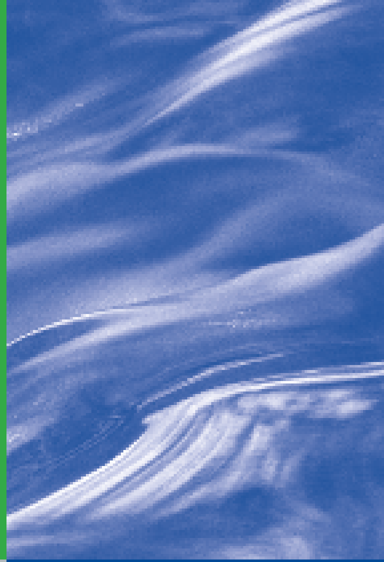
Are emission reductions from peatlands MRV-able?



WETLANDS INTERNATIONAL

Are emission reductions from peatlands MRV-able?

Hans Joosten & John Couwenberg, Greifswald University
Wetlands International, Ede, 2009
www.wetlands.org
Produced for the UN-FCCC meetings in Bonn, June 2009.

Summary

Globally very significant GHG benefits can accrue by avoiding peatland degradation and by actively restoring peatlands. This report addresses the question whether the results of such actions are measurable, reportable and verifiable.
The practice-oriented proxy methodologies currently under development in Europe and SE Asia (based on water level, vegetation, and subsidence) are critically discussed with respect to feasibility and costs. It is concluded that – whereas further development is necessary and is being pursued in running research and implementation projects – these methodologies will enable cost-effective and reliable baseline setting and monitoring of GHG emissions. This will allow inclusion of peatland conservation and rewetting in a post-2012 climate framework.

Introduction

The Bali Action Plan calls for climate mitigation actions that are measurable, reportable and verifiable (MRV). This implies that it must be possible for the results of individual actions to be quantified and – together with the methods of assessment – to be reported in a consistent and transparent way. Appropriate verification (by third party review) is important to build confidence among Parties and to ensure that adequate information is available to assess progress against the objectives of the UNFCCC.

In comparison to industry (with emission assessment via fuel input and standard technology) or forest management (with well-tried methodologies for estimating wood increment), the assessment of GHG fluxes from peatlands seems to be complicated. This relates to

- the general unfamiliarity with peatlands,
- the large diversity of peatlands and climatic conditions under which they occur,
- the spatial heterogeneity of sites, incl. varying peat thickness and land use,
- the various greenhouse gases involved with their divergent reactions,
- the transient dynamics of emissions upon land use change, and
- the variability of parameters (weather, water level, vegetation growth, land use...) that control GHG emissions over the year and between years.

This report discusses the possibilities of measuring, reporting and verifying emission reductions from peatlands: Is it possible, what are the methods, what is their reliability, and what can be said about the costs?

1. Why emission reduction from peatlands?

Peatlands are the most carbon-dense ecosystems of the terrestrial biosphere. The Giant Conifer Forests in the Pacific West of North America – with the highest trees in the World – come in second place, holding only half of the carbon stock of an average peatland per unit area. Covering merely 3% (4,000,000 km^2) of the World's land area, peatlands store 550 Gton of carbon in their peat soil, i.e. twice as much as the total global forest biomass (Parish *et al*. 2008). This huge carbon stock of peatlands is maintained by wetness. Natural peatlands are always wetlands. When peatlands remain wet, the peat carbon is conserved virtually forever.

Drainage of peatlands by land use (agriculture, forestry, deforestation, peat extraction…) can lead to significant emissions of GHGs for many decades, because the enormous peat carbon pool is gradually but continuously tapped. Fig. 1 shows an example for the conversion of rainforest to oil palm plantation that contrasts mineral with organic (peat) soils.

