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Trees of tropical peatland forest influence on variability of water and carbon input through stemflow

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Abstract. *Astiani D, Mujiman, Curran LM. 2017. Trees of tropical peatland forest influence on variability of water and carbon input through stemflow. Biodiversitas 18: 383-388.* Hydrology controls the chemical and biotic processes in peatlands, influencing interactions among vegetation, nutrient dynamics, and carbon fluxes. The effects of forest degradation revealed severe changes in the hydrological cycle such as variability of water input on forest floor, soil water storage and the ability to abstract water from soil depth. A study had been conducted to investigate part of the water cycle, the amount of water and carbon input through stemflow into peatland forest floor for 2 years. Stemflow was measured on 20 trees of each 3 blocks of forest with tree diameter ranging from 10-30 cm dbh using stemflow collectors. Then the trees were grouped to three bark types (smooth, mid, and coarse) to investigate whether it had influenced the inputs. Results showed that with mean annual precipitation of 3282 ± 128mm, annual mean stemflow for the area was 18.2% of the rainfall. Further analysis demonstrated that tree species with smoother bark textures tend to bring more water to forest floor compared to mid and coarse bark textures (46% and 42.5% more than coarse and intermediate consecutively). The carbon input also show similar trend. The results implied that tree species influence the amount of stemflow and significant amount of water could be slower down come to forest floor through this mechanism and protected forest soil.

Keywords*:* Annual stemflow, peatland forest, hydrological flow, tree barks, tree species

INTRODUCTION

Peatland hydrology is an important factor influencing peatland ecology, development, function, and processes (Dommain et al. 2010: Hooijer et al. 2010). Peatland epecially forested peatlands have critical ecosystem functions either by mitigating or intensifying flooding and/or by maintaining those hydrological functions including drainage and filtering inputs and outputs. Hydrology influences landform development by regulating interactions among vegetation, nutrient dynamics, and carbon fluxes (Camino-Serrano 2014), and alters gas diffusion rates, nutrient availability and cycling, and soil redox status (Holden 2005). Moreover, hydrological processes are vital for water resource management, flood prevention and stream water quality, and also affect carbon balane on peatland (Bispo et al. 2016).

Peatlands are also recognized as important storage of carbon (Page and Rieley 1998; Celine et al. 2013). In Kalimantan, Indonesian Borneo, they could contains approximatelly 650-1500 t carbon per meter depth (Astiani et al. 2017). Peat makes up of partially decomposed organic matter deposited in waterlogged lands ≈ 5,000-15,000 years ago. Peat litters from forest accumulates organic material that is more resistant to decompose than plant litter found on mineral soils. The combination of very low pH with waterlogged condition restricts the rate of decomposition below the rate of litter production, resulting carbon accumulation in peat lands. Therefore, explanation on their hydrological interactions is crucial for understanding carbon accumulation and carbon cycles (Holden 2005). Poor drainage, long periods of water saturation, high rainfall and substrate acidification create conditions in which plant residues accumulate much faster than they decay (Fontaine et al. 2007).

However, tropical peatlands, as well as other forest types, are converted to other land cover types at a high rate. Indonesia, especially Sumatra and Kalimantan, have under gone rapid deforestation since 1990 (FAO 2001; Archard et al. 2002). Forest degradation (Astiani 2016), fire disturbance, and land cover changes alter ecological functions especially within peat forest ecosystems. Forest land use change for agriculture has intensified groundwater recharge and increasing water tables (Bari and Smettem 2006; Astiani et al. 2015). In Amazonian forests, the effects of forest conversion from fires or to agricultural lands revealed severe changes in the hydrological cycle such as variability of soil water storage and the ability to abstract water from soil depth (Hodnett et al. 1995; Grip et al. 2004).

