13th International Peat Congress
8 to 13 June 2008, Tullamore, Ireland

For Section 5: Tropical Peatlands

Peat Dome Measurements in Tropical Peatlands of Central Kalimantan with a high-resolution Airborne Laser Scanner to achieve Digital Elevation Models

by
H.-D. Viktor Boehm,
Juergen Frank

Kalteng Consultants, Kirchstockacher Weg 2
D-85635 Hoehenkirchen near Munich, Germany + Palangkaraya, Indonesia
Phone: +49 8102 774848, e-mail: viktorboehem@t-online.de
www.kalteng.org

ABSTRACT / SUMMARY

With a high-resolution Airborne Laser Scanner (ALS) the topography of peatlands was measured in August 2007 by a helicopter. With this modern technology we achieve a 3-dimensional Digital Elevation Model (DEM), hydrological data, and bio mass data and combined with peat drillings the amount of carbon storage. The ALS-resolution is in elevation (z) +/-15cm and in x- and y-direction 0.5m. Compared to SRTM-images with 90m x 90m x 5m and Landsat-Satellite-images with 30m x 30m (without elevation) we got much better knowledge of peatlands.
DEMs are divided into two types of groups. The Digital Surface Model (DSM) gathers information by Laser Scanner with trees, bridges and house and the Digital Terrain Model (DTM) is filtered using the DSM and shows the topography of landscape without trees, bridges, houses etc. The infra-red Laser sends 100,000 pulses per second and receives many of them in the detector and determines the distance to the different objects.

The study area was the Ex-Mega Rice Project (MRP) Blocks A, B, C, E and the Sebangau National Park between the rivers Sebangau, Rungan and Katingan. Results will be presented only for the area between the rivers Rungan and Katingan at the upper part of Sebangau National Park.

To understand better the situation of that area peat drillings have been done in 4-2006 parallel to the Kalimantan highway along the transect Tangkiling and Kasongan and in 7-2007 from Katingan river to transmigration village Habaring Hurung south of Tangkiling. Results of these peat thickness measurements showed a peat depth up to 8.10 m res. 10.0m. The peat surface with peat dome was measured along the two transects using the ALS technology with 49.1m res. 40.8m. The airborne Laser penetrates the Peat Swamp Forest (PSF) and reaches the peat surface. We measured an average tree height of 35m

The stored peat volume and carbon for the northern Sebangau Catchment and Palangkaraya between Katingan and Rungan rivers up to the border of the heath forest has 7.1 Gm³ (res. 5.93 Gm³) peat volume. The content of carbon in 1 cubic meter of peat has been measured and is 154.3kg res. 131kg. We found by ALS-measurements and Peat drillings and interpolation a stored Carbon value of **0.92 to 1.1 Gtons** for this area.

Keywords: Peatland, Peat Dome, GIS, Airborne Laser Scanning, Peat Drilling, Digital Elevation Model, Carbon Storage, Central Kalimantan

INTRODUCTION

Tropical Peatland has been accumulated between the Rivers Rungan and Katingan in Central Kalimantan during the last 10,000 years with more than 3 Mio. ha. Since the 1980s peatland and Peat Swamp Forest (PSF) is being cleared for the construction of the Kalimantan highway between the rivers Rungan (at Tangkiling) and Katingan (at Kasongan). Before then access to that area of peatland was only possible by boat (Sieffermann et al. 1988, Rieley and Page 1997, Rieley et al. 2001, Boehm et al. 2005). Since then land development projects have taken place in form of human settlements, agricultural activities and plantations, which have greatly increased the risk of peatland fires during the dry season. In 1997, 2002 and 2006 El Niño prolonged the dry season considerably increasing the risk of fire. With the help of Remote Sensing, a Geographic Information System (GIS) and Airborne Laser Scanning (ALS) an exact survey is possible, providing information as changes in the landscapes and the situation of the environment. An integrated planning and management program has been achieved.
Kalteng Consultants has performed together with the German company Milan Geoservice GmbH many ALS-Helicopter Flight Trials in Central Kalimantan from 5th to 10th August 2007. The preparation of this high-technological flight campaign was not easy and took several months. Finally every thing came together like a miracle, e.g. the availability of the ALS-equipment, the procedure at the custom, the availability of the helicopter with an excellent pilot, good weather conditions, the procurement of many recommendation letters and a marvellous team, see Fig. 1.

The purpose of these trials was to get high-resolution three-dimensional information from the landscape in form of the topography, to measure the tree-height and to estimate the bio-mass, to get knowledge of the peat dome in that huge peatland area including data of carbon storage, the shape of the river basin Katingan and Rungan, to scan the Tangkiling mountains with Rungan Sari, to scan the Small Scale Gold Mining (SSGM) activities at Galangan, Kereng Pangi near the city Kasongan.
The ALS-data and ortho-photos have been processed and analysed and will be presented here for the upper Sebangau peatland area.

Fig. 1. German-Indonesian ALS team in front of Bell 206-Helicopter in Central Kalimantan: Juergen Frank, Detlef Klante, Suyud, Alam, Viktor Boehm, Jan Giehler and Mustafa Syafrudin

Geographic location of the research site

The Tangkiling District is located to the North of Palangkaraya in Central Kalimantan and has 7 unusual granite hills in the normally flat lowland peat land topography with high annual precipitation. Tangkiling village is located 34 km from Palangkaraya, the provincial capital, on the Kalimantan highway to Sampit. Approx. 45 km away from Tangkiling (79 km from Palangkaraya) is the city Kasongan capital of the Katingan region located on the Katingan river. Between the two rivers a huge amount of peat has been accumulated up to more then 10m depths. In order to estimate the stored carbon and to measure the precise water shed of the peat dome, peat drillings were carried out in spring 2006 with a distance of 500m parallel to the highway with 200m from the road. This research area is located in the northern part of the so called Sebangau Peatland Catchment and reaches up to the boarder of PSF and heath forest.

Landsat ETM images 118-61 acquired on 30 June 1991, on 16 July 2000 and 15 Feb 2003 were compared by using detailed analysis of the region around the Tangkiling granite hills and the black water rivers Rungan and Katingan. These images show major changes in this large remnant of tropical peatland due to high rates of deforestation and fires in 1997, 2002 and 2006 (Boehm et al. 1995, 2000, 2006). The 1991 and 2000 Landsat images show very clearly in different green colours the different PSF and peat lands (Fig. 3). With the peat drillings we analyzed the types of peat soil and the peat thickness. The ground survey confirmed the areas of tall and medium PSF showing by different green colours in the Landsat images. Also the peat volume and carbon was estimated in this area. Additionally we used SRTM-Data with the DEM information of approx. 5m in elevation. They were acquired in Feb. 2000 by the Shuttle Radar Topography Mission.

The Kalimantan highway was built in the 1980s and many people were able to enter the previously inaccessible interior of this peat land landscape, exploit residual timber resources, mostly on an illegal basis, and they uses fire as the most economical method of land clearing. It is important to restore this fragile flat tropical peatland to protect that area against the frequent fires with smoke and haze during each dry season.

METHODOLOGY

Technical equipments of Airborne Laser Scanning

The following equipments were used during the helicopter flight trials in August 2007.

- Inertial Navigation System (INS)
- Flight Management System (FMS)
- GPS-Antenna L1/2-band located at the helicopter tail boom and a
- DGPS-ground station
- ALS Equipment with Riegl Technology, LMS Q560,
- Several Recorder and a
- Digital RGB camera from Hasselblad with 22 MB pixel
- Power supplies and a mechanical support structure under the helicopter
- Displays in the helicopter

LMS-Q560 Airborne Laser Scanner	
Range	30 - 1500 m
Laser Puls Rate	Up to 100 000 Hz
Laser Wavelength	near Infrared
Beam Divergence	0.5 mrad
Scanner Unit	rot. Polygonmirror
Scanning Type	Parallel Lines
Scanning Speed	5 -160 scans/sec
Measuring Accuracy	±20 mm
Scan angle	± 22.5° and ± 30°
Min. Step Width	0.004° @ 100000 Hz
Wight	20 kg
Power	120 Watt

The Airborne Laser Scanner transmits Laser pulses which will be reflected from the sureface of the earth and received by the Laser Detector.

Table 1. Parameter of Airborne Laser Scanning System.
We used +/- 30° scan angle in approx. 500m flight altitude above ground

Peat Drilling and Carbon estimation

We used the normal peat drilling equipment and two Global Positioning Sensors (GPS) and a compass, ref. Boehm et al. 2006, see tracks in Fig. 2. Along the transect Kasongan at km79 to Tangkiling at km34.5 we drilled every 500m parallel to the Kalimantan highway at 200m distance peat holes to measure the peat thickness. Peat samples from 0 - 20 cm depth and the mineral soil below the peat were taken for pH, C and nutrient analysis to the Analytical Laboratory at Palangkaraya University. Additionally water samples were brought from the seven small rivers crossing the road to the laboratory for pH analysis. Nutrient analysis for the mineral soil was carried out on three samples near Tangkiling area for Rungan Sari and Transmigration area km38. Table 2 describes the test parameter and used method. Table 3 contains the 91 peat drillings with peat depth, the vegetation, the location, the ALS-peat surface (topography) and the mineral below the peat. Table 4 contains the bulk density and C-organic content of peat at 0-20 cm deep in certain places along transect Kasongan to Tangkiling.

