



Sampling Protocol for C-Assessment in Mangrove System

Daniel Murdiyarso and Boone Kauffman

THINKING beyond the canopy

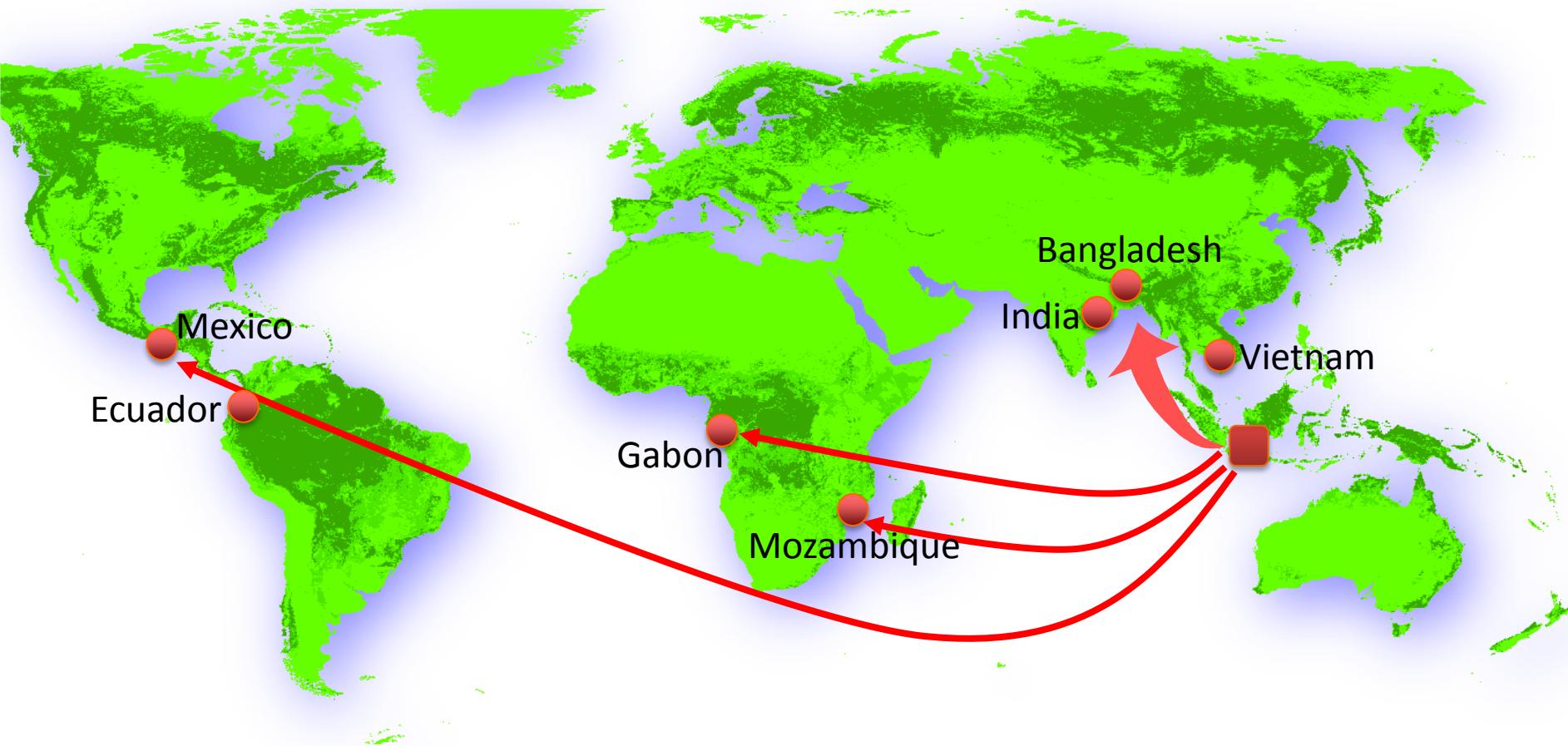




Outline

- Introduction
 - Establishing the network
 - Designing the sample plots
- The sampling protocol
 - Vegetation
 - Wood debris and litter
 - Soil
- Extrapolation: from plot to.....
- IPCC Guidelines:
 - Emission factor
 - Activity data

TWINCAM: A global survey



info brief

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Addressing climate change adaptation and mitigation in tropical wetland ecosystems of Indonesia

Daniel Murdiyarno and J. Boone Kauffman



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Key points

- While it is clear that tropical wetlands, especially peatlands and mangroves, are important in global carbon cycling, what we know about them is still rather patchy.
- Research addressing critical information needs and communicating such results on land use and carbon dynamics of tropical wetlands is greatly needed for sound policy decisions. It is important to study these ecosystems in Indonesia which has more tropical wetlands than anywhere else on Earth. Such science will be relevant to improving IPCC Guidelines on methodologies for greenhouse gas inventories.
- Standardised methods and protocols are needed for effective monitoring, reporting and verification of the land-use/land cover change-related emissions that arise from tropical wetlands.
- Low-lying coastal zones are prone to sea level rise and other oceanic-related climate change responses. Hence, mangroves are not only key to climate change mitigation but also play important roles in adapting to changing coastal conditions due to climate change.
- Conservation and reduction of degradation to tropical wetlands is not only a sound mitigation approach but is also an important adaptation strategy to climate change effects. Mitigation procedures that preserve ecosystem resistance and resilience to climate change are recommended as cost effective and ecologically sound adaptation strategies
- Ecosystem-based or whole watershed approaches could provide the best options for communities to cope with changing climate conditions.

Why are tropical wetlands so important?

Tropical wetland ecosystems, including mangroves and peatlands provide a broad array of ecosystem services. These ecosystems are often highly productive and harbor a unique assemblage of aquatic and terrestrial biodiversity. Wetlands also play an important role in affecting the timing and delivery of water from terrestrial to aquatic ecosystems and provide a buffering function against the transmission of pollutants across this interface.

Mangroves are important sources of energy and nutrients to coral reefs, buffer coastal zones from tropical storms, and are extremely valuable as fish and wildlife nurseries. Among the least studied value of global significance is their function as significant global carbon (C) pools.

According to a recent study (Koh et al. 2011), About 42% of the world's peatlands are found in Asia,

with 21% in Africa, 15% in North and Central America, 12% in Australia and Oceania, and 11% in South America (Giri et al. 2010).

Despite covering only about 0.25% of the Earth's land surface, tropical peatlands contain around 3% of the global soil carbon stocks and at least 20% of global peat carbon (Page et al. 2004, Page and Banks 2007). Indonesia harbors more than 20 Mha peatlands (WI 2003, WI 2004, WI 2006), with carbon stocks estimated at approximately 55 Pg C (Jaenidke et al. 2008). During 2000–2005, the deforestation rate in Indonesian peatlands was estimated around 0.1 Mha per year (MoF 2007). The deforestation was largely related to establishment of unsustainable oil palm and pulp wood plantations resulting in C emissions estimated at an annual rate of 660 Gg C¹ (Koh et al. 2011). The most significant emissions (63%) came from the peat respiration (Hergoualc'h and Verchot 2011).

