Net Ecosystem Carbon Exchange of Mangroves: Complexities in Developing Global Budgets

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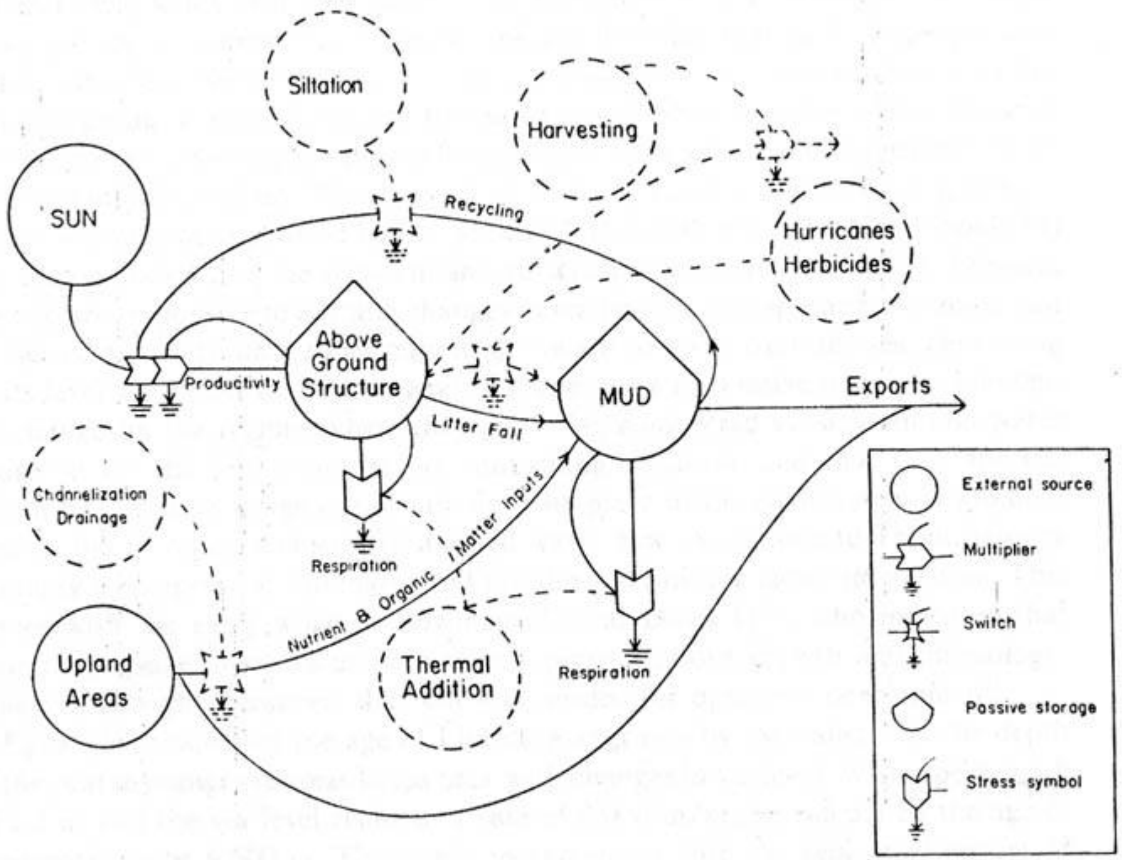

Figure 1 A simple energy model illustrating the major storages and flows in a mangrove ecosystem. Potential stresses are distinguished by dashed lines. In essence, the model is a series of differential equations graphically depicted using the ecological circuit language created by H. Odum (65).

THE ECOLOGY OF MANGROVES

❖4068

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INTRODUCTION

The Historical Perspective

Probably no other distinct plant community has attracted as much curiosity and scientific attention for as long as have the mangrove forests of the tropical and subtropical tidelands; a general bibliography would list some 1200 titles (L. Wilcox, personal communication). The first written account is reported by Bowman (7) from the Chronicle of Nearchus, dating back to the Greek mariners of 325 BC. The historical interest has been largely engendered by the unique adaptations (e.g. prop roots, pneumatophores, and viviparous seeds) of certain mangrove species and by their ubiquitous ability to function in a saline environment.

Unlike other terrestrial communities that can be lived in, managed, or exploited by man, mangroves offer only a few direct uses [tannin, construction timber, and charcoal (3, 69)], which may account for man's historical ambivalence concerning their value. This is revealed in the literature as attitudes that consider mangroves an academic curiosity at best, a nuisance at worst, and, in general, of little value to man and his works. In 1667, Du Terte (in 7) admonished travelers: "Wild boars and other savage beasts live in them . . . who lie in wait to surprise a person." Equally ominous were two Florida newspaper accounts[1] that reported "300 homes blackened" and "two men killed" by "mangrove root gas" in Miami, Florida. In 1938, Davis, whose mangrove research papers (17–20) are considered classics, referred to

[1]Respectively, the *Miami Herald*, Nov. 15, 1951, and the *Miami News*, Jul. 28, 1961.

' The basic mangrove ecosystem is depicted as two coupled storages (above-ground structure and muds) linked by cycling of matter and powered by the interaction of sunlight and matter through photosynthesis'

Energy Steady State of Ecosystem = Organic Carbon

NPP = GPP – Ra
Ra = respiration of autotrophs

NEP = GPP – R(a+h)
Ra = respiration of Autotrophs + heterotrophs

Ra + Rh = Re (Rt)
Respiration of ecosystem
NEP = (GPP + I) – (Re + E)

Energy Steady State of Ecosystem = Organic Carbon

$$NEP = (GPP + I) – (Re + E)$$

Lovett et al. 2006

$$\Delta Corg = NEP\ steady\ state$$

$$\Delta Corg = (GPP + I) – (Re + E + Ox_{nb})$$

$$NEP = (\Delta Corg + E + Ox_{nb}) - I$$

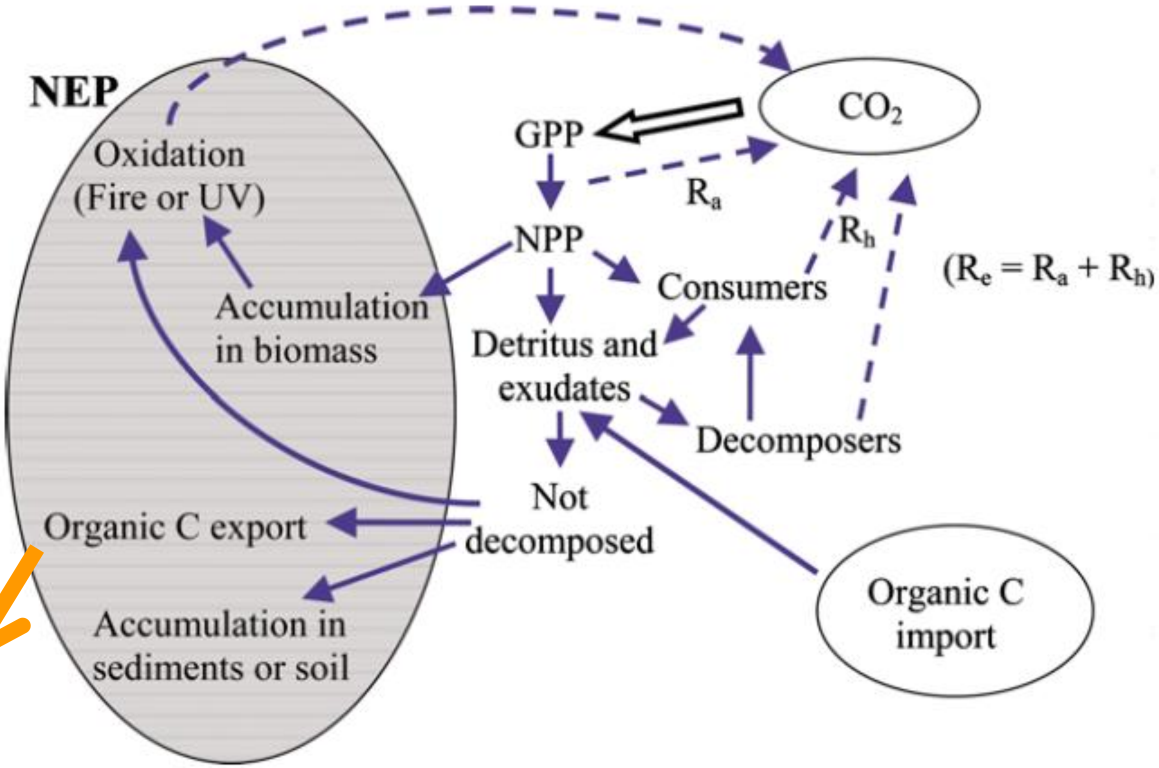


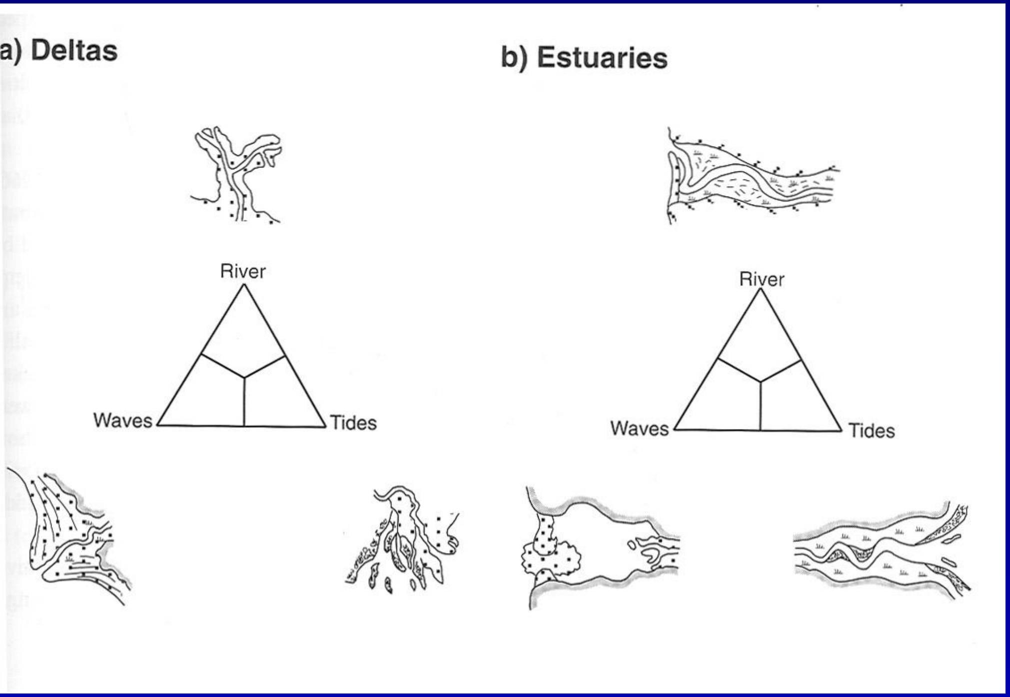
Figure 1. Fates of organic carbon (C) fixed in or imported into an ecosystem. Total ecosystem respiration (R_e) is the sum of autotrophic respiration (R_a) and heterotrophic respiration (R_h). The *shaded area* contains the components of the NEP of the system. "*Accumulation in biomass*" represents all biomass (plant, animal, or microbial); the *arrow* is drawn from NPP in this diagram because plant biomass accumulation is generally the largest biomass term. NPP, net primary production; NEP, net ecosystem production; GPP, gross primary production; CO_2, carbon dioxide; UV, ultraviolet.

