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ABOVE- AND BELOW-GROUND CARBON BUDGET OF DEGRADED TROPICAL PEATLAND REVEALED BY MULTI-TEMPORAL AIRBORNE LASER ALTIMETRY

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SUMMARY

Exact, objective and verifiable carbon budget was quantified both for underground peat depletion and above ground biomass change in the degraded peat swamp forest of Central Kalimantan, Indonesia by multi-temporal airborne laser altimetry of ground and vegetation canopy surfaces. In a period of four years between the initial and terminal airborne laser altimetry along the same transects totaling 530 km covering the study area of 5,800 km^2, the peat surface subsided an overall average of 33.8 cm, while the vegetation canopy rose by 102 cm, resulting in an overall carbon emission of 46.8 tC/ha/yr from combustive and aerobic decomposition of peat and net sequestration of 1.84 tC/ha/yr by vegetation regrowth.

KEY WORDS: degraded peat swamp, airborne laser altimetry, Mega-Rice Project, emission from peat, sequestration by vegetation regrowth

INTRODUCTION

One of the major obstacles hindering realistic projection of global warming is the uncertainty in the present carbon budget of the terrestrial ecosystems, not to mention its projection into the future. This difficulty arises partly from the complexity of terrestrial ecosystems both in their distribution and configuration, and partly from the difficulty of quantifying soil organic carbon losses by remote sensing. However, when it comes to tropical peatland, where massive carbon emission is suspected due to logging, farmland development, and fire but has seldom been exactly quantified, changes in surface levels of peat and vegetation canopy should be substantial enough to be quantified by repeated airborne laser altimetry over a period of some years. This is the idea, based on which the present study was conducted in the peat swamp forest of Central Kalimantan that has been degraded first by timber harvesting, then by drainage for developing an extensive rice paddy fields in the late 1990s and finally abandoned when the Mega Rice Project (MRP) failed.

MATERIAL AND METHODS

Study Area

The study area is located in the Province of Central Kalimantan, covering a rectangular area of 5,800 km^2 (150×40 km) including the provincial capital of Palangka Raya (Figs. 1 & 5). The area is divided into three sections distinctively different in degree of human interference. The forested portion west of the Sabangau River had been selectively logged late last century but has since been preserved as the Natural Laboratory of the University of Palangka Raya and as the Sabangau National Park. The east side of the river including the capital Palangka Raya is much more developed with an extensive system of canals draining the former MRP area. Its southern half is almost completely deforested for farmland development, but the northern half is covered by regenerating forest after the selective harvesting of the late 20th Century.