The most important changes in hydrological fluxes as the consequence of forest conversion is the alteration in the quantity of water intercepted and evaporated to the atmosphere from vegetation surfaces (Dietz et al. 2006). However, less information is available for more gradual changes in vegetation structure as created by logging practices or forest degradation. The water balance on earth surface can be disrupted because of forest degradation and conversion, especially in the partitioning of gross precipitation into throughfall, stemflow, and intercepted by tree canopy or stems (Sahin and Hall 1996). Generally, surface runoff and stream outflow increase when forest is cleared or degraded (Sahin and Hall 1996; Piao et al. 2007).

Until recently, we lacked of empirical studies in hydrological event dealing with carbon flow in tropical peatland forests especially focused carbon and nutrient flow as inputs partition from this ecosystem. To search how the water and nutrient input partition in peatlands forest can be calculated by defining the partition in the forest. This study aimed to investigate forest degradation influence on the quantity of water and carbon input to soil surface through stemflow mechanism and also, to investigate how tree species within peatland forest role in the input.

MATERIALS AND METHODS

Study site

The study was conducted on an ombrotrophic, or rain-fed coastal peat swamp forest in Kubu Raya District, West Kalimantan, Indonesia ($0^0$13' S and109^{0}26' E, ca~ 4 m a.s.l.). Mean annual rainfall in study are was 3.168 mm. For comparison, presipitation in Supadio Climate Station was 3212 mm ± 489 (mean ± s.d. 2009-2014, Supadio Airport, <5km from site). In 'normal' years, no months with≤100 mm rainfall are recorded, but some variation in dry season severity occurs at the onset of the El Niño Southern Oscillation (ENSO; e.g., three consecutive dry months, ≤100 mm rainfall). Recent ENSO associated droughts occurred in this region in 2004, 2006, 2009, 2012 with an ENSO frequency six decades is ~ 3-5.2 yrs (Supadio Airport Climate Data 2014). These forests have been degraded by low impact logging likely in 2002. This forest area was selected based on an extensive regional field survey and satellite image assessment that determined this was the least disturbed contiguous block of peatland forest available and was representative of peat land being converted or lost to fire.

Stemflow measurement

Stemflows were collected from forest trees also using flexible thin, flexible PVC pipe and polyurethane foam attached to tree trunks at 1 to 1.2 meter above ground. The stemflow water was drained using plastic tubes connected to water collectors in tree base (Figure 1.A). Stemflows were measured on 20 trees of 3 50x50m plots within the forest area with 10-30 cm dbh and from ~ 5m to 25m hts. Tree species selected were based on their richness within all peatland forest plots and/or their variability of bark structures (smooth, medium, and coarse). The bark structures criteria was defined based on tree outer bark thickness and roughness which was measured with caliper. Smooth, medium and coarse outer barks were defined when bark thickness and roughness was less than 0.2cm, 0,2-1,0 cm and >1,0cm respectively. The thirteen species with their local name, family, and type of their barks are presented in Table 1 and Figure 1.A,1.B, and 1.C.

Stemflows were collected once per week during rainy season and 2-4 week during dry season for quantity assessments. The stemflow were quantified collected with samples in 0.5 L amber capped glass bottles saved in 30 C refrigerator and were brought to the Laboratory to determine organic carbon quantity.

Laboratory analysis were separated into dissolved inorganic and particulate organic carbon, and along with pollutants potentially from atmospheric deposition (SO_4^{2-}-S, NO_3^--N).Water sample were transfer into 0.5 L amber capped glass vials. Samples were refrigerated at 2-3^{0}C before transferred to Balai Pengkajian Biotechnology Laboratory in Bogor (West Java) in an ice cooler and stored at 4°C to minimize any potential change in sample constituents. Before this analysis, samples were returned to room temperature. Samples were prepared by filtering through a 0.45μm membrane. DOC concentration was measured by ultraviolet oxidation technology using SGE AnaTOC analyzer. Water samples were filtered through a prewashed 0.45 μm membrane prior to analyzing DOC to separate the suspended particles. UV-Visible Spectrophotometer and APHA Standard methods 4500E and Brucine methods were applied to analysed SO_4^{2-}-S, NO_3^--N contents.