$$NEP = (\Delta Corg + E + Ox_{nb}) - I$$

$$NEP = (GPP + I) - (Re + E + Ox_{nb})$$

Functional types of mangrove forest

Relationship between functional types of mangrove forests and the dominant physical processes: River vs Tidal Forcings



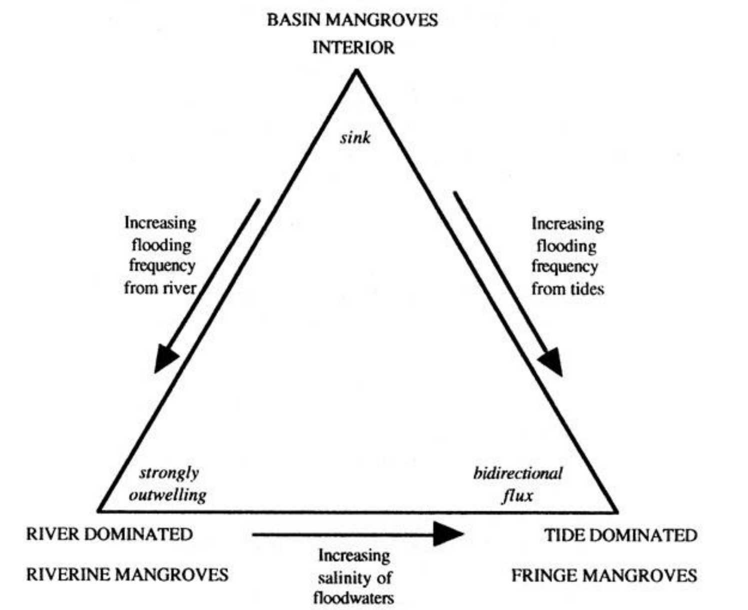
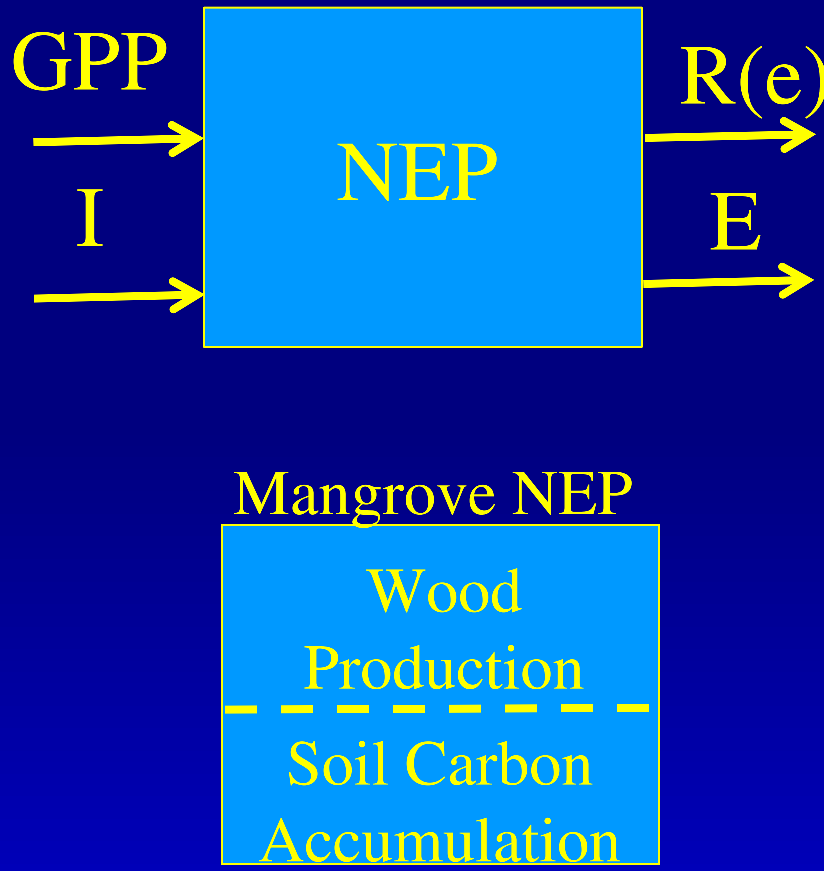


Fig. 6.8 Classification of the three functional types of mangrove forests, as proposed by Ewel et al. (1998b), in combination with their dominant physical processes as outlined by Woodroffe (1992).

Energy Steady State of Ecosystem = Organic Carbon



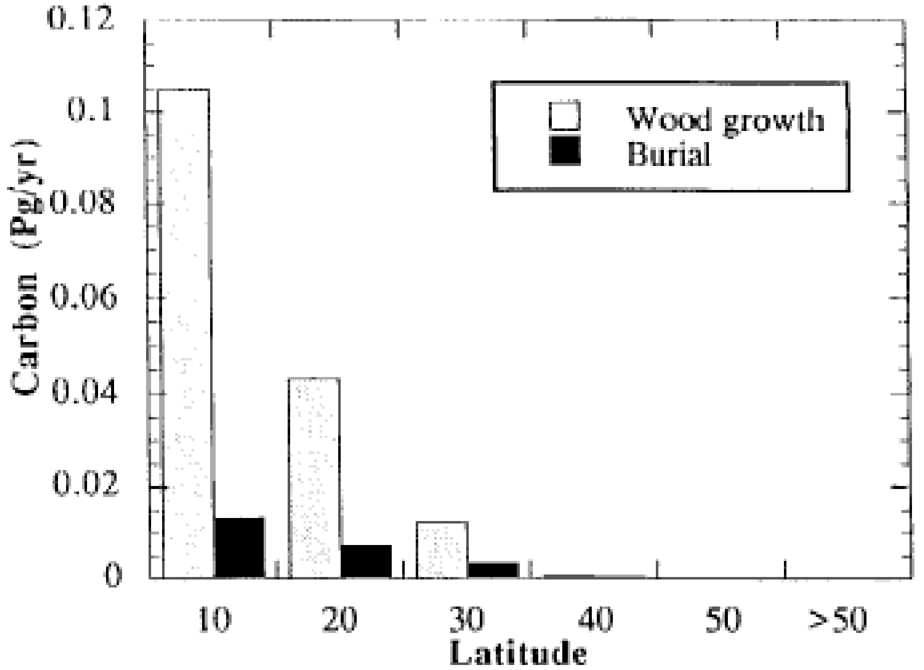


Figure 4. Estimates of annual carbon storage in mangrove wood and sediments.

Twilley, R.R., R.H. Chen, and T. Hargis. **1992**. Carbon sinks in mangroves and their implications to carbon budget of tropical coastal ecosystems. *Water, Air and Soil Pollution* 64: 265-288.

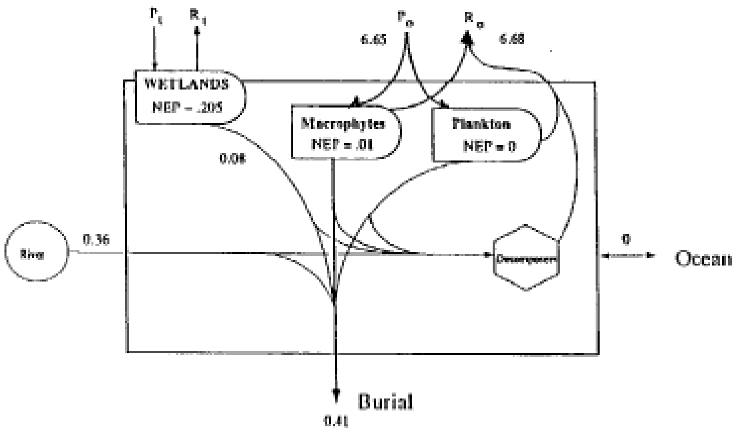


Figure 10. Mass balance of C for coastal ecosystems based on estimates of in situ net production and allochthonous inputs, minus losses associated with burial in coastal sediments. P and R represent net production and heterotrophic respiration, respectively, with exchange of CO_2 directly with atmosphere (t) or coastal waters (o).

NEP ranges from 112 to 200 TgC yr^{-1}

Table 3 – Major pathways of carbon flow through the world's mangrove ecosystems. Units = TgC $year^{-1}$ scaled to a common total global area of 150,000 km^2 (Spalding et al., 2010). Data from Bouillon et al. (2008) and Alongi (2009). Values are mean ± 1 SD. Abb.: POC, particulate organic carbon; DOC, dissolved organic carbon.

	Bouillon et al. estimate	Alongi estimate
Inputs		
GPP	NA	690 ± 264
NPP	204 ± 68	290 ± 107
Wood	63 ± 40	63 ± 42
Litter	64 ± 20	64 ± 20
Roots	77 ± 56	163
Outputs		
POC export	20 ± 22	27 ± 25
DOC export	23 ± 21	13 ± 12
Carbon burial	17	27 ± 20
Tree respiration	NA	396 ± 151
Soil + water respiration	39	72 ± 50
NEP	112 ± 85	155 ± 121

