Extended abstract No. 253

UPDATED CARBON BUDGETS UNDER DIFFERENT LAND USES ON TROPICAL PEATLAND IN INDONESIA

J.O. Rieley, School of Geography, University of Nottingham, University Park, Nottingham NG7 2RD, United Kingdom, +44194920920, jack.rieley@nottingham.ac.uk

S.E. Page, Department of Geography, University of Leicester, United Kingdom

SUMMARY

Lowland tropical peat swamp forests are one of the densest carbon stores on earth. Land use change releases large amounts of carbon dioxide to the atmosphere and dissolved organic carbon and particulate organic carbon into drainage streams and rivers. There are major implications of this for climate change processes, public health and the economy. We provide a reassessment and updating of information on the relative losses and transfers of carbon from peatland in Indonesia converted to oil palm and paper pulp tree plantations compared to the natural ecosystem and that deforested, drained and degraded but unused.

KEYWORDS: peat swamp forest, carbon, carbon dioxide, land use change, plantations

INTRODUCTION

Since the previous assessment of carbon losses under different land uses on peatland in Indonesia (Rieley & Page, 2008) more research has been carried out and uncertainty has been reduced. The total area of tropical peatlands and its carbon store have been reappraised and updated (Page et al, 2011) to 441,025 km^2 (11% of the global peatland area) and 88.6 Gt C (15-19% of the global peat carbon pool) respectively. The global area has been increased by 10% because of new information on the peatlands of tropical South America and the Caribbean (Wooler et al., 2007; Lähteenoja et al., 2009; Monacci et al., 2009) but, owing to a more comprehensive assessment of peat thickness throughout the tropical zone, the estimate of the size of the tropical peat carbon store has been increased by a staggering 70%. This takes into account the greater average thickness of peat in Indonesia and Malaysia than was acknowledged before and the greater area and thickness of peat in Africa and South America. This updated area and carbon store are based on a minimum peat thickness of 30 cm. If shallower Histosols and organic soils are included the total global area of these organic 'soils' becomes 657,430 km^2 with a carbon store of 91.9 Gt, which is about 6% of the global soil carbon store. More information has also accrued on the impact of land use change on the tropical peat carbon store and the rate at which it is released to the environment. According to Hooijer et al. (2010) of 27.1 million hectares of peat swamp forest in Southeast Asia 12.9 Mha had been deforested and mostly drained by 2006 and this rate of land conversion is still continuing (Miettinen & Liew, 2010).

The meta analyses by Murdiyarso et al. (2010), Couwenberg et al. (2010) and Hergoualc'h & Verchot, L.V. (2011) provide average values for CO_2 emissions equivalent to carbon losses as a result of subsidence caused by peat oxidation following deforestation and drainage. Murdiyarso et al. (2010) estimate a value of 59.4±10.2 t CO_2 ha^{-1}a^{-1} during the first 25 years following conversion to oil palm plantation. 25% of this is released as a result of land clearing and fire and 62% from decomposing peat over the time period. Couwenberg et al. (2010), on the other hand, provide an annualised value of 900 g CO_2 $m^{-2}a^{-1}$ for every 10 cm of additional drainage depth up to 50 cm. This equates to 54 t CO_2 $ha^{-1}a^{-1}$ and 90 t CO_2 $ha^{-1}a^{-1}$ for drainage depths of 60 cm and 100 cm, which are those commonly accepted for optimum growth of oil palm and *Acacia* pulp trees, respectively (Rieley & Page, 2005). Hergoualc'h & Verhot (2011) provide a lower estimate of peat carbon loss in oil palm plantation equivalent to 40 t CO_2 $ha^{-1}a^{-1}$. Recent studies carried out on an *Acacia* paper pulp tree plantation in Riau, Sumatra show a higher rate of CO_2 emissions of 100 t CO_2 $ha^{-1}a^{-1}$ as a result of subsidence (Hooijer et al. (in press)) and 80 t CO_2 $ha^{-1}a^{-1}$ from direct measurement of heterotrophic respiration (Jauhiainen et al. (2012).