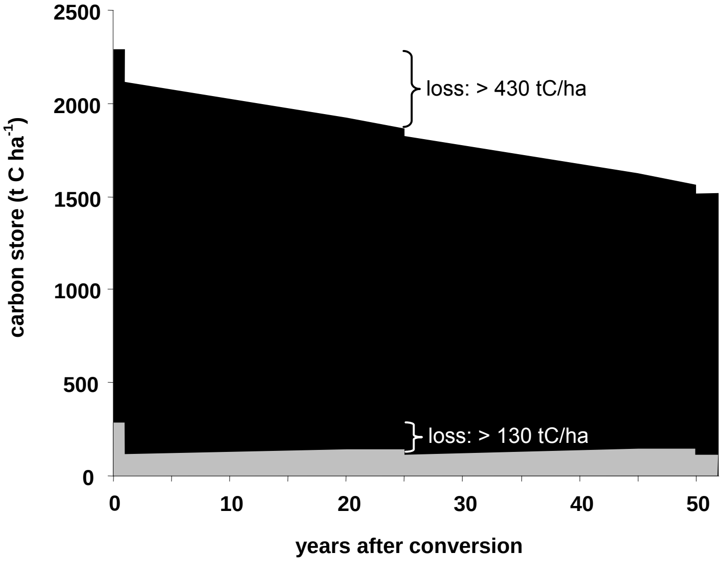


Fig. 1: Effect on carbon stocks of conversion of a tropical rainforest to oil palm plantation on organic (black) vs. mineral soil (grey). Assumed carbon stocks for tropical rainforest on mineral soil: 165 t C/ha aboveground biomass, 60 t C/ha belowground biomass, 60 t C/ha soil carbon (IPCC 2006); for oil palm an initial biomass of 15 t C/ha is assumed, increasing linearly to 45 t C/ha in a 20 year old plantation and reduced to 15 t C/ha after harvest in year 25 (www.mpoc.org.my). Mean standing biomass thus amounts to 32 t C/ha over the 25 year period. Clearance after 25 years is assumed not to involve fire. Assumed carbon content of organic (peat) soils is 2000 t C/ha (mean peat depth 4 m [cf. Jaenicke *et al*. 2008]; bulk density 0.1 g/cm^{-3}; carbon content 50%); emissions are conservatively estimated at 12 t C/ha/yr (Couwenberg *et al*. 2009). 25 years after conversion, carbon losses from plantations on organic (peat) soils are more than 3 times higher than from plantations on mineral soils, with the losses from peat soil continuing.

Next to sequestering CO_2, natural peatlands emit methane (CH_4). This emission depends on water level, being practically zero at levels lower than 20 cm below surface, but relevant at higher water levels (Couwenberg *et al*. 2009). The combined effect of CO_2 and CH_4 fluxes leads to a radiative forcing of pristine peatlands that– dependent on peatland type – is slightly positive or slightly negative on the 100 yr timescale. On the long run, all natural peatlands are climate coolers (*cf*. Frolking et al. 2006).
N_2O emissions from peatlands are generally restricted to water levels below -20cm. An important factor is land use: on drained peatlands in the temperate zone 2 – 9 % of the applied fertilizer N is emitted as N_2O, i.e. a larger proportion than on mineral soils (Couwenberg *et al*. 2008, 2009).

When peatlands are drained, CH_4 emissions decrease and CO_2 and N_2O emissions increase. This leads to net emissions from oxidizing peat of 10 up to possibly 100 ton CO_2-eq. per ha and year. Drainage associated fires increase these emissions substantially. Total global emissions from drained peatland amount to over 2,000 Mtons of CO_2 annually (Table 1).

Table 1: Global CO_2 emissions from drained peatlands (changed after Joosten & Couwenberg 2008)

	Drained area (Mio Ha)	CO_2 emission (ton ha/yr)	Total CO_2 emission (Mton/yr)
Drained peatlands in SE Asia	12	50	600
Peatland fires in SE Asia			400
Peatland agriculture outside SE Asia	30	25	750
Urbanisation, infrastructure	5	30	150
Peat extraction			60
Boreal peatland forestry	12	1	12
Temperate/tropical peatland forestry	3.5	30	105
Total	63		2,077