¹ 1 Gg = 1 Gigagram = 1×10^9 g

Bali, 11-15 April 2011

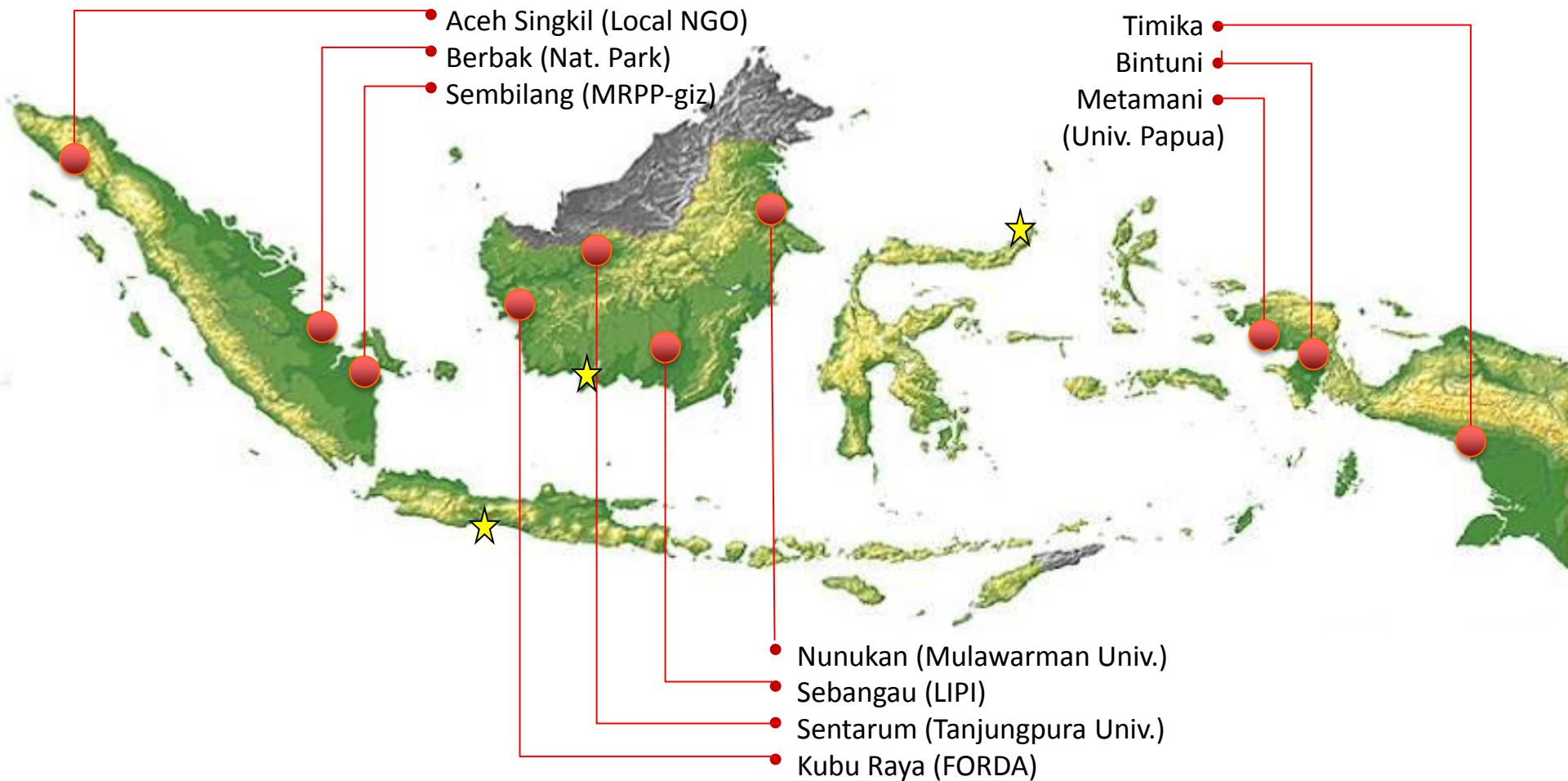
- Partnership with intl. community
- Capacity building
- Pilot
- Funding

Mangroves

- Indonesia has ca. 3 million ha or 23% world's mangrove area
- There are more mangroves in Indonesia than any continents

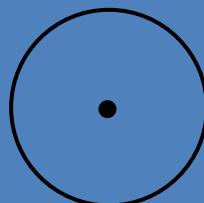


Research network in Indonesia

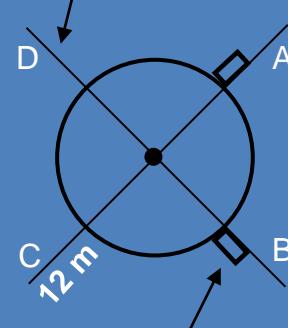


Sampling plot and sub plots

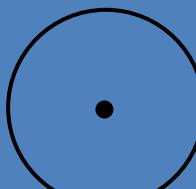
Trees >5 cm dbh
measured in 7m radius
(all plots)



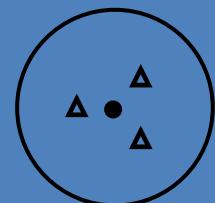
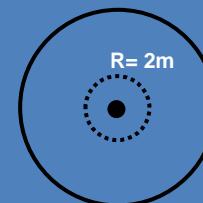
Wood debris transects
(4 per plot, all plots)



Understory/litter sample
(2 per plot, all plots)



Trees <5 cm dbh
measured in 2m radius
(all plots)



3 soil depth
measurements and 1
nutrient core (all plots)

Plot: 1



25 m

2



25 m

3



4

5

6

Marine ecotone



Sonneratia sp.



Rhizophora sp.



Avicennia sp.



Bruguiera sp.

Stem diameter for allometric equation



Allometric equations

Species	Equation	R ² ; N	Reference	Location	D _{max}
<i>Rhizophora apiculata</i>	B = 0.1709D ^{2.516}	0.98; N=20	Putz and Chan 1986	Malaysia	30
<i>Rhizophora apiculata</i> (wood mass)*	B _{wood} = 0.0695D ^{2.644*} p	0.89; N=191	modified from Cole et al. 1999 and Kauffman and Cole 2010	Micronesia	60
<i>Rhizophora apiculata, stylosa</i> (leaf mass)	B _{leaf} = 0.0139D ^{2.1072}	0.86; N=23	Clough and Scott 1989	Australia	23
<i>Rhizophora apiculata/stylosa</i> (Stilt roots)	B _{stiltroots} = 0.0068D ^{3.1353}	0.97; N=23	Clough and Scott 1989	Australia	23

Allometric equations

	N	D _{max}	Max H		R ²
General Equation	84	42		B = 0.0509 * ρ * (D) ² * ht	
<i>Bruguiera gymnorhiza</i>	325	132.0	34	0.0464 * (D ² H) ^{0.94275*} ρ	0.96
<i>Sonneratia alba</i>	345	323.0	42	0.0825 * (D ² H) ^{0.89966*} ρ	0.95
<i>Rhizophora apiculata</i>	193	60.0	35	0.0444 * (D ² H) ^{0.96842*} ρ	0.96
<i>Rhizophora mucronata</i>	73	39.5	21	0.0311 * (D ² H) ^{1.00741*} ρ	0.95
<i>Rhizophora spp.</i>	265	60.0	35	0.0375 * (D ² H) ^{0.98626*} ρ	0.95
<i>Lumnitzera littorea</i>	20	70.6	19	0.0214 * (D ² H) ^{1.05655*} ρ	0.93
<i>Xylocarpus granatum</i>	115	128.5	31	0.0830 * (D ² H) ^{0.89806*} ρ	0.95

B = biomass (kg), ht = height (m), D = diameter at breast height (cm), ρ = wood density (g cm⁻³), D_{MAX}= maximum diameter of sampled trees (cm). Additional equations can be found in Komiyama et al. (2008), and Smith and Whelan 2006.

