



## Does litter input determine carbon storage and peat organic chemistry in tropical peatlands?



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### ARTICLE INFO

Handling Editor: I. Kögel-Knabner

#### Keywords:

Carbon storage  
Decomposition  
Tropical peatland  
Rock-Eval pyrolysis  
*n*-Alkanes  
FTIR

### ABSTRACT

Tropical peatlands hold large amounts of carbon but the influence of litter inputs and variation in peat properties with depth on carbon storage are poorly understood. Here we present a stratigraphy of peatland carbon stocks and accumulation through the peat profile in a tropical ombrotrophic wetland and assess shifts in vegetation inputs and organic matter degradation using *n*-alkane distributions and Rock-Eval 6 pyrolysis. Mixed forest (including canopy palms and tropical hardwood trees) contained the greatest total carbon stock in the soil (1884 Mg C ha<sup>-1</sup>), followed by *Rhizophora mangle* (mangrove, 1771 Mg C ha<sup>-1</sup>), *Campnosperma panamensis* (hardwood, 1694 Mg C ha<sup>-1</sup>) and *Cyperus* (sawgrass) bog plain (1488 Mg C ha<sup>-1</sup>). The long-term apparent rate of carbon accumulation, determined by <sup>14</sup>C dating of the carbon stored in different layers in the peat profile, decreased from the edge to the interior of the peatland, with the highest accumulation rate in at the *Rhizophora* site (102.2 g C m<sup>-2</sup> y<sup>-1</sup>) and the lowest in the deeper peat layers at the *Cyperus* site (45.6 g C m<sup>-2</sup> y<sup>-1</sup>). High molecular weight *n*-alkanes dominated in surface peat in all four phasic communities, while deeper in the peat profile *n*-alkane profiles differed more among sites, suggesting contrasting litter inputs or decomposition environments. Deeper peat was depleted in carbohydrates and had a relatively larger thermostable C pool. Taken together our findings show (i) that different forest types hold varying C stocks and have different peat accumulation rates, even over relatively small distances, and (ii) progressive depletion of carbohydrates and thermolabile compounds with depth, despite strong variation in litter inputs throughout the peat profile.

### 1. Introduction

Global peatlands account for approximately 3% of the Earth's terrestrial area, of which 10% are situated within the tropics (Chimner and Ewel, 2005). Tropical peatlands consist of partially decomposed organic matter, which has accumulated under waterlogged, anaerobic conditions, typically over millennia, when vegetation input exceeds decomposition (Andriessse, 1988; Minasny et al., 2016; Wösten et al., 2008; Sjögersten et al., 2014; Hoyos-Santillan et al., 2015). Globally, peatlands are estimated to store 105 Gt C, equivalent to ca. 20% of the Earth's peatland carbon store (Jaenicke et al., 2008; Page et al., 2011; Dargie et al., 2017). However, over the last century the sink strength of tropical peatlands has been under threat from logging, drainage and fires, particularly in areas of increasing population growth and development (Chimner and Ewel, 2005; Hooijer et al., 2010; Limpens et al., 2008; Wösten et al., 2008). Climate change also has an impact on the functioning of tropical peatlands, due to changes in precipitation, which lead to increased risk of drought (Chimner and Ewel, 2005; Page

et al., 2011). These changes alter vegetation inputs and organic decomposition rates, and increase the risk of peatlands becoming carbon sources (Wösten et al., 2008).

Many tropical peatlands demonstrate a lateral sequence of vegetation types or phasic communities (Anderson, 1964; Page et al., 1999; Phillips et al., 1997). For example, a paleoecological study by Phillips et al. (1997) revealed spatial variation in the dominant peat-forming vegetation from the edge to the interior of a large domed coastal swamp in Panama. Surface vegetation type is a major control on peat properties, as it determines the quantity and quality of litter, which contributes to the peatland organic matter (Laiho, 2006; Sjögersten et al., 2011; Ward et al., 2015). In tropical peatlands, litter containing high concentrations of carbohydrates, the rate of decomposition is relatively fast, compared to lignin-rich litter (Hoyos-Santillan et al., 2015). Therefore, vegetation type controls, in part, the rate of carbon accumulation in tropical peatlands, causing variations spatially and with depth (Limpens et al., 2008; Sjögersten et al., 2011). It is therefore important to determine how phasic communities differ with regard to

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initial transformation of the litter input as it become incorporated into the peat, and total carbon stocks through the peat profile.