Peatland rewetting reduces the emissions from drained peatland: CO_2 and N_2O emissions strongly decrease, whereas CH_4 emissions increase but generally less substantially. In cases that abundant fresh biomass (crops, mellow grass) is flooded, CH_4 emissions may increase to such an extent that the climate effect of CO_2 and N_2O emission reduction is annihilated. This is caused by dying off of non-wetland plants, producing copious rotting material. These 'transient dynamics' are of limited duration as the availability of easily degradable fresh biomass strongly decreases when wetland plants have re-established. On the mid- and long-term, rewetting of peatlands may therefore be expected always to lead to a net reduction of climate relevant emissions from the peat body compared with the drained baseline (Joosten & Augustin 2006).

Three management strategies are meaningful with respect to peatland GHG fluxes:
1. Conservation: conserving the peat carbon stock,
2. Sequestration: maintaining/restoring net carbon sequestration capacity, and
3. Substitution: substituting fossil materials by renewable biomass.

Conservation management aims at conserving the existing peat carbon pools. In this respect it is important to recognize a fundamental difference between forests (where the biomass constitutes the major carbon pool) and peatlands (where the major C pool is the soil). Reducing the *rate* of peatland drainage leads still to an *increase* of emissions (Fig. 2). Absolute reductions in emissions can only be achieved by reducing the *total area* of drained peatlands, i.e. by conserving the natural peatlands *and* simultaneously rewetting already drained peatlands (Table 1). Strategic rewetting of 30% (20 Mio ha) of the world's drained peatlands could lead to an annual emission avoidance of almost **1,000 Mtons CO_2** per year.

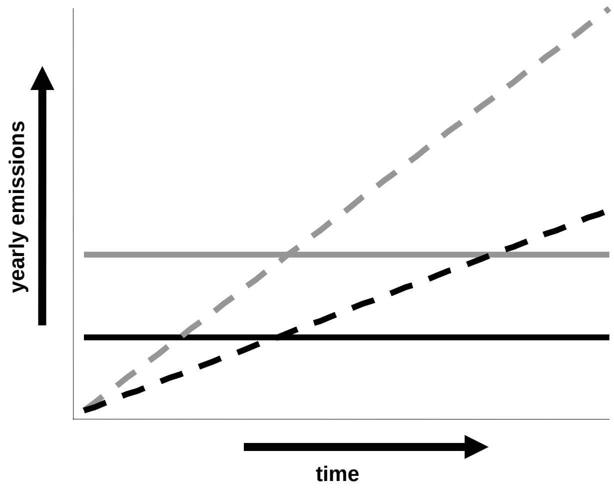


Fig. 2: Yearly emissions from deforestation vs. peatland drainage. Decreasing the rate of deforestation by half results in 50% lower yearly emissions (black solid) compared to the baseline (grey solid line). In contrast, decreasing the rate of peatland drainage by half (black dashed line vs. grey dashed baseline) still results in *increased* yearly emissions as areas drained in previous years continue to emit. Although deforestation results in higher immediate emissions on an area basis, emissions from peatland drainage are cumulative and surpass those of deforestation within decades, or only a few years if peatland fires are taken into account.

Sequestration management aims at increasing the peat carbon stock. Some 75% of the global peatlands are still pristine; they accumulate new peat removing and sequestering **200 Mtons CO_2** per year (Parish *et al*. 2008). Strict protection of these peatlands is critical for maintaining this capacity. Rewetting 200,000 km^2 of drained peatlands (see above) would – if peat accumulation is restored over half of that area – result in an additional long-term CO_2 sequestration rate of 10 Mtons per year.

Substitution management aims at replacing fossil resources (for energy and raw materials) by renewable biomass. Using biomass from *drained* peatlands is climatically counterproductive, as in general more CO_2 is emitted from oxidizing peat than sequestered by the useful biomass produced (Couwenberg 2007). Biomass harvesting from wet peatlands may, in contrast, lead to important climate benefits. Paludicultures (= wet agriculture and forestry, Wichtmann & Joosten 2007) implemented on 100,000 km^2 of rewetted, formerly drained peatland may substitute **100 Mtons** of CO_2 emissions from fossil resources annually.