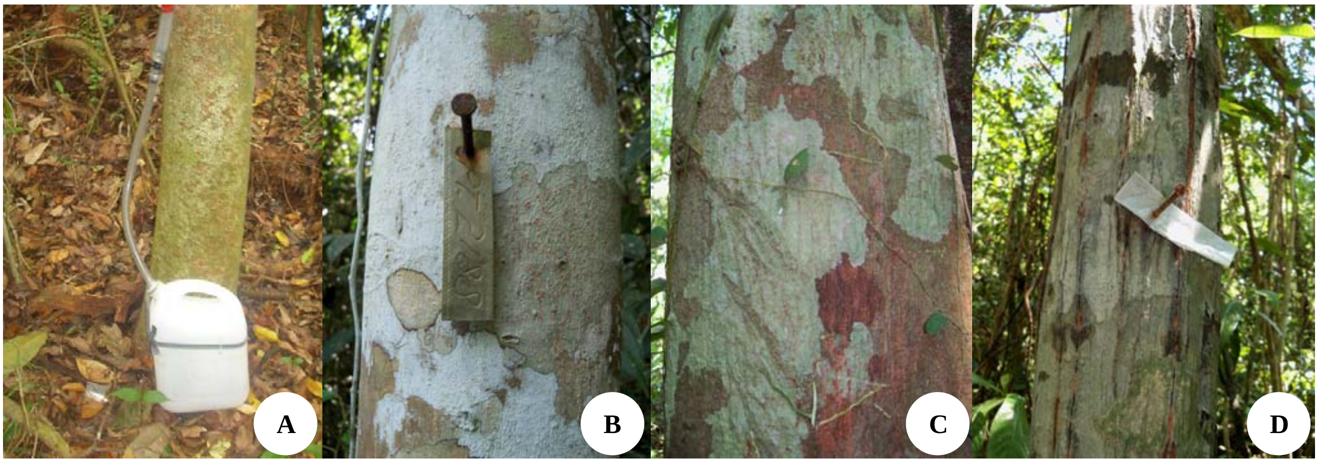

Figure 1. A. Stemflow collector, and B. smooth, C. medium, and D. coarse tree bark types

Table 1. List of species measured for their stemflow with their local names, families and their type of barks at peatland forest of Kubu Raya, West Kalimantan, Indonesia

Species name	Lokal name	Family	Bark type
Actinodaphne sphaerocarpa (Bl.) Nees	Medang Asam	Lauraceae	Medium
Blumeodendron takbrai (Blume) Kurz	Mengkajang	Anacardiaceae	Smooth
Elaeocarpus griffithii A. Gray	Mempening	Elaeocarpaceae	Smooth
Litsea gracilipes Hook.f.	Medang Lendir	Lauraceae	Medium
Litsea resinosa Blume	Medang Perawas	Lauraceae	Medium
Nephelium maingayi Hiern.	Rambutan Hutan	Sapindaceae	Smooth
Palaquium ridleyi King & Gamble	Nyatoh Banir	Sapotaceae	Medium
Pometia pinnata J.R. & G. Forst	Kasai	Sapindaceae	Smooth
Shorea teijsmanniana Dyer ex Brandis	Meranti Batu	Dipterocarpaceae	Coarse
Shorea uliginosa Foxw.	Meranti Bunga	Dipterocarpaceae	Coarse
Stemonurus scorpioides Becc.	Mempasir Daun Lebar	Icacinaceae	Medium
Syzygium lineatum (DC.) Merr.& L.M. Perry	Ubah Merah	Myrtaceae	Smooth
Tetramerista glabra Miq.	Punak	Tetrameritaceae	Coarse

Gross precipitation

Precipitation monitoring used tipping bucket rain gauge (Rain Wise Inc.). Two buckets of monitors were placed in in open land <300m from forested peatland and connected to data logger (Cambell Scientific, Inc). The data loggers have been programmed to record data of rainwater input within 30 minutes intervals. We used mean data from 2 bucket rain gauges. In addition, daily rainfall data have been obtained from Supadio Airport weather station (~5km from research area). These values were compiled and compared as gross precipitation of the area.

