Measuring peat motion and water table dynamics on tropical peatlands using high-resolution time-lapse camera in four different land cover types across South Sumatra and Central Kalimantan

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Measuring peat motion and water table dynamics on tropical peatlands using high-resolution time-lapse camera in four different land cover types across South Sumatra and Central Kalimantan

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Abstract. Peat soils are known to be the most capable soil type to store a huge amount of carbon. However, peatland ecosystems are often disturbed by anthropogenic activities such as excessive water drainage, leading to rapid peat subsidence and carbon loss. Due to its dynamic properties, peatland ecosystem needs to be monitored over time to prevent unwanted socio-economic and environmental impacts. Nonetheless, field measurement of peat motion and subsidence often requires complex and expensive tools. This research aims to measure peat motion and water table dynamics in four sites across South Sumatra and Central Kalimantan Provinces. Peat motion and water table data were observed using a time-lapse camera for approximately a year period. Results of this study showed a good relationship of peat surface motion and water table dynamics with R^2 values ranging from 0.74 and 0.95. In Central Kalimantan, peat surface motion indicates a downward motion with the amplitude of 1.66 cm and 0.56 cm, and net subsidence of 1.35 cm and 0.47 cm, over shrub and coconut plantation sites, respectively. In South Sumatra, peat surface showed a high degree of fluctuation, with amplitudes of 4.89 and 4.80 cm, and net subsidence of 1.70 and 0.62, observed on oil palm and forest sites, respectively.

1. Introduction

Peatlands play an important role in carbon sequestration and accumulate a high amount of carbon compared to other terrestrial ecosystems. Tropical peatlands alone could store around 50 to 105 Gt C, equivalent to 15% of the carbon deposited in peatlands globally [1]. This fragile ecosystem is threatened by massive pressure through land conversion by human activities. These activities often require draining processes, to decrease groundwater level, to make them suitable for agriculture, mostly by smallholder farmers and industrial oil palm and pulp plantations [2]. Draining process is often associated with several consequences such as increasing risk of peat fires and peatland subsidence. These phenomena occur due to a combination of compaction and consolidation, which leads to loss of buoyancy and shrinkage, resulting from the removal of water from pore space together with accelerated aerobic decomposition of the peat following exposure to oxygen [3]. Peat subsidence associated with elevated CO_2 emissions and socio-economic consequences such as damaging buildings and infrastructures, increasing risk of flooding, and loss of agricultural productivity [4, 5].

Naturally, peatland water table depth fluctuates vertically in response to seasonal and daily climatic variations. Peat soil characteristics themselves also correlate with how quickly water table responds to peat motion. On drained peatlands, in which mostly peat subsidence occurs, oxidation processes lead to an increase in peat's bulk density. This causes changes in its physical properties including pore structure, hydraulic conductivity and runoff production, and the water chemistry [6]. As water table rises, peat acts as a sponge that could store and deliver water to ground surface, and peat surface moves vertically depending on the water table dynamics. This phenomenon is often called 'bog breathing', which gives resilience to peatland ecosystem by enabling ground surface to track water table dynamics, maintaining wet conditions even during dry periods over the peat surface [7-9]. Peat's ability to self-regulate upon hydrological variations is diminished by the presence of drainage, leading to changes in peat soil parameters [9]. This vertical movement of peat is related to a combination of climatic variations and peatland management.

This fact could be exploited as an effective way to observe and to predict peat conditions, leading as a tool for evaluating peatland restoration activities. Despite this, only a few applicable methods that give a detailed measurement on how peat surface moves. In most cases, a simple approach of measuring subsidence involves metal rods or PVC poles being inserted into peat surface until underlying mineral soil [7, 8]. Thereafter, continuous manual measurements at defined intervals, or over a certain period of time, can be conducted to assess the annual subsidence. By using relatively affordable tools, peat surface vertical movement can be measured at hourly intervals and automatically store the data using a time-lapse camera. Recent method developed by Evans *et al.* [3] is applicable in tropical peatland, specifically in Indonesia.