These figures show that globally very significant GHG benefits can accrue by avoiding peatland degradation and by actively restoring peatlands. This is a strong argument for including peatland conservation and rewetting in a post-2012 climate framework.

2. Measuring emissions

Emission reductions must be quantifiable. The most obvious thing would be to measure on the project site all GHG fluxes (emissions and removals) that occur before, during, and after the intervention. Indeed, adequate techniques exist to measure these fluxes in detail. The chamber method, for example, enables measurements on the scale of a few dm^2 up to one m^2, whereas eddy-covariance allows assessing GHG fluxes over larger areas (typically 1 km^2).

GHG fluxes are dependent on a wide spectrum of site parameters that vary strongly over the year, including water level, temperature, vegetation growth and actual land use. Assessing annual GHG balances therefore requires highly frequent and prolonged observations to catch daily and seasonal variability. A sufficiently dense net of observations is necessary for the chamber method to cover the often fine-scale spatial patterns that are so typical for natural and degraded peatlands. And if we really want to assess the effects of the mitigation measures in terms of average annual GHG fluxes, the observations have to cover several complete years to reduce the effect of inter-annual differences in weather.

These requirements and the laborious and technically complex measurement make the methods too expensive for standard monitoring. In practise, direct measurements are only feasible for selected pilot sites to develop, calibrate and verify models that are sufficiently detailed, substantiated, and consistent to allow for reliable estimates. Emissions from other sites must then be assessed by applying these models. For reasons of practicality and verifiability (reproducibility) the models must have simple input parameters, i.e. must be based on simple indicators. It is here that the *proxies* come in.

3. Dealing with proxies

As GHG fluxes are difficult and expensive to measure directly, indirect methods – via so called proxy variables or 'proxies' – are used for assessing the fluxes. A proxy is something that in itself is not of interest for the question involved, but the variable of interest can be deduced from it. To be reliable, the proxy variable must have a close correlation with the variable of interest.

Also in climate politics the most important variables - GHG fluxes – are often addressed via proxies. A well-known proxy is carbon *stock change*. We use carbon stock changes to estimate CO_2 fluxes from vegetated land, where simultaneous uptake of CO_2 by photosynthesis and emission of CO_2 by respiration of plants, animals, and microbes make assessing net CO_2 fluxes complicated. Instead of measuring all fluxes to and fro, it is simpler to determine the change in carbon stock, which integrates all fluxes over longer time.

Whereas carbon stock change can thus be seen as a proxy for CO_2 fluxes, the stocks themselves are also not directly assessed. In forests, for example, we estimate the average increase in wood volume (m^3/ha/yr), multiply by the average C- content of wood and use the C-to-CO_2 conversion factor of $^{44}/_{12}$ to estimate the volume of sequestered CO_2 (ton/ha/year). The increase in wood volume is again approached by calculating – for example – the average increase in stem diameter at breast height (DBH) (cm/yr) of a sufficient large sample of trees. Using DBH increase as a proxy for CO_2 removal from the atmosphere is only possible when thorough statistical analysis has revealed a good correlation between the parameters.

With respect to forests these links are well known, because foresters have already for centuries been developing proxies for estimating the economically important wood increment in a simple and reliable way. Moreover, the link between wood increment and CO_2 removals is not fundamentally different from the link between burning fossil fuels and CO_2 emissions.

4. Proxies for peatland GHG fluxes

For peatlands the links are less evident. Of course, burning peat is not fundamentally different from burning other fossil fuels. But the relations between agriculture on organic soils on the one hand and CO_2 emissions on the other, or between peatland rewetting and CH_4 emissions are less obvious. 'Land use' has from the beginning of climate politics been deterrent because of its complexity, and peatlands – with their enormous carbon pools and their cocktail of greenhouse gases – were often conceived as a real nightmare.