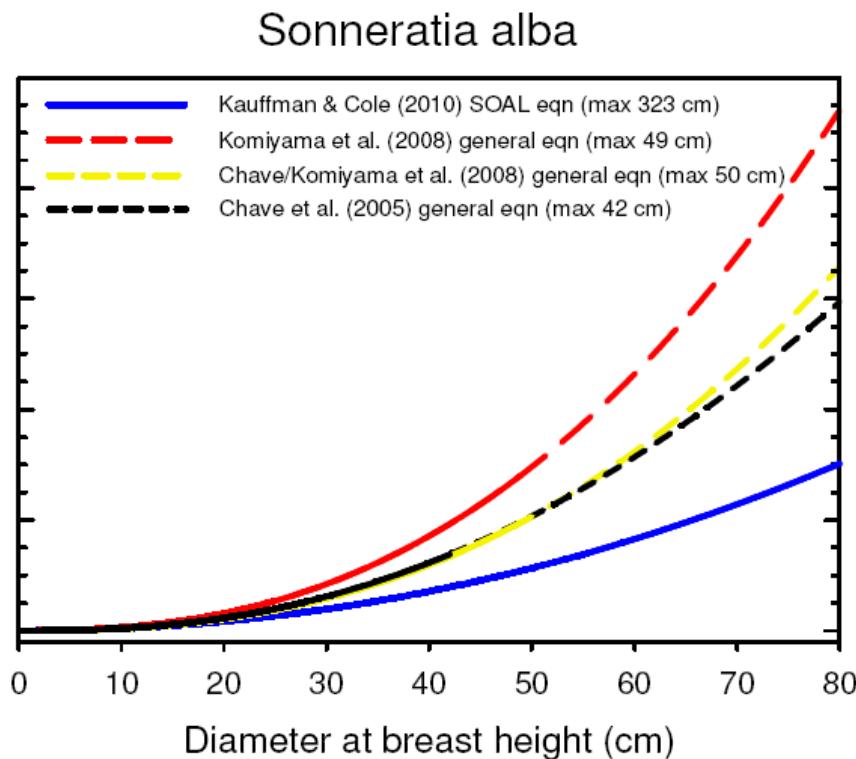
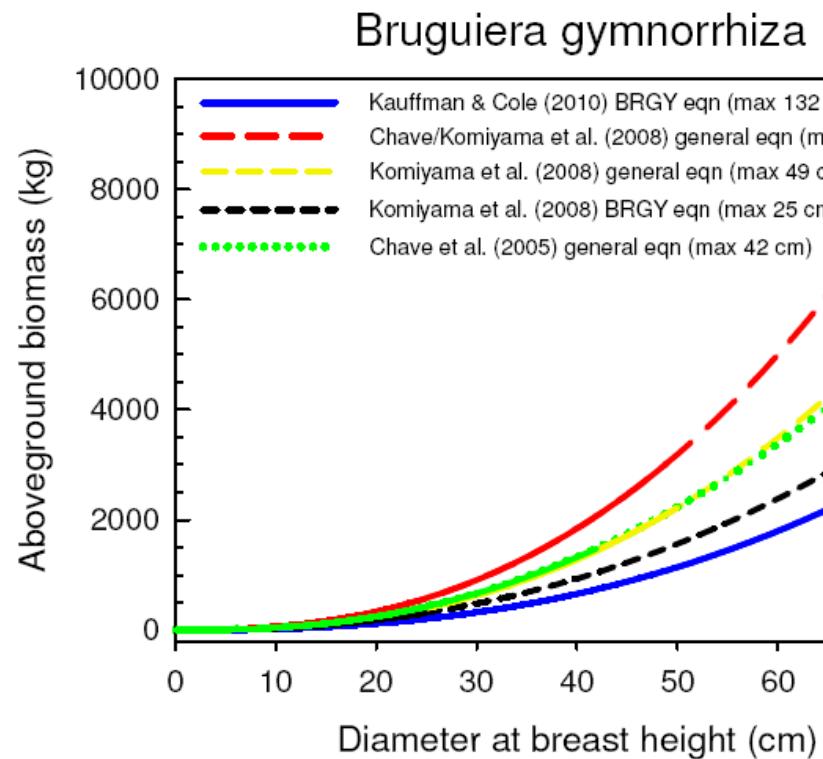




Wood density

Species	Wood density, ρ (g cm ⁻³)
<i>Rhizophora apiculata</i>	1.050
<i>Rhizophora mangle</i>	0.830
<i>Sonneratia alba</i>	0.0780
<i>Avicennia germinans</i>	0.661
<i>Laguncularia racemosa</i>	0.600
<i>Avicennia officinalis</i>	0.670
<i>Bruguiera gymnorhiza</i>	0.860
<i>Ceriops decandra</i>	0.960
<i>Excoecaria agallocha</i>	0.450
<i>Heritiera fomes</i>	1.074
<i>Sonneratia apetala</i>	0.559
<i>Xylocarpus granatum</i>	0.700
<i>Xylocarpus mekongensis</i>	0.725
<i>Site average of above values</i>	0.752

Comparisons: by species and diameter classes



Kauffman and Cole (2010)

Standing dead trees

Taper equation for estimating the top-diameter of a broken-topped dead tree:

$$d_{top} = d_{base} - \left[100 * ht * \left(\frac{(d_{base} - dbh)}{130} \right) \right]$$

d_{top} = estimated diameter at top of tree (cm)

d_{base} = the measured basal diameter (cm)

ht = tree height (m)

db.h = tree d.b.h. (cm)

Then volume is determined by assuming the tree is a truncated cone:

$$\text{Volume (cm}^3\text{)} = \left(\frac{\pi * (100 * ht)}{12} \right) * (d_{base}^2 + d_{top}^2 + (d_{base} * d_{top}))$$

