Uncertainties, deficiencies and unknowns in greenhouse gas emissions from tropical peatlands

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Summary

Tropical peat swamp forest forms one of the most efficient carbon-sequestering ecosystems and important carbon stores. Some peatlands, even in natural condition, are in steady-state and no longer accumulating peat. Large areas of tropical peat have been drained, resulting in an abrupt and permanent shift in the ecosystem carbon balance from sink to source.

Several tropical peat carbon store and carbon store change-connected issues are identified as unknowns, and therefore the role of natural peatland as a C sink is not clear. Data on tropical peat carbon exchange is still scattered and often poorly documented. Tropical peatlands are reclaimed faster than records can be updated. Records of land use history, cultivation methodology (drainage depth, use of fire, crops species, *etc*.) are not well known in reclaimed peatlands, which makes extrapolation of C-store changes difficult. Projections of future carbon emissions from tropical peatlands under different land use scenarios are needed, and actions must be taken. This must lead to the development of best peatland management practices that can reduce carbon loss now and in the future.

Key index words: Carbon dioxide, dinitrogen oxide, GHG fluxes, methane, land use

Introduction

In their natural state tropical peatlands are considered to function as carbon sinks and stores, but drainage and forest clearance can rapidly convert them from sinks to sources (Andriesse, 1988; Rieley and Page, 2002; Hirano *et al.*, 2007). Net carbon sequestration in tropical peat necessitates combination of high vegetation biomass (C-sequestration potential) and near soil surface remaining water table level, while drainage and disturbances (fire related haze) increase C-losses (Suzuki *et al.*, 1999; Hirano *et al.*, 2007). This condition is best observed in undrained forest. In replacement ecosystems net C-sequestration cannot likely be attained because of low biomass, frequent biomass cropping, deposited litter is not conserved in waterlogged conditions owing to usually low water table regime, fertilization enhancement of peat humification, fires, *etc*. (Hirano *et al.*, 2007).

Tropical peat swamp forests are challenging study areas and that is why there are a lot of uncertainties, deficiencies and unknowns in their GHG emissions as we show here.

Carbon cycle in tropical peatland

The carbon cycle in tropical peatland differs under natural and land use changed conditions and is influenced by different factors (Fig. 1). In their natural state, peat swamp forests have the ability to sequester carbon from the atmosphere in photosynthesis, retain this in plant biomass and store part of it in the peat. This ecosystem carbon sequestering process occurs mainly because of the waterlogged conditions in peat, which reduces the rate of decomposition and hence the rate of organic matter production exceeds its breakdown. Peatland utilisation, however, requires drainage, brings about changes in the vegetation type, destroys the C-sequestration capacity and leads to losses from peat C-stores. Carbon is lost from peat carbon store especially in the form of carbon dioxide owing to the deeper oxic peat profile caused by water level drawdown. High redox potentials created by drainage are known to favour microbial activity and nitrogen mineralization (Ueda *et al.*, 2000), which enhance C loss by peat oxidation.

Uncertainties and gaps in current knowledge

Carbon pools

There are major difficulties associated with evaluating the role of tropical peatlands as contemporary carbon pools. Some peatlands, even under natural conditions, are in a steady-state and no longer accumulating peat, whilst others are undergoing degradation (Sieffermann *et al.*, 1988; Moore and Shearer, 1997; Hirano *et al.*, 2007). Tropical peat swamp forests are sensitive to temperature and precipitation changes, and evidence shows that long periods of drought can change peat swamp forests from carbon sinks to carbon sources (Suzuki *et al.*, 1999; Hirano *et al.*, 2007). Also, large areas of tropical peatland have been drained and burned, which has altered the water table as well as water retention properties, shifting the peatland carbon balance from sink to source (Page *et al.*, 2002; Canadell *et al.*, 2007).

