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Ecosystem modelling of tropical wetlands

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4. Ecosystem modelling of tropical wetlands

Kristell Hergoualc'h, Steve Frolking, Pep Canadell, Stephen Crooks, Mark Harrison, Hans Joosten, Sofyan Kurnianto and Carey Yeager

4.1 Background

Modelling is essential for enhancing our understanding of the functioning of tropical wetland ecosystems, and for simulating future trajectories and testing for system thresholds. Anthropogenic activities such as drainage and land-use change can be integrated in models and their impacts on fluxes of greenhouse gas concentrations simulated. Models can also be used to test the response of peatlands and mangroves to climate extremes, variability and change, and to estimate reference levels and greenhouse gas emissions scenarios in the framework of climate change mitigation projects such as REDD+. In coastal settings, models are used to explore wetland resilience to sea-level rise. Finally, models can also be developed to support the decision making process by providing policy-relevant information on the consequences and trade-offs of adopting different management and climate scenarios.

4.2 State of the science

Different types of models of varying complexity exist but their applicability to tropical wetland ecosystems varies greatly. A number of allometric equations have been developed to quantify aboveground carbon stocks in tropical mangroves (Saenger 2002, Chave *et al.* 2005, Smith and Whelan 2006, Komiyama *et al.* 2008, Kauffman and Cole 2010, Kauffman and Donato 2011) and oil palm (Corley *et al.* 1971, Khalid *et al.* 1999, van Noordwijk *et al.* 2010) or *Acacia* plantations (Hiratsuka *et al.* 2003, Heriansyah *et al.* 2007). Fewer allometric relationships for estimating aboveground carbon stocks in virgin tropical peat swamp forests have been developed (Manuri *et al.* 2011). Three individual-based models (FORMAN, KIWI and MANGRO) describe neotropical mangrove forest dynamics (Berger *et al.* 2008).

Tropical wetlands have a large portion of their carbon stores belowground. Large carbon losses arising from anthropogenic activities and climate change are expected to come from this pool in particular (Crooks *et al.* 2011). However, few models have been developed that simulate carbon and nutrient dynamics in tropical peats and carbon rich mangrove soils. Several hydrological models are available for simulating water dynamics in tropical peats (e.g. SIMGRO –SIMulation of GROundwater flow and surface water levels [Wösten *et al.* 2006]).

Some simple empirical relationships have been developed for tropical peatlands between water table depth and subsidence rates, between CO_2 fluxes arising from peat decomposition and water table depth or pH or ash content, and between pH or peat temperature and peat mineralisation and CH_4 production (Murayama and Bakar 1996a, 1996b, Miyajima *et al.* 1997, Couwenberg *et al.* 2010, Hooijer *et al.* 2010). A more complex model based on ecophysiological studies of oil palms planted on peatlands simulates carbon sequestration and greenhouse gas emissions associated with oil palm cultivation and land-use change in peatlands (Henson 2009).

Two process-oriented models, the Holocene Peat Model (HPM)(Frolking *et al.* 2010) (Figure 4.1) and Estimation of Carbon in Organic Soils – Sequestration and Emissions (ECOSSE) (Smith *et al.* 2010) (Figure 4.2), both developed for temperate, boreal peatlands, may be appropriate for use in tropical conditions. The HPM model is currently being parameterised using data from tropical peatlands of Jambi, Sumatra.

Regarding mangroves, the Marshy Equilibrium Model (MEM2) (Morris *et al.* 2002) simulating sedimentation and carbon accumulation in