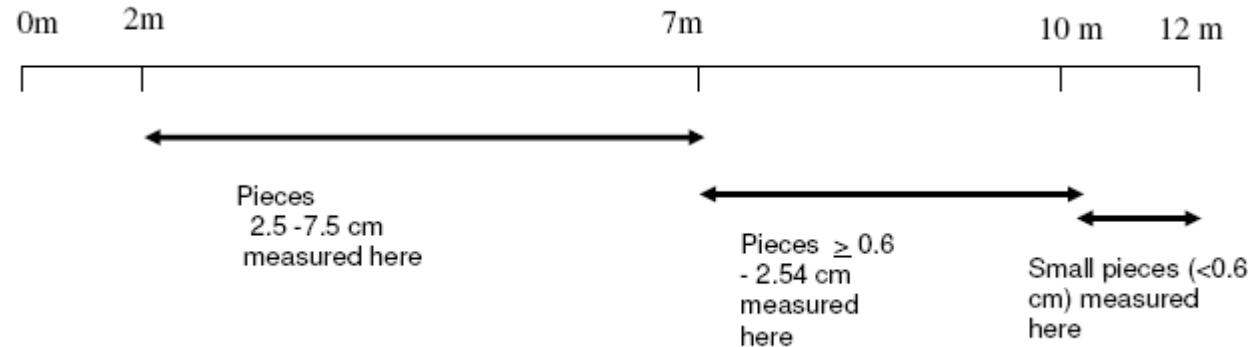
ht = tree height (m)

d_{base} = the basal diameter (cm)

d_{top} = the diameter at the top (cm) estimated from the taper equation (if taper equation results in negative number, use 0 for d_{top}).

Wood debris

- Fine : < 0.6 cm (count along 10-12 m)
Small : 0.6 - 2.5 cm (count along 7-10 m)
Medium : 2.5 - 7.5 cm (count along 2-7 m)
Large : >7.5 cm (measure, sound and rotten)

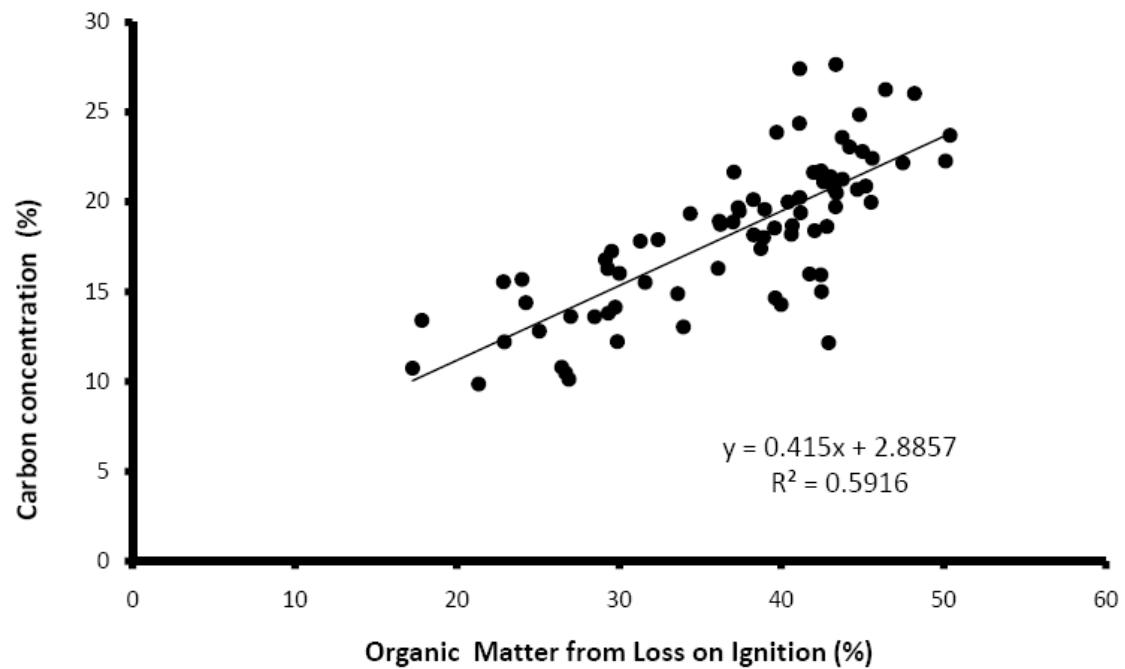


Soil depth and sampling

Intervals: 0-15 cm, 15-30 cm, 30-50 cm, 50-100 cm, 100-300 cm



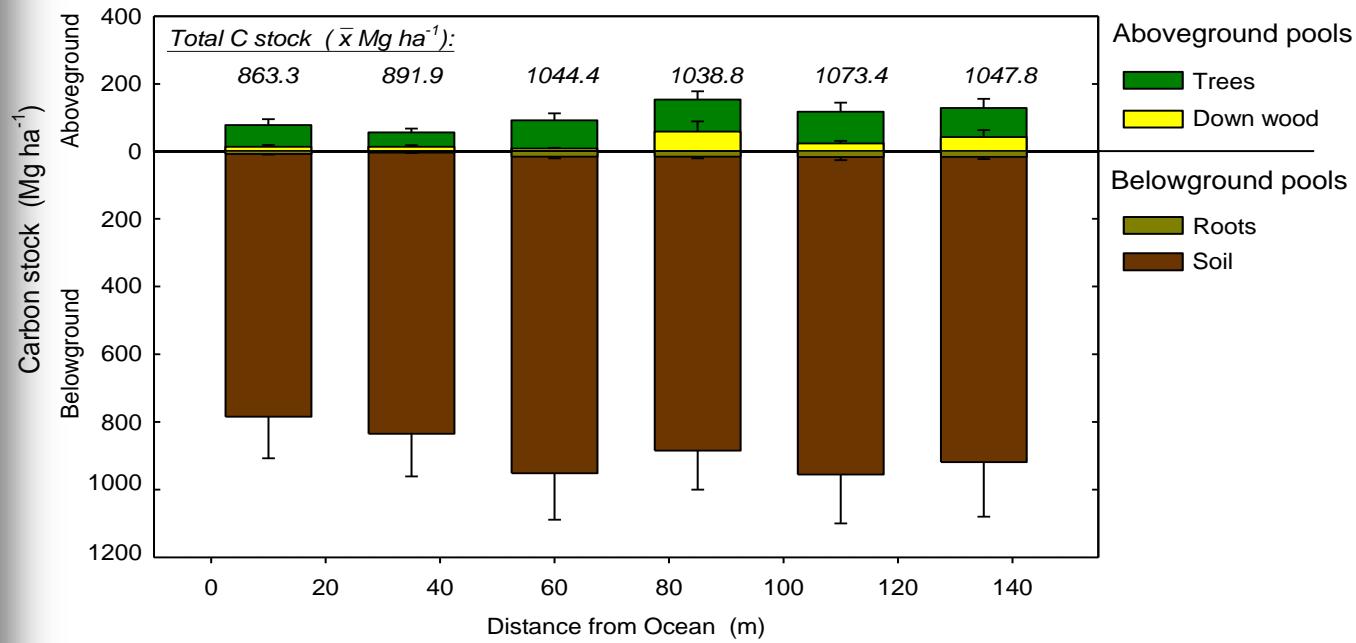
Soil sample analysis



Kauffman et al. (2011)



