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SUBSIDENCE AS AN ACCURATE MEASURE OF CARBON LOSS IN DRAINED PEATLANDS IN SE ASIA

A. Hooijer[1], W. A. Lee[2], X. X. Lu[2], A. Idris[3], Sugino[3], J. Jauhiainen[4], S. Page[5]

([1]Deltares, Rotterdamseweg 185, P.O. Box 177, 2600 MH Delft, The Netherlands, tel: + 31 (0)88 335 8273, aljosja.hooijer@deltares.nl; [2]National University of Singapore, Singapore; [3]University of Jambi, Indonesia; [4]University of Helsinki, Finland, [5]University of Leicester, UK)

SUMMARY

Peatland surface subsidence has long been used as a measure of carbon loss throughout the world. There are questions, however, on whether the method is always applied appropriately. In this paper, we show that it is necessary to measure over long periods and at a large number of locations to obtain meaningful results. Applying the most thorough protocol, subsidence rates in an around oil palm plantations in Jambi, Indonesia, are found to be quite constant at rates around 5 cm y^{-1}. This number applies both to young and mature plantations, at water table depths around 0.6 m on average.

KEYWORDS: subsidence monitoring, tropical peatlands, carbon loss, drainage, SE Asia

INTRODUCTION

Land surface subsidence has long been used as a measure of carbon loss from peatlands throughout the world, in combination with characterization of bulk density profiles (Schothorst, 1977; Stephens et al., 1984). Various studies in tropical and subtropical climates, applying this method, have concluded that oxidation is responsible for at least 61% of subsidence. In a recent comprehensive study of field data and literature, it was concluded that the oxidation percentage 18 years after drainage in industrial plantations was around 90% and would eventually be expected to approach 100% as the peat is fully depleted (Hooijer et al., 2011). It has been concluded that a subsidence rate around 5 cm y^{-1} applies to *Acacia* and oil palm plantations more than 5 years after drainage, and that this translates to a net carbon emission of around 75 t ha^{-1} y^{-1} CO_{2eq} (Hooijer et al., 2011; Jauhiainen et al., 2011). Higher subsidence rates and emissions apply in the first 5 years after drainage. Data from SE Asia provide no evidence of a substantial decrease in subsidence and emission over decades after drainage, and long-term field studies in subtropical peatlands in the USA show that a constant subsidence and carbon loss continues for well over 50 years (Stephens et al., 1984; Deverel and Leighton, 2010).

While the validity of using subsidence as a surrogate measure of net carbon emission is well established, there are questions on whether the method is always applied appropriately. Taylor and Ali (2001), for instance, report subsidence data over a period of only 5 months, which may be too short to yield meaningful results. DID Malaysia (1996); with the same data being used by Wösten et al. (1997), do not present long-term water depth and land use reconstructions that allow linkage of subsidence rate to water depth or management, and indicate that they can not exclude that the heavy iron subsidence poles used in their study actually subsided by themselves (reducing measured subsidence). Kool et al. (2006) present subsidence rates that were not measured but rather derived from analyses of peat characteristics alone, and that have been quoted inappropriately in reviews (Hergoualc'h and Verchot, 2011). Clearly, while the measurement of subsidence offers a robust method in principle, an understanding of the potential error sources is required to derive valid long-term projections and carbon loss figures.

METHODS

We have monitored subsidence and depth of the ground water table in and around oil palm plantations in the province of Jambi, Indonesia, at 85 locations (Table 1) distributed over an area of over 25 km across. Monitoring was organized along transects with 4 to 10 locations each, perpendicular to drainage and transport canals. Peat depths along transects ranged from 4.9 to 9.9 metres with an average of 7.7 metres. Preliminary data for one year for 42 of these locations, in mature oil palm plantations (19 years after drainage on average), were part of the 218 locations presented in Hooijer et al. (2011). Of the other 43 locations 29 were in young oil palm plantation (5 years after drainage on average) and another 14 on land that was drained, cleared and burnt but not converted to productive use and now mostly covered with ferns (also 5 years after drainage). The combined locations provide a representative sample of typical conditions in and around oil palm plantations.

The measurements continued at 14-day intervals for nearly three years (2009–2011) including three full dry seasons (June-September in this region). The year of 2010 had extremely high rainfall in what is normally the dry season, in fact higher than in the wet season which is very rarely observed in historical rainfall records. The years of 2009 and 2011 had quite similar rainfall patterns that were closer to the long-term average. No unusually dry year occurred in the monitoring period.

Water levels and peat surface levels were monitored using 5 cm diameter, perforated PVC tubes, inserted vertically through the peat and anchored firmly to at least 0.5 m in the underlying mineral substrate to ensure stability. To minimize measurement error, permanent markers made of light but durable wood were placed on the peat surface. Compression of the surface peat was avoided by ensuring field staff did not step within a 0.5 m radius around pole locations, and only on planks during installation. As a further precaution the initial period after installation, from 1 to 3 months as data allowed it, was excluded from analyses.

