Carbon budgets under different land uses on tropical peatland

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Summary

Tropical peatland contains about 3% of the total global soil carbon and much of this is being released from store to the atmosphere as greenhouse gases (GHG), mostly CO_2, and particulates (PM_{10}) as a result of over-intensive logging, deforestation, drainage, land use change and fire. Between 0.87 and 2.57 Gt of carbon were released to the atmosphere as a result of forest and peat fires in Indonesia in the 1997 El Niño year, equivalent to 3–10 Gt CO_2. In the subsequent 10 years it is estimated that up to 20 Gt CO_{2e} have been released from Indonesia's peatland as a result of peat subsidence (decomposition and oxidation) from land use change and fire (conversion to farming and plantations). We present 25 year life cycle comparisons of the impact of different land uses on tropical peatland in Indonesia (oil palm and pulp tree plantations) on CO_{2e} emissions compared to the natural, forested state and deforested, drained and degraded areas.

Key index words: tropical peatland, carbon, carbon dioxide, oil palm, climate change

Introduction

Tropical peatlands occupy around 400,000 km^2 (Page *et al.*, this volume), of which the largest portion (67%) is located in South-east Asia, particularly in Indonesia (55%, ~207,000 km^2), Malaysia (7%, ~25,000 km^2) and Papua New Guinea (4%, 17,000 km^2). Whilst they account for only some 10-12% of the global peatland resource by area, owing to their considerable thickness and high carbon (C) content, they contain a significantly larger proportion of the global peatland C pool. The tropical peatlands of South-east Asia alone contain an estimated 50 Gt[1] C (Page *et al.*, this volume), i.e. 9-14% of the global peatland C store (350-535 Gt C, Gorham, 1991) and up to 3.7% of the total soil C pool (1395 Gt C; Adams *et al.*, 1990). Large areas of peatland in Indonesia and Malaysia have been developed to provide land for cultivation, principally for oil palm and pulpwood (*Acacia*) plantations that produce raw materials for the vegetable oil, biofuel, pulp and paper industries. In addition to peatland that supports some level of economic production, there is also a substantial proportion, particularly in Sumatra and Kalimantan, which has been transformed into degraded wasteland, largely as a result of poor forest and land management policies. As a result, much of the C stored in tropical peatland is being released to the atmosphere as greenhouse gases (GHG), mostly CO_2, and particulates (PM_{10}), as a result of over-intensive logging, deforestation, drainage, land use change and fire. Between 0.87 and 2.57 Gt C were released to the atmosphere as a result of forest and peat fires in Indonesia in the 1997 El Niño year equivalent to 3–10 Gt CO_2 (Page *et al.,* 2002). In the subsequent 10 years, according to the PEAT-CO_2 Report (Hooijer *et al.,* 2006), it is estimated that up to 20 Gt CO_{2e} have been released from Indonesia's peatland as a result of peat decomposition and oxidation following land use change (conversion to farming and plantations) and fire. This is the basis for stating that Indonesia is now the world's number three CO_2 polluter, although most emissions come from non-industrial sources. Indonesia is a non-compliance country under the Kyoto Protocol, but the magnitude of the CO_2 emissions from its peatland is significant on a global scale and should be reduced greatly as a matter of urgency.

We have been studying the tropical peatland ecosystem of South-east Asia, and impacts upon it of land use change and fire, for almost 15 years and have recently made life cycle comparisons of the impact of different land uses. In this paper we present and compare C budgets for tropical peatland under four different, representative land use categories: (a) a baseline scenario for pristine, undrained peat swamp forest, (b) oil palm plantation, (c) pulpwood plantation, and (d) deforested, drained peatland that is affected by recurrent fire and is currently not being managed. Our objective is to quantify the net benefits of deforestation avoidance and peatland restoration (rewetting and revegetating) as a contribution to international efforts to stabilize GHG emissions.

[1] Gt = gigatonnes = billion tonnes = t x 10^9

Data, methods and assumptions

We use data from both primary and secondary sources to estimate the likely magnitude of the inputs to and outputs from tropical peatland C stores under different land uses and the changes that will take place to these stores over a period of 25 years representing the average economic life of an oil palm plantation (Corley and Tinker, 2003). Our focus is on carbon dioxide (CO_2). Methane emissions from tropical peatland under all land uses are very low (Jauhiainen *et al.*, 2005, Melling *et al.*, 2005), while emissions of other greenhouse active gases, notably NO_2, have not so far been studied in sufficient detail and are not included in this assessment.