The UNPAR staff drilled along the transect from river Katingan to transmigration village Habaring Hurung in July 2007. They drilled every 700m peat holes to measure the peat thickness. This area is covered by PSF and has a difficult access. Table 5 contains the 31 peat drillings with peat depth, the ALS-peat surface, the vegetation, the location and the bulk density. C analysis was carried out on 22 samples and bulk density analysis on 12 samples. pH value of the mineral soil below the peat was analysed for 21 samples along the transect (Sulistiyanto 2004).

	Parameter	Method
1	Peat, mineral soil, and water pH	pH meter
2	C-organic	Loss on ignition
	Bulk Density	Ring sample
4	N total	Kejhdahl method
5	Available P	P-Bray 1
6	K, Ca, Mg, and Na exchangeable	Ammonium Acetate pH 4.8
7	C E C (Cation Exchange Capacity)	Ammonium Acetate pH 4.8
8	Texture	Pipette method

Table 2. The method used for peat and mineral soil analysis

Data Processing

Land cover classes with peat land and PSF types:

Basic image processing was done using the Remote Sensing Software ENVI4.2. With a GPS points were collected during peat drillings using the waypoint mode of the GPS and during the ALS-helicopter flights we collected the GPS-tracks. With the GIS software ArcGIS 9.2 the peat drilling locations were superimposed to the SRTM and LANDSAT images from 2000 (Boehm *et al.,* 1995, Boehm & Siegert, 2000, Boehm et al. 2003, 2004, Boehm 2004 and 2006). The analysis was made first by visual interpretation in the images. We used for the estimation of stored peat volume and carbon for the northern area of Sebangau Catchment and Palangkaraya between rivers Katingan and Rungan up to the border of the heath forest the LANDSAT image from 1991, with the different visible colours for PSF types (Fig. 3, 13).

SRTM-DEM elevation data with existing vegetation types:

To get rough information about the elevation along the transect we used at the beginning the SRTM DEM data from February 2000 with approx. 5m resolution in elevation and 90m x 90m in x and y. Different heights of elevation lines were analysed in ArcGIS in combination with the peat drillings (Fig. 2), showing by different colours. Cross-sections along the transect were prepared for the highway without PSF and to the north parallel to the transect with PSF. The Radar do not penetrates the PSF therefore the canopy is detected only. The availability of the ALS-data improved the accuracy of the DEM drastically because it has a higher resolution and it penetrates the PSF.

ALS-DEM Data Processing

ALS-DEM processing and visualisation needs a lot of knowledge in the area of computing.
We used the following SW for our project:

- GlobalMapper 8 and Surfer 8
- LasEdit for classification and visualisation
- ArcGIS 9.2 with LP360 module
- ENVI and IDL
- TreesVis for producing DEM-Videos.

Additionally common SW was used: Adobe Photoshop CS2, ACDSEE, IranView, Garmin GPS with Map Source-SW, Google Earth Internet, different ALS-sensor-SW and Hasselblad-SW. There are many other SW for DSM and DTM processing available.
The geo-referenced raw data were delivered by Milan Geoservice GmbH in ASCII-Format and partly in Grid-Format.
With this data the ALS-tracks were analysed using the common LIDAR exchange format standard LAS-files which is a standard of the American Society of Photogrammetry and Remote Sensing (ASPRS) using the LasEdit SW. The LAS file format is a public file format for the interchange of LIDAR data between vendors and customers. This binary file format is an alternative to proprietary systems or the generic ASCII file interchange system used by many companies. The .LAS file format is a binary file format that maintains information specific to the LIDAR nature of the data while not being overly complex. ASPRS has endorsed and strongly supports the use of this standard. Further details are available at www.lasformat.org
The LasEdit SW classification / filtering module Surface Magic was used to get the topography (DTM), Fig. 3 to 12. The TIN (Triangulated Irregular Network) calculation for the DSM- and DTM products can be visualized by LasEdit and very good with LP360 in ArcGis. Both SW can produce cross-section of profiles, display pseudo 3D-presentation and create contour lines for maps. The LP360 module of ArcGis 9.2 is very capable to show the different ALS-tracks geo-referenced.

RESULTS and DISCUSSION

The ALS-technology has been demonstrated in Central Kalimantan successfully. High resolution ALS geo-coded data are available from the helicopter flights beginning of August 2007 with +/-0.5m resolution in x and y and +/-0.15m in z (elevation) which are referenced to

the Palangkaraya airport with elevation level of 25.0m. The data were analysed to get the profile of the peat surface and peat dome for topographical and hydrological maps and for estimation of the PSF tree height and for bio-mass calculation. The data were used with the processed DSMs and classified DTMs to analysis the transects between Kasongan and Tangkiling as well as between Katingan river and transmigration village Habaring Hurung.
The ALS is penetrating the PSF with 3% to 5% of the Laser beams, which are enough Laser data for producing topographical maps.
The highest peat dome was determined with 49.1m between Kasongan and Tangkiling res. 40.8m between Katingan and Habaring Hurung and the water surface at the Katingan river (-2.09292, 113.50867) was 23.1m on the 8.8.2007.
The visualisation of three dimensional data is not so easy and needs spe SW and skills of the operator. All the processed maps, graphs and profiles can not presen in this paper.

Table 3 shows the variation of peat depth and mineral soil below the peat from Kasongan to Tangkiling transect and the peat surface measured by the ALS-technology. Seven small black water rivers are crossing the Kalimantan highway. They have an average pH-value of 3.7. Very shallow peat can be found from km79 to km77.5 and in several locations there is no peat at all. There is deep peat from km77 to km76.5. This area is near to the black water river at km76.8. Between km76 and km64, there is fluctuation in peat depth from 0 cm (no peat) to 170 cm peat depth. At km69 are located the holy granite hills of Bukit Tjilik Riwut with 77m altitude, Fig. 9.
The dome shape is between km63.5 and km47. The thickness of peat increases gradually from km62.5 to km54 with the thickest peat depth at km53.5 with 810cm depth, Fig. 3, 5, 10, 11. At approx. this location the peat dome has also its maximum of 49.1m derived from the ALS-data. After km53.5 the thickness of peat decreases gradually until km47.5 with only 5cm depth. From km47 to km34.5, the thickness of peat is very shallow and several drilling holes had no peat at all, except at km40.5 and km40. On the river side the soil under the peat is sandier and under the rivers themselves are partly clay.
There is a variation on mineral soil types below the peat along the transect Kasongan to Tangkiling. Most of the mineral soil below the peat was sand (quartz sand) and hardpan, only a few places had clay.
The peat itself has in average a bulk density of 0.275 g/cm³ (measured from 12 samples 0 – 20 cm peat depth, Table 4). The average of C organic content is 56.1% (from 22 samples, from 0 – 20 cm peat depth, Table 4). From the data above we can calculate that the peat weight in 1 m^3 = volume x bulk density = 1,000,000 cm³ x 0.275 g/cm³ = 275 kg.
The amount **of C in 1 m^3 peat** = 0.561 x 275 kg = **154.3 kg** which is 56.1% of the peat weight of 275kg. Due to the mineral soil below the peat being mainly quartz sand of low fertility, this area is of doubtful utility for agriculture or for plantations. Nevertheless some areas along the transect were used for agricultural purpose especially near Kasongan and near Tangkiling. The peat is there shallow.
The degraded PSF has here a canopy height between 20m and 30m. The average height of the trees was confirmed with 24m by ground measurements.

Table 5 and Fig. 5 shows the different peat depth and mineral soil below the peat from transect Katingan to Habaring Hurung. We made 31 peat drillings in this transect mostly covered by PSF. The peat dome has an altitude of 40.8m at UTM Zone 49 East 799.2km and – South 225.1km, Fig. 3, 5-7. The dome shape is more pregnant compared to the Kalimantan road. The thickness of peat has his biggest value with 10.0m near to the river Katingan. This location is not the same as the peat dome. The total bulk density was measured for this transect by 28 samples with an average of 0.131 gr/cm^3. Shallow peat can be found on this transect at village Habaring Hurung. The average peat thickness is here 3.65m which is much higher than near to the road Tangkiling to Kasongan with opened peat land. The average tree height along this transect is approx. 30m to 40m near to the peat dome, Fig. 8.