Data analysis

Throughout the measurement of stemflow and gross rainfall, data are presented as mean and standard error (SE) in 95 % CI. To test stemflow for differences bark types classes, One-way repeated measures ANOVA analysis and then Pairwise comparisons were estimated among them. To convert volume of stemflow into mm depth, Bo et al (1989) formula was applied. Stemflow $S_1= 1/2 ((D_1 + D_2)/D_1) + (B_1 + B_2)/B_1) X V_c /A))$, where : D_1 is total number of trees in plots, D2 the number of uncollar trees, B_1 is total basal area of all tree (m^2 $plot^{-1}$), B_2 is basal area of uncollared trees, V_c is total volume of stemflow (L $plot^{-1}$), and A is the plot size.

RESULTS AND DISCUSSION

Rainfall, carbon and nutrient inputs

Monthly mean precipitation within the research area was 264.0±15.3 mm (n=68, Figure 2), lesser than the mean in climate station (267.7mm) in Pontianak (±5km from the research site). Based on monthly and annual precipitation, coupled with carbon content of rainfall (mean of 2,27 mg L^{-1}), annual carbon inputs were estimated from its content in precipitation as 0.07 ± 0.003 Mg C ha^{-1} or ≈ 0.25 ± 0.01 Mg CO_2-*e* ha^{-1}. Similar method was used in coupling N-NO_3 and S-SO_4 concentration (mean 1.65mg/l and 3.94mg/l). The mean annual input of N-NO_3 and S-SO_4 were 0.05 ± 0.002 Mg ha^{-1} and 0.12 ± 0.005 Mg ha^{-1} respectively. The amount of partial carbon input from precipitation was relatively small compared to carbon sequestration from ANPP which was 21.2 ± 1.0 Mg ha^{-1} y^{-1} biomass or ~38.3 Mg CO_2-*e* ha^{-1} y^{-1} on this peatland landscape (Astiani 2014).

Stemflow in peatland forests

Gross precipitation is partitioned into intercept water on tree canopy and branches, throughfall and stemflow before reaching a forest floor. This partitioning means that water can reach the forest floor in two different ways. The first is diffuse input as throughfall and the second point source input as stemflow (Taniguchi et al. 1996). Our results indicate that there was a significant amount of water input through stemflow mechanism to peatland soil. In West Kalimantan (Indonesian Borneo), rainfed peatland ecosystems, little, if any, water inputs are generated from surface inflow while inflow and outflow of ground water occurs. Because of peat dome formations, inflow and outflow of ground water occurs and thus stagnate to ground water. Therefore, stemflow input to peatlands soil is important to maintain their water balance.

Mean annual stemflow on each tree species sampled showed highly variation from 5.7 to 76.8 liter/tree (Figure 2). To estimated annual stemflow per unit area, we coupled these samples to mean tree basal area per hectar of 2009-2014 tree data, the stemflow within this peatland forests were 597.5 ±35.1mm, accounted to 18.8% of total water input from annual precipitation. This results were much higher compared to other previous results done in Lowland forest Selangor (Malaysia) which was only 2.5% (Ajinoor-Azida and Minjiao 2015). This could be the case due to higher density of tree in this peatland forest.

Among tree species, there were high variations on stemflow volumes on mean tree species measured. The variabilty of stemflow was also caused by different tree canopy charactersitics. Trees accumulate rainfall downward to soils via stemflow. When canopy structures are organized appropriately, stemflow can accomadate higher water flow through soils, transporting nutrients to biogeochemically active areas (Dezzeo and Chacon 2006). Carbon analisis in water (Dissolve Organic Carbon and Particulte Oorganic Carbon) resulted that mean carbon content found in stemflow water was 4.95 mg L^{-1}. This study found that carbon content in stemflow was significantly higher than it was in gross rainfall.