In contrast to boreal and temperate peatlands methane (CH_4) emissions from waterlogged tropical peatland are very low and do not contribute significantly to overall peat surface greenhouse gas emissions (Melling et al., 2005b; Jauhiainen et al., 2008; Rieley et al., 2008). Studies of nitrous oxide (N_2O) emissions from tropical peatlands are in their infancy but evidence so far suggests that these are minimal from natural peat swamp forest and degraded but unused tropical peatland but may be significant from peatland converted to agriculture and plantations, especially after the addition of nitrogen fertiliser.

This paper presents a reassessment of the carbon budgets in tropical peatland under different land uses. Data are updated from the previous assessment (Rieley & Page, 2008) and are extended to include the latest information from detailed studies carried out on oil palm and *Acacia* pulp tree plantations in Sumatra (Jauhiainen et al., 2012; Hooijer et al., in press) together with tentative information on N_2O emissions (Melling et al., 2007; Jauhiainen et al, 2012).

DATA, METHODS AND ASSUMPTIONS

These are similar to those used in the previous computation (Rieley & Page, 2008) using data from primary and secondary sources, peer reviewed publications and information obtained in the field. We have reconsidered, moderated and modified data input to the new assessment to take account of advances in measurement of CO_2 CH_4 and N_2O including the more detailed information available for degraded and converted tropical peatland. The carbon budgets under different land uses are standardised over a 25 year period that represents the life expectancy of one plantation cycle of oil palm or approximately four cycles of *Acacia crassicarpa* grown as a paper pulp tree. The principal focus of this assessment is carbon stocks in peat and natural vegetation (peat swamp forest) growing on it and the losses from these stocks as a result of land use change through drainage (peat oxidation) and fire (incineration). A recent study of CO_2 emissions from *Acacia* plantation in Riau, Sumatra makes it possible for the first time to separate autotrophic and heterotrophic respiration in the peat and therefore calculate carbon losses more accurately (Jauhiainen et al., 2012). The difference between the rates of carbon loss from the same *Acacia* plantation in Sumatra of 80 t CO_2 $ha^{-1}a^{-1}$ (Jauhiainen et al., 2012) and 100 t CO_2 ha^{-1} a^{-1} (Hooijer et al., in press) may be that removed as dissolved organic carbon and particulate carbon in drainage water, which is accounted for in the latter method but not in the former.

We compare the following scenarios:

1. Natural peat swamp forest with intact hydrology, vegetation and peat accumulation.

2. Natural peat swamp forest subject to adjacent drainage with impaired hydrology, vegetation cover and no peat accumulation.
3. Deforested peat swamp forest that has been degraded by drainage and fire but has not been converted to an alternative managed land use so far.
4. Peatland converted to oil palm plantation following deforestation, fire to remove tree debris and drainage followed by management to maintain the water table 60-80 cm below the surface comparing (1) data from the 2008 assessment and (2) incorporating new information on subsidence related carbon losses.
5. Peatland converted to *Acacia crassicarpa* plantation following deforestation, removal of tree debris and drainage followed by management to maintain the water table 80-100 cm below the surface. Three sub-scenarios are presented: (1) the 2008 assessment, (2) using data for peat subsidence and (3) applying heterotrophic CO_2 emissions (peat oxidation) from which autotrophic CO_2 emissions (root respiration) have been removed.

RESULTS

The carbon budgets under the seven scenarios were calculated based on the assumptions in Table 1 and are presented in Table 2.

Table 1: Assumptions made in the calculation of carbon budgets on tropical peatland in Indonesia under different land uses.