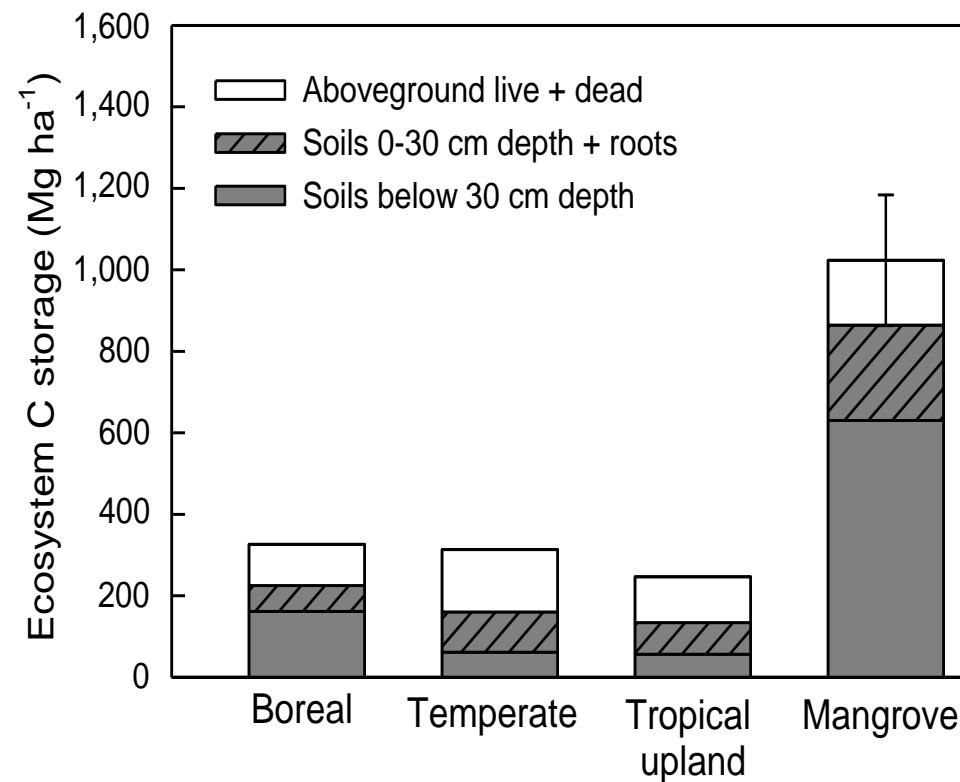
C-stocks in mangroves



Murdiyarno *et al.* (2010)



Large belowground pools



Donato et al., (2011)

Extrapolation

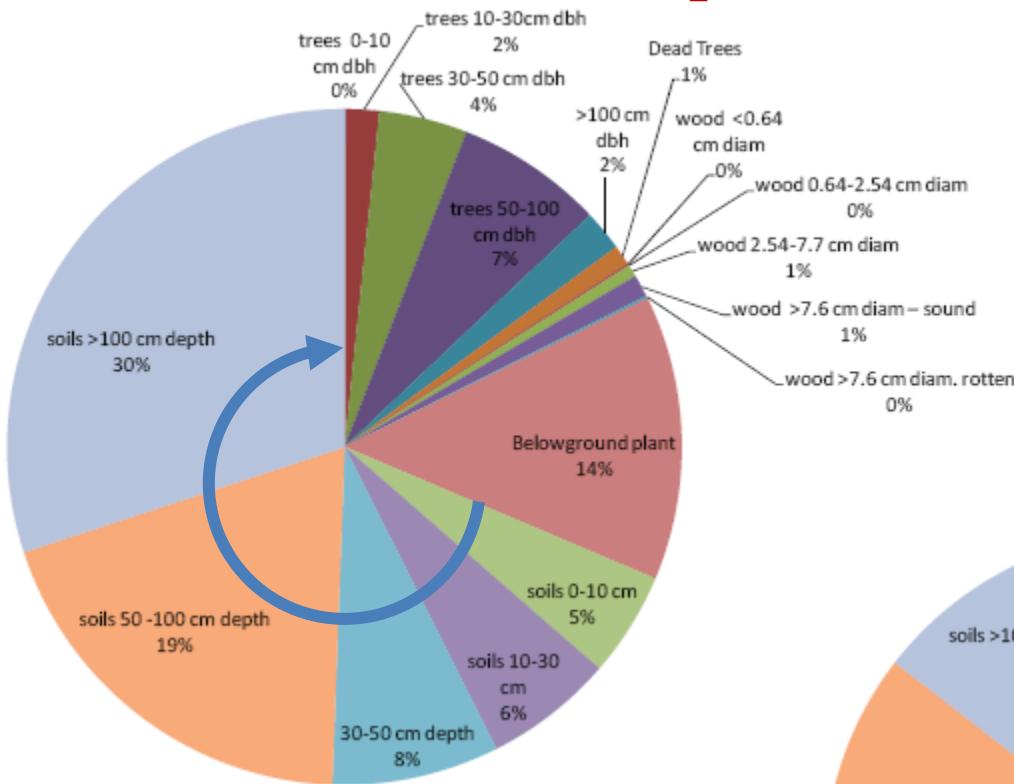
Component	Plot	Stand	Ecosystem C-pools	Nat/Sub national
Vegetation	Allometric (Mg plot ⁻¹)	Allometric (Mg ha ⁻¹)		
Wood debris	$QMD = \sqrt{(\sum d_i^2)/n}$	$SG \times (\pi^2(N_i \times QMD_i^2) + \pi^2(d_1^2+d_2^2..dn^2/8L))$ (Mg ha ⁻¹)	$\Sigma = TCS$ (V+WD+S)	TCS x area
Soil	BD x depth x %C (Mg plot ⁻¹)	Averaged plot (Mg ha ⁻¹)	(Mg ha ⁻¹)	(Mg)

- ↑
- By species
 - By biome

↑

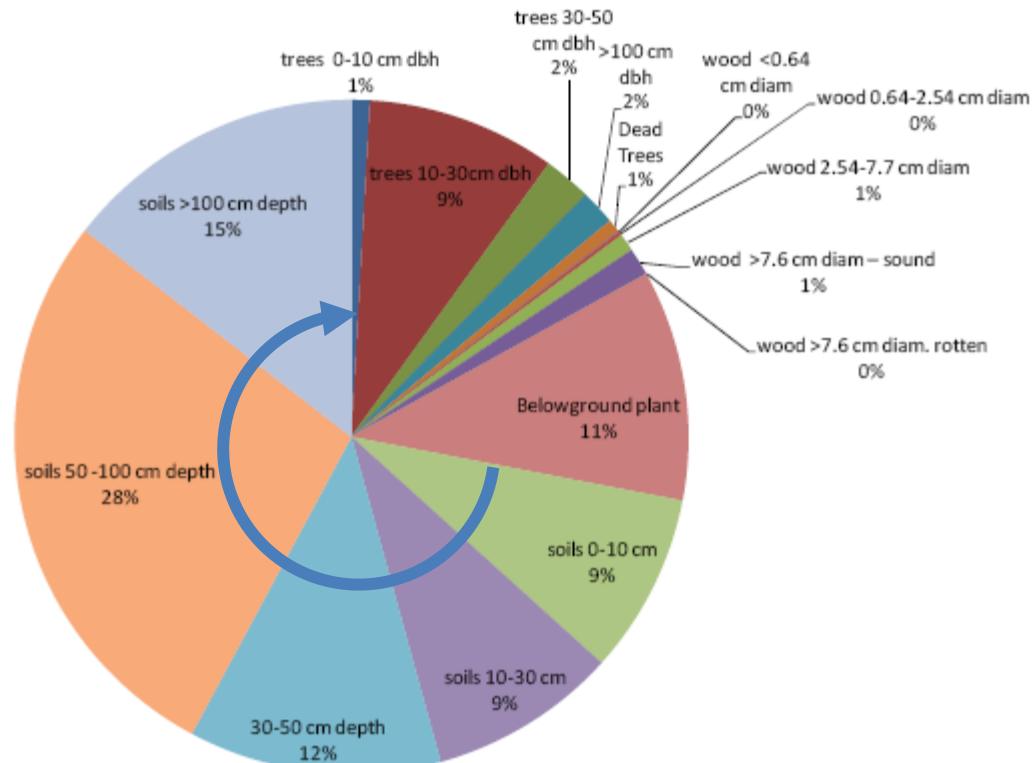
$\Delta C = \text{emission factor}$
(Mg y⁻¹)