The C budget of a tropical peatland can be summarised as follows:

$$C_I - C_o = \Delta C_s$$

$$\sum_{1} \Delta C_s = C_s$$

Where C_I = C input; C_o = C output; C_s = C stock; ΔC_s = peat increment

C stock: C stored in above- and below-ground biomass plus C in the peat.

C input: C sequestered from the atmosphere by photosynthetic plants (net primary production, NPP) resulting in biomass increment and peat accumulation.

C output: C emission to the atmosphere as a result of autotrophic and heterotrophic respiration (decomposition), vegetation/crop removal, and fire. No data are available on C losses in waterways draining tropical peatlands under different land uses (in the form of dissolved organic C (DOC), particulate organic C, dissolved inorganic C and dissolved CO_2) but these are likely to be small compared to gaseous emissions and are excluded from our calculations.

For the four land uses we make the following assumptions:

i. Scenario 1: Peat swamp forest represents the natural condition for lowland tropical peatlands in South-east Asia with intact hydrology, vegetation cover and peat accumulation.
ii. Scenario 2: Peatland converted to oil palm plantation involves removal of the forest and land preparation involving drainage and fire. The optimum water table depth for oil palm cultivation on peat is in the range 0.60-0.80 m below the surface (Rieley and Page, 2005). The harvesting cycle for oil palm fruits commences around 5-8 years after planting and continues for up to 25 years when the palm trees become too large for economic cropping and productivity is declining; replanting takes place following felling and disposal of the trees and preparation of the peat surface once more.
iii. Scenario 3: Peatland converted to pulpwood (*Acacia*) plantation also involves deforestation, drainage and fire. The optimum peatland water table depth for *Acacia* cultivation on peat is 0.80 – 1.00 m (Rieley and Page, 2005) although, in practice, water levels are usually much lower. The fast-growing *Acacia* trees are harvested at intervals of between 5 and 7 years and the land is then replanted; thus the 25 year time period selected for this study encompasses 4 to 5 crop rotations.
iv. Scenario 4: Degraded peat swamp forest is characteristic of peatland that has been deforested, through a combination of logging and fire, and is also subject to drainage and recurrent fires, for example, the former Mega Rice Project (MRP) area in Central Kalimantan (Page *et al.*, 2002). Using water table data for the MRP we assume an average annual drainage depth of 0.50 cm.

Results

C budgets were calculated based on the following data and assumptions for the various ecosystem components.

Vegetation above- and below-ground biomass carbon

The above ground biomass value for natural peat swamp forest of 300 t ha^{-1} was obtained by averaging the values for the two principal and most widespread forest sub-types, mixed swamp forest and low pole forest using data from Brady (1997) for South Sumatra and Sulistiyanto (2004) for Central Kalimantan. These authors also provide some data for tree root biomass for natural peat swamp forest enabling us to apply a combined average of 30 t ha^{-1} in this study. In both cases, they report values for fine roots only and no data are available for large supporting roots. We apply a wood C content of 50%. We assume that there is no net annual biomass increase in climax peat swamp forest and net ecosystem production (NEP) is balanced by decomposition of dead branches, leaves and roots. Crop biomass of oil palm and Acacia, both above and below ground, is not included in the budget since all of this is dissipated over or soon after the 25 year time period in the case of the former, when old palms are felled and disposed of, whilst Acacia is cropped on a 5-7 year cycle and then processed, thereby entering its own disposal chain. Palm oil fruits and kernels are not included either because, over the 25 year timescale, the products derived from these and their waste are utilised or disposed of, decomposed and their CO_2 returned to the atmosphere. Roots of oil palm and Acacia do not contribute to the peat C store because, in the aerated surface peat, they are decomposed with release of CO_2 throughout the 25 year period.