Attribute	Value	Reason/reference
Above ground biomass Above ground biomass carbon	300 t ha^{-1} 150 t ha^{-1}	Brady, 1997; Sulistiyanto, 2004
Tree root biomass Tree root biomass carbon	30 t ha^{-1} 15 t ha^{-1}	Brady, 1997; Sulistiyanto, 2004
ABGB of degraded recovering peatland ABGB degraded peatland biomass carbon	25 t ha^{-1} 12.5 t ha^{-1}	Brady, 1997; Sulistiyanto, 2004
Root biomass of degraded recovering peatland Root biomass carbon of degraded peatland	2.5 t ha^{-1} 1.25 t ha^{-1}	Brady, 1997; Sulistiyanto, 2004
Notional peat carbon store Mean current rate of peat accumulation in psf	2,464 t C ha^{-1} 2.2 mm a^{-1}	Page et al. (2004)
Peat subsidence Peat heterotrophic CO_2 emissions	100 t CO_2 $ha^{-1}a^{-1}$ 80 t CO_2 $ha^{-1}a^{-1}$	Hooijer et al. (in press) Juahiainen et al. (2011)
N_2O emissions	3 t CO_{2e} $ha^{-1}a^{-1}$	Takakai et al. (2006); Melling et al. (2007; Jauhiainen et al. (2011);
Fire	20 cm of peat burned during each fire event	Page et al. (2002); Rieley & Page (2008); Hoscilo et al. (2011)

	Natural peat swamp forest	Drainage affected peat forest	Degraded peat forest	Oil palm plantation (Rieley & Page, 2008)	Oil palm plantation (new estimate)	Pulp tree plantation (Rieley & Page, 2008)	Pulp tree plantation (new: subsidence data)	Pulp tree plantation (new: CO_2 emission data)
Peat deposit at start	2218	2218	2218	2218	2218	2218	2218	2218
Forest above ground biomass C at start	150	150	150	150	150	150	150	150
Forest root biomass at start	15	15	15	15	15	15	15	15
Forest AGB after 25 years	150	100	0	0	0	0	0	0
Forest RB after 25 years	15	10	0	0	0	0	0	0
Carbon pool at start (peat and vegetation)	2383	2383	2383	2383	2383	2383	2383	2383
Secondary vegetation after 25 years	0	0	27.5	0	0	0	0	0
Secondary root biomass after 25 years	0	0	2.75	0	0	0	0	0
Peat accumulation C over 25 years	38.5	0	0	0	0	0	0	0
Peat subsidence/CO_2 emission C loss over 25 years	0	-431.3	-862.5	-862.5	-681.25	-1715	-681.25	-545
Peat fire C loss over 25 years	0	0	-620	-135	-135	-68.6	-68.6	-68.6
Peatland carbon pool after 25 years (peat + vegetation)	2421.5	1896.7	765.75	1220.3	1401.75	434.4	1468.15	1604.4
Peat carbon store after 25 years	2256.5	1786.7	735.5	1220.5	1401.75	434.4	1468.15	1604.4
Peat carbon store gain/loss after 25 years	38.5	-431.3	-1482.5	-997.5	-816.25	-1783.6	-749.85	-613.6
Mean annual C gain/loss	1.5	-17.3	-59.3	-39.9	-32.7	-71.3	-30	-24.5
Mean annual CO_2 gain/loss	5.6	-63.5	-217.7	-146.5	-120.1	-261.7	-110.1	-90
Mean annual N_2O emission (CO_{2e})	-0.07	-2.2	-3	-1.12	-1.12	-3.1	-3.1	-3.1
Mean net CO_{2e} gain/loss	5.53	-65.7	-220.7	-147.62	-121.22	-264.8	-113.2	-93.1
Predicted lifespan of peatland after 25 years (years)	For ever	103	12	31	43	6	49	65
Predicted maximum lifespan of peatland (years)	For ever	128	37	56	68	31	74	90
Annual CO_2 sequestration/release from 1 Mha (Mt)	5.6	-63.5	-217.7	-146.5	-120.1	-261.7	-110.1	-90
Total CO_{2e} released in 25 years from 1 Mha (Mt)	138.3	-1589	-5517.5	-3690.5	-3030.5	-6620	-2830	-2327.5
Percentage contribution of N_2O to CO_{2e}	1.4	3.5	1.4	0.8	0.9	1.2	2.8	3.4

DISCUSSION

This reassessment confirms that any land use change on tropical peatland leads to large losses from the carbon store. The peat thickness of 4.4 m is for example only and is taken from the mean thickness throughout Block C of the Ex Mega Rice project area in Central Kalimantan (Page et al. 2002). Peat of greater thickness would have a longer life expectancy while thinner peat will disappear quicker than these models suggest.