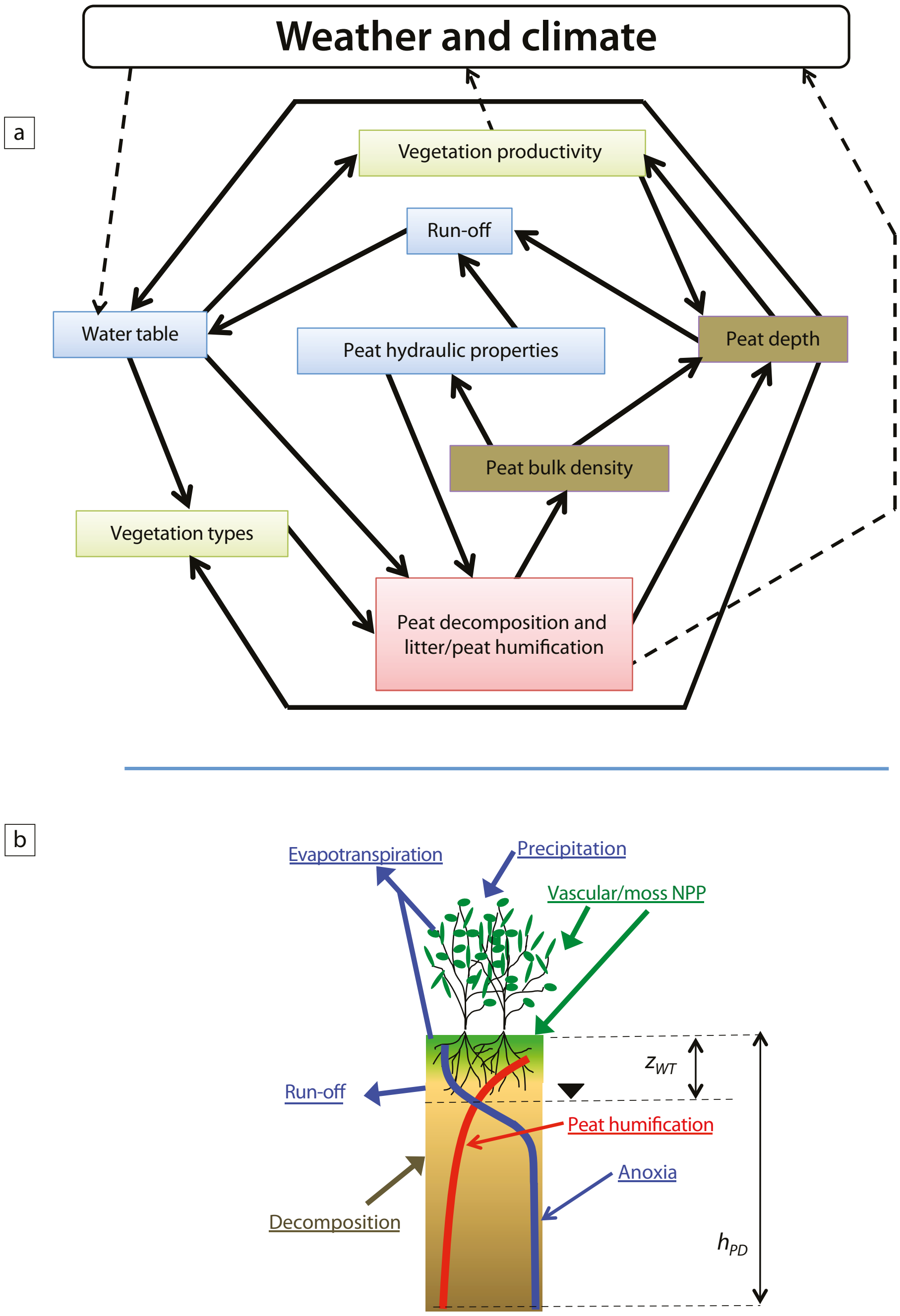

Figure 4.1. The Holocene Peat Model (HPM) that simulates the interaction of carbon and water and vegetation dynamics in peatland (a), and calculates the annual peatland carbon and water balance in one (vertical) dimension (b), where NPP is Net Primary Production

Source: Frolking *et al.* 2010

soil, has been developed for temperate coastal wetlands of the United States and could be further used in tropical mangrove ecosystems.[1] The DeNitrificationDeComposition model (DNDC) is also being tested in converted marshlands (rice fields) (Huang *et al.* 2010) and converted mangroves of Trinidad and Tobago (World Bank 2008).

In coastal settings, wetlands will respond to sea-level rise by building upwards and migrating landwards. The resilience of wetlands to sea-level rise will depend on a combination of mineral supply and root

1 This model is currently under expansion by a working group convened at the National Center for Ecological Analysis and Synthesis (http://www.nceas.ucsb.edu/featured/callaway).

material production to build soil matter to balance rising water levels. A number of 1D and 2D models have been developed and tested to simulate wetland response to sea-level rise in temperate systems but have yet to be applied in tropical settings (e.g. Orr *et al.* 2003, Reyes *et al.* 2003).