Table 1 Basic statistics of subsidence measurements in Jambi, 2009–2011.

	Mature oil palm	Young oil palm	Cleared and unused	All
Number of monitoring locations	42	29	14	85
Years since drainage	15–20	4–7	4–7	4–20
Average peat thickness (m)	7.6	7.4	9.3	7.8
Average water table depth over 3 years (m)	-0.64	-0.44	-0.51	-0.53
Avg water table depth 2009 and 2011 (m)*	-0.66	-0.46	-0.53	-0.56
Avg water table depth 2010 (m)	-0.56	-0.40	-0.47	-0.48
Avg. subsidence over 3 years (cm/y)	4.1	4.3	5.3	4.4
Avg. subsidence 2009 and 2011 (cm/y)*	4.5	4.6	5.9	4.8

** Rainfall and water depths in 2009 and 2011 are close to long-term averages.*

RESULTS AND DISCUSSION

From Fig. 1 it is clear that substantial subsidence occurred in all landcover types at any time after drainage. The highest rate of 5.3 cm y^{-1} occurred in drained and cleared but unused land near plantations, the lower values in mature and young oil palm plantations are very similar at 4.1 cm y^{-1} and 4.3 cm y^{-1} respectively. The overall average is 4.4 cm y^{-1}, but this becomes 4.8 cm y^{-1} if only the more or less average years of 2009 and 2011 are considered, i.e. excluding the very wet year of 2010.

Whereas limited spatial variation in subsidence was observed, there is substantial variation in time, ranging from practically zero in some months to over 1 cm in others (Table 1). Low values occur when water tables are high, though also sometimes when they are low and moderate rainfall occurs (unpublished data). High values only occur when water levels are low or when they are dropping sharply, i.e. in periods of low rainfall. It should be noted that this short-term variation can probably not be translated entirely into short-term fluctuations in carbon loss. Indeed, CO_2 flux measurements at some of the same locations yield a more constant pattern in time (unpublished data). It is likely that during dry periods, the peat structure and density re-adjusts to the loss of peat matter due to oxidation in the previous periods when the peat was more saturated; in such wet periods subsidence may be lagging the loss of peat matter, resulting in an effective reduction in peat bulk density in such periods. Therefore, the acceleration of subsidence early on in dry periods is likely to be greater than the acceleration of oxidation and carbon loss.

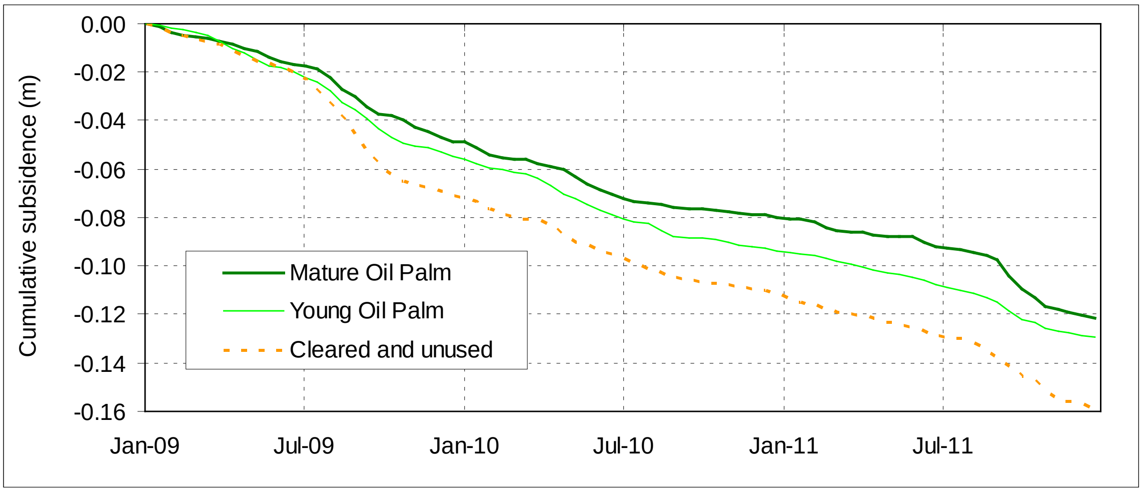

Figure 1. Cumulative subsidence in different land use types.