A value of 25 t ha^{-1} is considered to be a representative average for the above-ground biomass of degraded peatlands. Work in progress in Central Kalimantan shows a range from 50 t ha^{-1} for ten year old secondary forest on peat that has burned once in the last 30 years, to 25 t ha^{-1} on peat subjected to two fires within the last decade and 8-13 t ha^{-1} for peatland burned more than twice in the last ten years (Hoscilo, pers. comm.) There are no data on the below-ground biomass of secondary vegetation on degraded peat therefore we use a simple estimation approach based on the assumption that below ground biomass is approximately 10% of the above ground biomass, providing a value of 2.5 t ha^{-1}. We assume that there is no biomass gain over the 25 year period because degraded peatlands are subject to recurrent fire that prevents succession to forest vegetation.

Peat deposit carbon pool and peat (carbon) accumulation rate

The peat C pool (per hectare) is calculated for an average peat thickness of 4.4 m obtained from field studies in Central Kalimantan (Page *et al.*, 2002) and peat dry bulk density of 0.09 g cm^{-3} and peat C content of 56% derived from studies of a 960 cm long peat core collected in Central Kalimantan (Page *et al.*, 2004). These data provide a value of 2,464 t C ha^{-1} as the baseline for the C store in peatland in Indonesia. The current peat accumulation rate in natural peat swamp forest of 2.2 mm yr^{-1} is based on data obtained from the same source.

Peat subsidence

Peat subsidence occurs as a result of peat compaction and oxidation following drainage. In the constant high temperature conditions of the tropics, aerobic oxidation of organic material proceeds at a rapid rate. Peat oxidation results in CO_2 emissions to the atmosphere, with an estimated loss of 1,300 g m^2 yr^{-1} for every centimetre of peat subsidence (Wösten *et al.*, 1997).

Estimates of peat subsidence under oil palm plantations vary from 2 to 8.5 cm yr^{-1} (field monitoring data obtained from the Malaysia Agriculture Research and Development Institute); a median value of 5 cm yr^{-1} is applied in this study. Estimates of peat subsidence in pulpwood plantations are higher, at 10 cm yr^{-1}, owing to the lower water levels that are required for optimum growth and the disturbance to the peat surface layer caused by cropping at 5 yearly intervals, which enhances bacterial oxidation. We applied a subsidence rate of 5 cm yr^{-1} to the final land use scenario of deforested, drained and degrading peatland. In the peatland of the MRP, where there is uncontrolled drainage, the water table fluctuates throughout the year, with levels as low as 100-150 cm during the dry season and near or above surface levels during the wet season (Wösten *et al.*, in press).

Peat loss by fire

Fire is used to remove unwanted tree remains and ground vegetation, after timber removal, prior to plantation establishment. This is common practice before establishing oil palm plantations and is carried out before or coincident with drainage channel construction. Fire not only burns residual above-ground biomass but can also ignite the dry surface peat layer. We use a conservative estimate of 20 cm of surface peat lost as a result of fire during the forest clearance phase, but accept that during periods of extended drought, land clearance fires may burn to much greater depths. Fire is used less frequently in the development of pulpwood plantations but is still likely to have some impact and, therefore, we use a lower rate of loss of 10 cm in the clearance phase. Fire losses are greatest on deforested, degraded, undeveloped peatland which represents a highly fire-prone landscape. For example, the former MRP area is subject to regular fires, which are most severe during El Niño years. We use data obtained from studies of the former MRP to calculate average fire emissions based on data for the period 1997-2005 (Page *et al.*, 2002; Page *et al.*, accepted; Hoscilo, pers. comm.).

Comparisons of carbon and CO_2 budgets in natural peat swamp forest and tropical peatland under different land uses are provided in Table 1, incorporating the assumptions explained above.