Land use on peat soils involves only a limited set of greenhouse gases compared to industrial processes and peatlands are not more diverse than forests or the many types of manufacturing industries a country has to report on. Research has furthermore shown that peatlands all over the world have many similarities with respect to their GHG behaviour. And even when peatland related emissions were more complicated, their enormous importance for the climate should inspire more effort.

Peatlands are unknown and therefore unloved, and they are unloved and therefore unknown… Peatlands have until recently suffered from the 'Cinderella syndrome" (Lindsay 1992) and the development of proxies for measuring and monitoring peatland GHG emissions has only just started. But progress is rapid.

Three parameters are currently emerging as suitable proxies:

1. Water level
2. Vegetation
3. Subsidence.

Meta-analyses of a large amount of data from various parts of the world have revealed that mean **water level** is the best explanatory variable for annual GHG fluxes (Couwenberg *et al.* 2008, 2009). This is clearly the case for CO_2 emissions that are high with low water levels and low (and negative in case of peat formation) with high water levels. Fig. 3 shows this relation for mainland Western Europe.

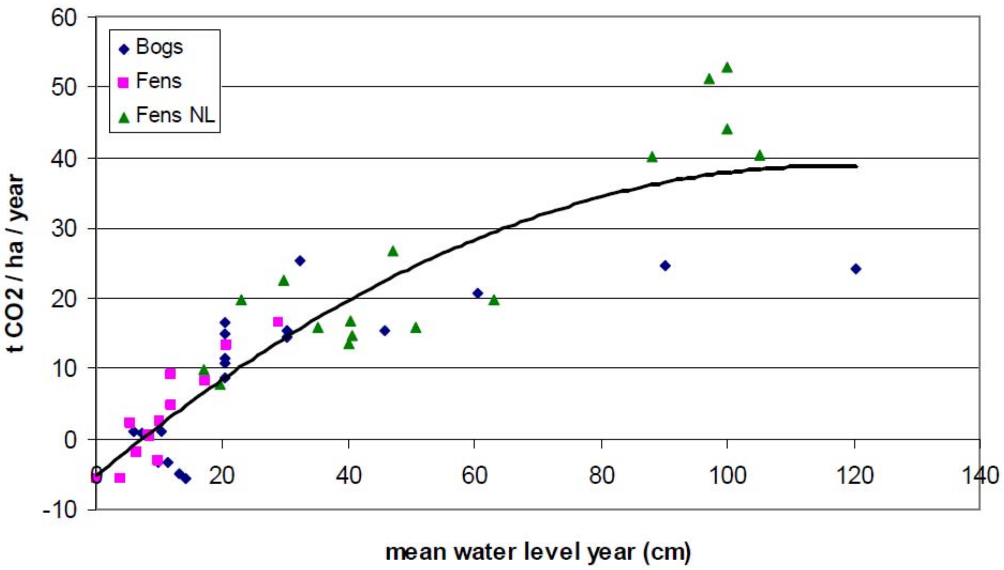


Fig. 3: Relation between mean water level below surface and annual CO_2 fluxes from peatlands in mainland Western Europe (Verhagen et al. 2009).

Also CH_4 shows a clear relationship with water levels (Fig. 4). Water levels of more than 20 cm below surface show negligible emissions, whereas values rise steeply with water levels above -20cm. The variation in measurements is, however, rather high, with very low values still occurring at higher water levels. Extra-tropical sites with high water levels but low emissions lack plant species with coarse aerenchyma (so-called 'shunt species', Couwenberg *et al*. 2008). Water levels above the surface are again associated with lower CH_4 emissions.