Datasets of field and laboratory observations are required for developing, parameterising, calibrating and validating models. Although a large amount of data has been collected in tropical peatlands, too much remains unpublished in peer-reviewed international journals. Well-studied sites, with available data for model development and testing, need to be identified. Improvement of dataset quality requires capacity building. It is suggested that joint field and modelling efforts, and collaborative partnerships are established for the collection of future datasets, with institutions such as the Ministry of Forestry, Indonesian Institute of Sciences (LIPI), Ministry of Research and Technology, Ministry of Environment and Ministry of Agriculture.

In the models, plant inputs enter the soil as resistant plant material (RPM) and decomposable plant material (DPM), and decompose into 'biomass' or active organic matter (BIO) and 'humus' or more slowly turning over soil organic matter (HUM). Organic matter that has become inert (IOM) is assumed to not contribute to the decomposition processes. Losses of carbon and nitrogen from the soil are gaseous (CH_4, CO_2, N_2O, N_2 and NH_3) and in solution (dissolved organic carbon [DOC], dissolved organic nitrogen [DON] and leaching nitrate nitrogen). Solid arrows indicate flow of material; dashed arrows indicate influence, LU: Land-use, NPP: Net Primary Production, and PET: Potential Evapotranspiration.

4.3 Priorities and recommendations

To conclude, the following priorities were identified:

- Empirical models should be developed for full carbon accounting for REDD+ projects in tropical freshwater peatlands, mangroves and coastal wetlands.
- Biogeochemistry models for tropical freshwater peatland and mangrove ecosystems should be developed and tested, utilising existing datasets, and in collaboration with ongoing and planned field studies. Several models have been mentioned above (e.g. ECOSSE, HPM, MEM2, DNDC), but this list is by no means exhaustive and other initiatives are encouraged.
- Decision support tools should be developed for policy makers that facilitate exploration of different climate change, land-use and disturbance scenarios, along with tools that can assess multiple ecosystem services in addition to carbon, such as biodiversity, food security, water resources, and trade-offs between these services (e.g. Koh and Ghazoul 2010).

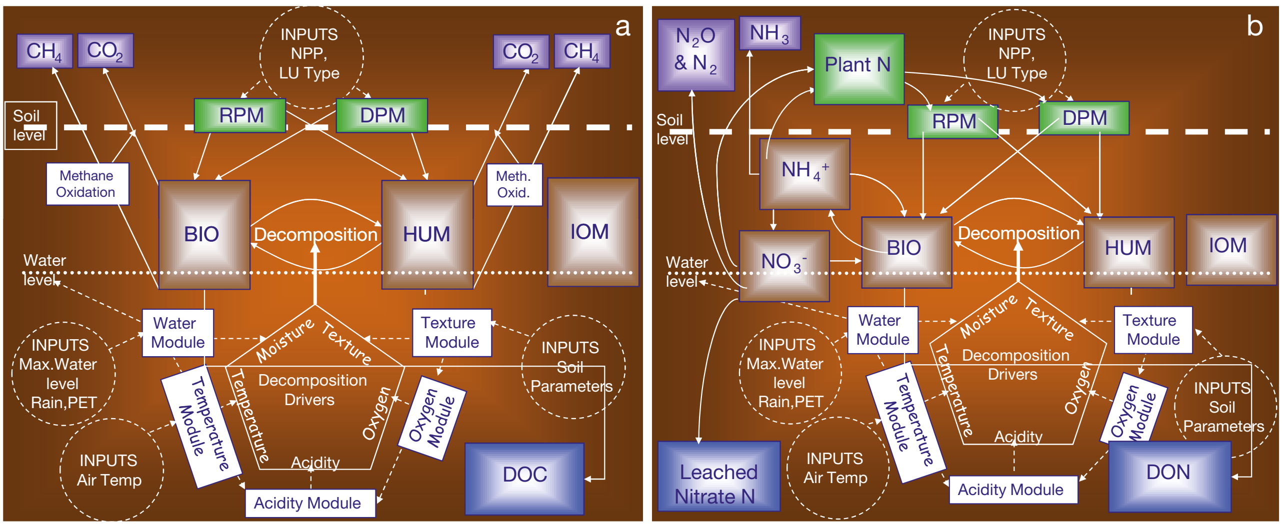

Figure 4.2. Structure of the carbon (a) and nitrogen (b) components of ECOSSE

Source: Smith *et al.* 2010