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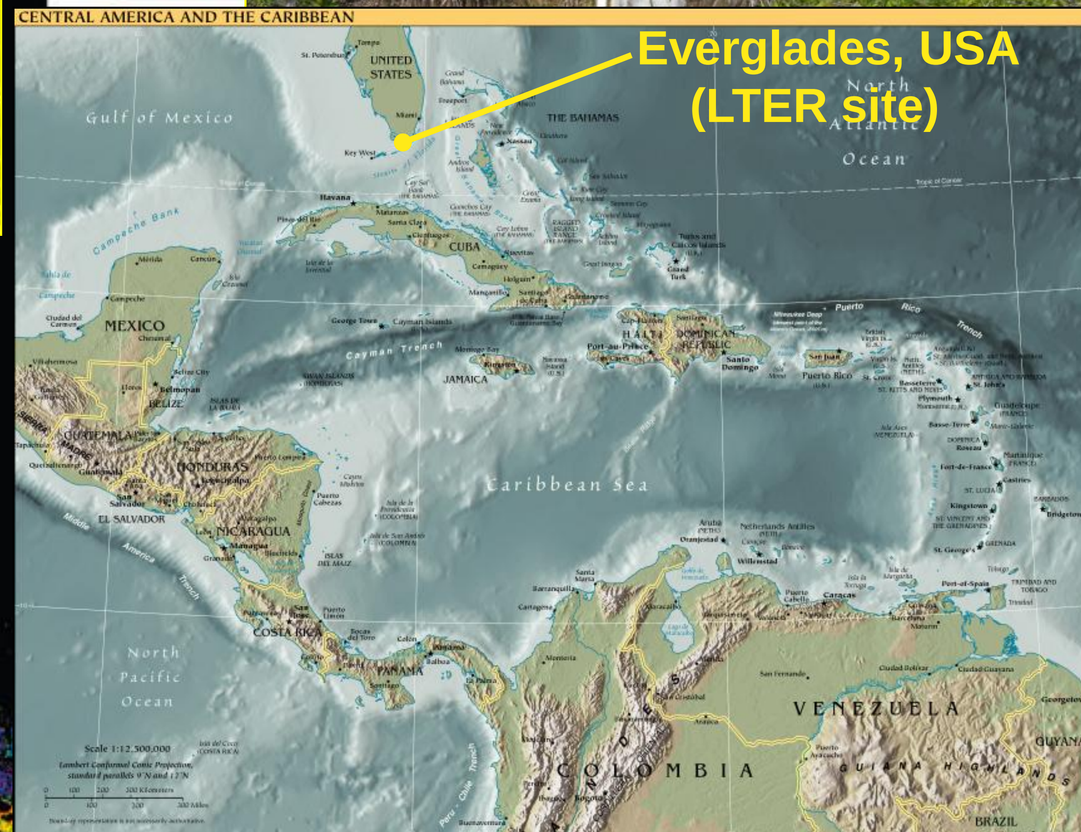
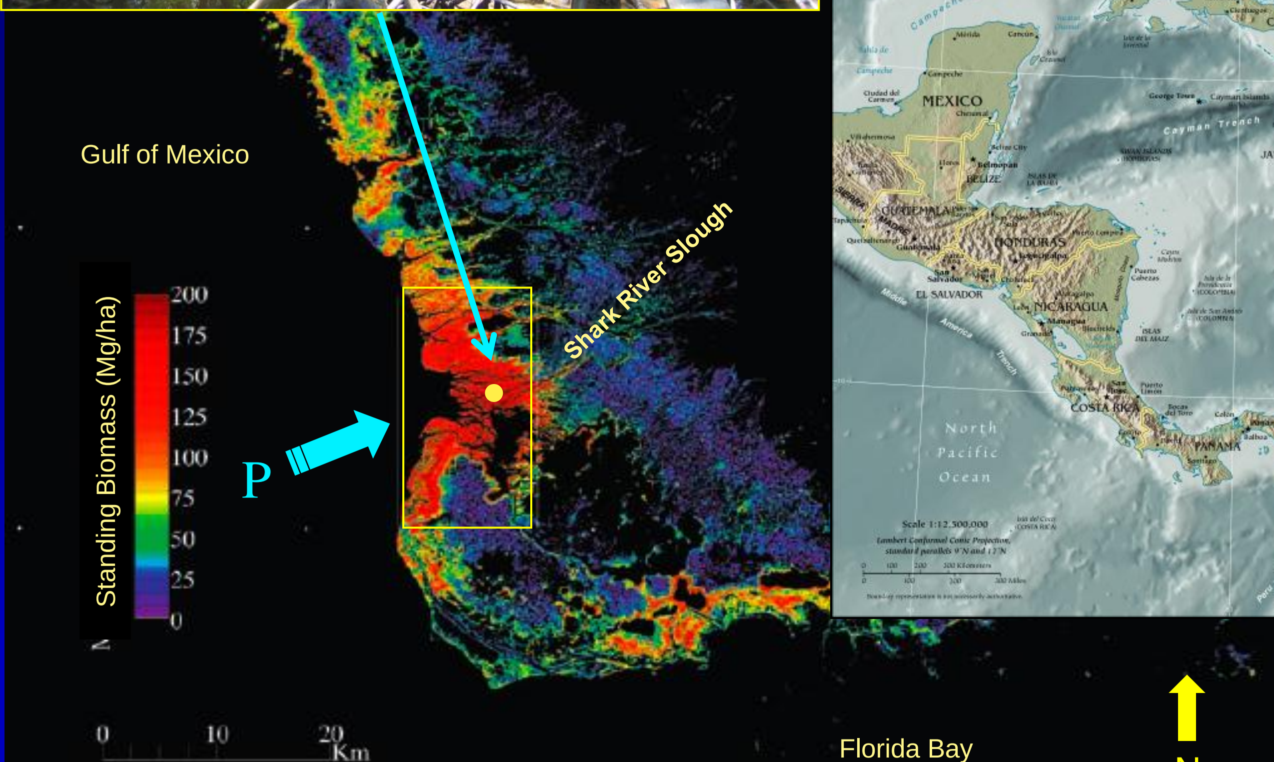
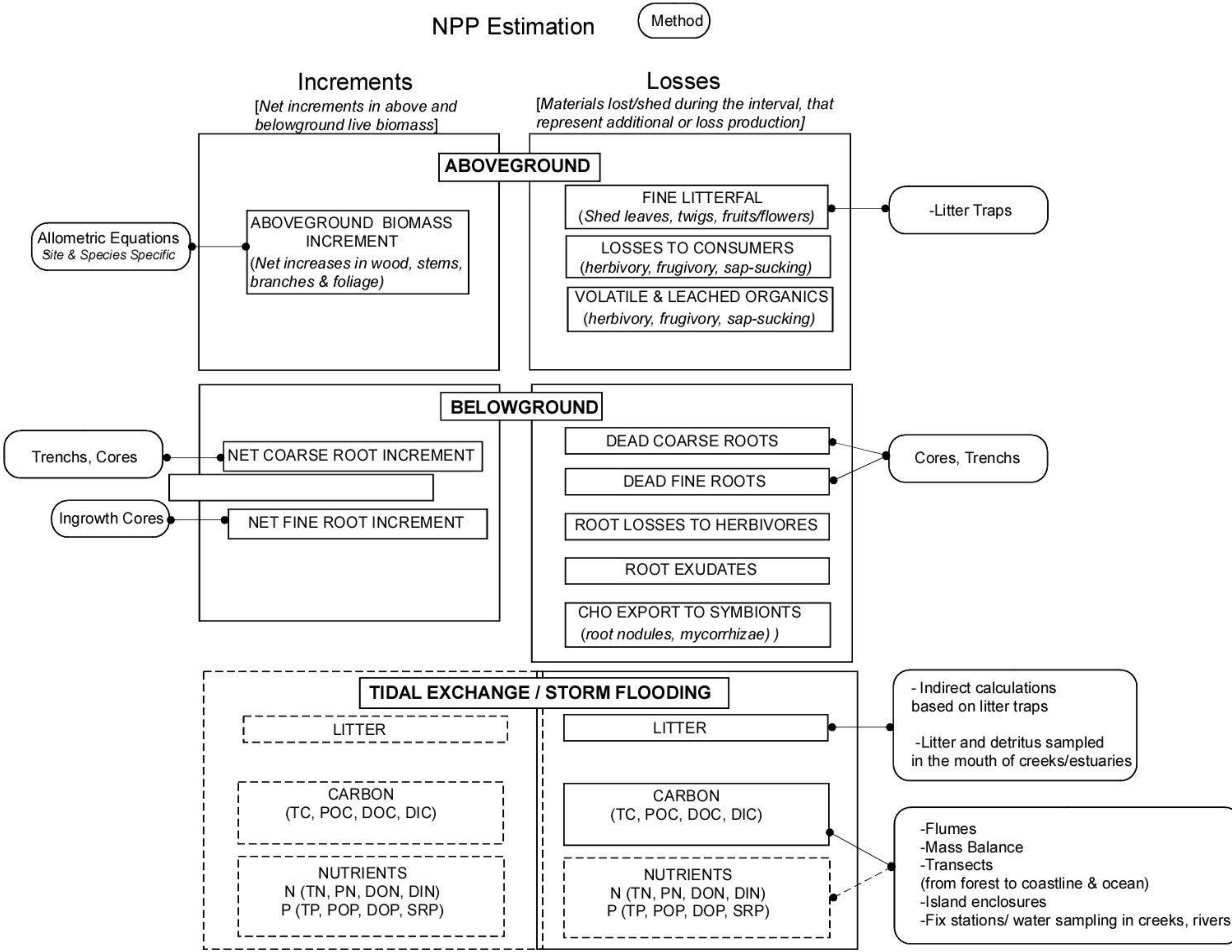




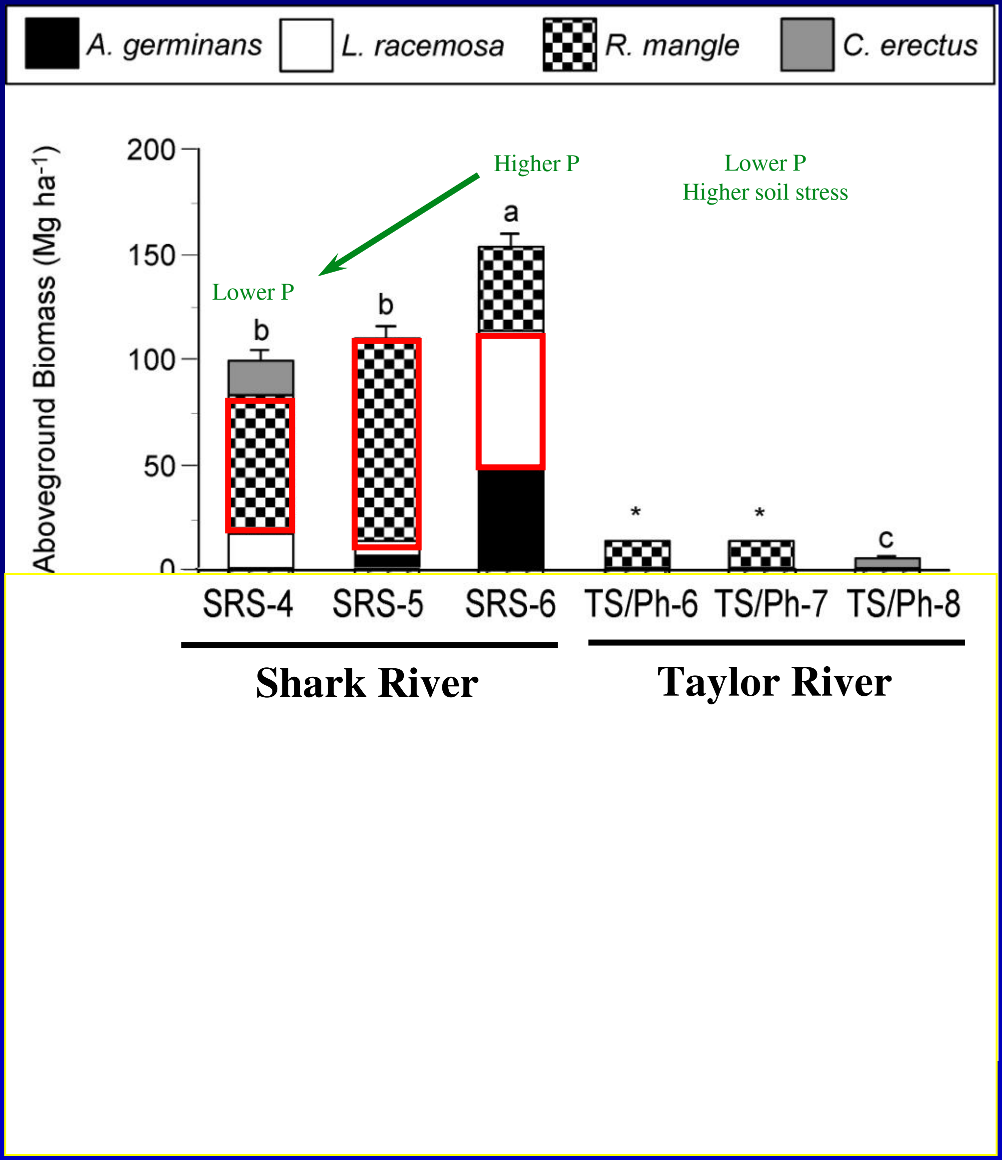
Simard et al. (2006); Rivera-Monroy et al. (2011)

P is supplied by the Gulf of Mexico during storm events.