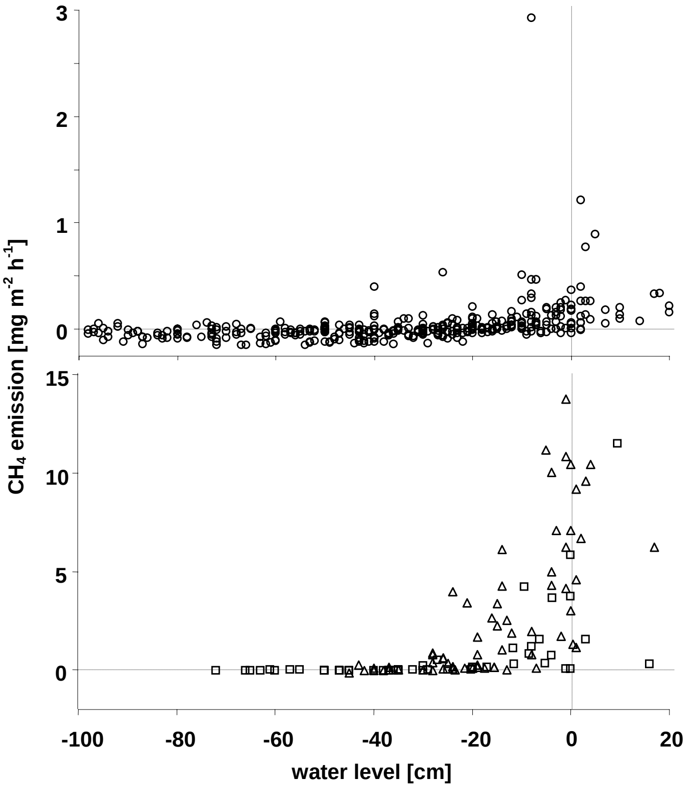


Fig. 4: Hourly methane emissions from tropical peatswamp soil (top) and from (Δ) boreal and (□) temperate sites (bottom). Note the fivefold difference in scale (Couwenberg et al. 2009).

A more sophisticated methodology using **vegetation** as GHG proxy is currently being developed for major peatland rewetting projects in Central Europe. This approach is also based on the strong correlation between GHG emissions and mean water levels, but uses vegetation as indicator of water level and therewith as a proxy for annual GHG fluxes. This is possible with a vegetation classification approach that integrates floristic and water level characteristics. The approach (the 'vegetation form' concept) departs from the observation that in an environmental gradient (e.g. from dry to wet) some species occur together, whereas others exclude each other (Fig. 5).

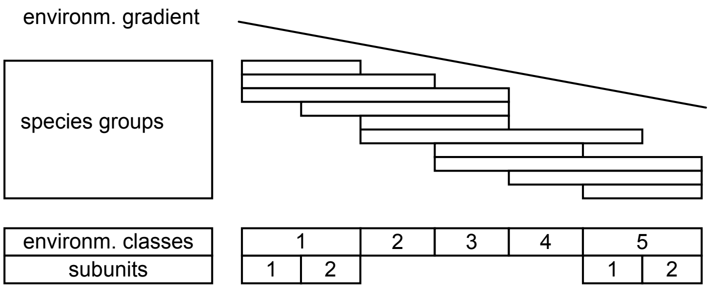


Fig. 5: The presence and absence of species groups provides a much sharper indication of site conditions (in our case water level classes) than individual species (Koska *et al*. 2001).

The co-occurrence (and absence) of specific species groups reflect water levels much sharper than individual plant species can do (*cf*. the well known Ellenberg indicator values for central Europe).

Vegetation is well qualified as a proxy for GHG fluxes because it

- reflects longer-term water level conditions and thus provides indication on the relevant time scale (GHG fluxes per ha per yr),
- is controlled by the same factors that additionally determine GHG emissions from peatlands (nutrient availability, acidity, land use…),
- is itself directly responsible for part of the GHG emissions by the quality of organic matter it produces (incl. root exudates) and by providing possible bypasses for increased methane emission via aerenchyma (‘shunt species’),
- allows fine-scaled mapping, e.g. on scales 1:2,500 – 1:10,000.

The disadvantages of using vegetation as a proxy are:

- its slow reaction on environmental changes: it may take 3 years or more before a change in mean annual water level is sufficiently reflected in a change in vegetation composition,
- the necessity to calibrated the approach for different climatic and phytogeographical conditions.

The concept has been developed for peatlands in Northeastern Germany (Couwenberg *et al*. 2008, Table 2,) and is currently being verified, calibrated and updated for use in large peatland rewetting projects in Belarus (Tanneberger *et al*. 2009).