The amount of stored peat volume and carbon can be estimated for the northern area of Sebangau Catchment and Palangkaraya between rivers Katingan and Rungan up to the border of the heath forest in the following calculation using the GIS information:
5m to 6m in average x 450x10 Mio m² = 2.25 to 2.7 Gm³ big peat area and 2.5m to 3m average x 1473x10 Mio m² = 3.68 to 4.42 x 10 Gm³ medium peat area, see Fig. 13.
The total sum is for this northern Sebangau Catchment **5.93 to 7.1 Gm³ peat volume.** One m³ peat contains for this peat land 154.3kg Carbon. So we estimated a stored **Carbon value of 0.92 to 1.1x10 Gtons** for this area. This is in line with the calculations of Page et al. 2002 for a bigger area in Kalimantan and other region of Indonesia.

Big peat layers are accumulated in Central Kalimantan between the rivers with up to 10m thickness in the transect between Katingan and Habaring Hurung. The peat layer are shallower down to the Java Sea with lower thickness.
A lot of carbon is stored in Central Kalimantan peat land. We estimated in the upper Sebangau a carbon value of approx. **1Gtons.**
Degraded Peatland without trees are sensitive for burning in the dry season.
The water-level should be kept high in the peat area of Ex-MRP, by blocking of the many channels with different sizes and the area should be replanted with forests, to avoid fires. Illegal logging should be kept very low.

ACKNOWLEDGEMENTS

The funding for the ALS-flights, the peat drillings and peat analyses at UNPAR was provided by Kalteng Consultants. The authors wish to thank Dr. Suwido Limin, Dr. Yustinus Sulistiyanto and their teams from UNPAR. Additional we would thank company Milan Geoservice GmbH with Operator Jan Giehler and Equipment Integrator Detlef Klante for the technical part of the ALS-flight campaign and M. Mustafa Syafrudin for good cooperation during the ALS-flight campaign.

REFERENCES

Boehm, H.-D.V., Haisch, S. and Friauf, E. (1995) Environmental Helicopter with Modular Sensor Concept: Example on Forestry Monitoring. *Paper presented at the Conference on Remote Sensing and GIS,* Jakarta, Indonesia June 6-8, 1995.

Boehm, H.-D.V. and Siegert, F. (2000) Application of remote sensing and GIS to monitor Peatland multi-temporally in Central Kalimantan. *Proceedings of the International Symposium on Tropical Peatland – TROPEAT*, Bogor, Indonesia, November 1999, pp 329-347.

Boehm, H.-D.V., Siegert, F., Limin, S.H. and Jaya, A. (2003) Land Use Change in Central Kalimantan over the Period 1991 - 2001 including Impacts of Selective and Illegal Logging, MRP Establishment and Fires. *Proceedings of the International Symposium on "Land Management and Biodiversity in Southeast Asia",* Bali, Indonesia, Sept. 17-20, 2002, ISBN4-9901827-0-7, March 2003.

Boehm, H.-D.V. and Siegert, F. (2004) The impact of logging on land use change in Central Kalimantan, Indonesia. *International Peat Journal,* 12: 3 – 10.

Boehm, H.-D.V., (2004) Land cover change on peatland in Kalimantan Indonesia between 1999 and 2003, *Proceedings of the 12th International Peat Congress,* Tampere, Finland 6 – 11 June 2004

Boehm, H.-D.V., (2006) Precise Measurements of Peatland Topography and Tree/Canopy Height with a High-Resolution Airborne Laser-Scanner to calculate Carbon- and Bio-Mass, presented during the Workshop on Vulnerability of Carbon Pools of Tropical Peatlands in Asia, Pekanbaru, Riau, Sumatra, Indonesia, 24-26 January 2006

Boehm, H.-D.V. and Sulistiyanto, Yustinus (2006) Peat depth, minerals below peat, carbon, fires and its characteristics a long transect between Tangkiling and Kasongan, Central Kalimantan, presented at International Workshop Tropical Rain Forest and Boreal Forest Disturbance and Their Affects on Global Warming in Palangkaraya, Kalimantan, Indonesia 17.-18. Sept. 2006 and published in proceedings

Boehm, H.-D.V., Rieley, J.O., Limin, S., Frank, J., Syafrudin M. (2007) Successful Helicopter Flight Trials with Airborne Laser Scanning Technology to measure PSF height and Peat domes in Central Kalimantan, presented at the International Symposium, Workshop and Seminar on Tropical Peatland, Yogyakarta, Indonesia, 27 - 31 August 2007 *"Carbon - Climate - Human Interactions - Carbon Pools, Fire, Mitigation, Restoration and Wise Use"*

Page, S., Siegert, F., Rieley, J.O., Boehm, H.-D.V., Jaya, A., Limin, S. (2002) The amount of carbon released from peat and forest fires in Indonesia during 1997. *Nature*, **420:** 61-65.

Rieley, J.O. and Page, S.E. (Editors) (1997), *Biodiversity and Sustainability of Tropical Peatlands: Proceedings of the International Symposium on Biodiversity, Environmental Importance and Sustainability of Tropical Peat and Peatlands,* Palangkaraya, Central Kalimantan, Indonesia, 4-8 September 1995, Samara Publishing Limited, ISBN: 1-873692-102

Rieley, J.O., Page, S.E, and Setiadi, B. (2001) *Peatland for People: Natural Resource Functions and Sustainable Management", Proceedings of the International Symposium on Tropical Peatland,* Jakarta, Indonesia, ISBN: 979-95183-3-4

Sieffermann, G., Founier, M., Triuotomo, S., Sadelman, M.T. and Semah, A.M. (1988) Velocity of tropical forest peat accumulation in Central Kalimantan Province, Indonesia (Borneo), 8th IPS Congress Organizing Committee, Ministry of Fuel Industry of RSFSR. Sadovaja Moscow.

Siegert, F., Boehm, H.-D.V., Rieley, J.O., Page, S.E., Jauhiainen, J., Vasander, H. and Jaya, A. (2001) Peat Fires in Central Kalimantan, Indonesia: Fire Impacts and Carbon Release, In: J.O. Rieley & S.E. Page (Eds), *Peatlands for People: Natural Resource Functions and Sustainable Management", Proceedings of the International Symposium on Tropical Peatland,* Jakarta, Indonesia, ISBN: 979-95183-3-4, pp. 142-154.

Sulistiyanto, Y. (2004). Nutrient dynamics in different sub-types of peat swamp forest in Central Kalimantan, Indonesia. Ph D. Thesis, University of Nottingham, Great Britain.

FIGURES AND TABLES

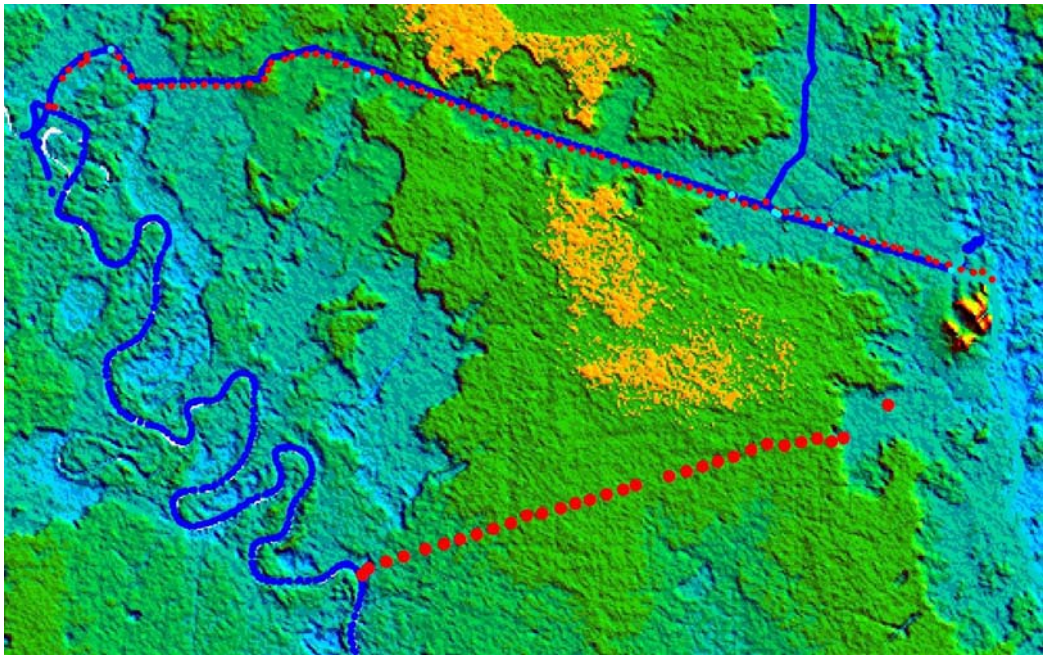

Fig. 2. SRTM DEM-Image from Feb. 2000 with GPS- tracks of peat drillings in red between Tangkiling and Kasongan of the upper Sebangau Nat. Park region. The elevation is shown in colours. The brown (very high tree canopies) and green colours are PSF, no penetration of trees. Cleared peat land is lower, especially along the highway with blue track points. River Katingan left, Rungan right and the Tangkiling hills can be identified. The peat drilling locations are marked by the red points parallel to the Kalimantan highway and between Katingan and Habaring Hurung PSF with 700m distances. Blue is the track on the Kalimantan highway and red are the 91 peat drillings..

