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UTILIZATION OF DISCRETE-RETURN AIRBORNE LIDAR FOR IDENTIFICATION OF SMALL CANALS IN THE CLOSED-CANOPY OF PEAT SWAMP FOREST IN CENTRAL KALIMANTAN INDONESIA

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SUMMARY

Peat swamp forests of South East Asia have contributed the largest portion of global greenhouse gas emissions, due to causes associated with forest resource extraction, including logging, land conversion to agriculture and fires. Accurate mapping of actual and historical infrastructure in peat swamp forests, in particular illegal roads and canals, is crucial for peat land management planning on hydrological restoration and forest protection activities. However, identifying these features using optical satellite imageries is still problematic, even using high resolution satellite imagery or aerial photos. They are often very narrow and covered by closed-canopy forests. Our study aims at identifying small canals and logging roads in peat swamp forest in Central Kalimantan using discrete airborne lidar data. These logging trails and small canals are associated with historical or illegal timber extraction. We used a lidar-derived spatial data layer (relative density model (RDM)) characterizing patterns in the 3-D forest canopy volume, and a normalized digital terrain model (DTM) generated from 2.8 pulse m^{-2} density lidar data for assessing existing logging trails and small canals. We visually digitized the logging roads and small canals from the models and compared the results with field measurement using GPS.

***Keywords**: ALS, digital terrain model, relative density model, peat swamp forest*

INTRODUCTION

Tropical peatlands play a crucial role in global carbon dynamics. In the last several decades, peatlands in South East Asia have contributed the largest portion of global greenhouse gas emissions, due to logging, land conversion to agriculture and fires (Hooijer *et al.* 2010; Page *et al.* 2002). More than 80% of South East Asia peatlands are located in Indonesia and stored more than 55 Gt of soil carbon (Jaenicke *et al.* 2008; Page *et al.* 2011). This amount is comparable to the carbon flux from global tropical deforestation over a century (Cramer *et al.* 2004). Given the fact that current rate of deforestation is hardly slowing down (Hansen *et al.* 2013; Miettinen *et al.* 2011), this could be a major concern in climate change mitigation efforts as this massive terrestrial carbon stock would likely be emitted.

Development of transportation networks allowing access to the forests increase human activities and thus forest degradation. During 1997-1998 drought, fire occurrences become more likely in more deforested areas and degraded forests (Siegert *et al.* 2001). This is because most of direct causes of fires were associated with human activities in land uses and forest resource extraction (Dennis *et al.* 2005). Starting from the early1980s, most of the pristine peat swamp forests in Sumatra and Kalimantan were managed under timber concession rights using selective cutting schemes, then followed by small scale illegal logging (Posa *et al.* 2011; Sorensen 1993) or government resettlement programs (Dennis *et al.* 2005). For large companies and government projects, establishing railways or large canals for accessibility were possible. While illegal loggers often developed transportation routes smaller in width, requiring small and portable tools such as chainsaw or machete. The small canals could be only 0.5 – 2.5 meter wide (Franke *et al.* 2012). Thus identifying small canals using optical satellite imageries is still problematic, even using high resolution satellite imagery or aerial photos.

The identification of canal and road networks in the existing peat swamp forests are not only useful for monitoring forest degradation but also for forest protection and hydrological restoration planning (Jaenicke *et al.* 2010). Canals constructed for accessibility and log transport are normally left open or abandoned in the dry season or when no more commercial timber is remaining. The canals drain the water from the peat dome to the adjacent rivers, which lower the water table and become susceptible to fires (Turetsky *et al.* 2015). Drainage also increases peat oxidation and carbon emissions (Wösten *et al.* 1997). Rewetting of the drained peatlands, through canal blocking, is an effective way to reduce fire risks and carbon emissions (Page et al, 2009). The position and the length of canals are important information for selecting and prioritising which canals to be blocked. Our study aims at identifying small canals and logging roads in peat swamp protection forest in Central Kalimantan using discrete-return airborne lidar data and compare with field measurement using GPS tracks.