NPP Estimation
Method
Increments
[Net increments in above and belowground live biomass]
Losses
[Materials lost/shed during the interval, that represent additional or loss production]
ABOVEGROUND
Allometric Equations
Site & Species Specific
ABOVEGROUND BIOMASS INCREMENT
(Net increases in wood, stems, branches & foliage)
FINE LITTERFAL
(Shed leaves, twigs, fruits/flowers)
-Litter Traps
LOSSES TO CONSUMERS
(herbivory, frugivory, sap-sucking)
VOLATILE & LEACHED ORGANICS
(herbivory, frugivory, sap-sucking)
BELOWGROUND
Trenchs, Cores
NET COARSE ROOT INCREMENT
Ingrowth Cores
NET FINE ROOT INCREMENT
DEAD COARSE ROOTS
DEAD FINE ROOTS
Cores, Trenchs
ROOT LOSSES TO HERBIVORES
ROOT EXUDATES
CHO EXPORT TO SYMBIONTS
(root nodules, mycorrhizae))
TIDAL EXCHANGE / STORM FLOODING
LITTER
CARBON
(TC, POC, DOC, DIC)
NUTRIENTS
N (TN, PN, DON, DIN)
P (TP, POP, DOP, SRP)
LITTER
CARBON
(TC, POC, DOC, DIC)
NUTRIENTS
N (TN, PN, DON, DIN)
P (TP, POP, DOP, SRP)
- Indirect calculations based on litter traps
-Litter and detritus sampled in the mouth of creeks/estuaries
-Flumes
-Mass Balance
-Transects
(from forest to coastline & ocean)
-Island enclosures
-Fix stations/ water sampling in creeks, rivers

Above- and Belowground Biomass (2001-2004)

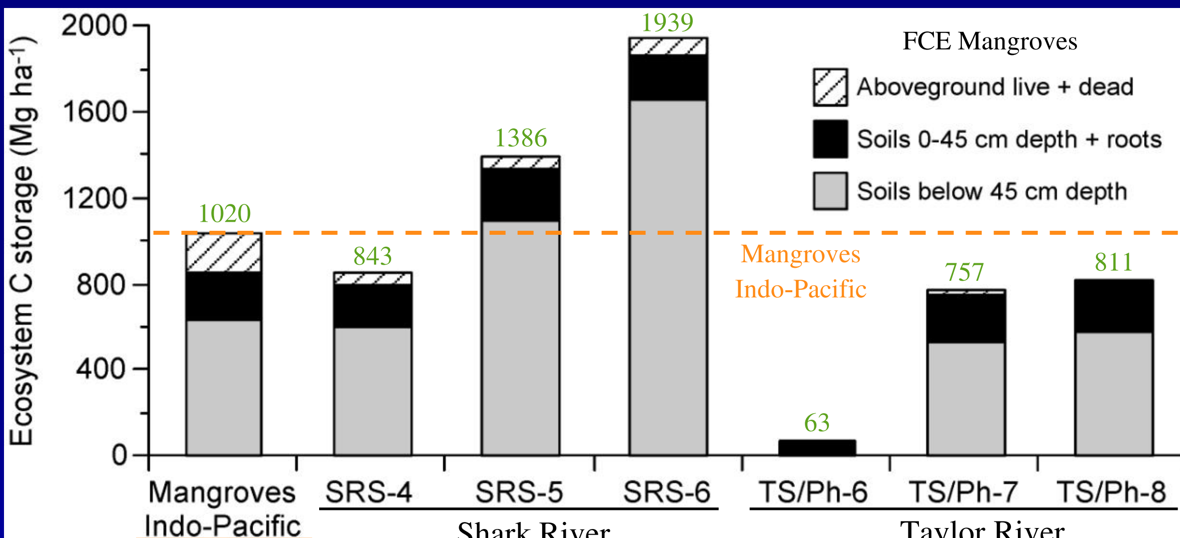


- Mean AG biomass:
  - Shark River = 122 ± 20 Mg ha^{-1}
  - Taylor River = 9.8 ± 2.7 Mg ha^{-1}
- *R. mangle*: 70-80% of total biomass in upstream sites of Shark River.
- *L. racemosa*: 43% of total biomass in SRS-6.
- Average BG biomass = 35 ± 4 Mg ha^{-1}
- Root biomass allocation was higher in mangrove sites with lower P fertility.

* TS/Ph-6 & 7: Coronado-Molina et al. (2004)

Riverine Mangroves along Shark River store more carbon compared to Indo-Pacific Mangroves

- Shark River: 1120 ± 316 Mg C ha^{-1}



1.4 - 2.8 m | 1.9 m | 2.5 m | 4.5 m | <0.5 m | 1.5 m | 1.5 m

Total Soil Peat Depth (to underlying bedrock)

Deep soil core section (1.95 - 2.45 cm)
(Russian Piston Corer)

Courtesy: Qiang Yao, Ph.D. ongoing dissertation, LSU

- Deep peat deposits represent a significant pool of the total C storage in Everglades mangroves.

- SRS-6 had the highest total ecosystem carbon storage in FCE, twice higher compared to mangrove forests in the Indo-Pacific.

Describe SRS6 with NEP budget (Organic Carbon)

$$NEP = (ANPP + BNPP + I_T) - (Re + E_T)$$

$ANPP = 1150\ gC\ m^{-2}\ yr^{-1}$

$BNPP = 311\ gC\ m^{-2}\ yr^{-1}$

$Re = 470\ gC\ m^{-2}\ yr^{-1}$

Net E_T $(I_T - E_T) = 550\ gC\ m^{-2}\ yr^{-1}$

Mangrove NEP

ANPP

BNPP + Soil OC

$$NEP = (1150 + 311) - (470 + 550)$$

$$= \mathbf{411}\ gC\ m^{-2}\ yr^{-1}$$

Describe SRS6 with NEP budget (Organic Carbon)

$$NEP = (ANPP + BNPP + I_T) - (Re + E_T)$$

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Mangrove NEP

ANPP

- - - - - - - -

BNPP + Soil OC

NEP = (1150 + 311) – (470 + 550)

= **411** gC m^{-2} yr^{-1}

Wood Production = 200 gC m^{-2} yr^{-1}

Soil C accumulation = 150 gC m^{-2} yr^{-1}

Org Car Accumulation = **350** gC m^{-2} yr^{-1}

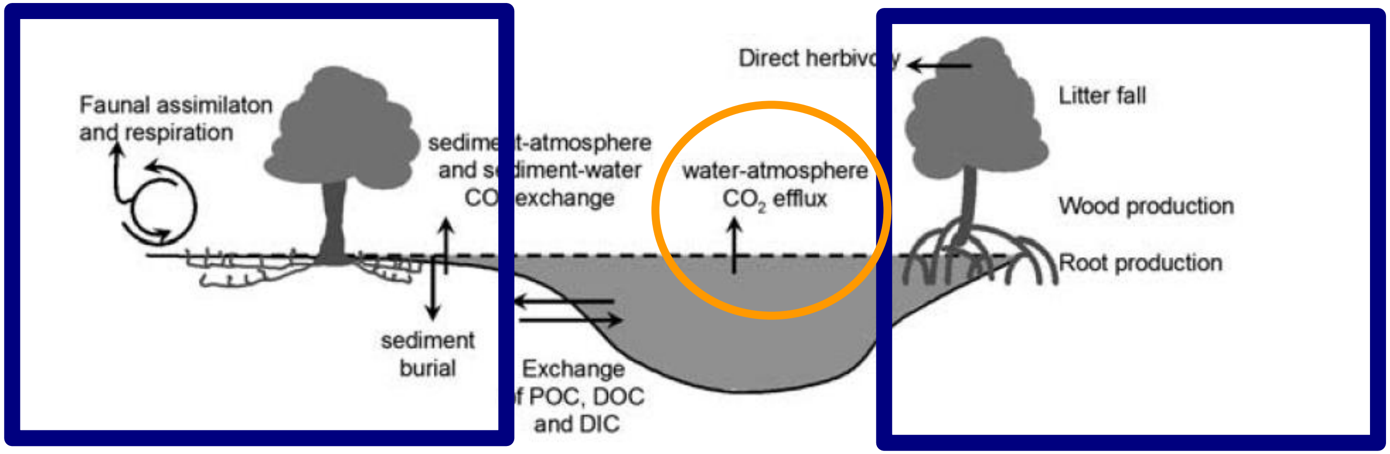
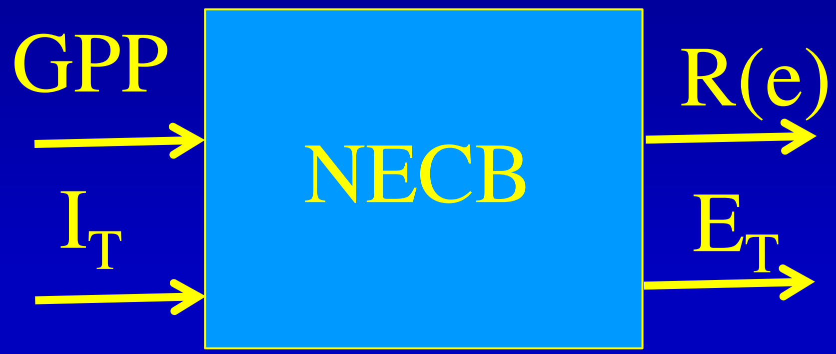


Figure 1. Summary of the major components in mangrove carbon budgets considered: primary production (litter fall, wood, and root production) and various sink terms.

Transition from 'Organic Carbon based NEP To Net Ecosystem Carbon Budget (NECB) (Chapin et al. 2006)