Discussion

It is clear from the data comparisons (Table 1) that any land use on tropical peatland, apart from protection as natural forest, leads to loss of stored carbon in the form of CO_2 emissions to the atmosphere. The four land use scenarios are benchmarked to specific assumptions and conditions and are indicative only. For example, the major assumptions of an average peat thickness of 4.4 m, peat bulk density of 0.09 g cm^{-3} and C content of 56% are the best estimates available but are subject to large uncertainties (Page *et al.*, this volume). Nevertheless, these data show quite unequivocally that only unlogged, undrained peat swamp forest or peat swamp forest that is being managed for sustainable forestry using the wise use approach (Rieley and Page, 2005), which ensures that biomass recovers over an appropriate regrowth period (50 years or more), has a positive C balance. This is the only management that can ensure that the C store not only remains intact but increases slowly as peat continues to accrue. Any form of land use that involves removal of the peat swamp forest, preparation of the peat for crop production (arable or plantation) through drainage and fire, followed by constant water management and regular cropping, leads to disappearance of the peat at rates that are determined by the intensity of the management regime. The lower the water table, the faster the rates of oxidation, subsidence and GHG emissions will be. Even degraded peatlands exhibit high rates of C loss; these include large areas of deforested peat swamp forest that have been extensively drained, are subject to frequent fires but have no formal land use because development projects have failed, for example the former MRP in Central Kalimantan and degraded peatlands in Jambi, Sumatra (Wösten *et al.*, 2006). These areas have been opened up to human access along drainage channels and local people use these to extract whatever timber or non-timber forest products they can in order to supplement their meagre livelihood. In the process, they further deforest any remaining patches of forest, and accidentally or deliberately set fires that during the dry season can easily go out of control affecting hundreds of hectares of peatland. Under this scenario it is fire, rather than oxidation, which is the principle contributor to attrition of the peat C store.

Oil palm cultivation on tropical peatland leads to a loss of ~150 t CO_2 ha^{-1} yr^{-1}, while the loss associated with Acacia plantation is higher at ~ 260 t CO_2 ha^{-1} yr^{-1}, exceeding that from abandoned, degraded peatland, despite the higher fire emissions under the latter scenario. These are extremely high rates of loss that will lead to the complete disappear-

Table 1. Tropical peat land-use carbon budgets calculated for a 25 year period (t C ha^{-1})

	Peat Swamp Forest (C pool)	Oil Palm Plantation	Acacia Pulp Plantation	Degraded Peatland e.g. ExMRP*
Peat deposit pool at start of 25 years (before land use change)	+2218	+2218	+2218	+2218
Forest above ground biomass	+150	0	0	0
Forest root biomass	+15	0	0	0
Peat accumulation	38.5	0	0	0
Peat subsidence	0	-862.5	-1,715	-862.5
Peat loss as a result of fire	0	-135	-68.6	-620
Secondary vegetation biomass after 25 years	N/A	0	0	+27.5
PEATLAND CARBON POOL AFTER 25 YR	2421.5	1220.5	434.4	763
C IMBALANCE WITH PSF ECOSYSTEM AFTER 25 YR	N/A	-1201	-1987.1	-1658.5
CARBON GAIN/LOSSES OVER 25 YEARS	+38.5	-997.5	-1783.6	-1455.0
MEAN ANNUAL C GAIN/LOSS	+1.54	-40.0	-71.3	-58.2
MEAN ANNUAL CO_2 GAIN/LOSS	+5.65	-146.8	-261.7	-213.6
annual CO_{2e} change for area of 1 Mha (Mt)	+5.65Mt	-146.8Mt	-261.7Mt	-213.6Mt
Predicted years with peat (after 25)	n	30	6	13
Predicted lifespan of peatland under each land use	Forever!	55yrs	31yrs	38yrs

N/A: not applicable
*ExMRP – The former Mega Rice Project area in Central Kalimantan.

ance of peat from large areas of coastal and sub-coastal Indonesia and Malaysia in human timescales of 55 years for oil palm, 31 years for Acacia plantation and 38 years for unused degraded peatland, assuming an average thickness of 4.4 m. Peat that is thinner will disappear quicker than indicated by these predictions and since development of shallow peat (0.5-3.0 m thick) for agriculture is being promoted strongly, especially by the Government of Indonesia, most of this peatland could be lost within the next 10-20 years. Degraded peatland offers opportunities for rewetting, fire control and revegetation under either formal or informal financial agreements to reduce CO_2 (GHG) emissions (e.g. carbon offset payment schemes). Initial restoration trials in the former MRP are currently underway to investigate the effectiveness of various forms of intervention to protect the remaining C store (Page *et al.*, in press). The greatest savings in terms of C emissions could, however, be obtained by protection of the remaining forested peatlands. Not only would this ensure that C storage and sequestration by forest biomass and peat are maintained for future generations, it would also deliver a range of additional benefits in terms of protection of biodiversity, forest resources and ecosystem functions.

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