2. Materials and method

2.1. Study sites

This research covered four tropical peatland sites scattered across South Sumatra and Central Kalimantan Provinces (Figure 1). Different land cover types were considered to give a better understanding of water table and peat subsidence relationship on each land typology. Two sites were located within the Burnai – Sibumbung PHU (Peat Hydrological Unit) in South Sumatra, under forest and oil palm plantation land cover types. The other two sites were located in Kahayan – Sebangau PHU and Kapuas – Barito PHU in Central Kalimantan, covered by coconut plantation and shrub.

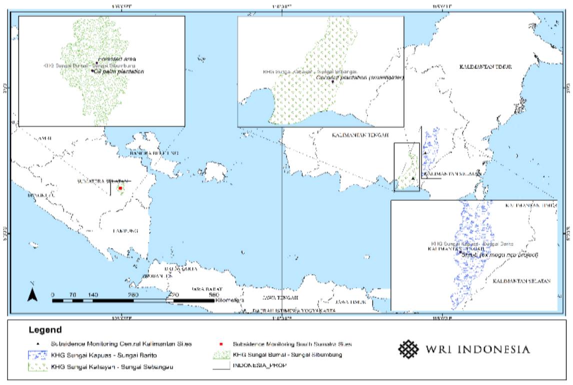

Figure 1. Site locations

2.2. Peat camera design and operation

A simple approach of measuring peat motion and water table dynamics has recently been developed by Evans *et al*. [3]. This low-cost (around $300 USD per unit) method allows measuring small-scale peat elevation changes over time along with water table depth (WTD) fluctuation by using commercially available Wingscapes Timelapse Cam Pro WCB-00121 camera, which is usually employed to monitor wildlife activities. The camera was placed on a metal stool inserted around 10 cm into peat soil and projected to a metal strip used for the reference level. The stool also has a metal subsidence pole inserted vertically into underlying mineral substrate, which acted as a fixed reference level, so that peat motion would not affect installed stool. It was attached to peat surface using screws on each leg. The stool (and camera) thus moved with peat surface movement, and camera automatically captured a photograph of the meter ruler on fixed subsidence pole.

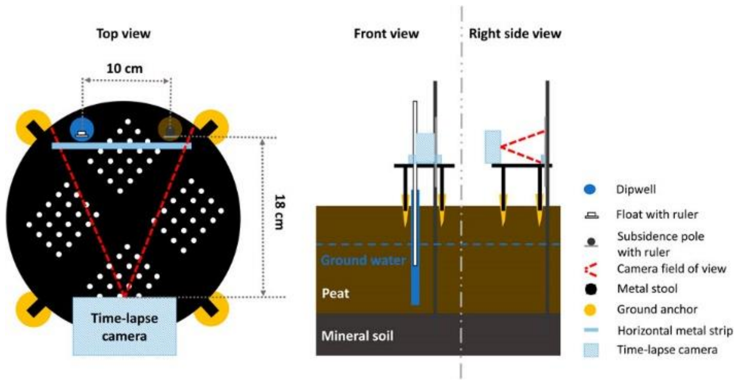

Figure 2. Peat camera design (Figure from Evans *et al*. [3]published under the terms of the Creative Commons Attribution License (CC BY))

In order to observe water table changes, a dipwell, consisting of a perforated PVC plastic pipe (7.5 cm diameter x 2.5 m length) was installed adjacent to the subsidence pole. A fishing float placed inside dipwell attached on the bottom side of a lightweight aluminum pole which tethered by a measurement scale. Although the dipwell was open, to allow the float and the pole to move freely, stool and metal plate on top of it acted as a protection against debris and therefore limited rainwater ingress. In order to observe peat motion compared to day-1 measurement, peat motion was plotted as a time series graph, which then called the *absolute* peat motion (where positive values indicate elevation of observed peat above initial datum, and negative values indicates subsidence). Relationship between peat vertical movement and water table dynamics was generated by plotting peat motion difference in 24 hours period, called *daily* peat motion.

2.3. Data collection

Time-lapse camera was programmed to take photographs every 3 hours. In order to improve night-time data capture, camera's flash was partially covered by transparent tape to reduce glare from the ruler so that the scale was readable. By taking multiple photographs each day, we recorded rapid fluctuations in peat elevation and water table, and ensured that at least one good image was obtained during rainy days.

Installed time-lapse cameras were powered by six C-cell alkaline batteries and were equipped by 32 Gigabyte SD Card. Cameras were left to autonomously run in the field for one to three months before downloading the data.