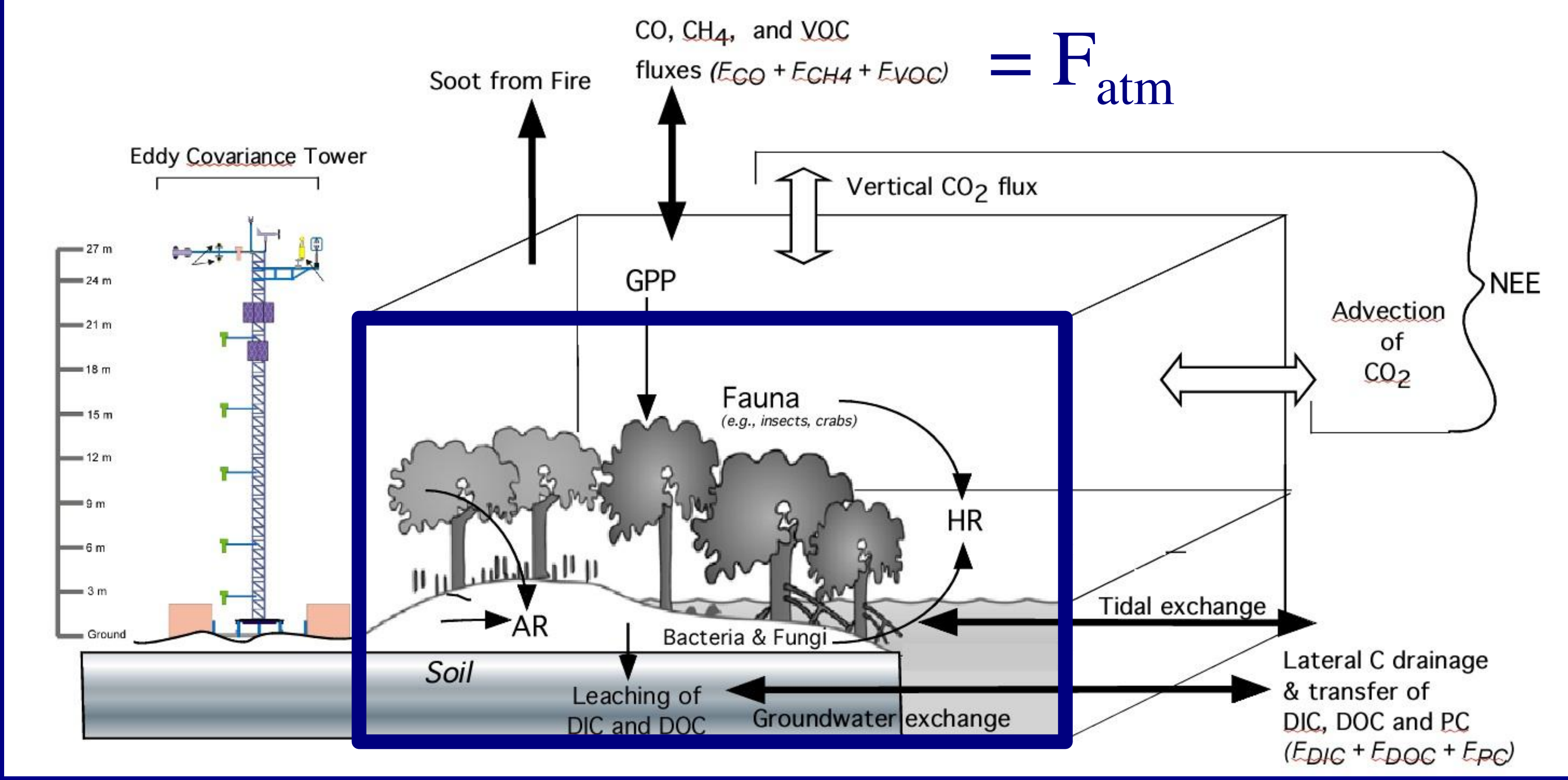


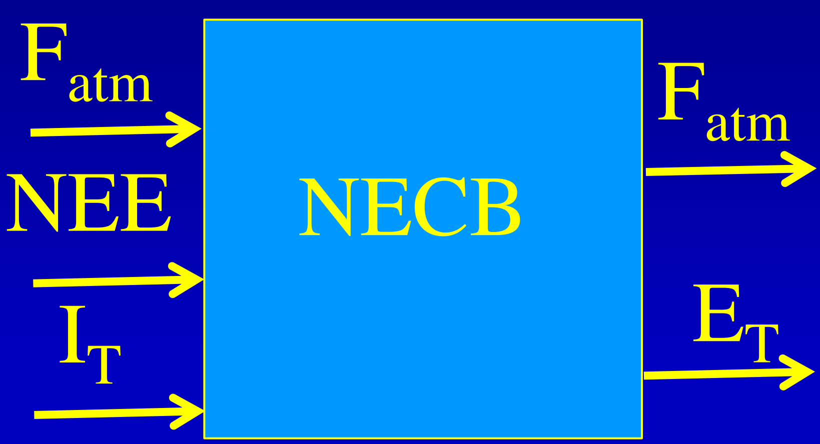
$$NEP = (GPP + I) – (Re + E)$$

$$E_T = DIC + DOC + PC$$

$$I_T = DIC + DOC + PC$$

Surface and Ground Water



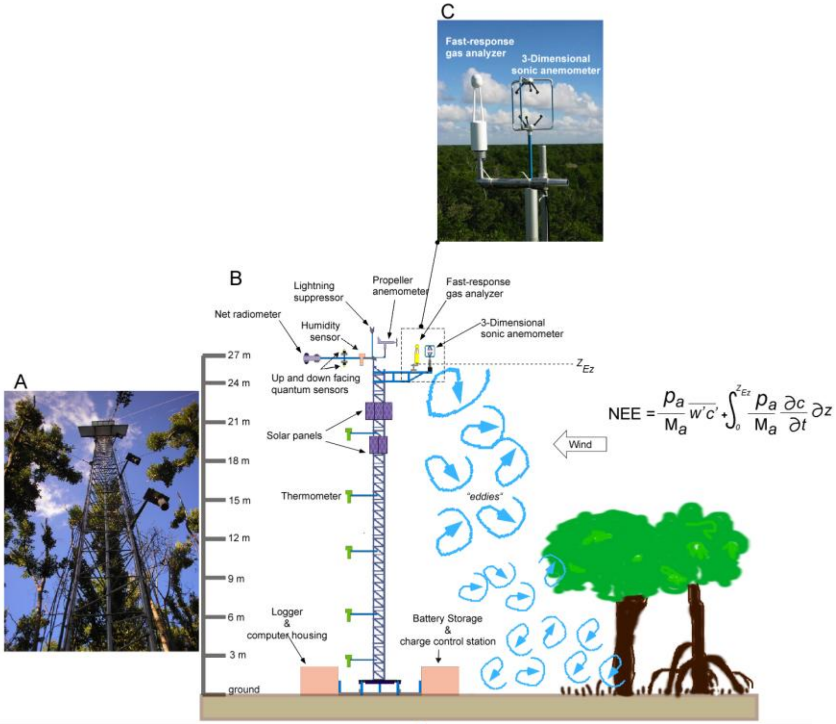


$$NECB = (NEE + I_T + F_{atm}) - (F_{atm} + E_T)$$

$$E_T = DIC + DOC + PC$$

$$I_T = DIC + DOC + PC$$

Surface and Ground Water



Jordan Barr, Jose Fuentes, Vic Engel, Joseph Zieman, FCE-LTER

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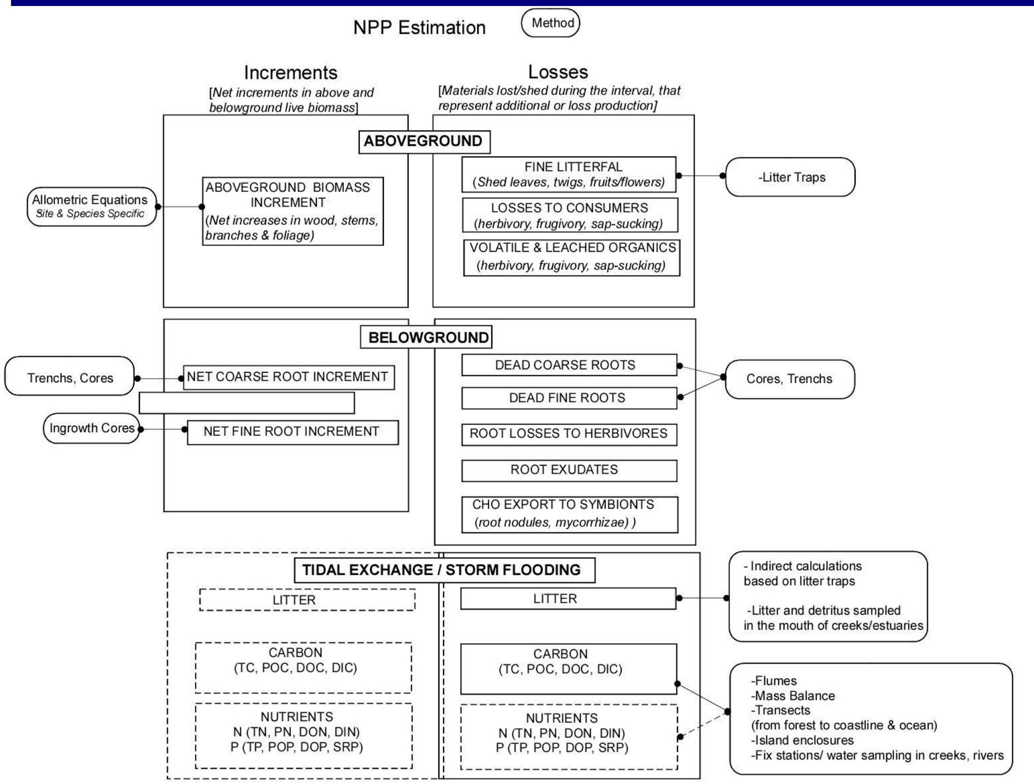
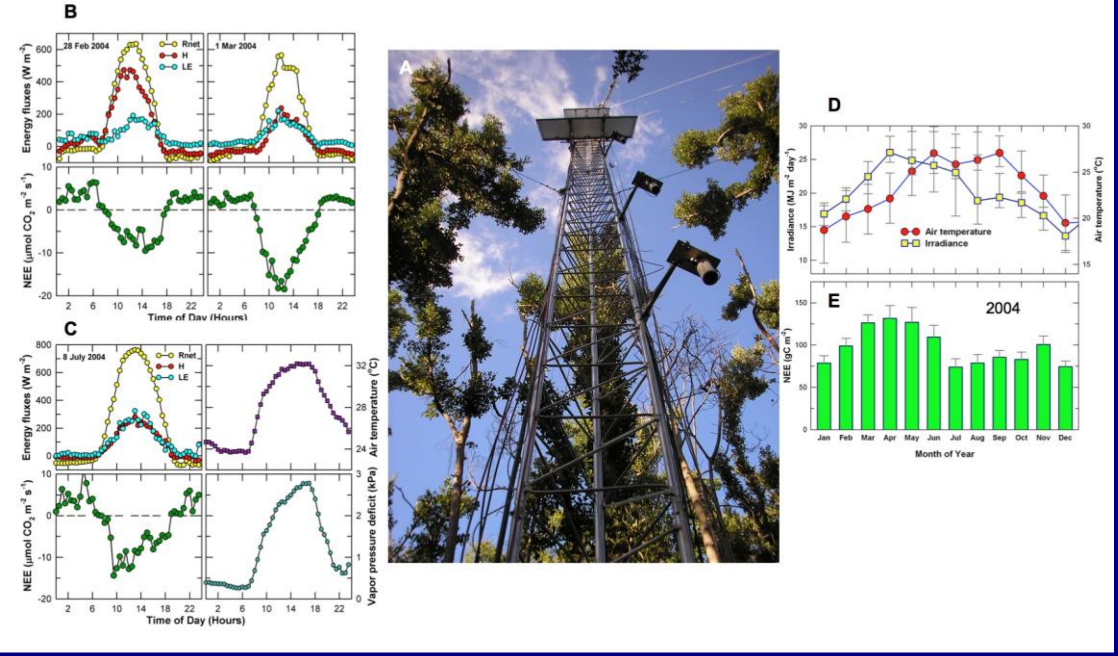
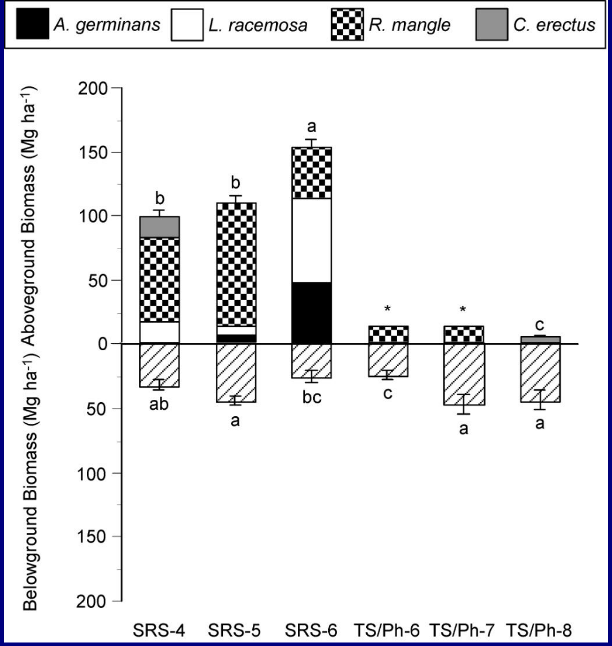






$$NECB = (NEE + I_T + F_{atm}) - (F_{atm} + E_T)$$

$$NEE = -\ 1170\ gC\ m^{-2}\ yr^{-1}$$

F_{atm} →

NEE →

I_T →

NECB

ANPP + BNPP – Re

(1150+311-470

= 991)