MATERIALS AND METHODS

Study Site

Our study site is located at the northern part of the ex Kalimantan Forest Carbon Partnership (KFCP) project area (114^o 23.5‘ – 114^o 40.3‘ E; 1^o 56.0‘ to 2^o 30.1‘ S). in Central Kalimantan Indonesia The study site encompasses 75,342 ha of tropical peat swamp forest with a range of degradation levels. The forest was selectively logged by timber concessionaires in the 1990s and by small-scale illegal logging to the present day. The percentage of forest cover in the study site is much larger than the southern part of the ex KFCP area.

Lidar Data

Lidar data sets were provided by the KFCP project. The calculated pulse density was 2.8 pulse.m^{-2}. All datasets were captured using Optech ALTM 3100 and Optech Orion M200 instruments mounted in Pilatus Porter fixed wing aircraft. Data were collected by the same vendor during the period of 15 August – 2 October 2011. The vendor provided a 1- meter resolution lidar-derived digital terrain model (DTM) for the KFCP area. Ground points were classified by the vendor. The vertical accuracy of the raw lidar data and the DTM product were 0.14 m and 0.18 m, respectively (Ballhorn *et al.* 2014).

GPS measurement

To validate the result from lidar analysis, we used a field measurement data provided by the Borneo Orang Utan Foundation (BOSF). A BOSF team of 5 person conducted the measurement in April 2014 in the south eastern part of the study site using small boat, about 2 years after lidar data acquisition (BOSF, 2014). The team measured position, length, width and direction of the canals using handheld Garmin GPS, compass, and cloth tape. The canal length, depth and width varies between 0.5 km – 10 km, 1 m – 3.8 m and 1.5 m – 3.8 m, respectively. Most of the surveyed canals were constructed in 1990s, none of them were constructed after lidar data collection. Some canals were abandoned or blocked by previous projects and thus inaccessible.

Lidar and spatial correlation analysis

We used FUSION v3.42 to process all point cloud lidar data (McGaughey 2014). The FUSION ―Cover" algorithm was used to compute the relative density models (RDM). We generated 5-m RDM for the study sites to identify logging trails. The calculation method of RDM was described in (Andersen *et al.* 2014; D'Oliveira *et al.* 2012). We used ArcGIS 10.3 desktop for additional pre- and post-processing. We generated normalized DTM with high resolution (1 meter). The normalized DTM was generated to identify pixels that abruptly different with the neighbours (Manuri et al, under review). We visually digitized canals and logging trails in the study site.

We evaluated the accuracy of lidar-derived canals identification using ground measurement data. Due to the inaccuracy of the handheld GPS for canals mapping, we buffered the lidar-derived canals with 15 m distance from both sides. We spatially compared by overlaying and intersecting the buffered canals and GPS-measured canals. We calculated the total length of the actual canals that fall into the 15-m buffer zone of lidar-derived canals. Unfortunately, we did not evaluate the logging trails result due to the absence of ground measurement data.

RESULTS AND DISCUSSION

Lidar-derived Models based on ground and aboveground point cloud were used to identify small canals and old logging trails. We found that canal detection using only DTM for was more difficult (Figure 1a) than using normalized DTM (Figure 1b). In the relatively flat peat swamp forest, DTM shows a smooth increase of the elevation towards the centre of peat dome. Small canals were very hard to identify in the DTM. The normalized DTM, on the other hand, was able to differentiate micro depressions. Long and narrow depressions were identified as potential canals.