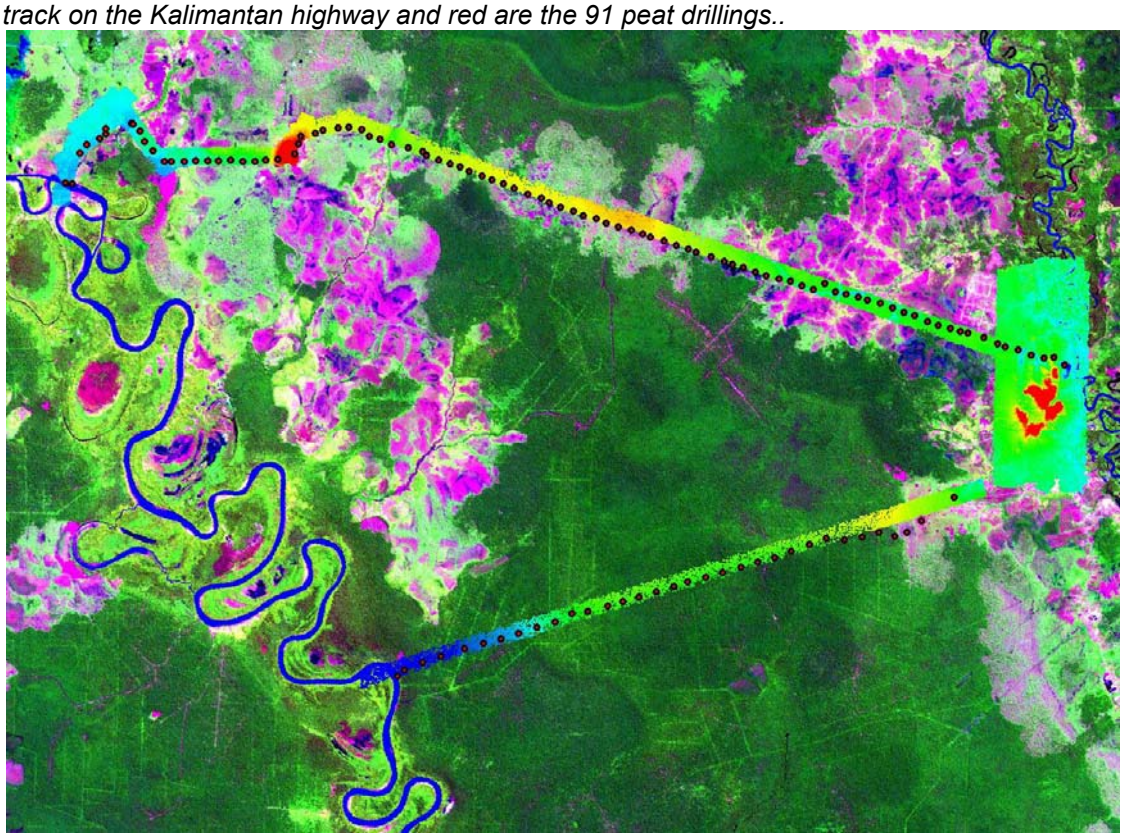

Fig. 3. ALS-Tracks from 8.8.2007 showing the topography (DTM, classified) of peatland and peat-drillings between rivers Katingan and Rungan superimposed on a Landsat-image 2000. The peatland elevation is presented in different colours, red is high and blue low. The ALS penetrates the canopy and produces 3% - 5% return pulses through PSF. ALS-Track widths is approx. 500m.

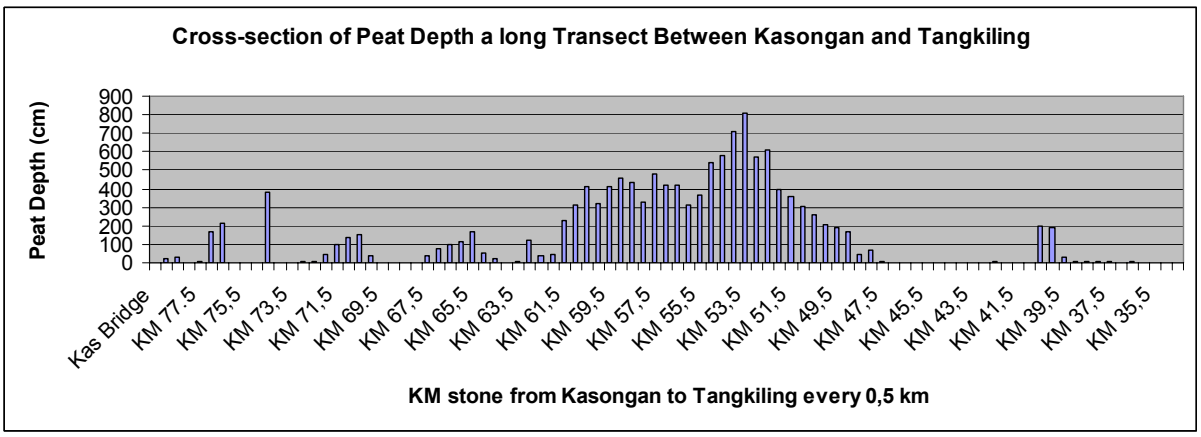

Fig. 4. Measurements of peat depth along the Kalimantan highway Kasongan to Tangkiling between the rivers Katingan and Rungan. At km 53.5 is the peat depth 8.10m and there is also approx. the peat dome, see ALS-data.

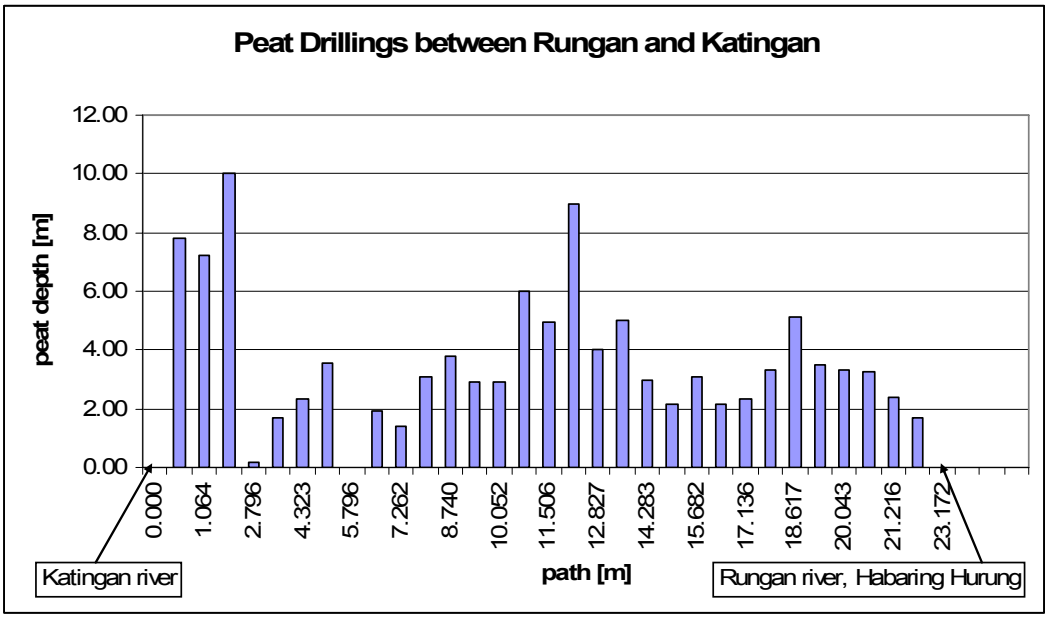

Fig. 5. Peat depth along the Katingan to Habaring Hurung-transect: Peat depth variation between 10m and shallow peat layer.