Roles of tree species in stemflow

Variability of tree species in contributing to stemflow is described in Figure 3. Further data analysis indicate that there were significant amount of stemflow among tree bark classes or bark structure significantly affects stemflow. The separation of tree bark texture among trees sampled showed that tree species with smoother bark textures significantly brought more water to forest floor compared to mid and rough bark textures (46% and 42.5% more than rough and intermediate consecutively, Figure 4).

Trees in peatland forest acts as mediator on precipitation water transferred to soil. They alter water capture through : (i) tree and stand structure properties, e.g., leaf morphology foliage, branches, tree age, and density (Ahmad-Shah and Rieley 1989; Nadkarni and Sumera 2004; Levia and Frost 2006; Holder 2007); and (ii) landscape features e.g., topography, slope aspect, prevailing winds and landscape position (Dietz et al. 2006; Weathers 2006).

Our results show that tree bark types were significantly different on stemflow quantities. Tree species demonstrated their variability in stemflow. Those results were supported by Herwitz and Levia (1997) that stemflow is highly correlated with crown projection, bark texture and tree architecture, and differences among and within species, and atmospheric polutants in urban environments (Levia and Frost 2002).

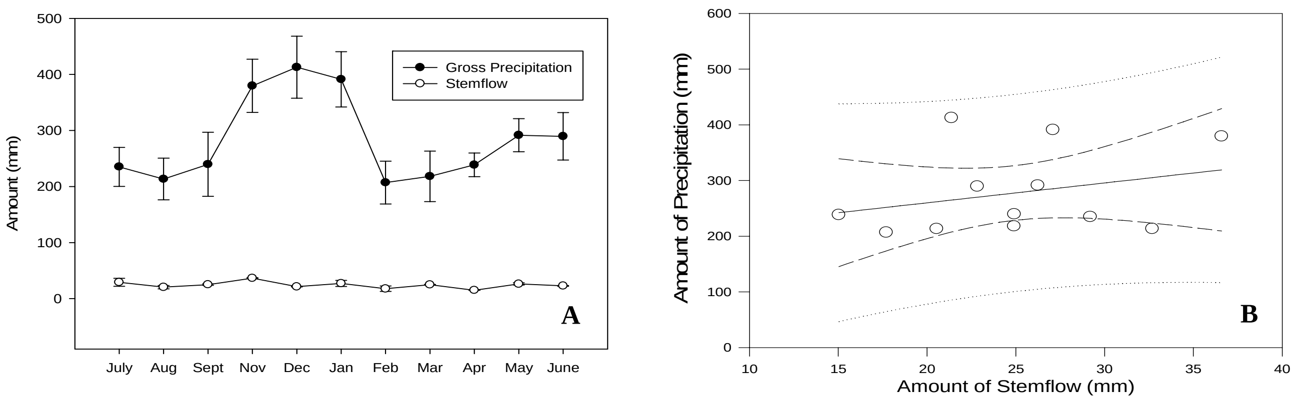

Figure 2. A. Monthly gross presipitation and stemflow (mm) (2009-2014) on peatland forests area of Kubu Raya West Kalimantan, and B. the both variables were positively correlated

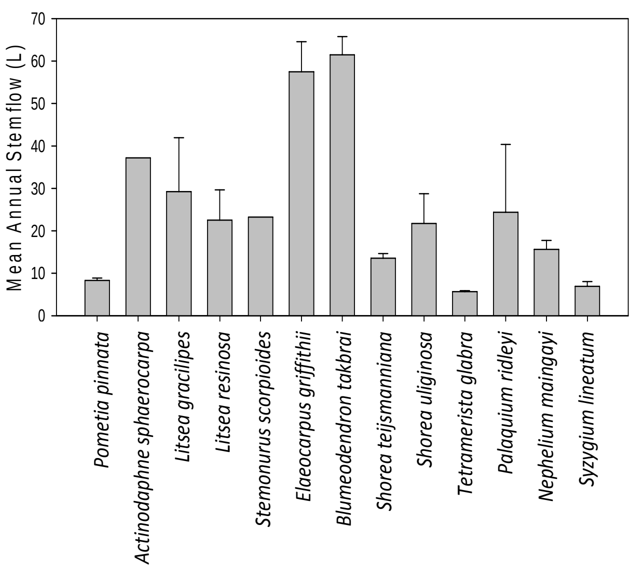

Figure 3. Mean annual stemflows distribution (in liter) among species within peatland forest