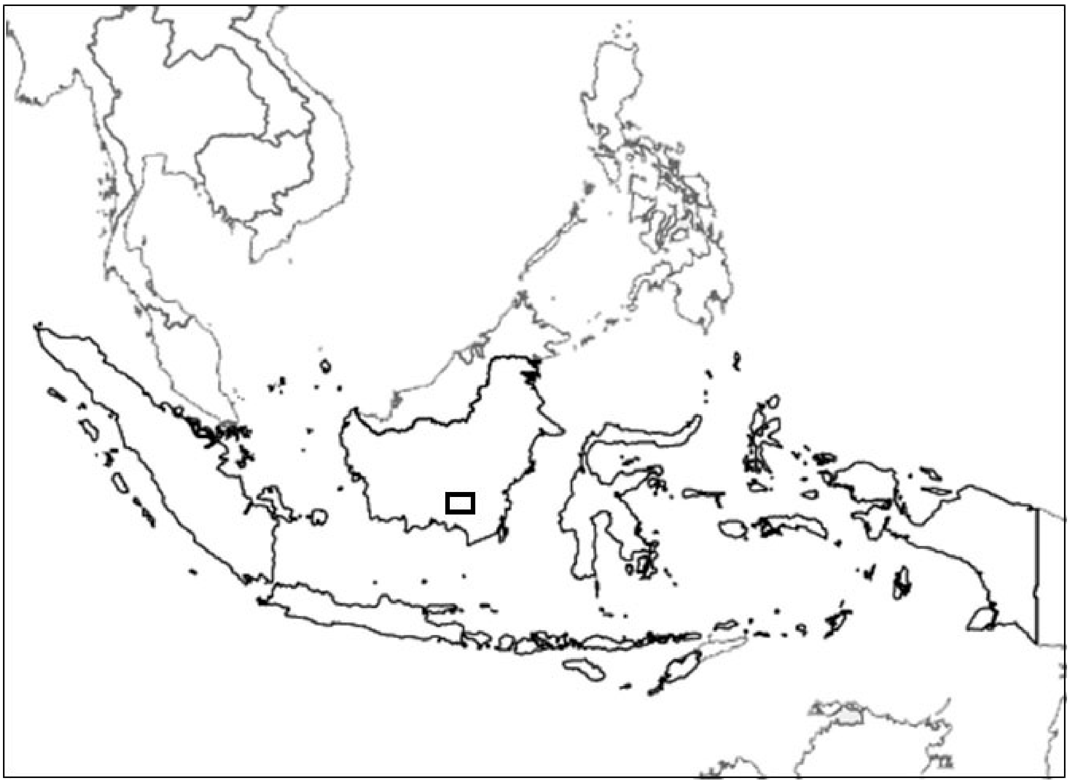

Fig. 1. Study area

Airborne Laser Altimetry

Airborne laser altimetry missions were flown twice along the same transect consisting of 12 straight flight lines totaling 530 km at a four-year interval in August 2007 and 2012, respectively, using a helicopter-borne Riegel LMS-Q560 laser altimeter. In each mission a total of some one billion laser returns were retrieved resulting in average laser point density of 2-4/m^2, from which both the ground and canopy surfaces were reconstructed as in Figs. 2 and 4.