Table 2: Selected NE-German vegetation types and their indication value for water level (WL) classes, CH_4 and CO_2emissions, and total Global Warming Potential GWP (all expressed in CO_2-eq., N_2O excluded, Couwenberg *et al*. 2008).

Vegetation type	**Typical/differentiating species**	**WL class**	**CH_4**	**CO_2**	**GWP CO_2-eq**
Sphagnum-Carex limosa-marsh	*Sphagnum recurvum* agg., *Carex limosa*, *Scheuchzeria*	5+	12.5	<0 (±0)	12.5
Sphagnum-Carex-Eriophorum-marsh	*Sph. recurvum* agg., *Carex nigra*, *C. curta*, *Eriophorum angustifolium*				
Drepanocladus-Carex-marsh	*Drepanocladus* div. spec., *Carex diandra*, *Carex rostr.*, *Carex limosa* - *Carex* dominated				
Scorpidium-Eleocharis-marsh	*Scorpidium*, *Eleocharis quinqueflora* - *Carex* (shunt) dominated				
Sphagnum-Juncus effusus-marsh	*Juncus effusus*, *Sphagnum recurvum* agg.				
Equisetum-reeds	*Equisetum fluviatile*				
Scorpidium-Cladium-reeds	*Cladium*, *Scorpidium*				
Sphagnum-Phragmites-reeds	*Phragmites*, *Solanum dulcamara*	5+	10	<0 / ±0	10
Solano-Phragmitetum	*Scorpidium*, *Eleocharis quinqueflora* - *Phragmites* + *Solanum* without *Urtica*-gr.				
Rorippa-Typha-Phragmites-reeds	*Typha latifolia*, *Phragmites*, *Rorippa aquatica*, *Lemna minor*				
Bidens-Glyceria-reeds	*Glyceria maxima*, *Berula erecta*, *Bidens tripartita*, *B. cernua*				
Red or green *Sphagnum* lawn (optimal)	*Sph. magellanicum*, *Sph. rubellum*, *Sph. fuscum*, *Sph. recurvum* agg.	5+	5	-2	3
Green *Sphagnum* hollow	*Sph. cuspidatum*, *Scheuchzeria*	5+	10	-2	8
Polytrichum-lawn	*Polytrichum commune*	5+	2	<0	2

Also **subsidence**, the loss of peatland height, looks promising as a proxy for GHG emissions, especially in the tropics. A methodology based on subsidence is currently being developed by the Australian AusAID Kalimantan Forests Carbon Partnership.
Whereas subsidence is also a function of the original peat type (degree of decomposition; mineral content), fire history, fertilizer regime and several other factors, water depth is again the most important factor. Subsidence rates reveal a linear relationship with mean water level. Subsidence in SE Asia increases by 0.9 cm a^{-1} for each 10 cm of additional drainage depth (Hooijer *et al*. 2006, Couwenberg *et al*. 2009, Fig. 6). Rates are different in other parts of the world.