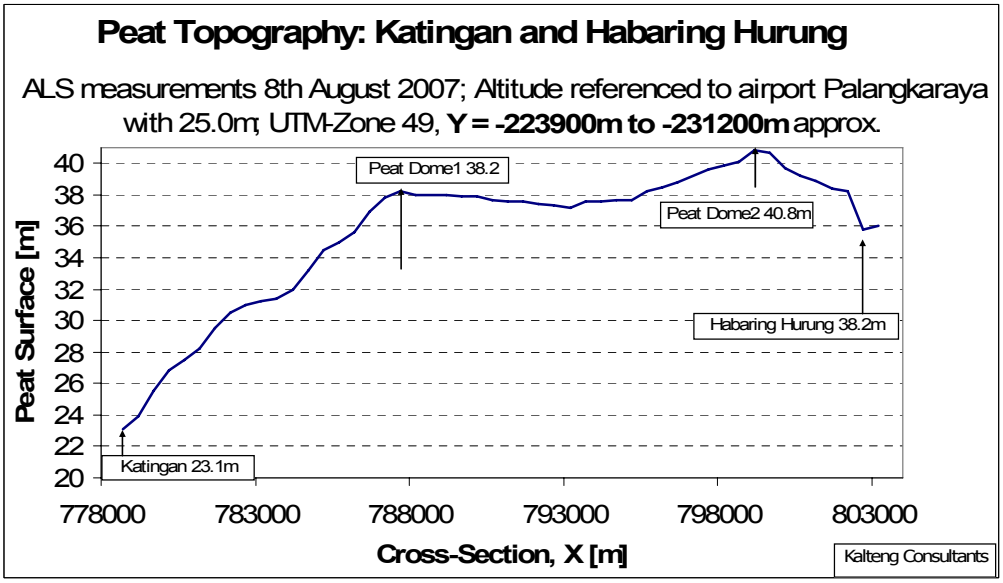

Fig. 6. ALS-DTM x-cross-section (24.5km) between river Katingan and village Habaring Hurung (y=7.3km). The Peat dome has an altitude of 40.8m, referenced to PKY airport with 25.0m

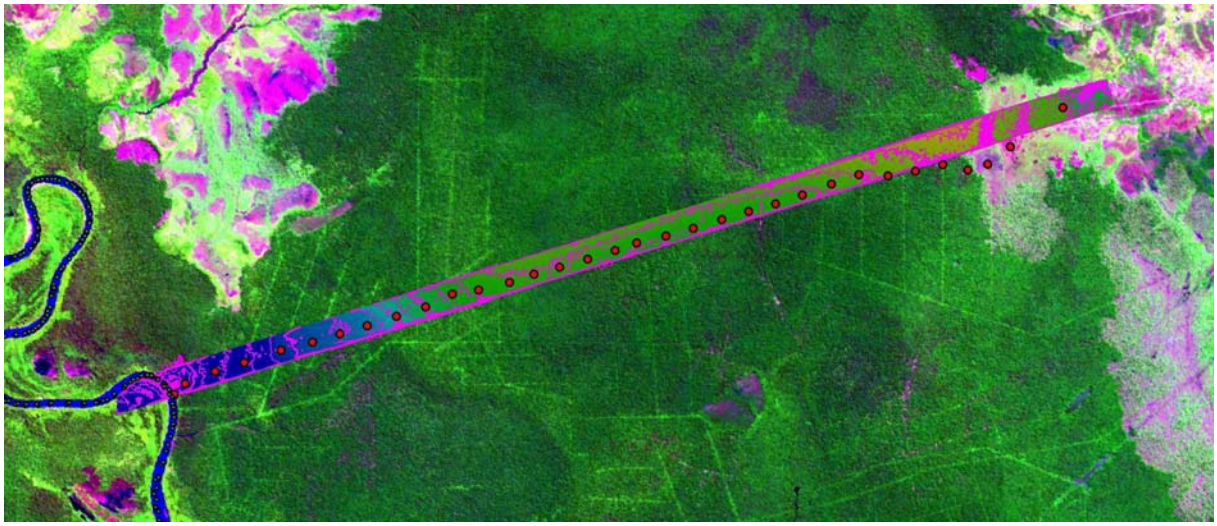

Fig. 6. ALS-Track from river Katingan to transmigration village Habaring Hurung (right side) superimposed on a Landsat-image. The ALS-data are processed and show the DTM as topography with contour-lines in 1m steps starting from 23.1m at Katingan river up to 40.8m at this peat dome, reference to PKY airport with 25.0m. On the right side is the peat dome, which can be located by the canopy colours in the Landsat image RGB = 543.

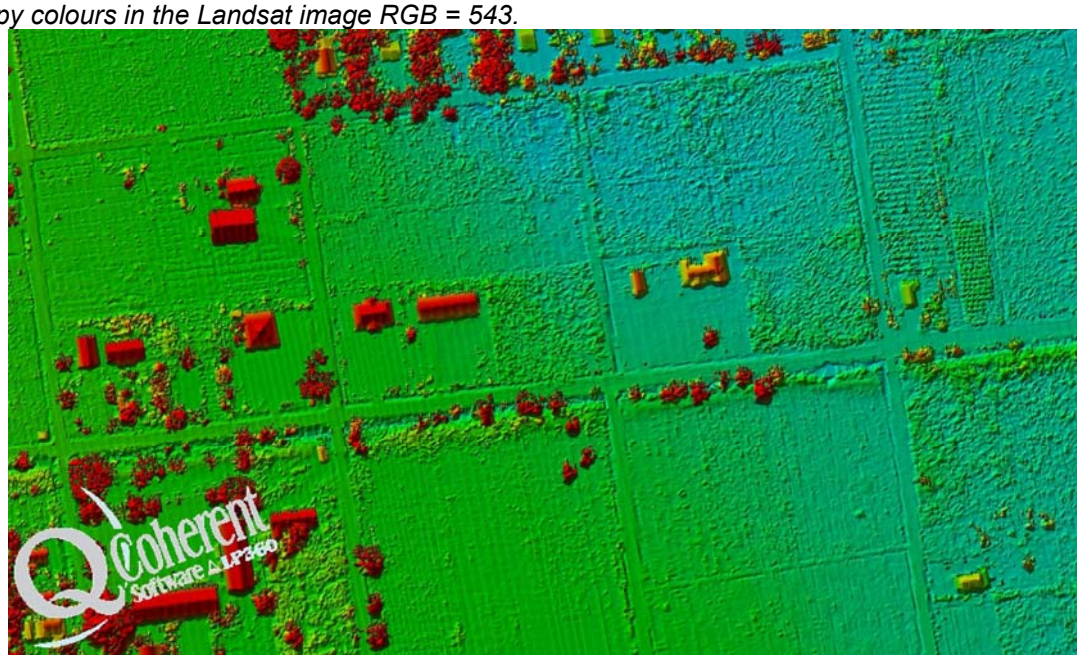

Fig. 7. ALS-image from Transmigration village Habaring Hurung as DSM in a TIN-presentation showing huts, fields, trees and plantations with 1mx1m resolution. On the right side the field level drops down to river Rungan. Here are shallow peat layers with approx. 1m-2m thickness.

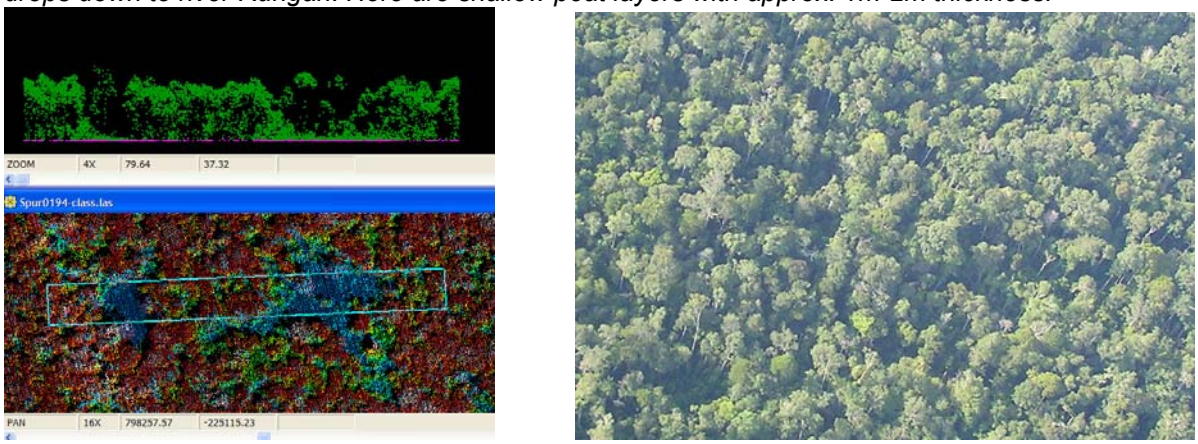

Fig.8. ALS-DSM-image from PSF, cross-section with 35m tall trees, the canopy and aerial photo (right) on the peat dome near Habaring Hurung. ALS single tree detection is possible.