The only land use that ensures the large carbon store remains in place is natural peat swamp forest with its ability to sequester CO_2 from the atmosphere and transfer a proportion into the accumulating waterlogged peat. Peat formation is a slow process that takes place over thousands of years (Page et al. 2004) when it can attain a thickness of 10m or more in the tropics (Page et al. 1999). All other land uses that involve deforestation, drainage, fire and fertiliser addition lead to large losses of carbon stored in the peat and the formation of N_2O (Page et al. 2011). Fire is used as a land clearance tool but after drainage the higher peat surface temperatures that result lead to frequent fires, especially in the extended dry season in El Niño years (Page et al. 2002; Hosciło et al. 2011).

Applying these new data to *Acacia* pulp tree plantations reduces the previous estimates of CO_2 emissions by about 60%. For oil palm plantation the reduction is much less at about 18%. In addition, we are able to revise the estimates of the length of time 4.4 m of peat will take to disappear under these different land use scenarios. In natural peat swamp forest peat will continue to exist and accumulate as long as the prevailing climatic conditions permit waterlogging and reduce organic matter decomposition. The life expectancy of peatland under *Acacia* has trebled in this assessment from 30 to a maximum of 90 years while that under oil palm has increased slightly from 56 to 68 years. The worst case scenario is deforested, drained and degraded peatland that is neither being managed nor rehabilitated. Its future spans less than 40 years and this may be its best case scenario. We included drainage affected peat swamp forest in this new assessment because there are numerous remnants of peat swamp forest in the former mega rice project area but also some are retained as buffer zones or biodiversity reservoirs and wildlife refuges in and around plantations. The results show, however, that although the rate of peat disappearance is slower than in the plantations on peat this is still a progressive process and the peatland will still disappear after a hundred years or so. As peat subsidence under plantation management proceeds and water tables in these forest remnants fall the rate of peat disappearance may increase.

The contribution of N_2O emissions to the carbon store and losses from it is zero but they contribute in a small way (1-3.5%) to the overall global warming potential of GHG emissions from the peat surface. They are highest in *Acacia* plantation and drainage affected forest and lowest in oil palm plantation and natural peat swamp forest. These are percentages of total CO_{2e} emissions and the low values in oil palm are because the CO_2 emissions are high.

This assessment is based on a mean peat thickness of 4.4 m but around one third of the peatland in Indonesia is less than 1m thick so the time for these peats to disappear under land use change will be much shorter. We estimate under our revised scenario for *Acacia* that on peat 2 m thick the peat will disappear in just over 25 years while peat only 1 m thick will be gone in only 10-15 years.

ACKNOWLEDGEMENTS

We are grateful to the numerous peatland researchers we have worked with over many years for their information and views and especially Al Hooijer, Jyrki Jauhiainen and Suwido Limin.

REFERENCES

Brady, M.A. (1997) Organic Matter Dynamics of Coastal Peat Deposits in Sumatra. Ph.D. Thesis, Faculty of Graduate Studies, Department of Forestry, University of British Columbia, Canada

Couwenberg, J., Dommain, R. and Joosten, H. (2010) Greenhouse gas fluxes from tropical peatlands in Southeast Asia, Global Change Biology, 16, 1715–1732.

Hergoualc'h, K. and Verchot, L. V. (2011) Stocks and fluxes of carbon associated with land use change in Southeast Asian tropical peatlands: A review, Global Biogeochemical Cycles, 25, GB2001, doi:10.1029/2009GB003718.

Hooijer, A., Page, S., Jauhiainen, J., Lee, W.A., Lu, X.X. Idris, A. and Anshari, G. (in press) Subsidence and carbon loss in drained tropical peatlands: reducing uncertainty and implications for CO_2 emission reduction options, Biogeosciences Discussions.