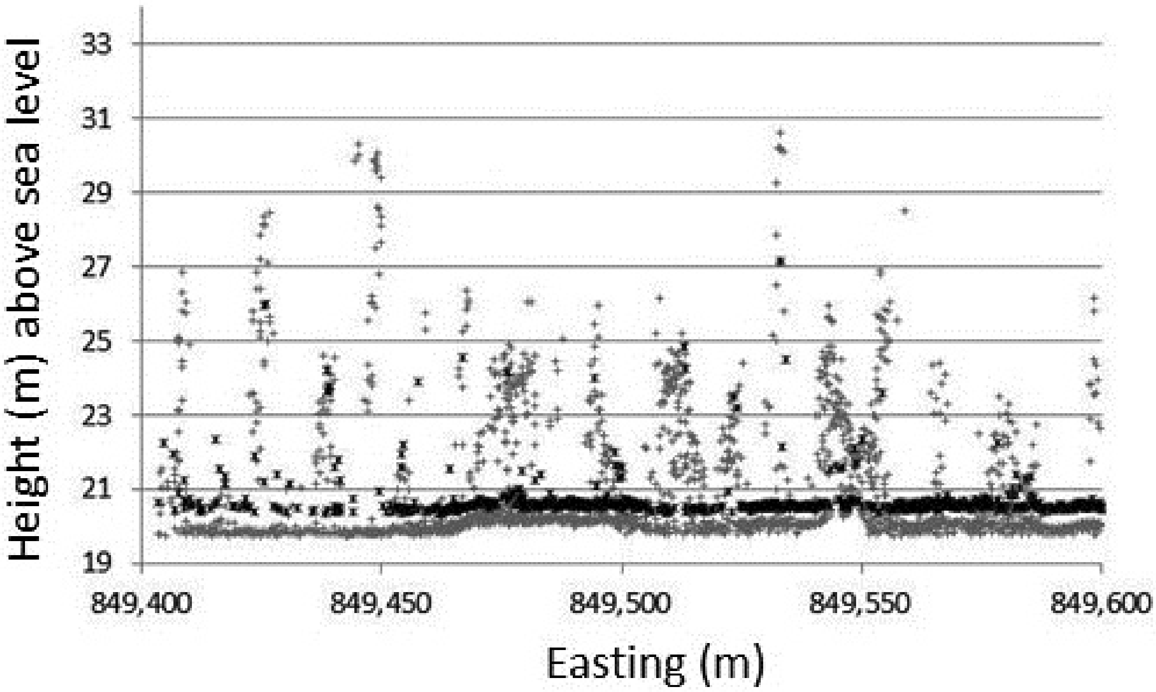

Fig. 2. 2-dimensional view of peat subsidence and vegetation growth

Change Detection and Quantification

As a general rule the peat surface subsided due to fire and aerobic decomposition, while the canopy rose due to vegetation growth except for the portions subjected to wild fire, or illegal timber harvesting or both.

The peat subsidence obtained as a difference between the 2007 and 2011 ground levels along the laser transect were interpolated over the entire study area for volumetric peat loss as shown in Fig. 3, where the flat transparent surface represents the level of null subsidence. For subsequent conversion to carbon emission, bulk density of 0.11 g/cm^3 obtained by field measurement of boring cores and carbon content of 50% (IPCC 2003) were used.

Carbon sequestration/emission by growing/retarding vegetation was obtained as a difference between the standing biomass at the term start (2007) and term end (2011). To obtain the

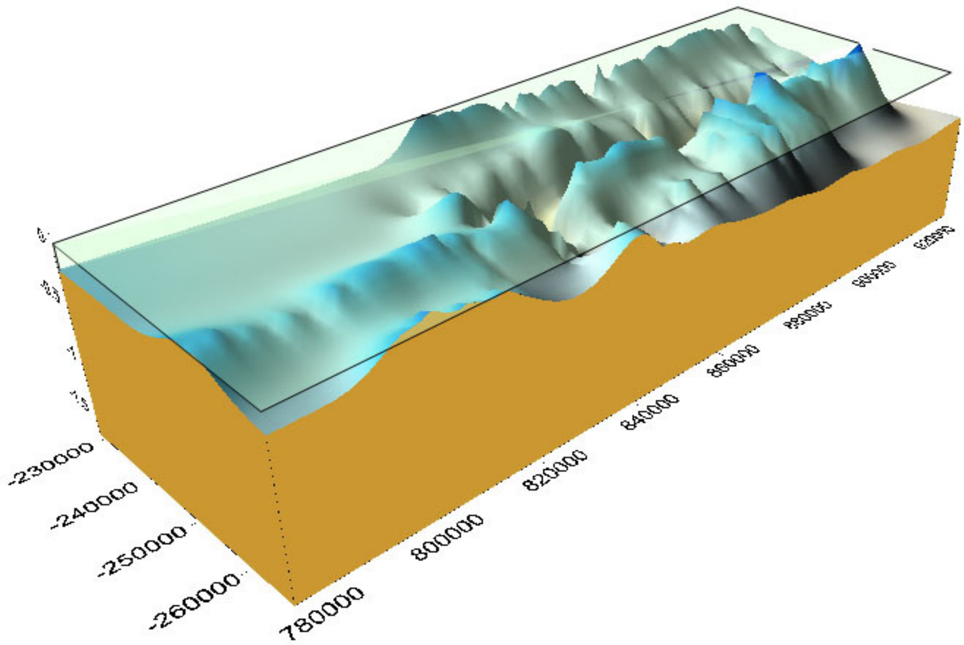

Fig. 3. 3-dimensional view of peat subsidence

standing biomass, the vegetated space between the canopy surface and ground level was calculated using interpolated laser reflection points as in Fig. 4, which then was converted into biomass and carbon stock using an allometric regression developed on the basis of actual measurement of standing biomass in some 60 ground plots laid out directly beneath the laser flight path.

