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Peat soil carbon monitoring and management in Indonesia

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Abstract
The high carbon (C) stock of 14.9 million ha of Indonesian peatland is greatly affected by land use change and land management systems. This research was aimed at estimating C stock and C dynamics related to land use change and management systems. The country's peat soil C stock is 22.7±6.8 Pg (mean ± stdev.) as estimated using mean peat depth of 246±232 cm and C density of 617±184 Mg $(ha.m)^{-1}$. Site level peat C loss was monitored using peat subsidence data and heterotrophic respiration : subsidence (H/S) ratios of 40% for non compacted peat and 60% for compacted peat. Overall mean subsidence rate for drained peat was 4.08±1.75 cm yr^{-1} and mean annual peat C loss was 11.17±1.42 Mg ha^{-1}. Using the IPCC (2014) emission factor default values, and historical land use change, annual C loss of Indonesia's peatland was around 76.3 Tg in 2000-2003 period. If the business as usual (BAU) land use change trajectories continues, peat C loss could reach 123.9 Tg in 2024-2033 period. Our mitigation scenarios, including no new large scale plantation development on peat and rewetting of degraded peat forests could reduce up to 19% C loss from peat decomposition.

Keywords: Land use, Land Management system, subsidence, heterotrophic respiration, BAU, Mitigation scenarios

Introduction
Monitoring of peat carbon stock and carbon dynamics is important as a basis for developing sustainable use and management of peatland, managing climate-related hazards, and mitigating greenhouse gases emissions. Indonesia has the largest (14.9 Mha) tropical peatland area and several districts has more than 30% of their land is peatland, giving them low flexibility, but to use peatland for livelihood. Therefore the high carbon (C) stock land is under high pressures for its dual functions: environmental quality protection and economic development. Under the current social and economic circumstances, winning one function likely sacrificing the other function (Agus et al. 2016). This is because peat soil C is conserved under high water table, whilst most economic crops produce satisfactorily under drained peat.
The government has launched several regulations for improving peat sustainability, including the suspension of new permits for peatland utilization and the formation of Peat Restoration Agency, mandated for restoring degraded peatland. With these new policies it seems reducing peat soil C loss is more promising.
This research was aimed at evaluating the national peat C stock and drained peat subsidence rate, assessing the rate of peat soil C loss at plot scale, as well as estimating national scale peat C loss.

Methodology
Three main items related to C stock and C dynamics were elaborated in this paper. These include estimates of: (i) National level C stock, (ii) Plot scale C loss monitoring, and (iii) National level peat C loss over time.

(i) National level C stock
The national level peat C stock was estimated using the peat depth and area data of peatland map by Ritung *et al*. (2011). The peat depth classes were 50-100 cm, 100-200 cm, 200-400 cm and >400 cm. This map is a significant refinement of the older version maps, because it includes more soil survey data of peat

distribution as well as depth. Weighted average peat depth was calculated based on the mid-value of depth classes and the area of each class as the weighting factor. For the >400 cm depth, the average depth was assumed 600 cm (Wahyunto, pers. Comm. 2017). Peat depth by area provides the peat volume. Peat C density was based on mean of C density data of three peat maturity classes provided in Agus *et al*. (2011). C stock is the product of peat volume and C density.

(ii) Plot scale C loss monitoring

Closed chamber is the most common method for estimating greenhouse gas fluxes and, different from the Eddy Covariance technique, it has a high flexibility to monitor fluxes from different treatments and land cover types. However, soil CO_2 flux is often interfered by root respiration which lead to an over estimate of the true peat C loss through heterotrophic respiration. Therefore, peat subsidence approach in combination with the closed chamber and the root exclusion technique is often used to minimize the effect of root respiration (e.g. Wakhid *et al*. 2017).

We have installed 33 pieces of subsidence poles of 6 cm diameter and various length steel pipes. One m top part protrudes above ground and the remaining length penetrate the peat until 1 m bottom penetrate the clay beneath peat layer. The poles were installed at different times starting in April 2012 to Sept. 2013 in Sumatra and Kalimantan with on peat with depths of 497±186 cm. The peat has been drained for about nine years in Dec. 2016. Land uses range from oil palm plantation, annual crop, rubber and shrub. Five poles were also installed in Timika, Papua in April 2014, under sago plantation, but monitoring is less frequent and the data are not presented in this paper.