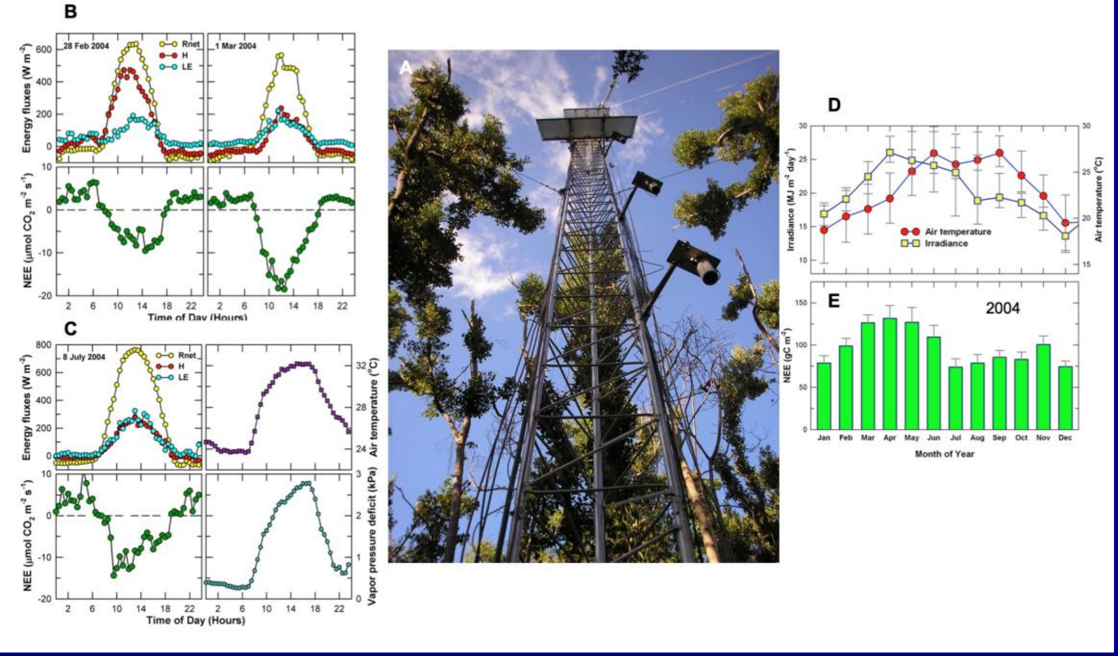
→ F_{atm}

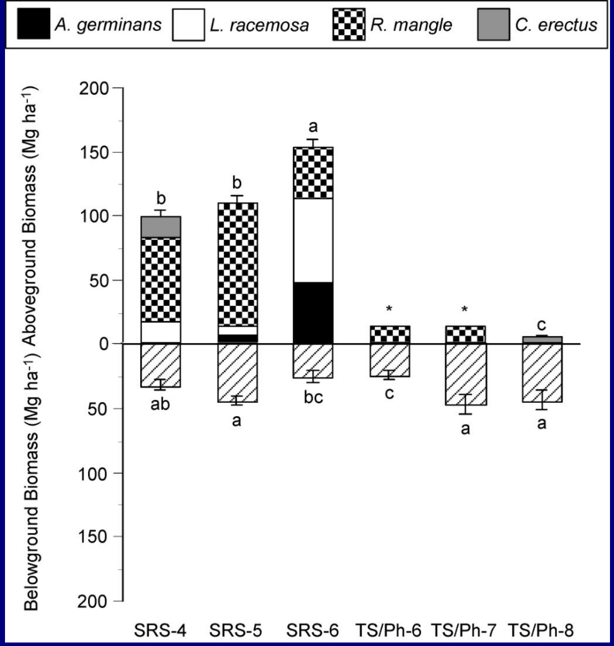
→ E_T

$$NECB = 991\ gC\ m^{-2}\ yr^{-1}$$

$$Net\ E_T = 550\ gC\ m^{-2}\ yr^{-1}$$

$$NEE = (NECB + E_T) = 1541\ gC\ m^{-2}\ yr^{-1}$$





$$\text{NECB} = (\text{NEE} + I_T + F_{atm}) - (F_{atm} + E_T)$$

$$\text{NEE} = -\ 1170\ \text{gC m}^{-2}\ \text{yr}^{-1}$$

F_{atm} → NEE → I_T →

NECB
Wp + Soil Accum
(ΔCorg)
(200 + 150
= **350**)

→ F_{atm}
→ E_T

$$\text{NECB} = 350\ \text{gC m}^{-2}\ \text{yr}^{-1}$$

$$\text{Net } E_T = 550\ \text{gC m}^{-2}\ \text{yr}^{-1}$$

$$\text{NEE} = (\text{NECB} + E_T) = \mathbf{900}\ \text{gC m}^{-2}\ \text{yr}^{-1}$$

What is the Question – Define the flux (carbon accumulation vs carbon exchange)

What is the Question – Define the boundary (mangrove wetlands vs mangrove ecosystems – downstream fluxes)

Determine the F_{atm} – what about CH_4, VOC, CO?

What about Nitrogen – Nitrogen sinks in coastal zone – N_20, N fixation vs denitrification,

Sulfur budgets ?

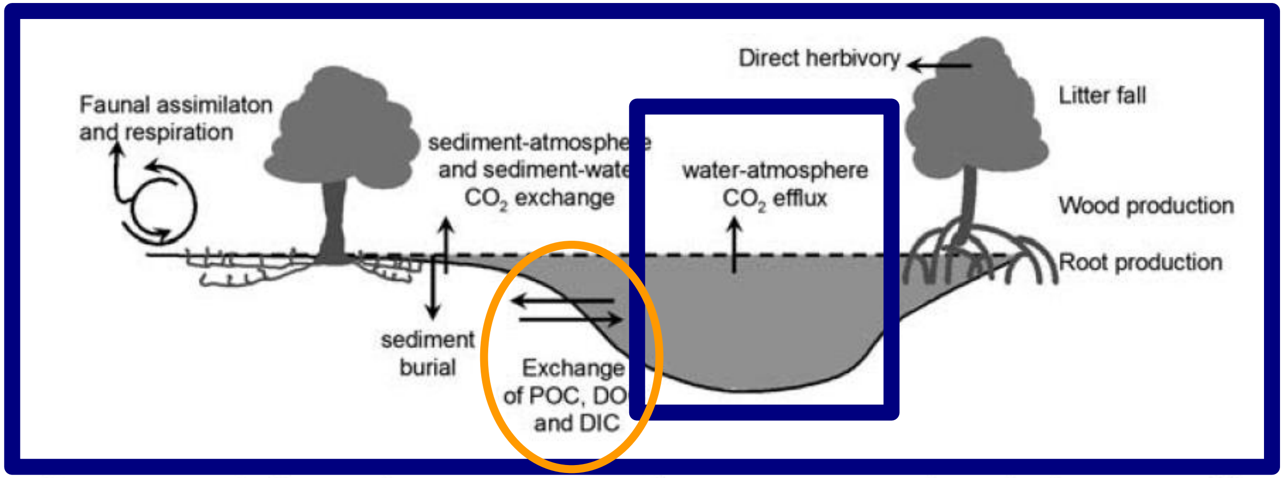


Figure 1. Summary of the major components in mangrove carbon budgets considered: primary production (litter fall, wood, and root production) and various sink terms.

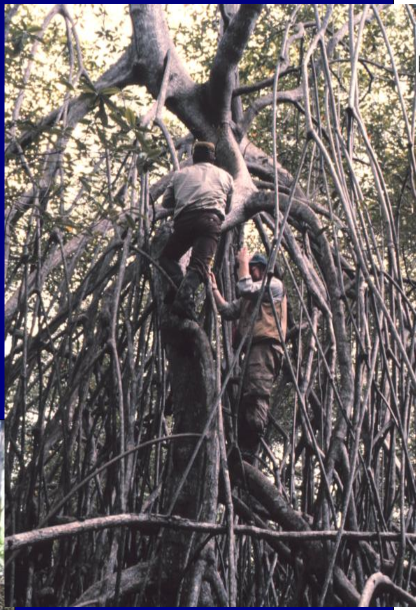
$$NECB = (NEE + I_T + F_{atm}) - (F_{atm} + E_T)$$

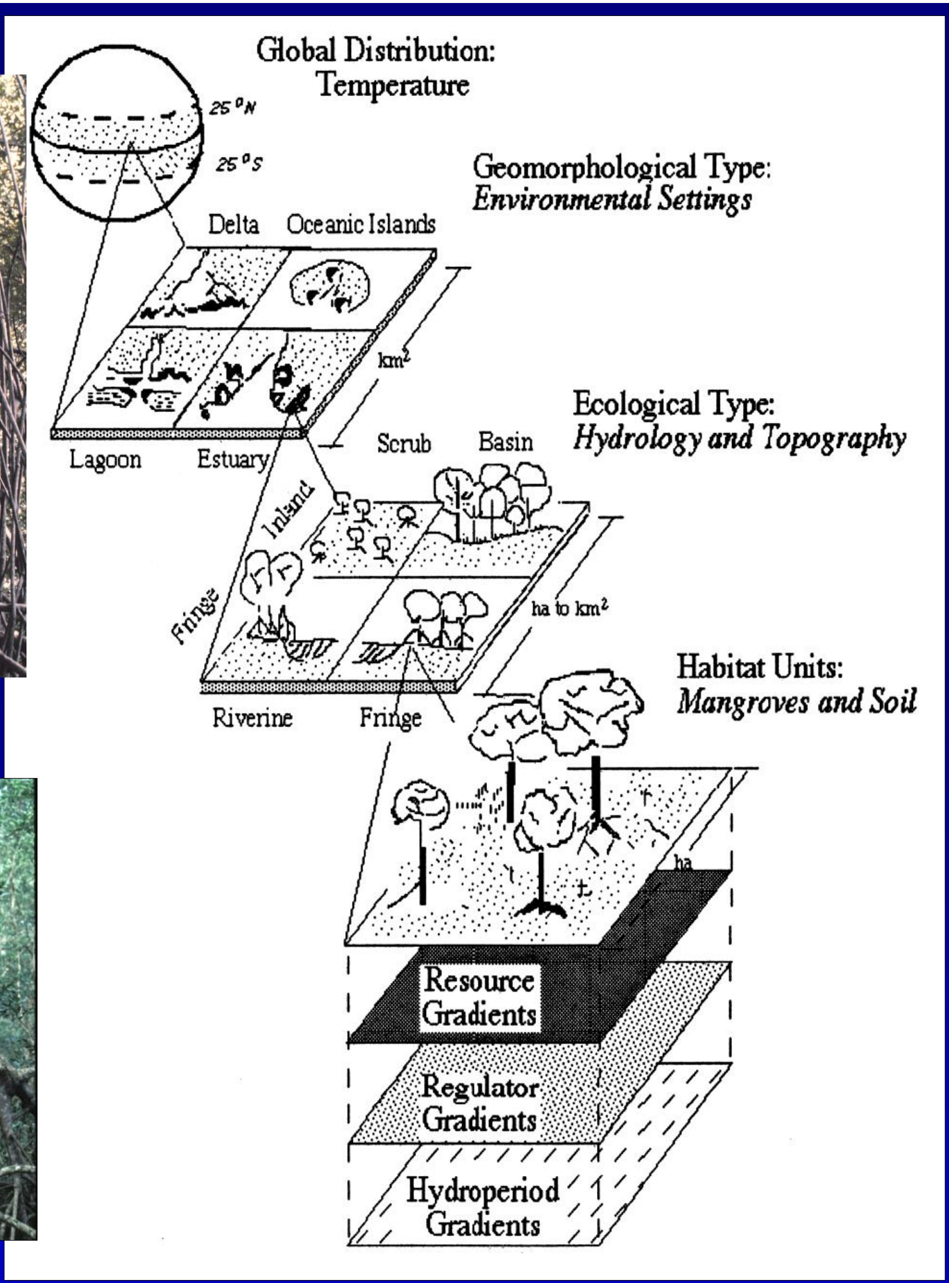
$$NEE = -1170 \text{ gC m}^{-2} \text{ yr}^{-1}$$