Litter decomposition alters the organic matter chemistry over time with different litter species and tissue types degrading at different rates (Wright et al., 2013; Hoyos-Santillan et al., 2015; Vane et al., 2013a,b). Furthermore, decomposition alters peat physical properties resulting in denser, less porous peats (Huat et al., 2011; Tonks et al., 2017; Brain et al., 2017). Indeed, changes in bulk density are important in controlling carbon storage, which often varies throughout peatlands (Warren et al., 2012; Tonks et al., 2017). However, despite the importance of litter inputs and subsequent decomposition for carbon storage in tropical peatlands (Sjögersten et al., 2014), the long term fate of litter inputs remain poorly understood. A key knowledge gap hampering our understanding of peat accumulation in tropical wetlands is how carbon accumulation is affected by variation in litter inputs and decomposition due to differences in successional vegetation communities.

Spatial and depth variation in the physical properties and biogeochemistry of organic matter corresponding to shifts in phasic communities within the San San Pond Sak peatland in Panama have been reported by Cohen et al. (1989), Phillips et al. (1997), Sjögersten et al. (2011), Wright et al. (2011) and Cheesman et al. (2012). Therefore, we used the San San Pond Sak peatland to assess how carbon storage capacity and peat organic chemistry was linked to shifting vegetation inputs and decomposition through the peat profile. In this study, we present a stratigraphy of peatland physical properties and an assessment of the degree of decomposition in four common distinct vegetation communities within the San San Pond Sak peatland. Specifically, we determined carbon stocks and accumulation rates through the peat profiles, to assess shifts in vegetation inputs and organic matter degradation we analysed peat profile *n*-alkane distributions while Rock-Eval 6 pyrolysis was used to develop high resolution depth profiles of the peat thermal stability, which is linked to its organic matter composition. Rock-Eval 6 pyrolysis has been used to investigate carbon dynamics within a range of systems e.g. mangrove (Marchand et al., 2008), marine sediments (Hare et al., 2014), freshwater and saltmarsh peats (Engelhart et al., 2013; Newell et al., 2016; Kemp et al., 2017), as well as trends in SOM dynamics through soil profiles (Sebag et al., 2006; Delarue et al., 2013; Biester et al., 2014; Sebag et al., 2016), providing a powerful tool for rapid assessment of shifts in peat organic geochemistry among vegetation types and depth.

We used the data to test the following hypotheses: (1) long-term rates of carbon accumulation (LORCA) vary spatially across the vegetation gradient; (2) surface peat is dominated by long chain *n*-alkanes while deeper peat contain more mid chain length *n*-alkanes reflecting decay of vegetation inputs; (3) increased peat degradation with depth will result in depletion of carbohydrates relative to aromatics overriding variation in litter inputs due to successional changes in the vegetation and hence litter inputs over time (Phillips et al., 1997); (4) the thermal stability of the peat is related to litter input and increases with depth as the peat become more degraded.

## 2. Methods

### 2.1. Study site and sampling

The San San Pond Sak peatland is located in the Bocas del Toro Province on the coast of western Panama (Wright et al., 2011). The area contains a mixture of freshwater and marine influenced wetlands and includes the Changuinola peat deposit, which is estimated to have formed up to 4000 years ago (Phillips et al., 1997). Seven distinct phasic communities have been identified across the peatland, in roughly concentric rings (Phillips et al., 1997). Starting from the periphery, these communities have been designated as (i) *Rhizophora mangle* mangrove swamp, (ii) mixed back mangrove swamp, (iii) *Raphia taedigera* palm forest swamp, (iv) mixed forest swamp (consisting of