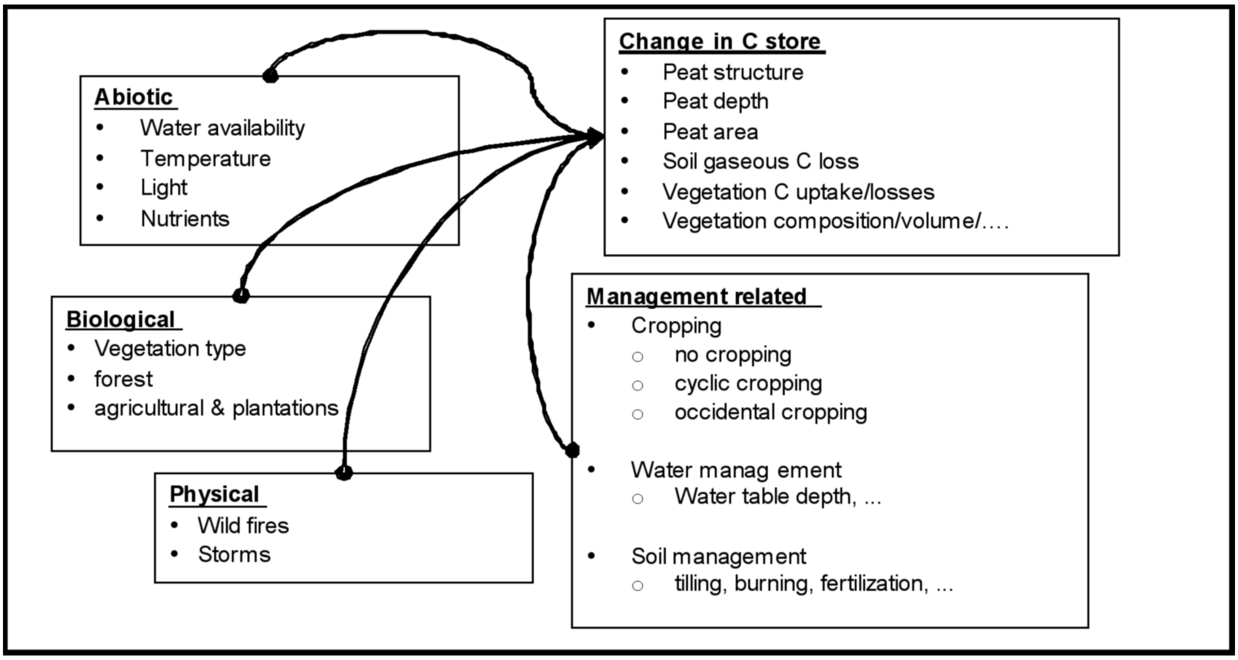

Figure 1.Major abiotic, biological, physical and land management related factors related to carbon store change in tropical peat.

Gaseous carbon fluxes

Data concerning tropical peat CO_2 fluxes and their biological controls are still limited (e.g. Chimner, 2004; Jauhiainen *et al.*, 2004, 2005; Melling *et al.*, 2005), and variations in environmental conditions (especially in peat hydrology), peat, and vegetation characteristics make comparisons between datasets difficult. In drained areas there is lack of datasets including long-term soil water levels, time periods after drainage, and different crop systems. Peat carbon gas flux measurements are important in order to provide information on peat carbon dynamics, but cannot be obtained yet for all major sinks and sources in forested peatland ecosystems.

Net peatland carbon flux is determined largely by the net balance between CO_2 uptake in photosynthesis and C-release by ecosystem (autotrophic and heterotrophic) respiration. Studies on ecosystem carbon balance are most limited (e.g. Suzuki *et al.*, 1999; Hirano *et al.*, 2007). For example, the lack of accurate data on the amount of CO_2 sequestered by vegetation in photosynthesis is a major problem for evaluating the total C budgets. The complex structure of tropical rain forest vegetation adds to the magnitude of this problem, and technical challenges for ecosystem level C balance determination are created by high reaching forest canopies.