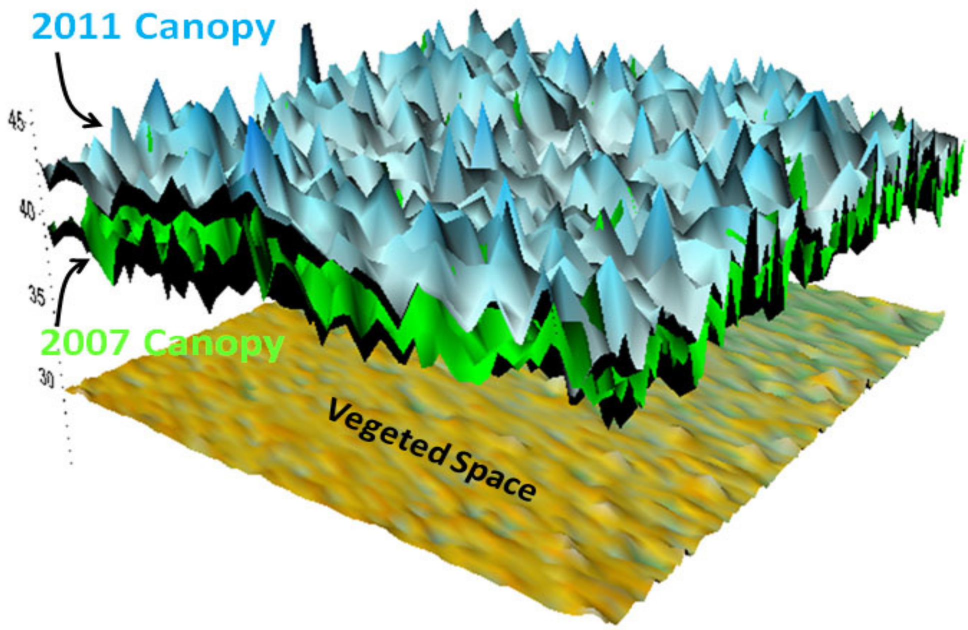

Fig. 4. Change in vegetated space in accordance with vegetation growth

RESULTS

Peat Subsidence and Carbon Emission

Fig. 5 is a contour representation of Fig. 3 overlain on a Google map. The most outstanding subsidence is observed in the Ex-MRP area along the Main Primary Canal (MPC) and Kahayan River. The former is a 100-m wide twin canal running E-W for 100 km between the Barito and Kahayan Rivers draining the north side of the MRP area. Another characteristic is a series of conical depressions as deep as 1.7 m (Fig. 3) at the intersection of the MPC and N-S oriented Main Canals.

Though significantly less than the developed area east of the Sabangau River, the protected area on the west bank also subsided resulting in net carbon emission. This is most probably due to small canals, dug by local people for extracting timber in the late 1990s and by illegal loggers in the early 2000s after the concession logging terminated in the late 1980s, but is still draining the area.

