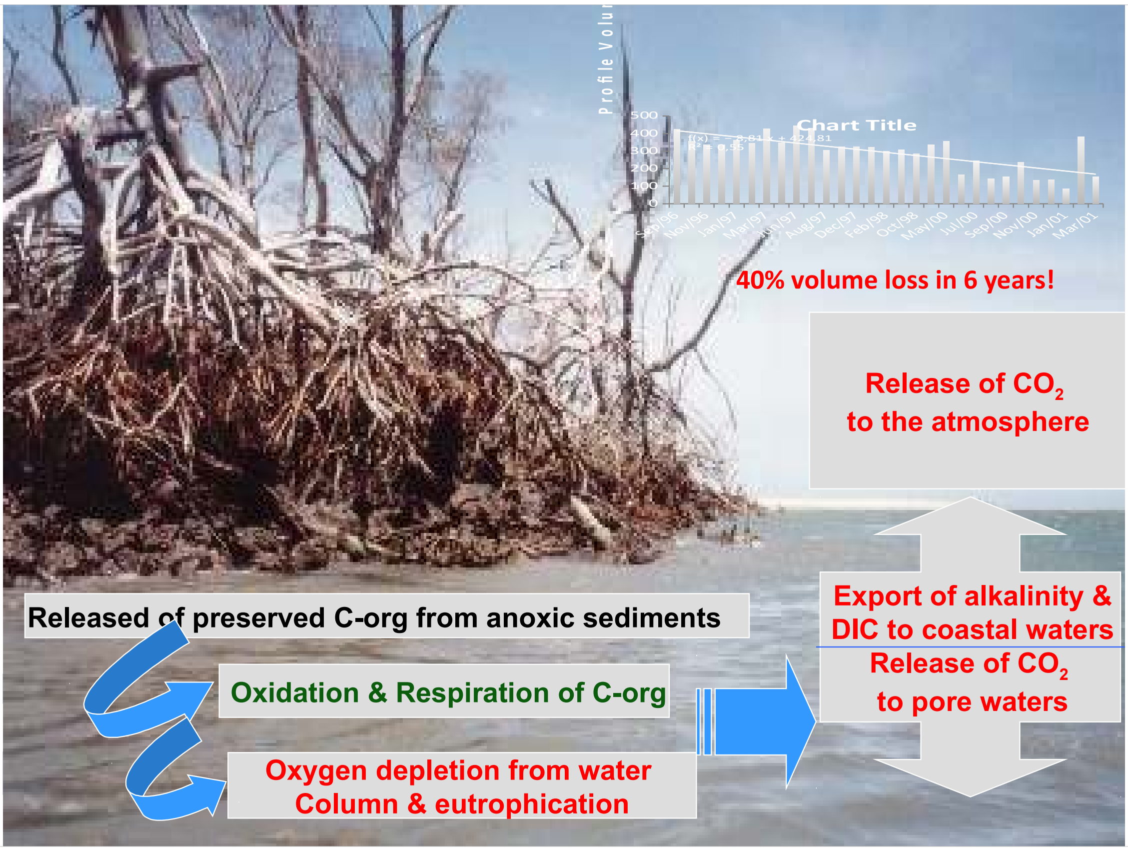


Chart Title
40% volume loss in 6 years!
Release of CO_2 to the atmosphere
Export of alkalinity & DIC to coastal waters
Release of CO_2 to pore waters
Released of preserved C-org from anoxic sediments
Oxidation & Respiration of C-org
Oxygen depletion from water Column & eutrophication

Carbon balance under diferent environmental scenarios

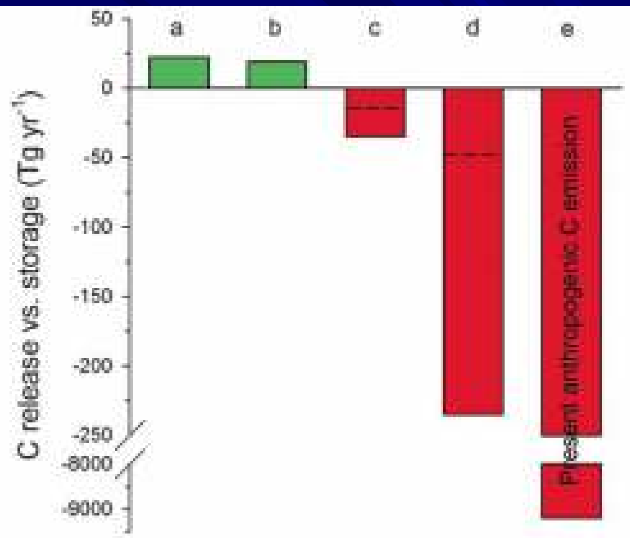
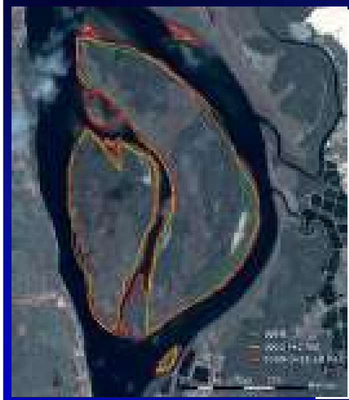
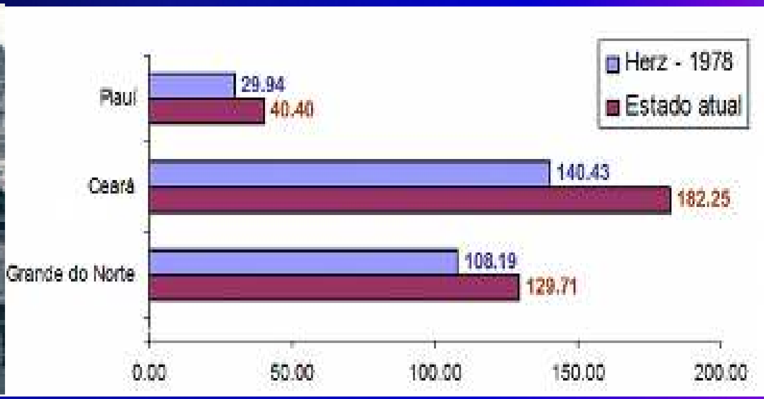