With the subsidence measurement we have high certainty of subsidence rate, but estimation of heterotrophic respiration/subsidence (H/S) ratio remains a source of uncertainty. Several values were introduced, ranging from 25% (Wahid *et al*. 2017), 40, 60, and even around 92 (Couwenberg and Hooijer 2013). The higher ratio seems more appropriate for mature peat, while the lower ratios are for newly drained peat. In our case, with nine year period since the drainage system commenced, it seems the H/S ratio of 40% has the closest proximity of C loss rate as the values from closed chamber technique if the peat soil is not compacted during land preparation, while the H/S ratio of 60% is more reliable for the compacted peat such as in the case of large plantations. Peat C density was based on Agus et al. (2011) like in the case of Section (i) above.

(iii) National level peat C loss over time

For the national greenhouse gas inventory, we used the default emission factor of IPCC (Drösler *et al*. 2014) and adapted for the 22 land cover types of Indonesia. These default values were based on various research in Indonesian and Malaysia using closed chamber and subsidence techniques. As such, this could be assumed qualified for Tier 2 inventory in Indonesia. The activity data were generated from land use change trajectories of two to 3 year intervals from 2000 to 2015 and the projection of land use change beyond 2015 was based on the historical land use change of 2006-2015. Projected land use change was generated by the LUMENS program (http://www.worldagroforestry.org/output/lumens). Scenarios for mitigation were based on the most rational assumptions taking into account the current national policies on peatland utilization.

Results

(i) National level C stock

Although in places we found peat with depth of >1000 cm, but the dominant (31% and 31% of the total area) peat depths were 50-100 and 100-200 cm, respectively. That with 200-400 cm depth represents 18%, while the one with >400 cm depth is 20% of the total peatland area. The deep peat are distributed mainly in Riau, Jambi, and Central Kalimantan. The country's peat soil C stock is 22.7±6.8 Pg (mean ± stdev.) and the mean depth is 246±232 cm.

(ii) Plot scale C loss monitoring

Table 1 shows that subsidence ranged from 2.49±0.19 cm yr^{-1} for peat under oil palm plantation in Jambi to 5.15±2.48 cm yr^{-1} for peat under shrub and traditional rubber plantation. Oil palm plantationn normally used buldozers during land preparation and thus compacted the peat, while under traditional system or under degraded forests the land were not compacted. The compaction is attributable to the relatively low subsidence rate. The overall mean subsidence rate was around 4.08±1.75 cm yr^{-1} and mean peat soil C loss was 11.17±1.42 Mg $(ha.year)^{-1}$.

Table 1: Peat subsidence rate and estimated carbon loss using 40% and 60% root heterotrophic respiration/subsidence (H/S) ratios for different sites and land uses in Sumatra and Kalimantan

Site and land use	Time since drained	N	Peat depth	Subsidence rate	Assumed C loss	
					40%	60%
	(year)		(cm)	cm yr^{-1}	Mg C $(ha·yr)^{-1}$	Mg C (ha·yr)
Rasau Jaya, W. Kalimantan; Annual crop rotation	6	5	379±18	4.71±1.26	**11.62±3.10**	17.42±4.65
Pelalawan, Riau; Oil palm	9	5	576±46	2.78±0.37	6.85±0.91	**10.27±1.36**
Pelalawan, Riau; Shrub, Rubber	9	6	608±49	5.15±2.48	**12.72±7.11**	19.07±9.16
Arang-arang, Jambi; Oil Palm	11	7	224±29	2.49±0.19	6.13±0.48	**9.20±0.72**
Jabiren, C. Kalimantan, Rubber	10	10	642±140	4.89±1.45	**12.07±3.57**	18.10±5.35
Mean	9	33	497±186	4.08±1.75	**10.07±4.32**	15.10±6.49
Overall mean1)					**11.17±1.42**	

1)Using H/S ratio of 40% for non-compacted (traditionally managed) and 60% for compacted (usually under large-scale plantations) peat during land preparation.