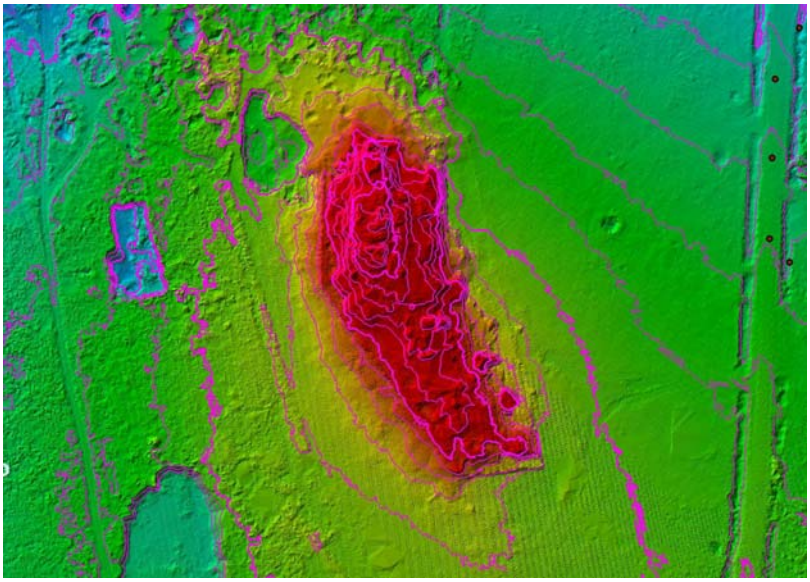

Fig.9. ALS-TIN-DTM image with contour-lines of 1m distance from Bukit Tjilik Riwut at km 69. The granite top has 77m altitude referenced to PKY airport with 25m. On right side is the road with ditches.

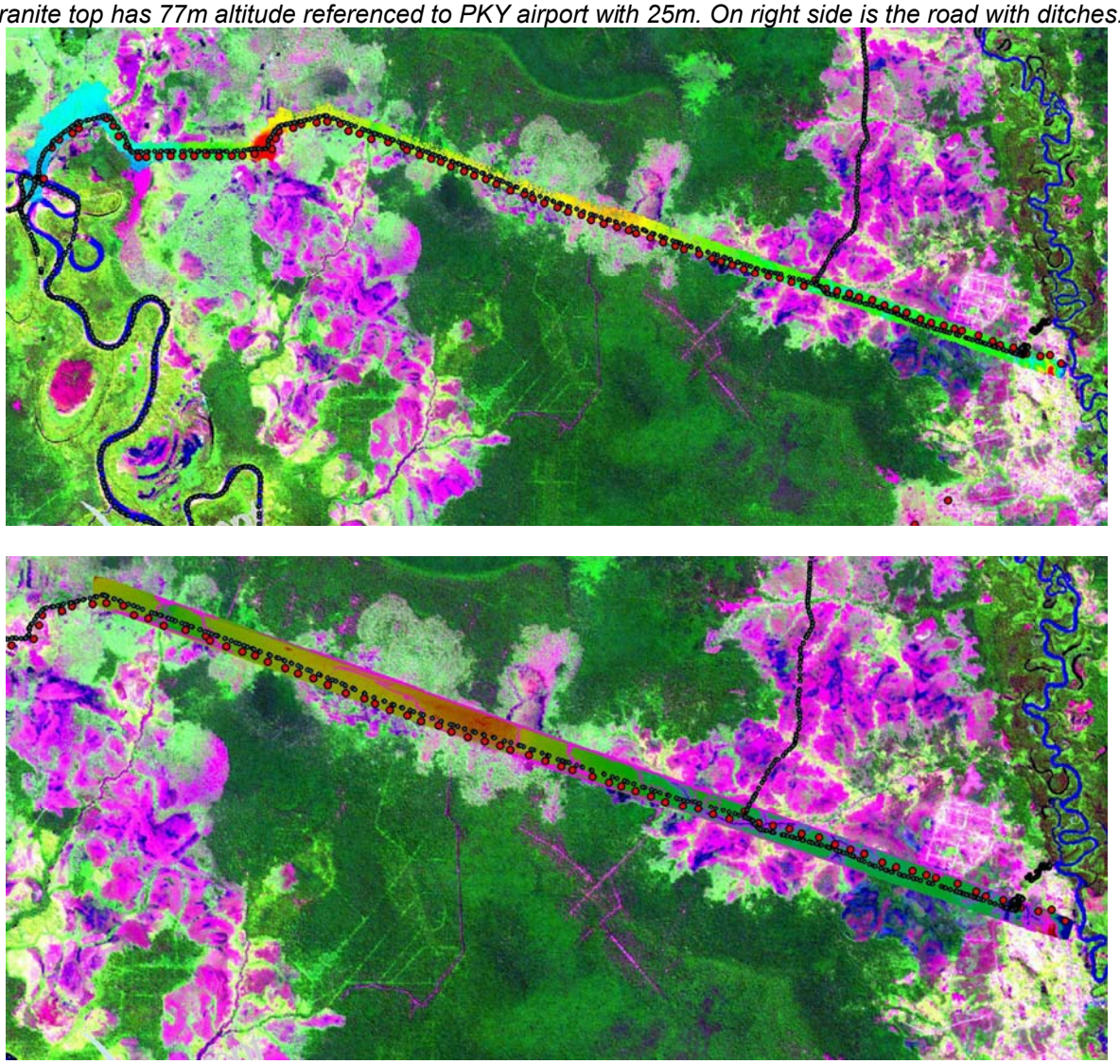

Fig. 10+11. ALS-Tracks above as LAS and below as TIN, from river Rungan (right side) along transect road to Kasongan superimposed on a Landsat-image. The ALS-TIN-data are processed and show the DTM as topography with contour-lines in 3m steps starting from Rungan with 20.8m up to 49.1m at peat dome km53.2km, reference to PKY airport with 25.0m. The peat dome is at km53.2 in the middle, which can be located by the red colour of the DTM. Km69 shows the Bukit Tjilik Riwut, see Fig. 9+10.

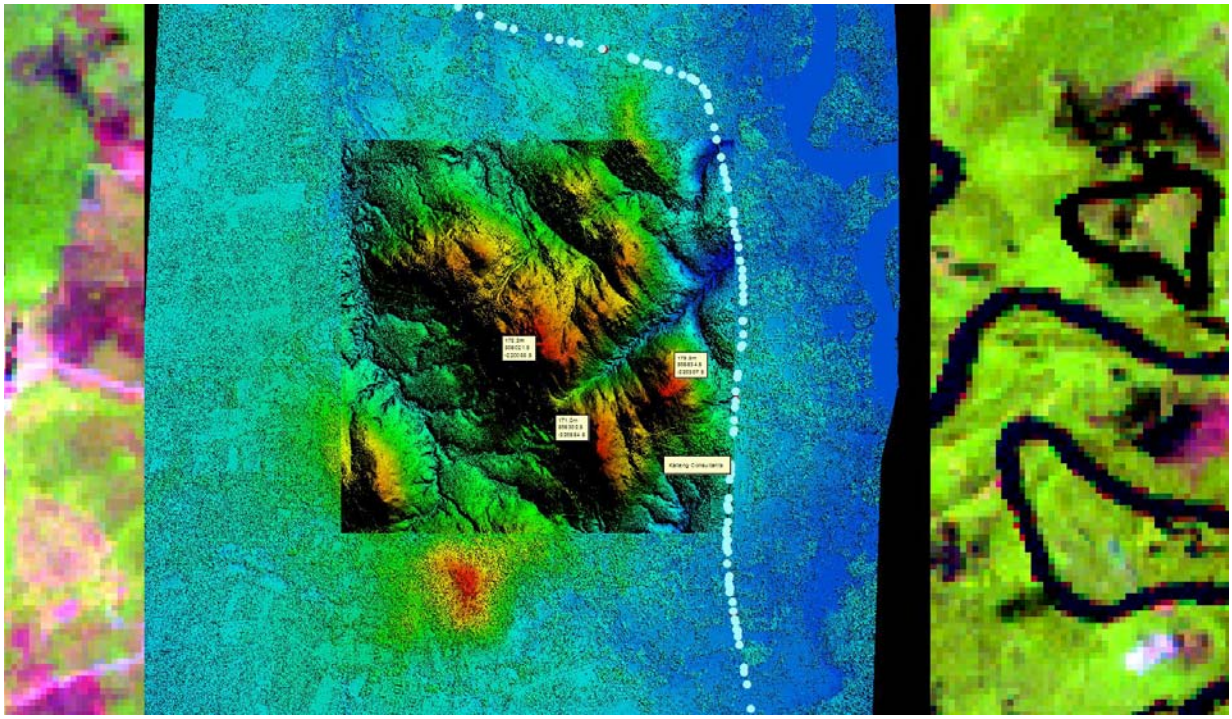

Fig. 12. ALS processed image as ALS-DTM showing the 7 Tangkiling Granite Hills (approx. 180m) in the middle, surrounded by an ALS-DSM image from the peatland and on the left und right side is visible a Landsat image from that area with river Rungan on the right side.