It is found that the subsidence rate in young oil palm 5 years after drainage is nearly identical to that in mature oil palm 19 years after drainage. While other research confirms that the rate of subsidence is constant more than 5 years after drainage (Stephens et al., 1984; Hooijer et al., 2011), it is also known that higher carbon loss occurs when soil temperatures are higher. On that basis, one might expect subsidence to be higher in young oil palm where ground exposure to direct sunlight is greater. This effect may be counteracted, however, by the fact that the young plantations studied have considerably higher water levels, of 0.46m on average compared to 0.66m in mature plantation. Literature suggests that such a difference of 20 cm would cause a substantial difference in subsidence and carbon emission (Hooijer et al. 2011;

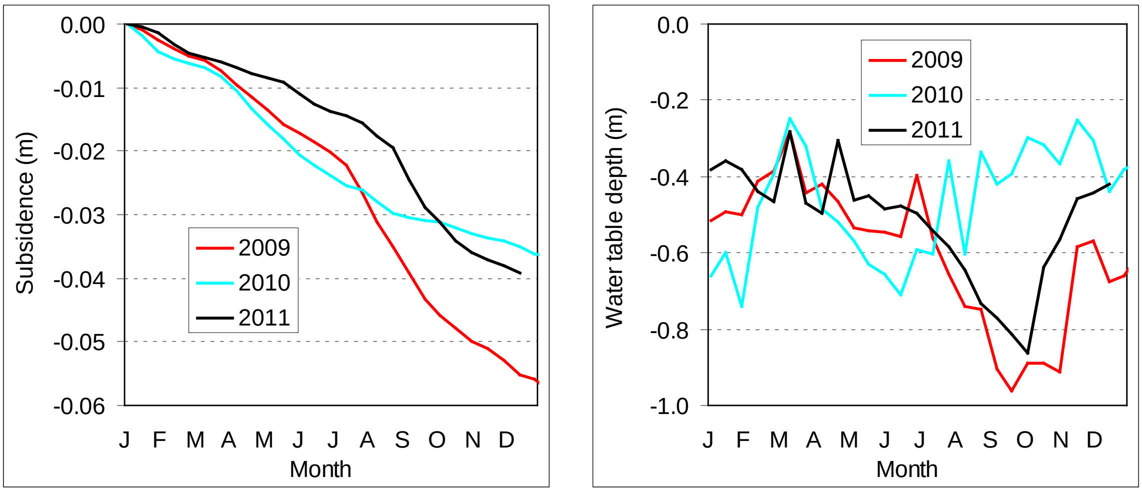

Figure 2 Annual subsidence and water table depth for three consecutive years, averaged over all landcover types.

Jauhiainen et al., 2011). The effect of soil temperature (unpublished data) may, however, explain the difference of 20% in subsidence rate between young oil palm plantations and unused plots that were drained at the same time and have similar water depth, with the latter having lower soil temperature owing to higher vegetation ground cover.

Considerable year-to-year difference in subsidence rate (Fig. 2) demonstrates the effects of water table depth and soil moisture content (unpublished data), and maybe also temperature, resulting from year-to-year differences in rainfall regime. Further identification of these relations is in progress.

The cumulative subsidence in mature oil palm plantation, from 5 to 19 years after drainage assuming a constant rate of 5 cm y^{-1}, is 0.7 metres. If we add a subsidence of 1.4 metres to account for the initial 5 year period (Hooijer et al., 2011), cumulative subsidence since drainage is 2.1 metres excluding the effect of fires. This corresponds very well with total subsidence that is evident relative to stable structures in the field (Fig. 3).

CONCLUSIONS

The study confirms that subsidence rates can be measured very accurately if proper methods are applied. Apart from precautionary measures in subsidence pole installation and data use, we also show that it is necessary to measure over periods of at least two years and at a large number of locations to obtain meaningful results. In the three years of this study, it is possible to find 6-month periods with less than 1.5 cm and more than 3.5 cm of subsidence, at the same locations. Such variations appeared to be controlled more by variable weather conditions rather than longer-term water management conditions, suggesting that high rates of carbon loss will occur in these plantations under any management regime. Studies reporting that subsidence in drained peatland is negligible may not have applied proper methods, or may have been conducted in peat of very limited thickness and high mineral content that is known to have a different response to drainage than deep peat of low mineral content (Hooijer et al. 2011).

Figure 3 Elevation surveys in a mature oil palm plantation indicate that the peat surface has come down at least 1 metre relative to this weir, that itself experiences only limited subsidence because its foundations are in the mineral (loam) subsoil. The weir bottom is now dry most of the time, i.e. it is above the water level. The weir was built at least one year, and probably 2 to 3 years, after drainage. Accounting for an additional subsidence of at least 1 metre for the initial period after drainage (DID Sarawak, 2001, Hooijer et al., 2011), total subsidence over 20 years is at least 2 metres. Accounting also for fires that are known to have preceded drainage in this area, which may have caused another 0.5 metres of subsidence (Page et al., 2002), the peat surface may have been lowered by 2.5 to 3 metres.

Subsidence rates are found to be quite constant between locations and different land cover types, with differences not greater than 25%, suggesting that subsidence rates and indeed carbon loss in many other peatlands may also be found to be rather uniform if measured properly. The average subsidence value of 4.8 cm y^{-1} in normal years confirms the rate of 5 cm y^{-1} proposed for plantations on deep peat in SE Asia in general, and the associated carbon loss. It should be noted that the overall average water levels in the plantations studied is 0.56 m (Table 1), which is very close to the value of 0.6 m that is the optimum target in oil palm plantations on peat (DID Sarawak, 2001). This suggests that the scope for reducing these impacts by bringing up water levels is limited.

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