Ecosystem C-pools



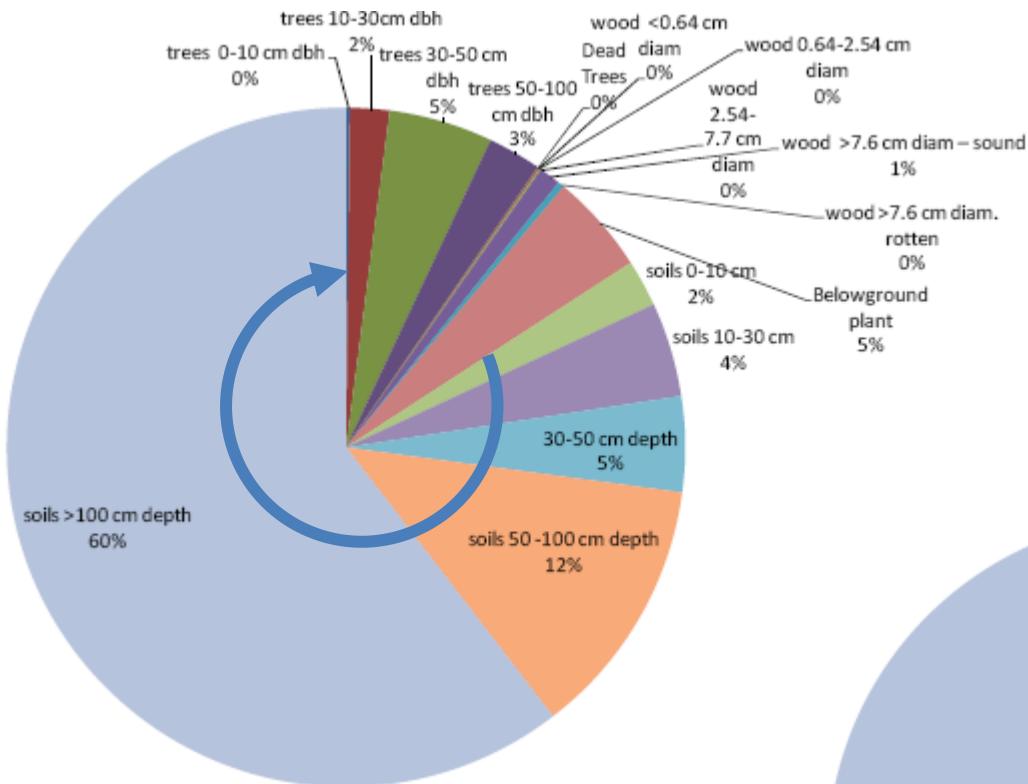
Coastal Fringe Yap FSM
1066 Mg/ha
(68%)

Coastal Fringe, Republic of Palau
723 Mg/ha
(73%)



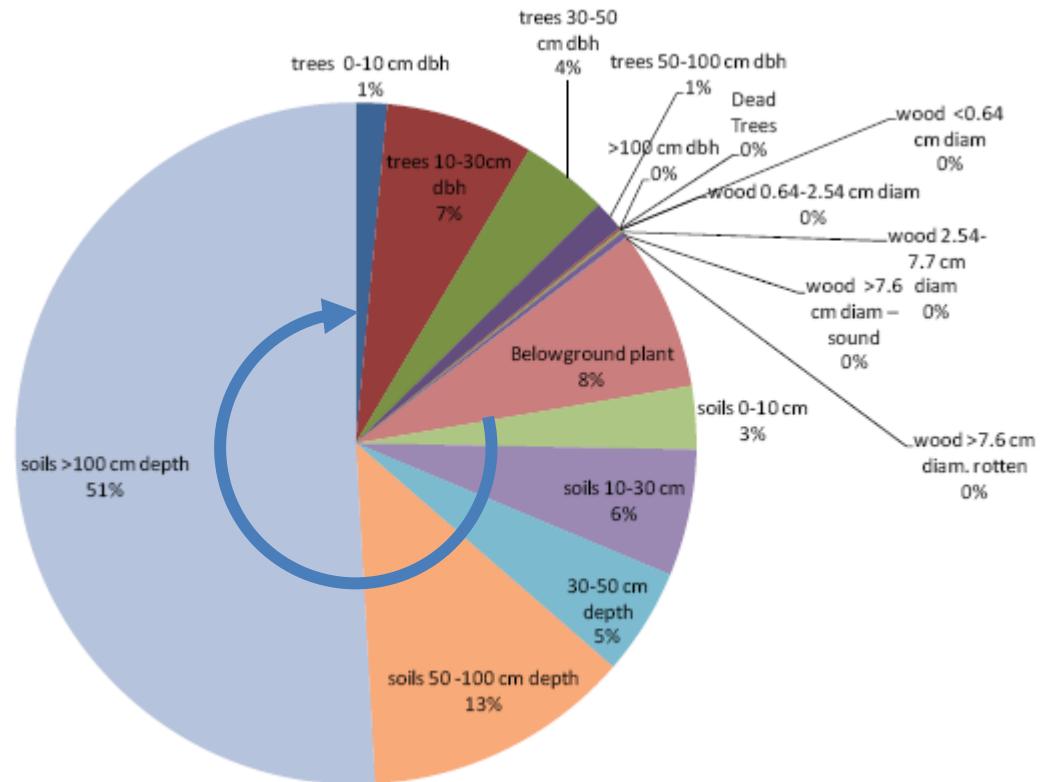
Kauffman and Donato (2011)

Ecosystem C-pools



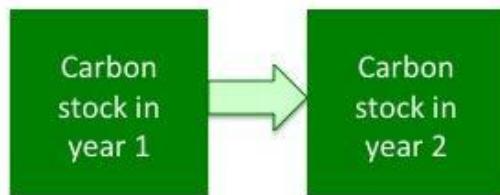
Kalimantan, Indonesia Riverine
1259 Mg/ha
(83%)

Sundarbans, Bangladesh
566 Mg/ha
(78%)