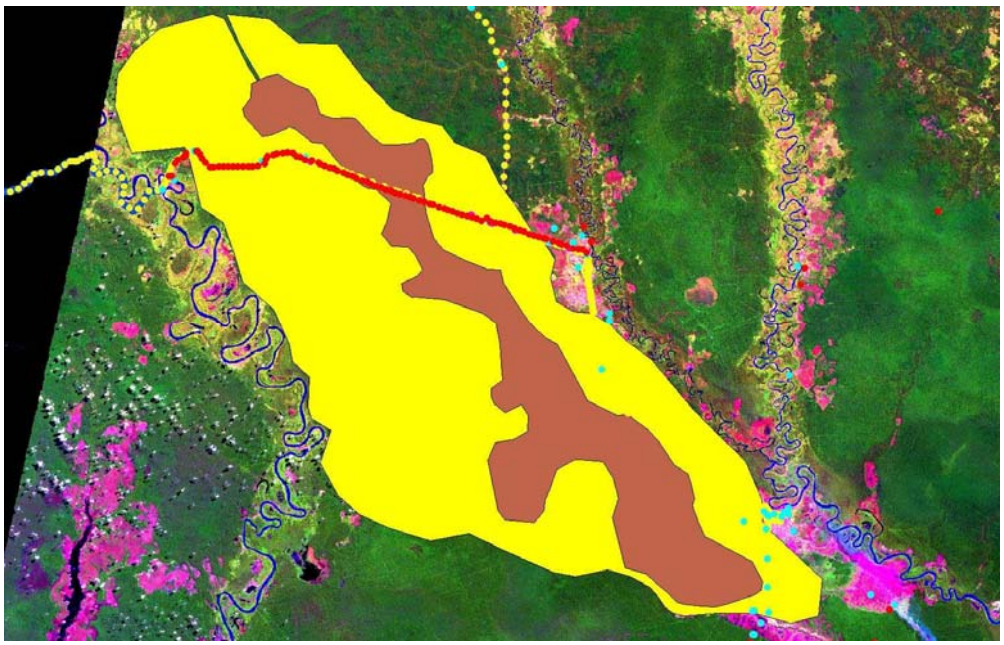

Fig. 13. Estimated area of stored peat volume and carbon for the northern area of Sebangau Catchment and Palangkaraya between rivers Katingan and Rungan up to the PSF-border to the heath forest analysed in the Landsat image from 1991 with two types of peat thickness (brown 5 to 6m and yellow 2.5 to 3m). Tangkiling and Kasongan area and locations near the rivers are not included in the estimation!

No	Location	Brief description of location	Position (GPS) in degree (°)	Peat depth (cm)	ALS-Peat surface (m)	Mineral below peat
0	Kasongan Bridge	Near river	-1.90673 113.38414	0	30.5	Clay
1	Kasongan Bridge 200 m south	Near river	-1.90708 113.38669	0	31.4	Clay

2	KM 79 200 m south	Agriculture land	-1.89556 113.38958	25 cm	31.1	Clay
3	KM 78.5 200 m south	Agriculture land	-1.89247 113.39217	30 cm	31.3	Clay
4	KM 78 200 m south	Agriculture land	-1.89011 113.397	0 cm	31,2	Clay
5	KM 77.5 200 m south	(back yard of new building)	-1.88836 113.39936	10 cm	32.4	Clay
6	KM 77 200 m south	Near black water river	-1.8865 113.39936	170 cm	32.5	Sand
-	KM 76.8	Black water River	-1.88439 113.40887		30.9	Water
7	KM 76.5 200 m south	Near black water river	-1.88469 113.40964	210 cm	30.9	Sand
8	KM 76 200 m south	Bush	-1.88744 113.41197	0 cm	34.4	Sandy
9	KM 75.5 200 m south	Bush	-1.89144 113.41394	0 cm	36.1	Sandy
10	KM 75 200 m south	Bush	-1.89489 113.41706	0 cm	34.1	Sandy
11	KM 74.5 200 m south	Forest	-1.89886 113.42122	380 cm	30.4	Clayey
12	KM 74 200 m south	Bush	-1.89889 113.42394	0 cm	33.8	Sandy
13	KM 73.5 200 m south	Agriculture land	-189875 113.42872	0 cm	36.1	Sandy
14	KM 73 200 m south	Forest	-1.89856 113.43297	Litter 5 cm	34.3	Clayey
15	KM 72.5 200 m south	Forest	-1.89856 113.4375	Litter 7 cm	36.6	Sandy
16	KM 72 200 m south	Forest	-1.89847 113.44156	48 cm	38.2	Clayey
17	KM 71.5 200 m south	Forest	-189822 113.446	99 cm	38.7	Clayey
18	KM 71 200 m south	Forest	-1.89872 113.45056	140 cm	38.6	Clayey
19	KM 70.5 200 m south	Bush	-1.89858 113.45519	150 cm	38.8	Clayey
20	KM 70 200 m south	Bush	-1.89825 113.45919	35 cm	43.8	Sandy
21	KM 69.5 200 m south	Bush	-1.89781 113.46367	0 cm	55	Sandy
22	KM 69 200 m south	Bush Bukit Tjilik Riwut	-1.89597 113.46992	0 cm	62.7	Sandy
23	KM 68.5 200 m south	Bush	-1.89211 113.47136	0 cm	59.6	Sandy
24	KM 68	Bush	-1.88933	0 cm	58.5	Sandy

	200 m south		113.47233			
25	KM 67.5 200 m south	Forest	-1.88814 113.47775	40 cm	57.8	Sandy
26	KM 67 200 m south	Forest	-1.88683 113.48058	75 cm	53.5	Clayey
27	KM 66.5 200 m south	Bush	-1.88617 113.48631	100 cm	46.5	Hardpan
28	KM 66 200 m south	Forest	-1.88578 113.49022	114 cm	46.6	Clayey
29	KM 65.5 200 m south	Forest	-1.88661 113.49494	170 cm	46.1	Hardpan
30	KM 65 200 m south	Forest	-1.88922 113.49794	50 cm	45.4	Hardpan
31	KM 64.5 200 m south	Forest	-1.89022 113.50194	20 cm	45.5	Hardpan
32	KM 64 200 m south	Bush	-1.89219 113.50619	0 cm	42.2	Sandy
33	KM 63.5 200 m south	Forest	-1.89336 113.51236	5 cm Litter	43.9	Sandy
34	KM 63 200 m south	Forest	-1.895 113.518	120 cm	44.2	Clayey
35	KM 62.5 200 m south	Forest	-1.89636 113.51922	40 cm	44.7	Hardpan
36	KM 62 200 m south	Forest	-1.89806 113.52381	45 cm	45.3	Hardpan
37	KM 61.5 200 m south	Forest	-1.89947 113.52814	230 cm	45.5	Hardpan
38	KM 61 200 m south	Forest	-1.90058 113.53175	310 cm	45.8	Hardpan
39	KM 60.5 200 m south	Forest	-1.90236 113.53531	410 cm	47	Hardpan
40	KM 60 200 m south	Forest	-1.90414 113.54019	320 cm	46.5	Hardpan
41	KM 59.5 200 m south	Forest	-1.90561 113.54381	410 cm	46.5	Hardpan
42	KM 59 200 m south	Forest	-1.90697 113.54808	455 cm	46.8	Hardpan
43	KM 58.5 200 m south	Forest	-1.90875 113.55211	437 cm	46.9	Hardpan
44	KM 58 200 m south	Forest	-1.91103 11355714	330 cm	46.7	Hardpan
45	KM 57.5 200 m south	Forest	-1.91244 113.56228	482 cm	46.7	Hardpan
46	KM 57 200 m south	Forest	-1.91397 113.56525	420 cm	47.1	Hardpan
47	KM 56.5 200 m south	Forest	-1.91728 113.57428	420 cm	47	Hardpan