$$\text{Net } E_T = 550 \text{ gC m}^{-2} \text{ yr}^{-1}$$

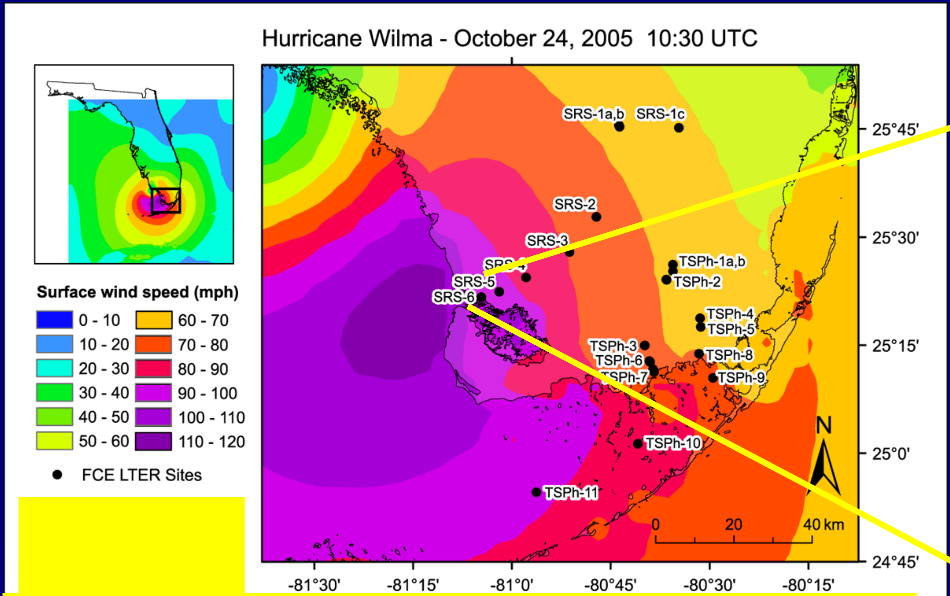
(DIC + DOC + PC)

Hierarchical Framework : Landscape Patterns of Adaptations





Pulsing Drivers: Hurricane Wilma Impacts on FCE Mangrove Forests



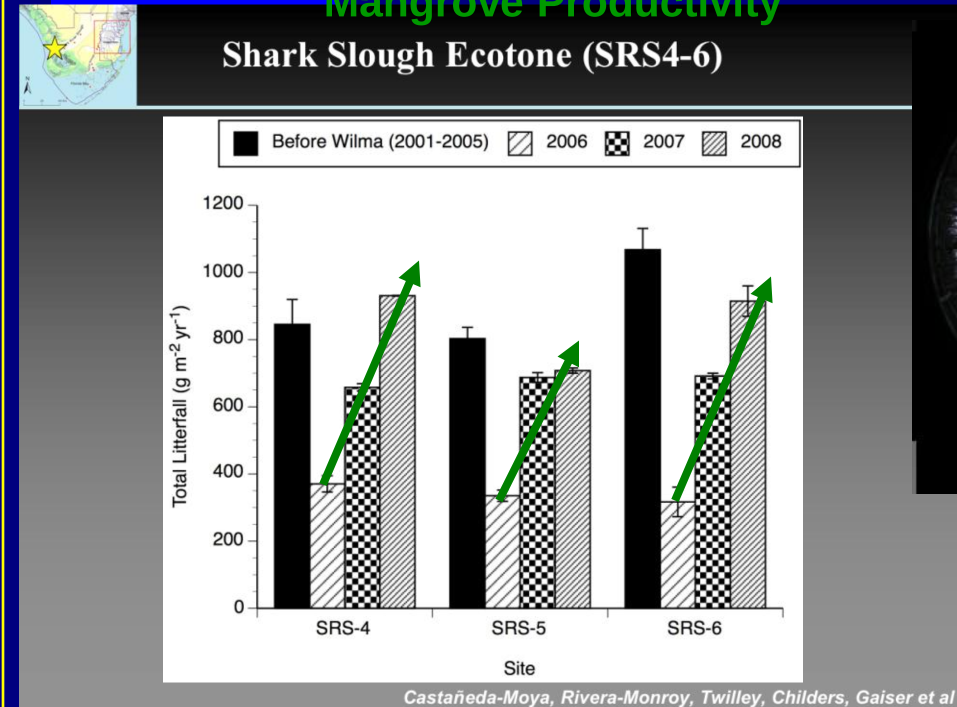
Wind speeds reached 45-50 m/s at Shark River mouth compared to weaker winds (30-35 m/s) in the Joe Bay area (TS/Ph-8)