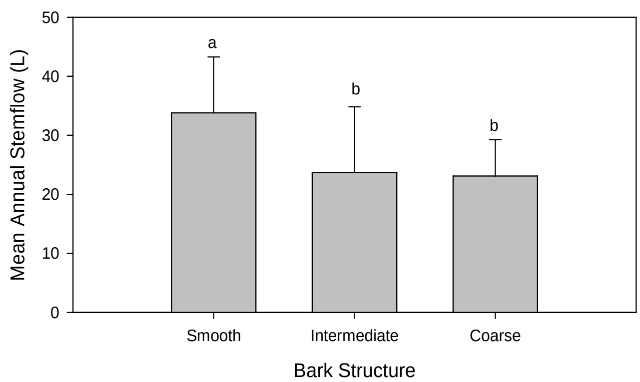

Figure 4. Mean Annual Stemflows among tree bark structures (smooth, intermediate, and rough), smooth tree bark was significantly flowing rain water higher than coarser barks (p>0.043)

Our results was supported also by Van Stan et al. (2016) that bark structure significantly affects stemflow.

Generally, throughfall density increases while stemflow amount decreases as canopy surface area declines (Stogsdill et al. 1989; Ponette et al. 2009). Landscape features such as elevation, aspect, and edge also have a major role in water distribution (Weather 2006). Several studies on the effect of logging on rainfall partitioning yielded the following results. In a lowland mixed Dipterocarp forest in Central Kalimantan, Indonesia, the rainfall interception was 11% of precipitation in a nearby unlogged natural forest and 6% of precipitation in a logged forest (Asdak et al. 1998). In another lowland mixed Dipterocarp forest in northern Borneo, (Sabah, Malaysia), 91% of precipitation reached the ground as throughfall in an unlogged natural forest, whereas 80% and 84% of throughfall were recorded in plots of moderately and highly damaged patches of forest (Chappell et al. 2001) indicating interception rates increase with disturbance intensity. Both studies from lowland mixed Dipterocarp forests highlight contrasting effects of logging on rainfall partitioning from only two empirical studies.

Precipitation is a significant tool of nutrient movement from the forest canopy to soils. Our results show that dissolved organics carbon materials in precipitation are the principal input of plant nutrients to ombrothrophic peat. This result was supported by Moore et al. (2013) which most dissolved material reach soil thhrough this mechanisme. In forested peatlands, some bulk precipitation falling on tree canopies is intercepted while the reminder reaches the forest floor as throughfall and stemflow which carrying in nutrients and pollutants. Leaching of the foliage, branches and stems also transfer dry deposited material from canopy to soil surface. Dezzeo and Chacon (2006) also found significant inputs of nutrient in throughfall and stemflow compare to incident rainfall-with throughfall and stemflow amounts representing 71-77% and 2-8% of the annual incident rainfall, respectively. In addition, Dezzeo and Chacon (2006) declared that, except in throughfall, decreasing tree density leveled off the nutrient inputs in stemflow.

This study results show the important roles of stemflow mechanisme as a partial water that reach peatland forest soil and significant contribution on nutrient input.. It was also interesting finding that each tree species with their bark characteristics has their variation on the role of water and nutrient. The existance of forest on peatland and their contribution on inducing water and nutrient input to tropical peatland forest imply that it is necessary to maintain peatland forest ecosystem for inducing water and nutrient input.

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