2.4. Data analysis

Images captured by the time-lapse camera were then processed using a customized program that was written in Python language via a graphical user interface (GUI). Peat height was automatically extracted into a spreadsheet with detailed image information (date, time, image number, warnings). The script requires an initial image for calibration and an initial visual assessment. The initial image was also classified into two categories (day and night). The initial reading for calibration was manually conducted, and the script compares images with the initial image within the area of interest (AOI). Image analysis/feature matching was done using ORB (Oriented FAST and Rotated BRIEF) method [10]. Key points were characterized by their coordinates, orientation and scale. Since the script has a GUI (Figure 3), analysis was relatively straightforward, which included: selection of variables, selection of reference images, drawing area of interest, drawing calibration segment, reading initial height, data quality checking and calculation of daily WTD/peat motion.

Figure 3. Screenshot of Python script GUI to automate image reading

3. Results and discussion

3.1. Central Kalimantan – shrub

Peat subsidence often occurs in large scale areas with relatively long (annual) time period. With this extent, the proposed method offers a good measurement of vertical movement or peat motion in a small-scale area, yet extensible in larger scale with longer time period. Peat motion on shrub area in Central Kalimantan is provided in Figure 4. The highest peat surface elevation recorded in the measurement period was 0.31 cm, and the lowest elevation was -1.35 cm, relative to the initial peat surface installation. The maximum and minimum vertical movement in this observation period represented the amplitude on each graph. Peat motion tended to move downward with an amplitude of 1.66 cm. Relationship of the absolute peat motion (PM) and WTD was considered high with R^2 value of 0.74, while low relationship of daily PM and WTD was observed with R^2 value of 0.43. This probably happened because of high variation data as seen on Figure 4. However, Figure 5 shows that there was a clear relationship between daily peat motion and water table dynamics; whenever water table rises, peat surface tends to move upward and vice versa.

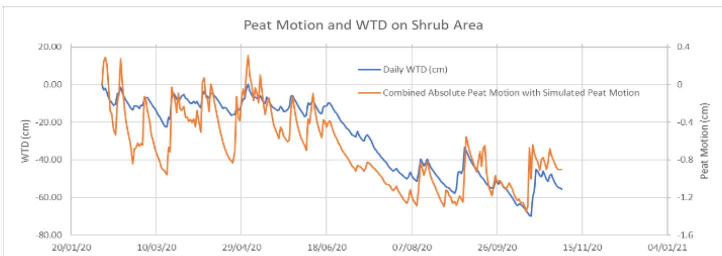

Figure 4. Absolute peat motion compared to WTD dynamics in shrub area

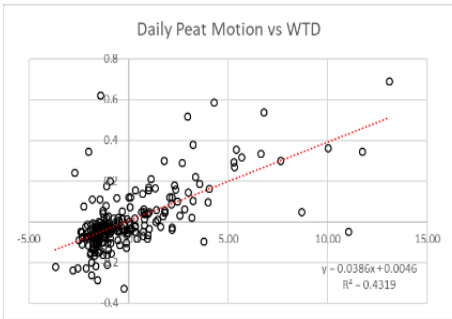

Figure 5. Daily peat motion vs. WTD correlation

3.2. *Central Kalimantan – coconut plantation*

Peat subsidence on coconut plantation in Central Kalimantan is provided in Figure 6. Absolute peat motion provided a good relationship with water table dynamics. The highest elevation of the peat surface recorded during measurement was 0.09 cm, and the lowest elevation was -0.47 cm, relative to the initial peat surface installation. Peat motion tended to move downward with the amplitude of 0.56 cm. Relationship of absolute peat motion (PM) and WTD was considerably high with R^2 value of 0.91. This happens because vertical peat movements were negligible compared to other locations.