48	KM 56 200 m south	Forest	-1.91728 113.57428	314 cm	47.3	Hardpan
49	KM 55.5 200 M south	Forest	-1.91878 113.57819	363 cm	48.8	Hardpan
50	KM 55 200 m south	Forest	-1.92003 113.58308	542 cm	48.4	Hardpan
51	KM 54.5 200 m south	Forest	-1.92186 113.58661	580 cm	**49.1**	Hardpan
52	KM 54 200 m south	Forest	-1.92331 113.59131	710 cm	48.8	Hardpan
53	**KM 53.5 200 m south**	**Forest Peat-Dome**	**-1.92447 113.59608**	**810 cm**	**48.6**	**Hardpan**
54	KM 53 200 m south	Forest	-1.92569 113.60025	570 cm	48.2	Hardpan
55	KM 52.5 200 m south	Forest	-1.92681 113.60314	610 cm	46.8	Hardpan
56	KM 52 200 m south	Forest	-1.92836 113.60831	395 cm	45.7	Hardpan
57	KM 51.5 200 m south	Forest	-1.93003 113.61291	360 cm	45.4	Hardpan
58	KM 51 200 m south	Forest	-1.93153 113.61742	305 cm	46.3	Hardpan
59	KM 50.5 200 m south	Forest	-1.93256 113.62042	260 cm	46.3	Hardpan
60	KM 50 200 m south	Forest	-1.93439 113.62608	205 cm	44	Hardpan
61	KM 49.5 200 m south	Forest	-1.93603 113.63078	190 cm	43.8	Hardpan
62	KM 49 200 m south	Forest	-1.93714 113.63411	170 cm	43.1	Hardpan
63	KM 48.5 200 m south	Forest	-1.93844 113.63814	47 cm	42.5	Sand
64	KM 48 200 m south	Forest	-1.93992 113.64247	65 cm	42.1	Sand
65	KM 47.5 200 m south	Forest	-1.94153 113.64647	5 cm	39.9	Sand
66	KM 47 200 m south	Bush	-1.94272 113.65131	0 cm	38.2	Sand
67	KM 46.5 200 m south	Bush	-1.94347 113.65564	0 cm	33	Sand
68	KM 46 200 m south	Bush	-1.94506 113.65986	0 cm	40.4	Sand
69	KM 45.5 200 m south	Bush	-1.94653 113.66433	0 cm	39.9	Sand
70	KM 45 200 m south	Bush	-194422 113.66864	0 cm	40.1	Sand
71	KM 44.5	Forest	-1.94758	0 cm	40.9	Sand

	200 m North		113.67259			
72	KM 44 200 m North	Bush	-1.94833 113.67656	0 cm	39.6	Sand
73	KM 43.5 200 m North	Bush near river	-1.94933 113.68111	0 cm	34.5	Sand
74	KM 43 200 m North	Bush	-1.95056 113.68453	0 cm	38.4	Sand
75	KM 42.5 200 m North	Bush	-1.95161 113.68939	5 cm	41.1	Sand
76	KM 42 200 m North	River	-1.95353 113.69392	2 cm	33.5	Sand
77	KM 41.5 200 m North	Bush	-1.95508 113.69819	0 cm	37.3	Sand
78	KM 41 200 m North	Bush	-1.95622 113.70206	3 cm (litter)	37.5	Sand
79	KM 40.5 200 m North	Forest	-1.95858 113.70711	200 cm	39.7	Clayey
80	KM 40 200 m North	Forest	-1.95994 113.71092	190 cm	39.8	Sand
81	KM 39.5 200 m North	Forest	-1.96103 113.71556	30 cm	40.5	Sand
82	KM 39 200 m North	Bush	-1.96217 113.71936	5 cm	41.8	Sand
83	KM 38.5 200 m North	Bush	-1.96294 113.72211	10 cm	42.1	Sand
84	KM 38 200 m North	Bush - Transmigration	-1.96458 113.72822	5 cm	41.1	Sand
85	KM 37.5 200 m North	Bush	-1.96683 113.73336	5 cm	40.7	Sand
86	KM 37 200 m North	Bush	-1.96808 113.73606	2 cm	35.8	Sand
87	KM 36.5 200 m North	Bush	-1.96917 113.74094	7 cm	39.5	Sand
88	KM 36 200 m North	Rungan Sari development	-1.96712 113.74586	-	38.2	Sand
89	KM 35.5 200 m North	Bush	-1.97222 113.75078	2 cm	41.9	Sand
90	KM 35 200 m North	Agriculture land	-1.97186 113.75444	0 cm	43.7	Clay
91	KM 34.5 200 m North	Agriculture land	-1.97489 113.75836 Average value	0 cm **150cm**	29.4 with 7 rivers	Clay and agriculture

Table 3. Measurements of peat depth (April 2006) and ALS-peat surface along the Kalimantan highway Kasongan to Tangkiling between the rivers Katingan and Rungan. At km 53.5 the peat depth is 8.10m and there is also approx. the peat dome.

No.	Place of sample	Bulk Density (g/cm3)	C - Organic (%)
1	Km 40	0.33	57.13
2	Km 49	0.26	57.26
3	Km 50	-	57.48
4	Km 51	0.26	56.50
5	Km 52	-	57.34
6	Km 53	0.30	57.23
7	Km 54	-	56.16
8	Km 55	0.31	57.21
9	Km 56	-	57.54
10	Km 57	0.29	56.91
11	Km 58	-	56.92
12	Km 59	0.23	56.79
13	Km 60	-	56.85
14	Km 61	0.25	53.87
15	Km 62	-	54.06
16	Km 63	0.28	57.13
17	Km 65	0.27	54.47
18	Km 66	-	55.34
19	Km 67	0.26	56.44
20	Km 70	-	55.29
21	Km 71	0.26	55.13
22	Km 72	-	50.77
	Average	**0.275**	**56.1**

Table 4. Bulk density and C-organic content of peat at 0-20 cm depth in certain places along transect Kasongan to Tangkiling. Remark: Distances in km measured from Palangkaraya

No	Peat Thickness (m)	ALS Peat-Surface (m)	Water Table cm)	Coordinate Point	Bottom Layer	Vegetation	Bulk density (gr / cm ^{3})	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
End of Road Village Habaring Hurung				-2.02514 113.71722			0- 50 cm (surface)	Above Bottom layer
1	1.70	38.4	17	-2.03417 113.70492	Granite	Fern, Karamunting , Burnt		
2	2.40	39.7	3	-2.03828 113.69961	Granite	Tumih, Fern, burnt	0.204	0.130
3	3.25	40.1	17	-2.03969 113.69489	Granite	Hangkang>20 m high, mixedforest		
4	3.30	**40.8**	2	-2.03842 113.68906	Granite	Tumih,burnt, gerunggang	0.1777	0.128
5	3.50	40.1	31	-2.03997 113.68264	Granite	Fern, burnt		
6	5.10	39.7	15	-2.0119 113.67622	Granite	Hangkang>20 m high, mixed forest	0.144	0.112
7	3.30	39.4	10	-2.04083 113.66931	Granite	Mixed forest, hangkang		
8	2.35	39.1	22	-2.04306 113.66289	Granite	Mixed & tall forest	0.133	0.123
9	2.14	38.5	26	-2.04569 113.65608	Granite	Mixed & tall forest		

10	3.10	38.1	19	-2.04778 113.64981	Granite	Mixed & tall forest	0.198	0.092
11	2.15	37.7	16	-2.04964 113.64353	Granite	Mixed & tall forest		
12	2.95	37.5	38	-2.05158 113.63722	Granite	Mixed & tall forest	0.160	0.150
13	5.00	37.4	29	-2.05358 113.63047	Granite	Mixed & tall forest		
14	4.04	37.3	25	-2.05542 113.62411	Granite	Tumih, pandan, mixed forest	0.181	0.133
15	9.00	37	42	-2.05708 113.61728	Clay	Mixed & tall forest		
16	4.95	37.5	24	-2.05892 113.61222	Granite	Mixed & tall forest	0.196	0.112
17	6.00	37.4	30	-2.06094 113.60569	Clay	Mixed & tall forest		
18	2.91	37.7	27	-2.06294 113.59914	Sand	Mixed & tall forest	0.177	0.104
19	2.90	37.7	30	-2.06453 113.59317	Sand	Mixed & tall forest		
20	3.76	37.9	52	-2.06650 113.58733	Sand	Mixed & tall forest	0.156	0.099
21	3.06	37.6	65	-2.06828 113.58014	Sand	Mixed & tall forest		
22	1.39	36.5	60	-2.06922 113.57403	Sand	Pandan, mixed forest	0.153	0.097
23	1.95	34.8	70	-2.07231 113.56767	Sand	Mixed & tall forest		
24	0.00	33.2	-	-2.07456 113.56083	Sand	Bintangor≤15 m, lampesau, jambu-jambuan,	- tumih, gerunggang, orchid	-
25	3.56	31.6	55	-2.07669 113.55408	Clay	Mixed & tall forest		
26	2.34	30.9	35	-207872 113.54758	Clay	Mixed & tall forest	0.151	0.093
27	1.70	30.4	35	-2.08056 113.54111	Granite	Mixed & tall forest		
28	0.16	29.6	-	-2.08258 113.533383	Sand	Mixed & tall forest	0.149	0.115
29	**10.0**	27.6	22	-2.08547 113.52514	Clay	Mixed & tall forest		
30	7.24	26.5	50	-2.08758 113.51825	Clay	Mixed & tall forest	0.155	0.120
31	7.80	23.6	15	-2.09044 113.51128	Clay	Mixed & tall forest		
Katingan River surface 23.1 m on 8.8.2007				-2.09292 113.50867				
Peat depth average is 3.65m						**Average**	**0.1556**	**0.107**
						Average total	**0.131 gr/ cm ^{3}**	

Table 5. Peat drillings along transect Katingan to transmigration village Habaring Hurung, July 2007 and ALS-Peat surface measurements on 8.8.2007