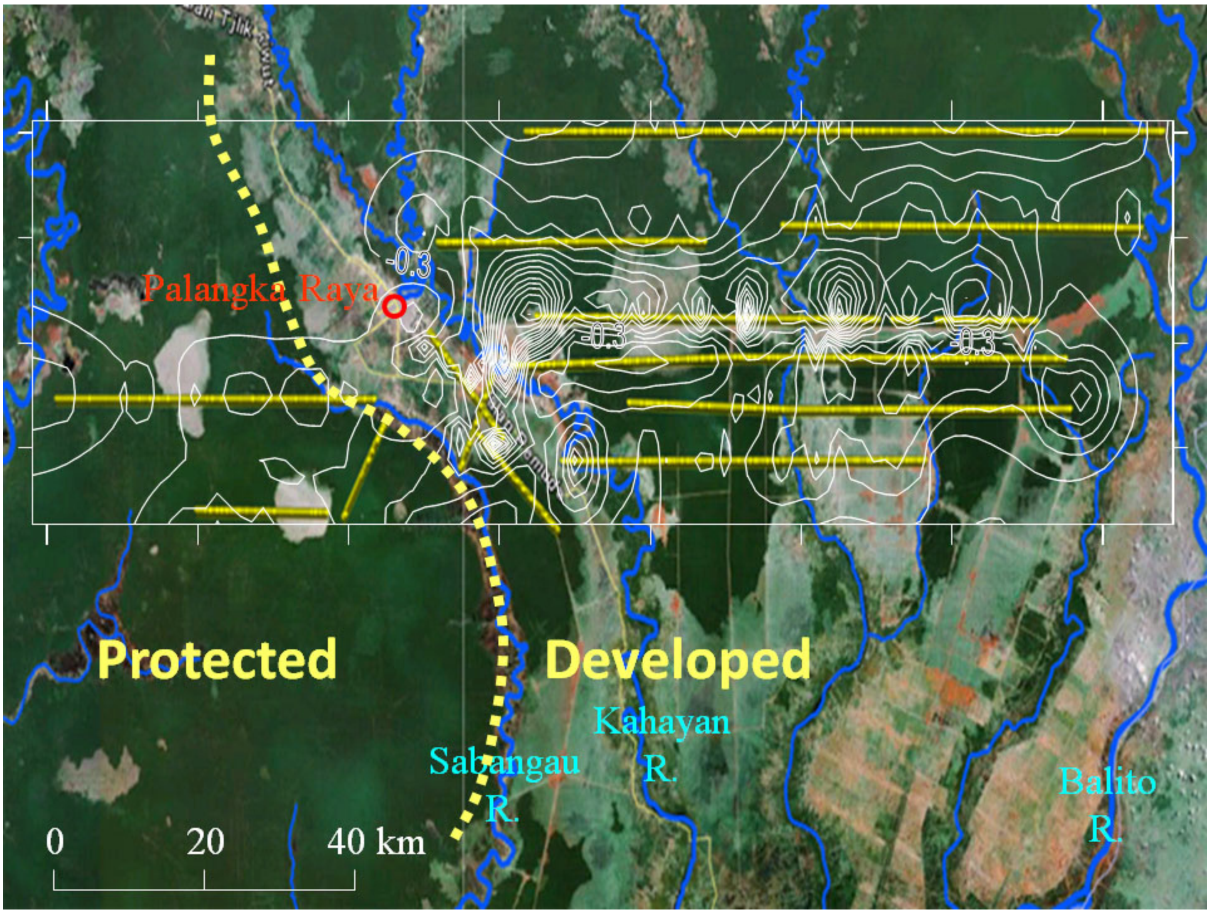

Fig. 5 Geographical distribution of peat subsidence

Obviously the major components of peat subsidence are wild fires and aerobic decomposition due to peat desiccation by drainage though the exact contribution of each component is not clear. As shown in Table 1 overall average subsidence was 33.8 cm with volumetric peat loss of 1.9 km^3 for the entire study area of 5,800 km^2, which translates to annual carbon emission of 46 tC/ha/yr.

Table 1. Peat subsidence and carbon emission

Area (km^2)	Cut	49.3	0.85%
	Fill	5761.6	99.15%
	To'l	5811.0	100%
Volume (km^3)	Cut	0.004	0.24%
	Fill	1.967	99.76%
	Net	1.963	
Mean Subsidence	(cm)	33.80	
	(cm/y)	8.44	
C Emission (t/ha/y)		46.87	
	bulk density (g/cm^3)	0.11	top 50cm
	C content (%)	50.0	IPCC

Vegetation Growth and Carbon Sequestration

The laser-measured change in vegetation height can be utilized in two ways, i.e. for assessing the vegetation recovery and degradation, as well as for calculating above-ground carbon budget. Based simply on mean height, the vegetation along the laser transect was classified into five categories, i.e., Burn (<0.2 m), Grass (0.2-1.0), Bush (1.0-3.0), Low Forest (3.0-10.0) and Tall Forest (≧10.0) both for 2007 and 2011, and compiled into a vegetation transition matrix shown in Table 2. Approximately half of the study area is covered by Tall Forest, and the rest is more or less equally divided among the other vegetation types. As for the change in four years, 60% of the study area remained under the same vegetation types, while 26% was improving and 13% retarding. The retardation is mainly due to logging and forest fire and to some tiny extent to wind throw by tropical storms. It is interesting to note that the vegetation showed a general trend of recovery in spite of the rather extensive wildland fire in the El Nino year of 2009.