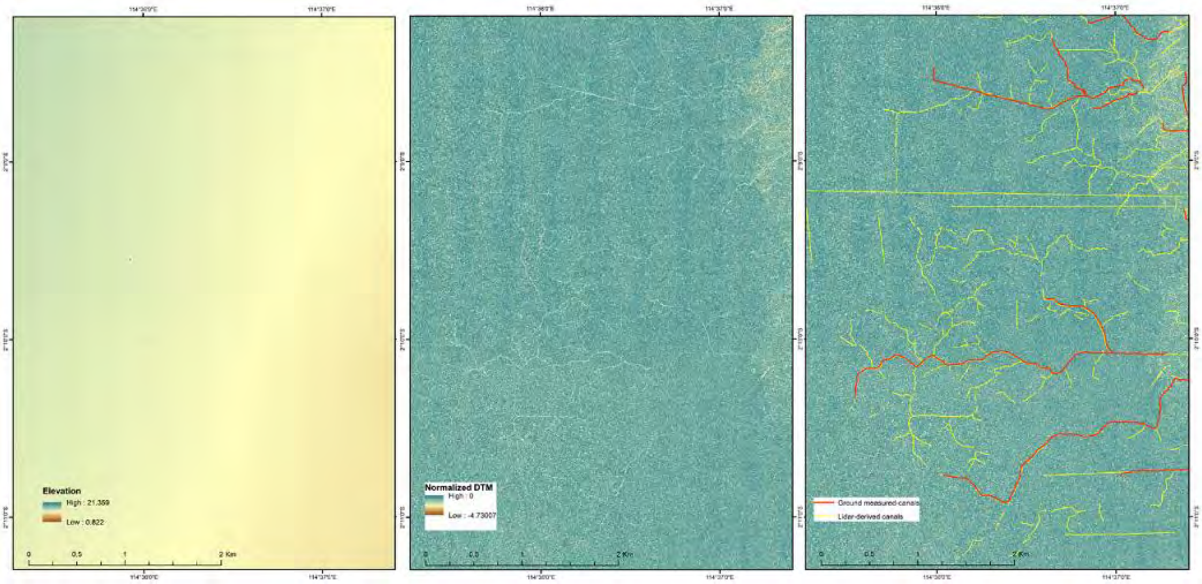

Figure 1: A DTM map from the eastern part of the study area depicting a very flat elevation (a), the normalized DTM showing terrain depressions (b) and the normalized DTM superimposed by digitized (yellow lines) and field-measured (red lines) canals (c).

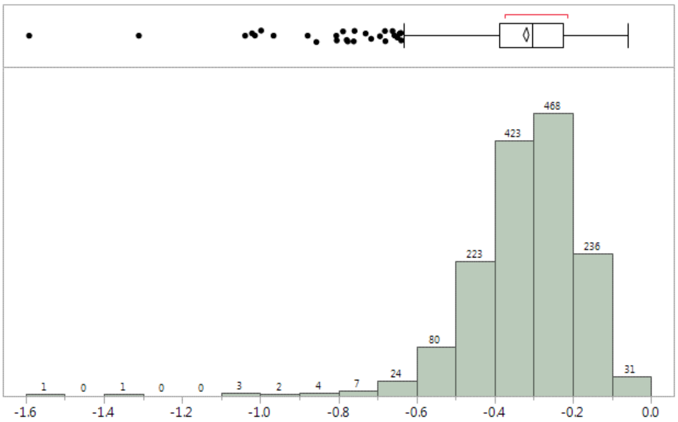

Figure 2: Frequency distribution of depression depth data (in meter) from random points along digitized canals.

We successfully identified small canals (Figure 1c) and old logging trails in the study site using lidar-derived datasets, with total length of 520 km and 276 km, respectively (Table 1). From the comparison analysis, we found that more than 76% of the actual canals were also identified in our digitized canals (Table 1, Figure 1c). Potential reasons for this include the fact that some parts of the canals are very narrow with the size could be only 0.5 – 1 m width (Franke et al). Thus our 1-m resolution DTM data will be unable to capture this very small terrain variation. Closed canopy forest also reduce the possibility of lidar to penetrate to the ground. Most of the canals were built in 1990s for timber transportation and abandoned (BOSF, 2014). At some points, the team that conducted the field survey faced challenges in accessing some canals and was forced to walk in the canals instead of using a boat. The canals were possibly closed due to biomass accumulation from dead vegetation.