In drained areas there is a lack of reliable datasets that include long-term combinations of constant water levels, differing time periods after drainage, and different crop systems. The large amount of CO_2 emitted from the peat swamp forest floor is likely to be mostly or completely reabsorbed by the vegetation it supports making it CO_2 neutral in high water table level conditions. If the ecosystem is accumulating peat, then it must bind atmospheric CO_2 besides capturing the emitted CO_2. On the other hand, degraded and drained peat swamp forest, although it can be releasing comparable amounts of CO_2 to undrained forest, with its greatly reduced vegetation will not absorb as much CO_2, and enhanced organic matter decomposition in drainage affected peat will therefore result for most of the time.

Key difficulties in drawing general patterns of gas fluxes are due to: i) CO_2 emissions from root respiration in various vegetation types that should be separated from emissions caused by decomposition, ii) short-term effects (shortly after drainage) of drainage on gas fluxes differ from long-term effects, and iii) water level and peat hydrology is often insufficiently monitored. Surface peat CO_2 emissions contribute considerably to total ecosystem respiration, and are influenced greatly by water table depth. Stability of hydrology, forest floor microtopography and vegetation structure are other factors influencing peat CO_2 dynamics in undrained peatland. In contrast, CO_2 dynamics in drained peatland are determined by time from initial drainage, vegetation type, drainage depth, and land management procedures such as tilling and fertilization systems. Carbon losses from fire and dissolved in groundwater may be important, especially on drained peatlands.

The role of methane in the tropical peat carbon balance is relatively small on the basis of currently available results. It is possible, however, that some of the CH_4 produced may escape to the atmosphere through vascular plant organs (e.g. leaves and pneumatophores), and thus avoid oxidation in the surface aerobic peat. Remote sensed observations indicate CH_4 is released from tropical forests (Frankenberg *et al.*, 2005; Sinha *et al.*, 2007) but the role of peat swamp forest vegetation in these emissions has still to be clarified.

Besides CO_2 and CH_4 there are other important GHG fluxes especially from drained organic soils (Martikainen *et al.* 1993; Maljanen *et al.* 2007). For example, the amounts of N_2O emissions in drained peat swamp forests still needs to be clarified. Dinitrogen oxide is by far a more powerful GHG than C gases but there are still insufficient data to clarify its significance (Melling *et al.*, 2007).

Dissolved carbon

Waterways (streams, rivers and drainage channels) may release C in the form of dissolved organic carbon (DOC), particulate organic carbon (POC), dissolved inorganic carbon (DIC) and dissolved CO_2. Studies of these potential carbon release pathways from tropical peatlands are very limited but a recent one by Baum *et al.* (2007) suggests that Indonesian rivers, particularly those draining peatland areas, transfer large amounts of DOC into the oceans that would represent approximately 10% of the global riverine DOC oceanic input (Baum *et al.*, 2007). The character and magnitude of fluvial carbon release from tropical peatlands are likely to be influenced by a range of biotic and abiotic processes, including land use change. Increases in DOC concentration and flux may be associated with major droughts and decrease in the peatland water table, which has implications for C release from tropical peatlands under different land management and climate change conditions. Also, the drainage water can become anoxic and may constitute a methane source because of the solid and soluble organic residues they contain.

Conclusions

Peatland gas fluxes cannot be used as a measure for maintenance of peat carbon deposits, which require continuous and sufficient biomass allocation into waterlogged peat for prolonged periods. Although there are a number of published GHG flux numbers from tropical peat, the measurements often do not represent site characteristics and do not cover variation in environmental conditions. Together with poor description of methods and sites this makes information generalization difficult.

The best C sequestration potential owing systems (forests) have likely higher emission rates in comparison to drained sparsely vegetated sites if the decomposition and vegetation root respiration originated CO_2 is not separated. This is one of the reasons why both sequestered and released carbon (*i.e.* ecosystem level C balance) needs to be known in quantification of tropical peat ecosystem role as a carbon sink, storage or source. Data on peatland system net carbon balance is very limited and virtually non existent on drained peatlands. Thus we urge for ecosystem-level measurements of gaseous carbon and other GHG fluxes together with process-based studies in order to determine the true overall carbon gas balances on undrained, degraded and developed tropical peatland.

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