Fig. 7.4 Annual mangrove carbon storage (*green*) and release (*red*) today (*a*) and under 10–15% loss (*b* and *c*) and total loss scenarios (*d*) until the year 2100 compared to the present-day (i.e., 2012) anthropogenic carbon emissions (*e*). *Dashed lines* denote the lower limit of carbon release from mangroves as reported in the text (Data sources: Ciais et al. (2013), Donato et al. (2011) and data sources in the text. Note the break in the *Y*-axis)

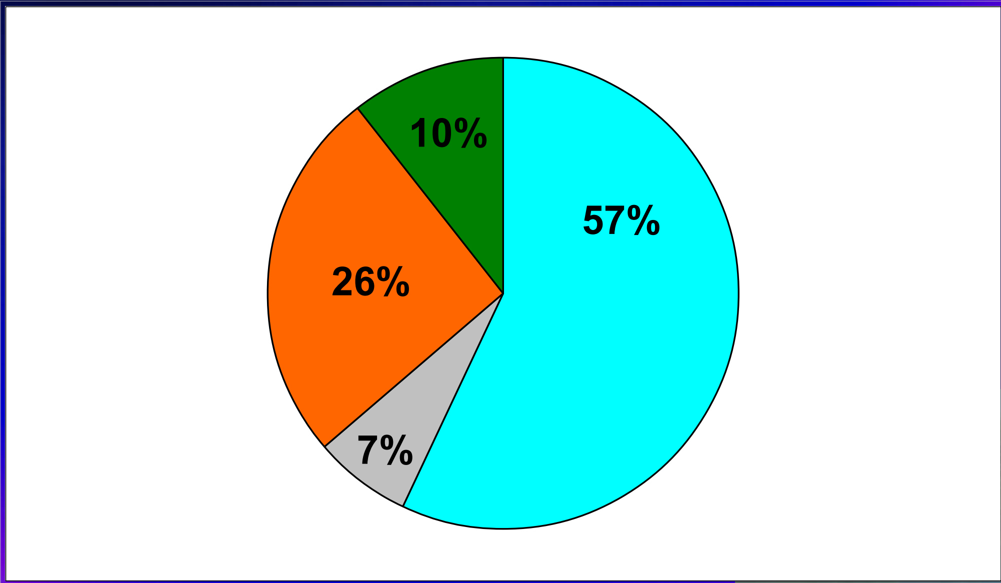
Changes in mangrove extension in 27 estuaries along the semiarid coast of Brazil (Maia et al., 2006), Mangrove Atlas of NE Brazil.
www.insitutomilenioestuarios.com.br





Parameter	km²	%	
Total mangrove area in 1978	278		
Total mangrove area in 2004	352		
Increase (uncertainty)	74	21%	(± 8%)

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



Some conclusions and gaps

- Drivers of impacts on mangroves have changed drastically, this has reduced the effectiveness of some important societal responses towards conservation and sustainable management .

- It is clear that rehabilitation strategies and conservation and management legislation and practices of existing forests shall take into consideration not only local anthropogenic drivers but the climate change scenario. However…

- How global climate change interacts with local anthropogenic drivers?

- Does and how typology influences the impacts onto and the response of mangrove forests to climate change?

- How major anthropogenic drivers presently affecting mangroves may maximize or minimize impacts from climate change?

Acknowledgements

The International Tropical Timbre Organization provided full financial support for the author's participation. Special thanks are due to Dr. Hwan-ok Ma, for the help in organizing this presentation.

The International Society for Mangrove Ecosystems, and in particular, Prof. Shigeyuki Baba for supporting my application to participate in the meeting and support for the many projects coordinated together within ISME's framework.

Sincere thanks to the Ministry of Environment and Forestry of Indonesia for hosting the conference and kindly welcome me to your beautiful country.