IPCC Guidelines - 2006

Stock-change approach



$$\Delta C = (C_{t2} - C_{t1}) / (t_2 - t_1)$$

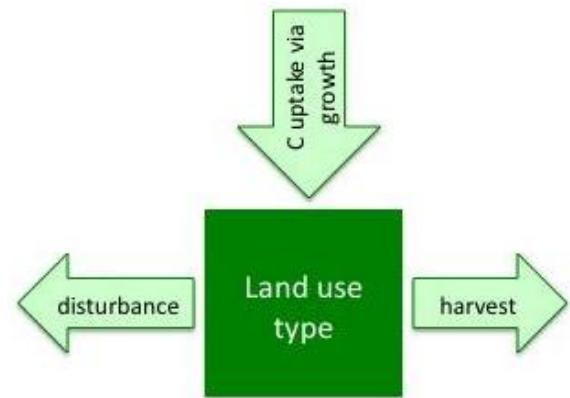
Where:

ΔC = annual carbon stock change in pool (t C/yr)

ΔC_{t1} = carbon stock in pool at time t_1 (t C)

ΔC_{t2} = carbon stock in pool at time t_2 (t C)

Flux-change approach



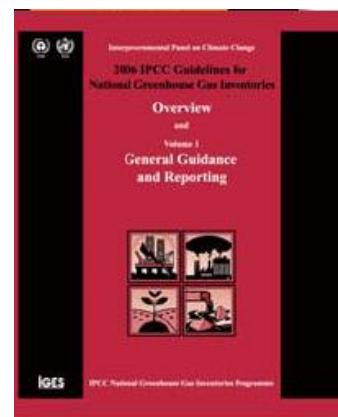
$$\Delta C = \Delta C_{\text{gain}} - \Delta C_{\text{loss}}$$

Where:

ΔC = annual carbon stock change in pool (t C/yr)

ΔC_{gain} = annual gain in carbon (t C/yr)

ΔC_{loss} = annual loss in carbon (t C/yr)



Source: IPCC (2006)

IPCC Guidelines - 2006

TABLE 7.1 SECTIONS ADDRESSING MAJOR GREENHOUSE GAS EMISSIONS FROM MANAGED WETLANDS		
Land-use category/GHG	Peatlands	Flooded Land
Wetlands Remaining Wetlands		
CO ₂	Section 7.2.1.1	No Guidance ¹
CH ₄	No Guidance ²	Appendix 3
N ₂ O	Section 7.2.1.2	No Guidance ³
Lands Converted to Wetlands		
CO ₂	Section 7.2.2.1	Section 7.3.2.1 and Appendix 2
CH ₄	No Guidance ²	Appendix 3
N ₂ O	Section 7.2.2.2	No Guidance ³
NOTES:		
¹ CO ₂ emissions from <i>Flooded land Remaining Flooded land</i> are covered by carbon stock change estimates of land uses and land-use change (e.g., soils) upstream of the Flooded Land.		
² Methane emission from peatlands is negligible after drainage during conversion and peat extraction.		
³ N ₂ O emissions from Flooded Land are included in the estimates of indirect N ₂ O from agricultural or other run-off, and waste water.		

Side Event – Don't miss it....!



Photo by Daniel Murdiyoso

Friday

10 June 2011

18.15 – 19.45

RAIL room,

Ministry of Transport

Programme

Chair:

Daniel Murdiyoso, CIFOR

1. Stocks and fluxes of carbon associated with land use change in Southeast Asian tropical peatlands: A review
Louis Verchot, CIFOR

2. Targeting tropical wetlands for climate adaptation and mitigation
Matthew Warren, US Department of Agriculture's Forest Service

3. Development of IPCC guidance on wetlands
Simon Eggleston, IPCC Task Force on National Greenhouse Gas Inventories

4. Challenges of climate change adaptation in Sundarban mangrove forest of Bangladesh
S.M. Munjurul Hannan Khan, Government of Bangladesh

Discussion

Refreshments will be served.

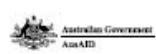
Tropical wetlands initiative for climate change adaptation and mitigation

Recent studies demonstrate that carbon stocks in peatlands and mangroves of Southeast Asia are almost five times higher than carbon stocks in upland tropical and temperate forests. However, methodologies are lacking for countries to assess and communicate their greenhouse gas inventories. Even IPCC guidelines are not readily applicable to such ecosystems in the tropics, which could very well benefit from REDD+. Emissions factors associated with land use change and activity data in these ecosystems need to be revisited so that peatlands and mangroves are included in mitigation schemes.

Climate change is already affecting these wetlands and the people whose livelihoods depend on them, through rising sea levels, increasing soil salinity, changing temperature and rainfall patterns, increasing number and severity of cyclones, and increasingly frequent extreme weather events. These stressors require adaptation strategies. Bundling adaptation and mitigation strategies would enhance the benefit to communities that have relatively low capacity to adapt and yet most vulnerable to and hard hit by climate change.

This side event will present a conceptual framework, what we know to date and lessons learnt to enhance the roles of wetlands in climate change adaptation and mitigation.

For more information, contact Daniel Murdiyoso at d.murdiyoso@cgiar.org.



Bonn, SB-34 Side event

- SBSTA-32 to revise the IPCC 2006 for Annex 1 reporting guidelines for GHG emissions and removals
- Invited IPCC to hold an Expert Meeting to “*explore the need to clarify methodological issues related to... wetlands...*
- Synergizing adaptation strategies and measures
 - Tropical wetlands should be in the agenda

Thank you



Two recent publications

PNAS
PNAS

Opportunities for reducing greenhouse gas emissions in tropical peatlands

D. Murdiyars¹, K. Hergoualc'h, and L. V. Verchot
Center for International Forestry Research, Jalan CIFOR, Situgede, Bogor 16115, Indonesia
Edited by Ruth S. DeFries, Columbia University, New York, NY, and approved October 12, 2010 (received for review October 22, 2009)

The upcoming global mechanism for reducing emissions from deforestation and forest degradation in developing countries should include and prioritize tropical peatlands. Forested tropical peatlands in Southeast Asia are rapidly being converted into agribusiness, such as oil-palm and pulpwood plantations, causing large greenhouse gas (GHG) emissions. The Intergovernmental Panel on Climate Change Guidelines for GHG Inventory on Agriculture, Forestry, and Other Land Uses provide an adequate framework for emissions inventories in these ecosystems; however, specific emission factors are needed for more accurate and cost-effective monitoring. The emissions are governed by complex biophysical processes, such as peat decomposition and compaction, nutrient availability, soil water content, and water table level, all of which are affected by management practices. We estimate that total carbon loss from converting peat swamp forests into oil palm is 59.8 ± 10.2 Mg of CO₂ per hectare per year during the first 25 y after land-use change, or which 61.6% per year from the peak. Of the total amount ($1,486 \pm 183$ Mg of CO₂ per hectare over 25 y), 25% are released immediately from land-clearing fire. In order to maintain high oil-palm production, nitrogen inputs through fertilizers are needed and the magnitude of the resulting increased N₂O emissions compared to CO₂ losses remains unclear.

drainage | respiration | gain-loss approach | stock-difference approach

Globally, peatlands cover an area of 400 million hectare, which is equivalent to 3% of the Earth's land area. These ecosystems store a large fraction of terrestrial carbon, as much as 528 Pg (Pg = 1×10^{15} g), or one-third of global soil carbon (1). This quantity is equivalent to the amount of burning fossil fuels that would be emitted to the atmosphere from burning fossil fuels at the current annual global rate (approximately 7 Pg in 2007) for the next 75 y.