Table 1: Summary data of lidar-derived canals and comparison with field-measurement data

	Total digitized from lidar data (m)	density (m/km2)	Total measured in the field (m)	Intersected with 15-m buffer zone of lidar-derived data (m)	% intersected
small canals	520,557	691	50,502	38,570	76.4

The normalized DTM is simply calculating the depth of depression, which is the vertical difference between canal bank and water level (as lidar can not penetrate water) or ground level if not inundated. Thus it is not the depth of the canals. The deepest depression identified in the study area was -4.7 meter, and most depressions were near large canals and rivers. Most of the digitized small canals had depression depths between 0.1 – 0.5 meter

(Figure 2). Given the vertical accuracy of the DTM is 0.18 m (Balhorn, 2009), many shallow depressions may not be detected.

Due to the low impact of the small scale logging in peat swamp forests, monitoring using medium resolution of optical-satellite imageries is still difficult (Franke et al, 2012). This study found that 5-m RDM can be used for detecting logging trails. Figure 3 shows the results of detailed mapping on canals and logging trails using airborne lidar over large area of closed canopy tropical peat swamp forest.

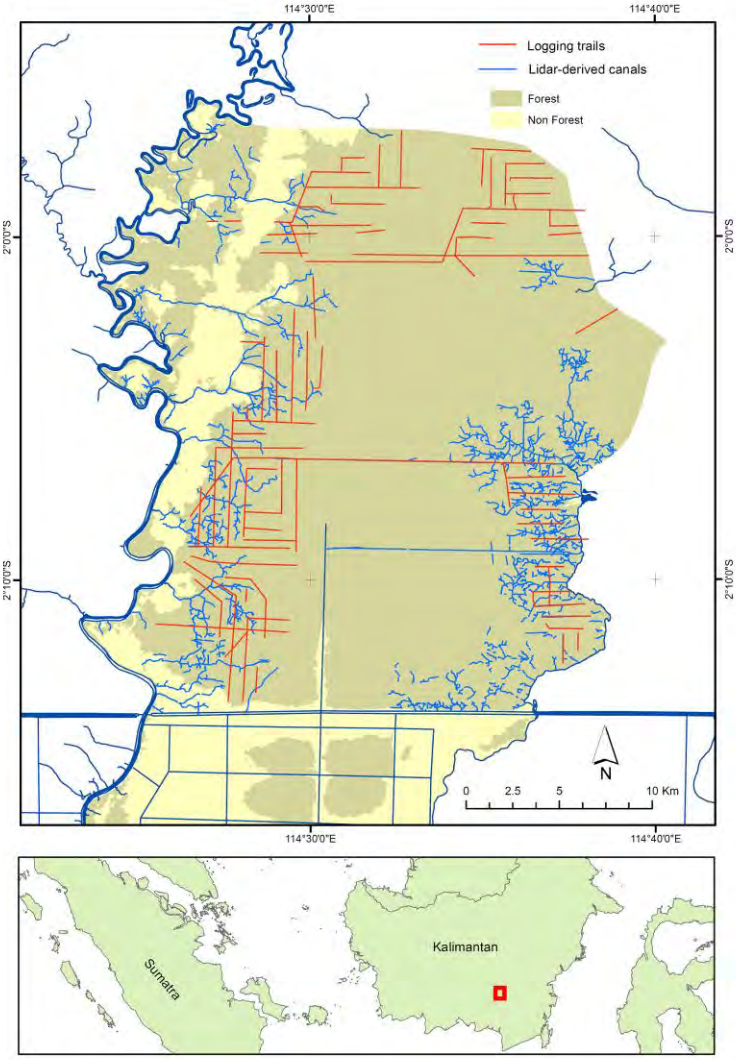

Figure 3: Map depicting old logging trails (red line) and small canals (thin blue line) in the study site

CONCLUSION

Detailed mapping of small canals and logging trails in closed canopy peat swamp forests is feasible using airborne discrete lidar data. The difficulty in identifying narrow canals, even with high resolution aerial photogrammetry, can be overcome using 2.8 m-density airborne lidar. The high resolution normalized DTM, generated using lidar data, was used for identifying small canals with good accuracy.

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