Table 2. Vegetation-type transition matrix

From \ To	B	G	S	L	T	Total
Burn	0.31	0.63	0.05	0.01	0.00	1.0
Grass	0.06	0.55	0.32	0.07	0.00	1.0
Shrub	0.04	0.15	0.40	0.38	0.03	1.0
Low F.	0.01	0.02	0.03	0.41	0.53	1.0
Tall F.	0.03	0.07	0.00	0.09	0.82	1.0

Table 3 shows the mean changes in vegetation height, above-ground biomass and carbon budget for each of the 12 flight lines. As has been envisaged from the qualitative recovery of vegetation, both the line-wise and overall above-ground carbon budget turned out to be positive with forests revealing more carbon sequestration than the non-forest vegetation types.

Table 3. Above-ground carbon budget (sequestration)

Laser Lines	Line Length (km)	Mean Vegetation Height (m)			Mean Biomass				Carbon Fixation
					Stock (t/ha)		Growth (t/ha)		
		2007	2011	Diff.	2007	2011	Gross	/yr	(tC/ha/yr)
Line 1	43.4	10.46	11.92	1.47	144.91	165.23	20.32	5.08	2.54
Line 2	75.5	6.72	7.41	0.69	93.16	102.71	9.55	2.39	1.19
Line 3	17.8	9.29	11.05	1.76	128.69	153.11	24.42	6.10	3.05
Line 4	49.7	4.21	5.06	0.85	58.41	70.12	11.71	2.93	1.46
Line 5	79.6	10.33	10.80	0.46	143.19	149.61	6.42	1.61	0.80
Line 6-1	22.2	10.21	11.79	1.58	141.49	163.44	21.95	5.49	2.74
Line 6-2	38.1	4.01	4.67	0.67	55.52	64.74	9.22	2.30	1.15
Line 7-1	36.4	9.95	12.28	2.33	137.84	170.16	32.32	8.08	4.04
Line 7-2	49.0	9.08	10.37	1.29	125.86	143.74	17.88	4.47	2.24
Line 8-1	36.6	0.52	1.18	0.66	7.27	16.38	9.11	2.28	1.14
Line 8-2	31.3	0.27	0.62	0.35	3.76	8.61	4.85	1.21	0.61
Diagonal 1	11.6	13.43	14.87	1.44	186.05	206.06	20.01	5.00	2.50
Diagonal 2	10.0	0.05	0.48	0.44	0.65	6.71	6.06	1.51	0.76
Diagonal 3	14.4	0.74	0.81	0.07	10.31	11.27	0.96	0.24	0.12
Diagonal 4	14.4	9.44	9.78	0.34	130.84	135.58	4.74	1.19	0.59
Weighted Mean				1.02				3.54	1.83

CONCLUSION

Although the above ground carbon budget turned out to be positive at a net sequestration rate of 1.83 tC/ha/yr, it was overwhelmingly cancelled by 46.87 tC/ha/yr emission from peat, resulting in a huge negative budget of 45.25 tC/ha/yr comparable to the estimate of Page et al. (2002). This fact indicates that suppressing emission from peat by damming the drainage canal is much more effective than recovering vegetation and planting trees for emission control at least into some immediate future.

Another important conclusion of the present study is the competence of airborne laser altimetry as a powerful tool of carbon budgeting enabling simultaneous quantification of above-ground and below ground carbon especially in peatland where the latter has been much more elusive and thus sought after.

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