Hosciło, A., Page, S.E., Tansey, K.J. and Rieley, J.O. (2011) Effect of repeated fires on land-cover change on peatland in southern Central Kalimantan, Indonesia, from 1973 to 2005. International Journal of Wildland Fire, 20, 578-588.

Jauhiainen, J., Hooijer, A. and Page, S.E. (2012) Carbon dioxide emissions from an *Acacia* plantation on peatland in Sumatra, Indonesia, Biogeosciences Discussions, 8, 8269-8302.

Jauhiainen, J., Silvennoinen, H., Hämäläinen, R., Kusin, K., Limin, S., Raison, R.J. and Vasander, H. (2011) Nitrous oxide fluxes from tropical peat with different disturbance history and management, Biogeosciences Discussions, 8, 5423-5450.

Lähteenoja, O., Ruokolainen, K., Schulman, L. and Oinonen, M. (2009) Amazonian peatlands: an ignored C sink and potential source. Global Change Biology, 15, 2311–2320.

Melling, L., Hatano, R. and Goh, K. J. (2005a) Soil CO_2 flux from three ecosystems in

Melling, L., Hatano, R. and Goh, G.J. (2007) Nitrous oxide emissions from three ecosystems in tropical peatland of Sarawak, Malaysia, Soil Science and Plant Nutrition, 53, 792–805.

Miettinen, J. and Liew, S.C. (2010) Degradation and development of peatlands in peninsular Malaysia and in the islands of Sumatra and Borneo, Land Degradation and Development, 21, 285–296.

Monacci, N.M., Meier-Grühagen, U., Finney, B., Behling, H. and Wooler, M. (2009) Mangrove ecosystem changes during the Holocene at Spanish Lookout Cay, Belize. Palaeogeography, Palaeoclimatology, Palaeoecology, 280, 37–46.

Murdiyarso, D., Hergoualc'h, K. and Verchot, L. V. (2010) Opportunities for reducing greenhouse gas emissions in tropical peatlands, Proceeding of the National Academy of Sciences USA, 107(46), 19655–19660.

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

Page, S.E., Wüst, R.A., Weiss, D., Rieley, J.O., Shotyk, W. and Limin, S.H. (2004) A record of Late Pleistocene and Holocene carbon accumulation and climate change from an equatorial peat bog (Kalimantan, Indonesia): implications for past, present and future carbon dynamics. Journal of Quaternary Science, 19(7), 625–635.

Page, S. E., Rieley, J. O., and Banks, C. J. (2011) Global and regional importance of the tropical peatland carbon pool, Global Change Biology, 17, 798–818.

Rieley, J.O., Page, S.E. (eds.) (2005) Wise Use of Tropical Peatlands - Focus on Southeast Asia. Wageningen, ALTERRA, 168 pp. + appendices

Rieley, J.O. and Page, S.E. (2008) Carbon budgets under different land uses on tropical peatlands. Proceedings of the 13th International Peat Congress, 8-13 June 2008, Tullamore, Ireland, pp. 245-249. International Peat Society, Jyväskylä, Finland.

Rieley, J.O., Wüst, R.A.J., Jauhiainen, J., Page, S.E., Ritzema, H., Wösten, H., Hooijer, A., Siegert, F., Limin, S., Vasander, H. and Stahlhut, M. (2008) Tropical Peatlands, Carbon stores, Carbon Gas Emissions and Contribution to Climate Change Processes. In: Strack M. (Ed.) Peatlands and Climate Change. IPS. Saarijärvi. pp. 148-181.

Sulistiyanto, Y. (2004) Nutrient dynamics in different sub-types of peat swamp forest in Central Kalimantan, Indonesia. Ph.D Thesis, University of Nottingham. 351 pp + 9 Appendixes.

Takakai, F., Morishita, T., Hashidoko, Y., Darung, U., Kuramochi, K., Dohong, S., Limin, S.H. and Hatano, R. (2006) Effects of agricultural land-use change and forest fire on N_2O emission from tropical peatlands, Central Kalimantan, Indonesia. Soil Science and Plant Nutrition 52, 662-674.