(iii) National level peat C loss over time

Agriculture, both large plantations and small scale farmings expanded relatively rapidly on peatland. Most of the current agricultural systems on peat use drainaged system. As long as the drained condition is maintained, expansion of drained areas translates to increasing C loss from peat. C loss monotonously increased from 76.3 Tg in the period of 2000-2003 to 101.5 Tg in 2013-2015. The projected C loss keeps increasing, reaching 123.9 Tg in 2024-2033 period under the BAU scenario. The proposed additive mitigation scenarios including no new permit (and hence clearing and draining) for plantation expansion and rewetting of part of degraded forests will lead to significant amount of mitigation, which is up to 19% below the BAU level in 2024-2033 period.

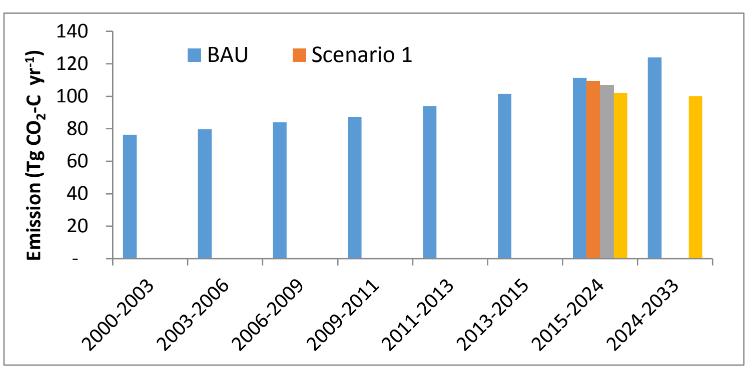

Fig. 1: Annual historical and projected peat carbon loss through CO_2 emissions from heterotrophic respiration by time period under the business as usual (BAU) scenario, Scenario 1 (no plantation expansion on peat primary and secondary forests), Scenario 2 (Scenario 1 and no plantation expansion on degraded forests, and Scenario 3 (Scenario 2 and rewetting of 40% of remaining degraded forests in two future consecutive nine year periods)

Discussion

With the total C stock of 22.7±6.8 Pg, each ha of peat has an average of around 1500 Mg C; a figure about seven times higher than the biomass C stock of primary forests (Agus *et al*. 2013). Estimation of peat depth is more difficult for deep peat which are mostly located remotely around the centre of peat dome. Being a very labile C, when peat forest is drained, the stored C has a high potential to contribute to the national greenhouse gas figure.

Drained peat subsides at a high rate shortly after the drainage system is put in place. The rate of subsidence under this study was 4.08±1.75 cm yr^{-1}. With time the subsidence will decrease (Couwenberg and Hooijer 2013). With subsidence rate of 4.08±1.75 cm yr^{-1} in one cycle of plantation, which is typically 20 years, the total subsidence could reach about 80 cm. This will have implication to the vulnerability of the land to inundation. At the same time, this also leads to high carbon losses as our data shows in Table 1 and Figure 1.

The subsidence will continue until the peat reaches the undrainable level as its surface elevation may reach the similar level of the average river water level.

Several mitigation scenarios, including raising of water table, banning the use of peatland for agriculture, and rewetting the degraded peatland, theoretically plausible. However, the implementation remains challenging as, under the current economic and agronomic systems, most of high value and high market demand crops are suitable under drained systems. For the land owners, conserving carbon without economic compensation will be impossible. Therefore alternative (undrained) land use systems will only be implementable soon after the technology provides economically competitive options, or else compensation should be provided to the land holders for conserving carbon.

Conclusions

The unstable peat carbon needs to be conserved by conserving the remaining forests and raising water table in existing agricultural lands. Rewetting of degraded peatlands reduces peat carbon loss significantly. However, the success of voluntary rewetting depends on the ability to develop economically attractive and high market demand crops suitable for paludiculture system.

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