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

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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

\[ \text{NPP} = \text{GPP} - \text{Ra} \]
\[ \text{Ra} = \text{respiration of autotrophs} \]

\[ \text{NEP} = \text{GPP} - \text{R}(a+h) \]
\[ \text{Ra} = \text{respiration of Autotrophs + heterotrophs} \]

\[ \text{Ra} + \text{Rh} = \text{Re} (\text{Rt}) \]
\[ \text{Respiration of ecosystem} \]
\[ \text{NEP} = (\text{GPP} + \text{I}) - (\text{Re} + \text{E}) \]
Energy Steady State of Ecosystem = Organic Carbon

\[ \text{NEP} = (\text{GPP} + I) - (\text{Re} + E) \]

Lovett et al. 2006

\[ \Delta \text{Corg} = \text{NEP} \text{ steady state} \]

\[ \Delta \text{Corg} = (\text{GPP} + I) - (\text{Re} + E + \text{Ox}_{nb}) \]

\[ \text{NEP} = (\Delta \text{Corg} + E + \text{Ox}_{nb}) - I \]
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.

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

$$\text{NEP} = (GPP + I) - (R_e + E + Ox_{\text{nb}})$$
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

Mangrove NEP
Wood Production
Soil Carbon Accumulation

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

<table>
<thead>
<tr>
<th></th>
<th>Bouillon et al. estimate</th>
<th>Alongi estimate</th>
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<tbody>
<tr>
<td><strong>Inputs</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GPP</td>
<td>NA</td>
<td>690 ± 264</td>
</tr>
<tr>
<td>NPP</td>
<td>204 ± 68</td>
<td>290 ± 107</td>
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<tr>
<td>Wood</td>
<td>63 ± 40</td>
<td>63 ± 42</td>
</tr>
<tr>
<td>Litter</td>
<td>64 ± 20</td>
<td>64 ± 20</td>
</tr>
<tr>
<td>Roots</td>
<td>77 ± 56</td>
<td>163</td>
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<tr>
<td><strong>Outputs</strong></td>
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<tr>
<td>POC export</td>
<td>20 ± 22</td>
<td>27 ± 25</td>
</tr>
<tr>
<td>DOC export</td>
<td>23 ± 21</td>
<td>13 ± 12</td>
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<tr>
<td>Carbon burial</td>
<td>17</td>
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<tr>
<td>Tree respiration</td>
<td>NA</td>
<td>396 ± 151</td>
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<tr>
<td>Soil + water respiration</td>
<td>39</td>
<td>72 ± 50</td>
</tr>
<tr>
<td>NEP</td>
<td>112 ± 85</td>
<td>155 ± 121</td>
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</table>
Carbonate-based setting Florida Coastal Everglades (FCE)

- Different mangrove types at the same latitudinal gradient.
- Oligotrophic P-limited system.
- P is supplied by the Gulf of Mexico during storm events.

Holdridge’s Life Zone: Subtropical Moist

Total area: 144,000 ha

Florida Bay

Simard et al. (2006); Rivera-Monroy et al. (2011)
**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:** $1120 \pm 316 \text{ Mg C ha}^{-1}$

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

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

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

**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)

**SRS-6**

*Courtesy: Qiang Yao, Ph.D. ongoing dissertation, LSU*
Describe SRS6 with NEP budget (Organic Carbon)

\[
\text{NEP} = (\text{ANPP} + \text{BNPP} + \text{I}_T) - (\text{Re} + \text{E}_T)
\]

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\(^{-1}\)

\[
\text{NEP} = (1150 + 311) - (470 + 550) = 411 \text{ gC m}^{-2} \text{ yr}^{-1}
\]
Describe SRS6 with NEP budget (Organic Carbon)

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\[
\text{NEP} = (1150 + 311) - (470 + 550)
\]

\[
= 411 \text{ gC m}^{-2} \text{ yr}^{-1}
\]

- **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\(^{-1}\)
Transition from ‘Organic Carbon based NEP To Net Ecosystem Carbon Budget (NECB) (Chapin et al. 2006)

\[ \text{NEP} = (\text{GPP} + I) - (\text{Re} + E) \]

\[ \text{ET} = \text{DIC} + \text{DOC} + \text{PC} \]

\[ I_T = \text{DIC} + \text{DOC} + \text{PC} \]

Surface and Ground Water
NECB = (NEE + I_T + F_{atm}) - \(F_{atm} + E_T\)

\(E_T = \text{DIC} + \text{DOC} + \text{PC}\)

\(I_T = \text{DIC} + \text{DOC} + \text{PC}\)

Surface and Ground Water
Jordan Barr, Jose Fuentes, Vic Engel, Joseph Zieman, FCE-LTER

Victor Rivera-Monroy, Edward Castaneda, Steve Davis, Robert Twilley, FCE-LTER
$$\text{NECB} = (\text{NEE} + I_T + F_{\text{atm}}) - (F_{\text{atm}} + E_T)$$

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

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

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

$$\text{NEE} = (\text{NECB} + E_T) = 1541 \text{ gC m}^{-2} \text{ yr}^{-1}$$
\[ \text{NECB} = (\text{NEE} + I_T + F_{\text{atm}}) - (F_{\text{atm}} + E_T) \]

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

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

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

\[ \text{NEE} = (\text{NECB} + E_T) = 900 \text{ gC m}^{-2} \text{ yr}^{-1} \]
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$_2$O, 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.

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

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

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

\[
(DIC + DOC + PC)
\]
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
Mangrove Productivity

Shark Slough Ecotone (SRS4-6)


Total Litterfall (g m⁻² y⁻¹)

Site

Castañeda-Moya, Rivera-Monroy, Twilley, Childers, Gaier et al.

Shark River

2005  2008

Litterfall Production (g C m⁻² y⁻¹)

2001 2002 2003 2004 2005 2006 2007 2008 2009 2010
Global Cumulative Cyclone Tracks
Frequency Coastal Disturbance; and tropical zone with little cyclone activity
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