One-third of the carbon stored in peatlands (191 Pg) is located in the tropics (3, 4), of which 60% is in Southeast Asia with an estimated area of 25 million hectare (Mha). The majority (84%) of Southeast Asian peatlands are found in Indonesia (around 21 Mha), whereas East Malaysia (2–2.5 Mha), Thailand (around 45,000 ha), and relatively small areas are found in Vietnam, Brunei, and the Philippines (5).

Tropical peatlands are an important terrestrial carbon pool, but they are highly vulnerable and have become a major source of carbon emissions that requires policy changes to allow mitigation measures to take place. During the period of 2000–2005, the deforestation rate in Indonesian peatlands was estimated around 0.1 Mha per annum (6). Adding to this, the area of peatlands burnt during the big fire in 1997 was 2.12 Mha (7).

The main driver of tropical peatlands deforestation is the development of oil-palm and pulpwood plantations (8). Indonesia and Malaysia, which currently account for 85% of the world's supply of crude palm oil, aim at supplying Chinese, Indian, and European markets. If crude palm oil demand increases, there could be much more pressure on the forested land in the region. For example, in order to substitute 1% of fossil fuel use with biofuels for electricity production, Europe would consume the oil production of at least 2 Mha of oil-palm plantations (9).

Author contributions: D.M. and L.V.V. designed research; D.M. and K.H. performed research; D.M., K.H., and L.V.V. analyzed data; and D.M., K.H., and L.V.V. wrote the paper.
The authors declare no conflict of interest.
This article is a PNAS Direct Submission.
To whom correspondence should be addressed. E-mail: d.murdiyars@cgiar.org.
doi:10.1073/pnas.091966108/DCSupplemental.

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SPECIAL FEATURE

ENVIRONMENTAL SCIENCES

AGRICULTURAL SCIENCES

nature
geoscience

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Mangroves among the most carbon-rich forests in the tropics

Daniel C. Donato^{1*}, J. Boone Kauffman², Daniel Murdiyars³, Sofyan Kurnianto³, Melanie Stidham⁴, and Markku Kanninen⁵

Mangrove forests occur along ocean coastlines throughout the tropics, and support numerous ecosystem services, including fisheries production and nutrient cycling. However, the areal extent of mangrove forests has declined by 30–50% over the past half century as a result of coastal development, aquaculture expansion and over-harvesting^{1,2}. Carbon emissions resulting from mangrove loss are uncertain, owing in part to a lack of broad-scale data on the amount of carbon stored in these ecosystems, particularly below ground³. Here, we quantified whole-ecosystem carbon storage by measuring tree and dead wood biomass, soil carbon content, and soil depth in 25 mangrove forests across a broad area of the Indo-Pacific region—spanning 30° of latitude and 73° of longitude—where mangrove area and diversity are greatest^{4,5}. These data indicate that mangroves are among the most carbon-rich forests in the tropics, containing on average 1,023 Mg carbon per hectare. Organic-rich soils ranged from 0.5 m to more than 3 m in depth and accounted for 49–98% of carbon storage in these systems. Combining our data with other published information, we estimate that mangrove deforestation generates emissions of 0.02–0.12 Pg carbon per year—as much as around 10% of emissions from deforestation globally, despite accounting for just 0.7% of tropical forest area^{6,7}.

Deforestation and land-use change currently account for 8–20% of global anthropogenic carbon dioxide (CO₂) emissions, second only to fossil fuel combustion⁸. Recent international climate agreements highlight Reduced Emissions from Deforestation and Degradation (REDD+) as a key and relatively cost-effective option for mitigating climate change; the strategy aims to maintain terrestrial carbon (C) stores through financial incentives for conservation (for example, carbon credits). REDD+ and similar programs require rigorous monitoring of C pools and emissions^{9,10}. No studies so far have integrated the necessary measurements for total mangrove C storage across broad geographic domains.

In this study we quantified whole-ecosystem C storage in mangroves across a broad tract of the Indo-Pacific region, the geographic core of mangrove area (~40% globally) and diversity^{4,5}. Study sites comprised wide variation in stand composition and stature (Fig. 1, Supplementary Table S1), spanning 30° of latitude (8° S–22° N), 73° of longitude (90°–163° E), and

including eastern Micronesia (Kosrae); western Micronesia (Yap and Palau); Sulawesi; Java; Borneo (Indonesia); and the Sundarbans (Ganges-Brahmaputra Delta, Bangladesh). Along transects running inland from the seaward edge, we combined

above- and below-ground C pools as a function of distance from the seaward edge in two major geomorphic settings:

estuarine/river-delta and oceanic/fringe. Estuarine mangroves

Overlooked in this discussion are mangrove forests, which occur along the coasts of most major oceans in 118 countries, adding ~30–35% to the global area of tropical wetland forest over peat swamps alone^{10,12}. Renowned for an array of ecosystem services, including fisheries and fibre production, sediment regulation, and storm/tsunami protection^{1–4}, mangroves are nevertheless declining rapidly as a result of land clearing, aquaculture expansion, overharvesting, and development^{1–4}. A 30–50% areal decline over the past half-century¹³ has prompted estimates that mangroves may functionally disappear in as little as 100 years (refs 1,2). Rapid twenty-first century sea-level rise has also been cited as a primary threat to mangroves¹⁴, which have responded to past sea-level changes by migrating landward or upward¹⁵.

Although mangroves are well known for high C assimilation and flux rates^{16–22}, data are surprisingly lacking on whole-ecosystem carbon storage—the amount which stands to be released with land-use conversion. Limited components of C storage have been reported, mostly tree biomass^{7,11,21}, but evidence of deep organic-rich soils^{22–25} suggests these estimates miss the vast majority of total ecosystem carbon. Mangrove soils consist of a variably thick, tidally submerged subsoil layer (variously called ‘peat’ or ‘muck’) supporting anaerobic decomposition pathways and having moderate to high C concentration^{16,20,21}. Below-ground C storage in mangrove soils is difficult to quantify^{5,24} and is not a simple function of measured flux rates—it also integrates thousands of years of variable deposition, transformation, and erosion dynamics associated with fluctuating sea levels and episodic disturbances¹⁵.

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including eastern Micronesia (Kosrae); western Micronesia (Yap and Palau); Sulawesi; Java; Borneo (Indonesia); and the Sundarbans (Ganges-Brahmaputra Delta, Bangladesh). Along

transects running inland from the seaward edge, we combined

above- and below-ground C pools as a function of distance from the seaward edge in two major geomorphic settings:

estuarine/river-delta and oceanic/fringe. Estuarine mangroves

(n = 10) were situated on large alluvial deltas, often with a

protected lagoon; oceanic mangroves (n = 15) were situated in

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