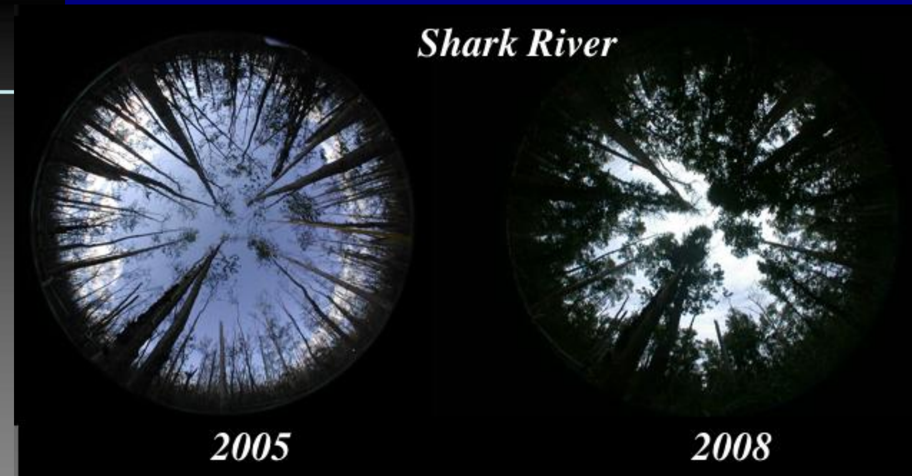
Major defoliation of forest canopy

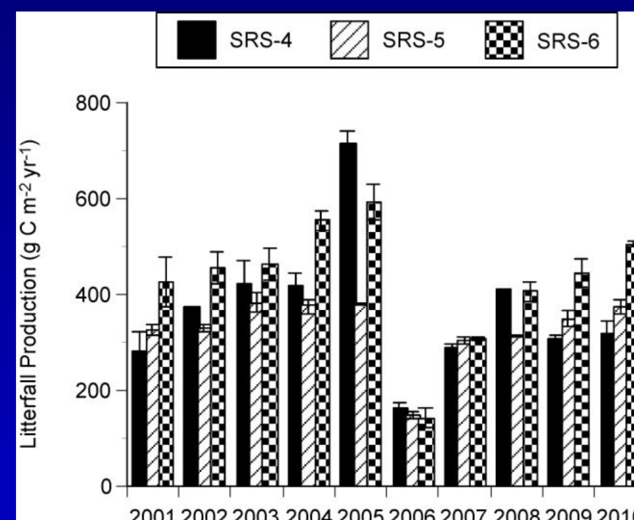
Mangrove Forest in SRS6 before Wilma

PROGRESS

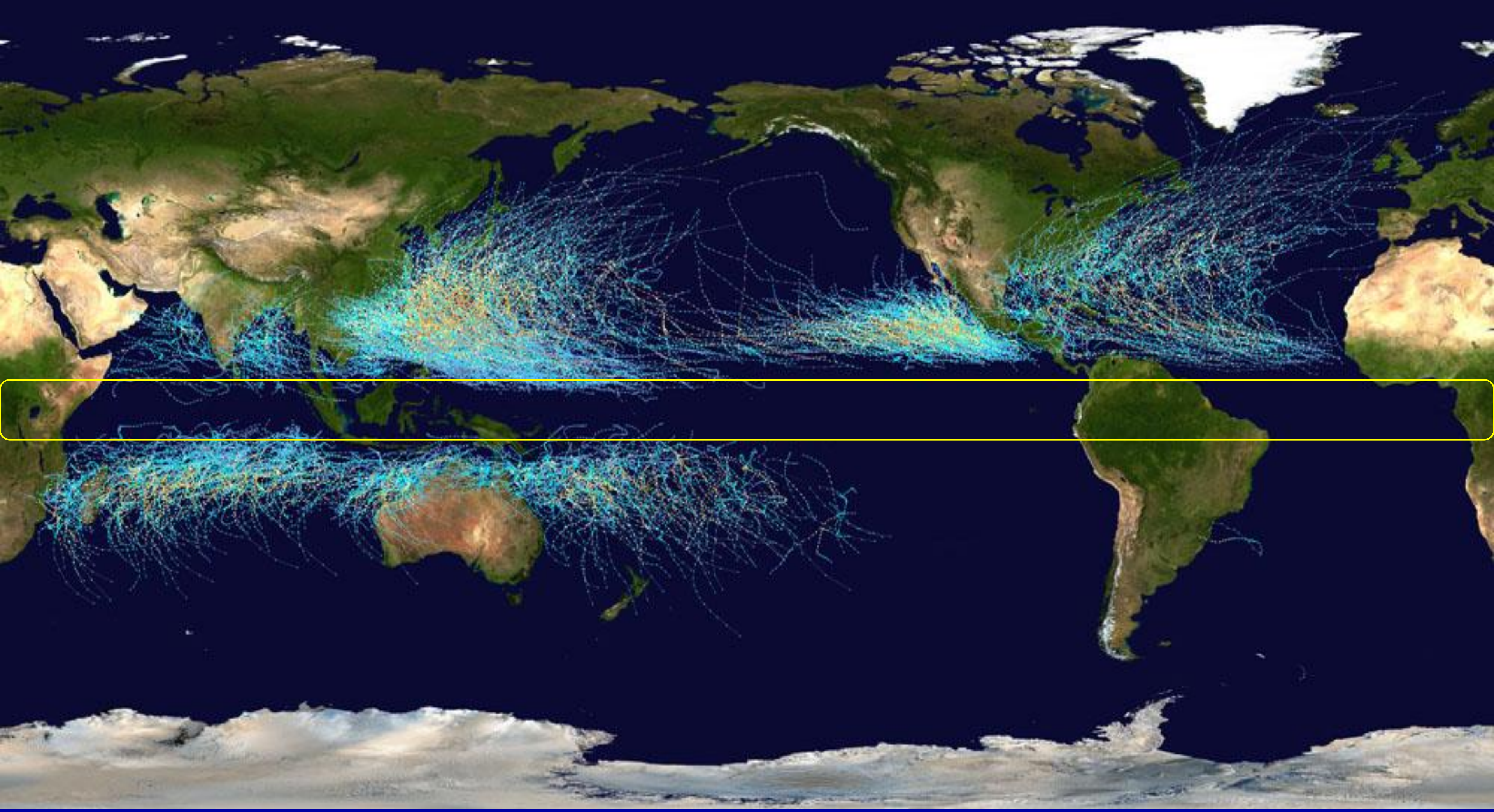
Mangrove Productivity







FCE LTER



Global Cumulative Cyclone Tracks

Frequency Coastal Disturbance; and tropical zone with little cyclone activity

LSU

UNIVERSITY OF LOUISIANA Lafayette

NSF

NCED
Earth · Water · Life

NATIONAL CENTER FOR EARTH-SURFACE DYNAMICS

A NATIONAL SCIENCE FOUNDATION SCIENCE & TECHNOLOGY CENTER

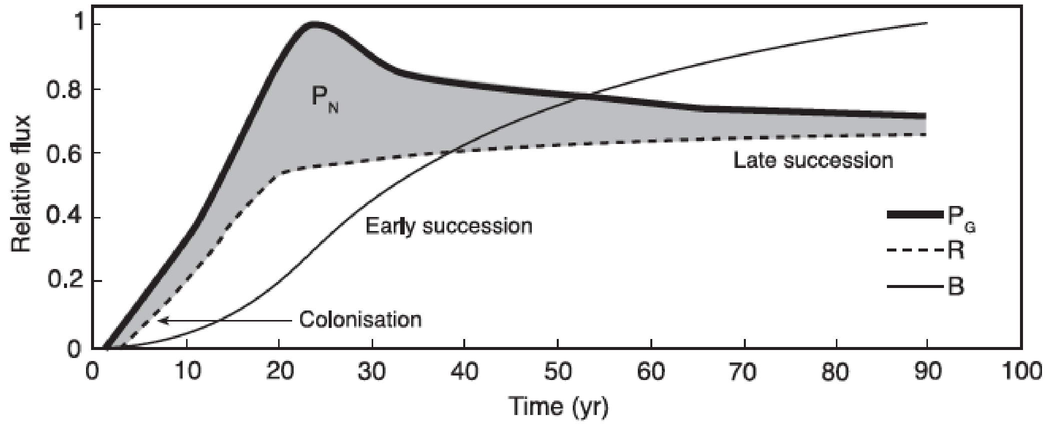


Fig. 1 – The original concept of ecosystem development over time.Modified from Odum (1969).

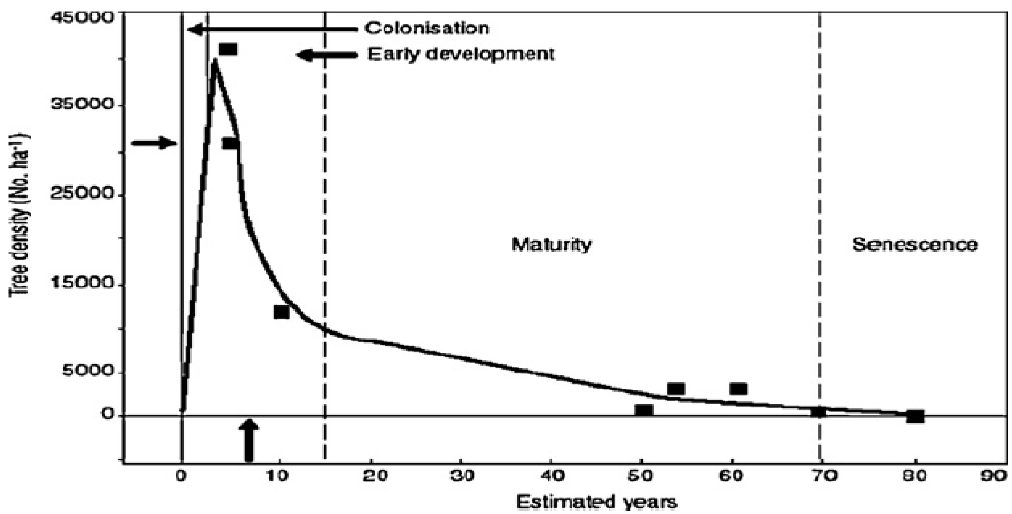


Fig. 2 – Development of mangroves along the French Guiana coast over time.Modified from Fromard et al. (1998).

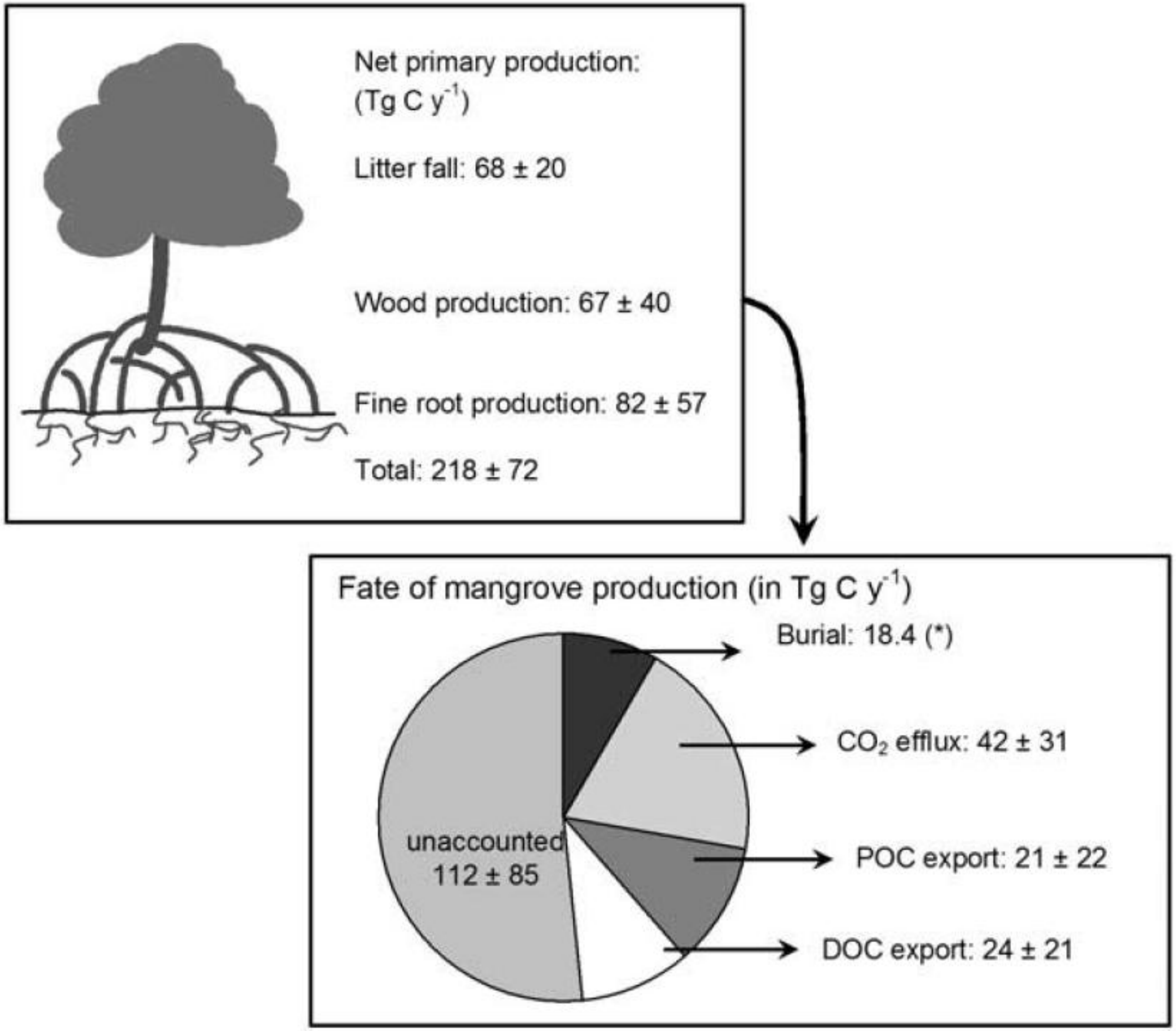
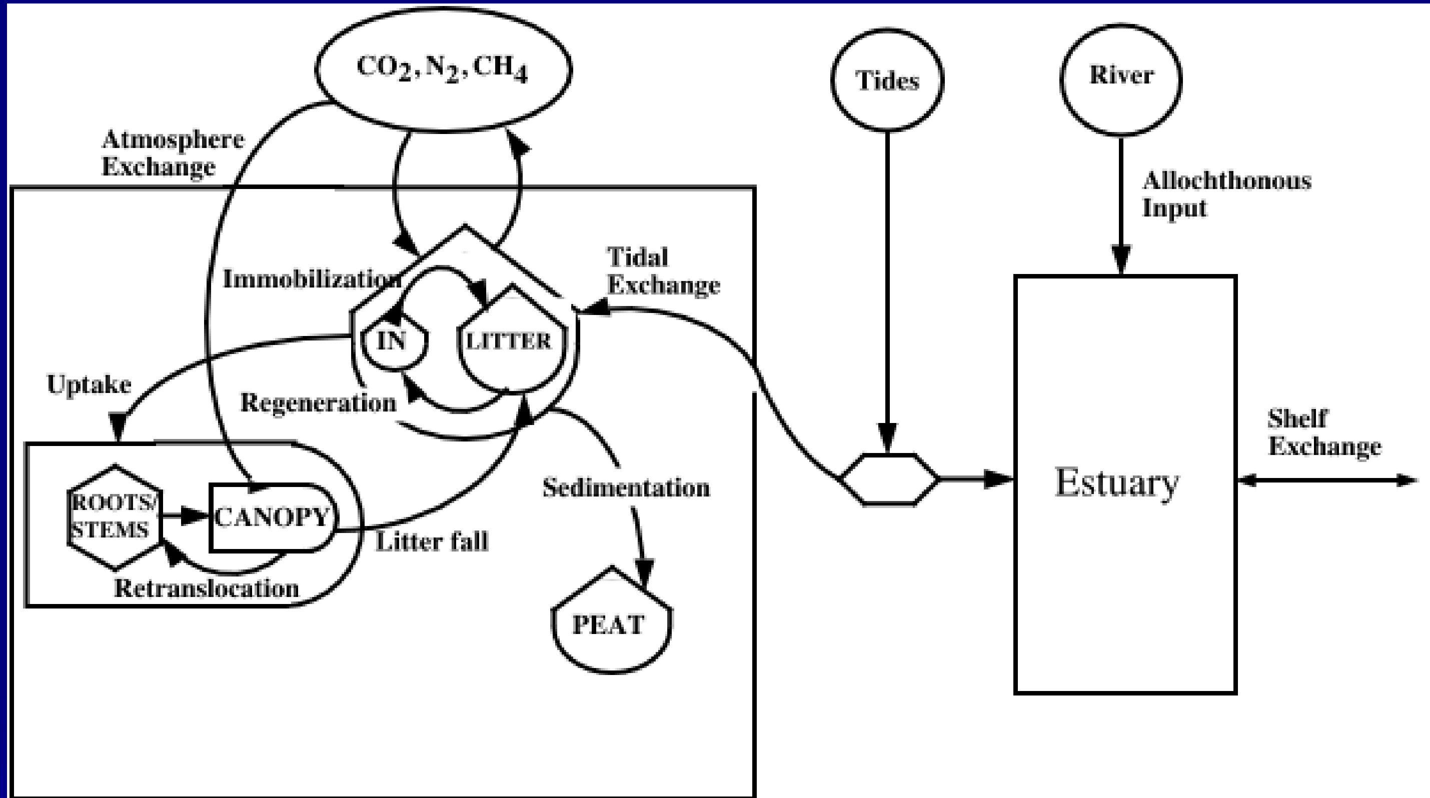


Figure 5. Synthesis of current literature estimates of the fate of mangrove production and a comparison with our estimates of total NPP. Asterisk in Figure 5, bottom, indicates no error estimate reported for organic carbon burial rates.



Atmosphere Exchange = AE
Immobilization = IM
Litter Fall = LF
Retranslocation = RT
Regeneration = RG
Sedimentation = SD
Tidal Exchange = TE
Uptake = UT