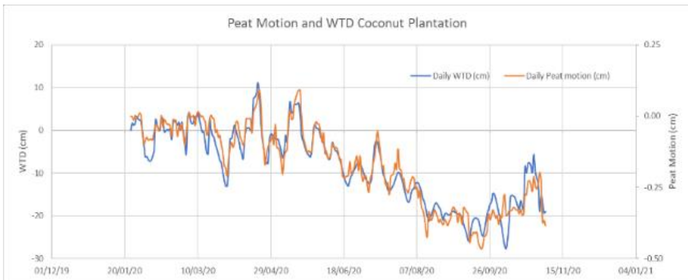

Figure 6. Absolute peat motion compared to WTD dynamics in coconut plantation

3.3. *South Sumatra – oil palm*

Peat subsidence over oil palm plantation in South Sumatra is depicted in Figure 7. Absolute peat motion and daily peat motion showed a good relationship with water table dynamics. The highest and the lowest elevation of peat surface during the survey were 3.2 cm and -1.7 cm respectively. Peat motion fluctuated with the amplitude of 4.89 cm. Absolute peat motion (PM) and WTD data were well associated with the R^2 value of 0.86. Hence, this suggests that peat surface movement is in line with the dynamics of water table.

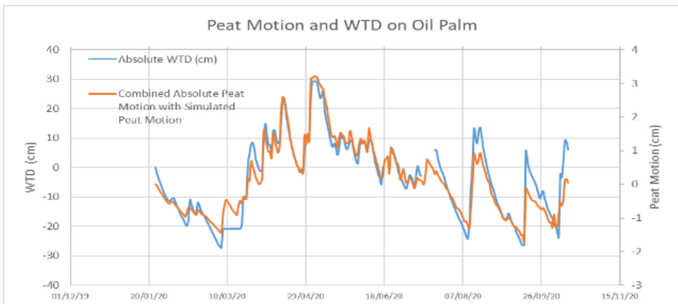

Figure 7. Absolute peat motion compared toWTD dynamics in oil palm plantation

3.4. South Sumatra – forested areas

Figure 8 displays the outcome of peat subsidence monitoring on forested area in South Sumatra. Due to field measurement issue (i.e. broken camera), the figure only shows 7 months of data acquisition period. Either absolute peat motion or daily peat motion showed agreement to water table dynamics. The highest peat surface elevation recorded was 4.18 cm, while the lowest elevation was -0.62 cm, relative to the initial peat surface installation. Peat motion appeared to ascend with the amplitude of 4.80 cm. High R^2 value (0.95) was observed between absolute peat motion and WTD.

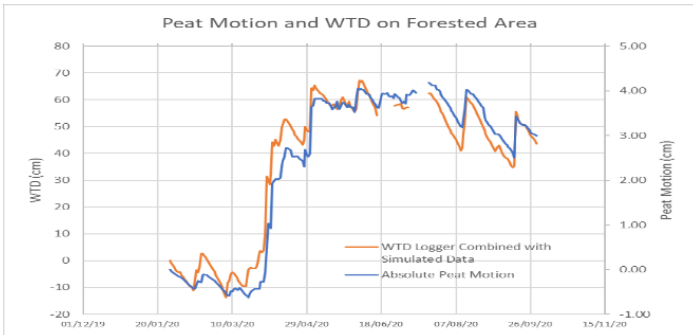

Figure 8. Absolute peat motion compared to WTD dynamics in forested area

4. Conclusion

This study demonstrated a good relationship between absolute peat surface motion and the dynamics of water table, as indicated by R^2 values ranging from 0.74 – 0.95. As summarized in Table 1, Central Kalimantan peat lands indicated a downward motion and fluctuated with amplitudes of 1.66 cm and 0.56 cm over shrub and coconut plantation sites, respectively. In South Sumatra, peat surface highly oscillated with upward-downward combination (on oil palm) and upward motion (on forest) with the amplitudes of 4.89 cm and 4.80 cm over oil palm plantation and forest, respectively. Local settlement/peat surface downward motion occurred in shrub, coconut, and oil palm plantations which possibly lead to peatland subsidence. It should be noted, however, that coverage area of this method remains unclear. Authors would recommend further studies regarding the spatial extent, combined with a longer period of measurement.

Table 1. Peat motion, water table dynamic, and net subsidence on four different typologies

Typology	Amplitude of Peat Motion (cm)	Amplitude of WTD (cm)	Net Subsidence (cm)
Shrub	1.66	70.17	1.35
Coconut Plantation	0.56	38.85	0.47
Oil Palm Plantation	4.89	56.66	1.70
Forest	4.80	80.93	0.62

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