both palm and evergreen broadleaved hardwood trees), (v) *Camposperma panamensis* forest swamp, (vi) sawgrass/stunted forest swamp and (vii) *Myrica-Cyrilla* bog-plain. In this study we focused on (i), (iv), (v) and (vi) of these phasic communities to traverse the full range of successional stages and also as these were the main communities identified along a transect from the coast to the centre of a secondary peat dome to the east of the main peat dome. The species composition of the phasic communities and soil properties are detailed in Phillips et al. (1997) and Sjögersten et al. (2011, 2018). Briefly, the mangrove site is dominated by *Rhizophora mangle*; the mixed forest is the most diverse sites with regards to tree species with the most common being *C. panamensis*, *Euterpe precatoria*, *Symphonia globulifera*, *R. taedigera*, *Chamaedorea pauciflora*, *Cassipourea elliptica*; the *Camposperma panamensis* forest swamp is monodominant (i.e. > 80% of the trees are *C. panamensis*); the bog-plain was tree-less and vegetated by *Cyperus* species. The mean annual precipitation of the area is  $3092 \pm 181$  mm, and the mean annual air temperature in the area is  $25.9 \pm 0.3$  °C (Hoyos-Santillan et al., 2015). There is no distinct seasonality in the region, the water table remains close to the surface of the peatland throughout the year (range is  $-40$  to  $+40$  cm during shorter periods of drought and high rainfall). At the central areas (phasic community IIV) of the peatland track tracks are flooded for a large part of the year. There are two distinct periods of lower rainfall in February–April and September–October (Hoyos-Santillan et al., 2015; Wright et al., 2011).

Study sites were established across a transect of a small dome to the east of the main deposit. The sites are shown in Fig. 1 and were located within four of the main phasic communities as described by Phillips et al. (1997).

At these sites, peat cores of 50 cm length were collected down to 630 cm for *Rhizophora*, 510 cm for mixed forest, 529 cm for *Camposperma* and 530 cm for *Cyperus* using the same method to that described in Nikitina et al. (2014) and Vane et al. (2013a,b). Upon collection cores were wrapped in cling film to avoid peat oxidation and stored in the dark at 4 °C to minimise photo and biodegradation.

### 2.2. Sample processing

#### 2.2.1. Bulk density and carbon storage

To determine the bulk density (BD), samples of 10 cm were taken every 50 cm down each peat column. These samples were then weighed, oven dried at 105 °C for 48 h, and then re-weighed for dry weight. BD was calculated by: mass of dry peat (g)/volume (cm<sup>3</sup>) (Tonks et al., 2017). The carbon stock (Mg ha<sup>-1</sup>) was then calculated by multiplying the carbon per unit volume of soil (Cv) (BD multiplied by TOC) by the volume per layer (m<sup>3</sup> ha<sup>-1</sup>) (depth per layer (m) multiplied by 1000) (Agus et al., 2011).

#### 2.2.2. <sup>14</sup>C dating and peat accumulation rates

Samples for were taken from the basal peat and at a point of change in peat texture and/or colour part way up the core at: 354–356 and 314–316 cm for *Rhizophora*; 438–440 and 234–236 cm for mixed forest, 507–509 (this date was not correct) and 234–236 cm for *Camposperma* and 502–506 and 234–236 cm for *Cyperus*, and analysed by Beta Analytic for radiocarbon dating. Peat accumulation rates were calculated as in Phillips et al. (1997), with the depth to the surface or next date, divided by the peat age (BP).

#### 2.2.3. Gas chromatography of saturated hydrocarbons

Differing carbon chain lengths of leaf wax *n*-alkanes are produced from different plant types, and can be used to recognise past vegetation types (Nichols et al., 2006). Short chain mainly odd numbered homologues, from C<sub>13</sub>–C<sub>25</sub> maximising at C<sub>15</sub> or C<sub>17</sub>, are mainly synthesized by aquatic algae and plankton; whereas long chain odd numbered homologues, C<sub>23</sub>–C<sub>35</sub> maximising at C<sub>29</sub>, C<sub>31</sub> or C<sub>33</sub>, are often synthesized from vascular plants (Newell et al., 2016). It has also been suggested that even numbered mid-chain *n*-alkanes (C<sub>21</sub>–C<sub>26</sub>) may indicate

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