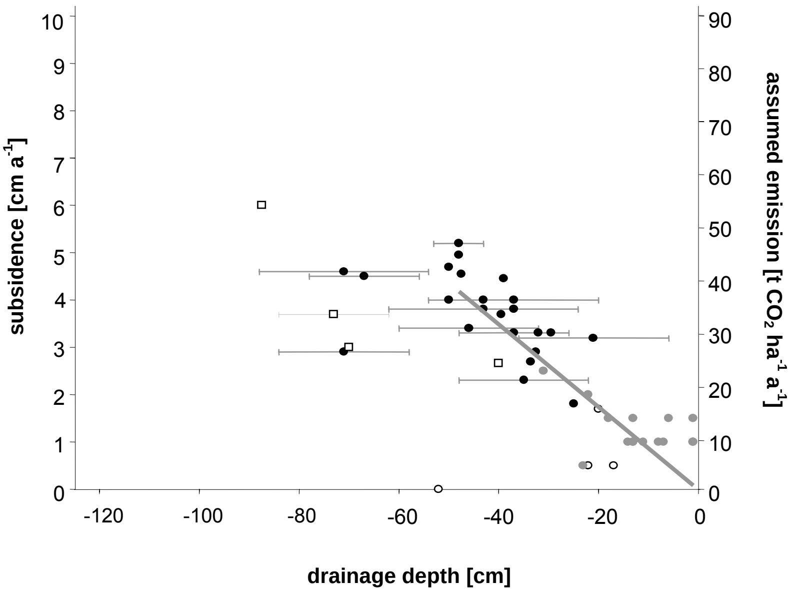


Fig. 6. Rate of subsidence in relation to mean annual water level below surface (Couwenberg *et al*. 2009). Horizontal bars indicate standard deviation in water table (where available). Open circles denote unused, drained forested sites, these were not taken into account in the regression that applies to water levels ≤50cm below surface only (slope = -0.09, r^2 = 0.95). Land use: (□) agriculture, (●) oil palm (recorded 13 to 16 or 18 to 21 years after drainage), (●) degraded open land in the Ex Mega Rice Project area, recorded ~10 to ~12 years after drainage, (○) drained forested plots, recorded ~10 to 12 years after drainage. Emission values are based on volumetric carbon content of 0.068 g C cm^{-3} (*cf*. Dommain *et al*. subm.) and a 40% oxidative component to total subsidence.

In Figure 6 the subsidence rate is translated into CO_2 emissions based on the assumption that 40% of total subsidence is attributable to oxidation. The latter is at the lower end of the (wide) range of 35-100% found in studies from other parts of the world (Couwenberg *et al*. 2009.).
Further development of subsidence as a proxy of GHG emissions makes an improved understanding of the relative contribution of mechanical compaction and oxidation to subsidence necessary. This requires further subsidence monitoring and analysis of peat characteristics, linked to monitoring of water depth, soil moisture and GHG emissions. Such research is currently in progress in Sumatra (pers. comm. Aljosja Hooijer and Jyrki Jauhiainen, April 2009) and planned for Kalimantan.
Subsidence includes water- and airborne losses from dissolved (DOC) and particulate organic carbon (POC). These POC and DOC losses are governed by land management and lead to GHG emissions off-site (*cf*. Raymond & Bauer 2001) that are not covered by direct on-site gas emission measurement. It may be assumed that the losses will be reduced after rewetting (Holden *et al*. 2004).

One drawback of using subsidence as an emission proxy is that it works well for CO_2 losses from drained peatlands, but less for decrease in these losses under rewetting. After rewetting, peatlands may show ‘swelling’ because of higher water content. This change in surface height is then by no means a simple measure for carbon dynamics – as it was in the drained situation. More research into this issue is thus needed.

5. Monitoring

Peatland rewetting and conservation projects have some special features that are relevant for monitoring:
First, we are dealing primarily with emission *avoidance*. This means that establishing a clear baseline for reference is of importance.
Secondly, peatland occurs in a *wide range of land use categories*. Forest, cropland, grassland, wetland and other land uses may all be found on peat soil, i.e. may all be peatland. This is generally not sufficiently acknowledged. It goes without saying that different land use categories may require different approaches to reduce GHG emissions *and* to monitor these reductions. In a cropland, for example, it makes less sense to use vegetation as an emission indicator, because plant growth is actively controlled. Land use may furthermore enhance GHG emissions from peat, for example through plowing (enhancing peat oxidation), N-fertilization (boosting N_2O-emissions), or tree removal (affecting hydrology, also in undrained peat swamps).
And last but not least, we are dealing with large areas and possibly *huge amounts* of carbon per ha. The quality of peatland inventories differs strongly between countries and, particularly for large countries with a large peatland extent (Russia, Canada, USA, Indonesia, Finland), also within the country.
The distribution, extent and degradation status of peatlands can reliably and rather easily be assessed on a regional level by remote sensing and limited ground truthing (e.g. Schuman *et al*. 2008). For determining peat stocks we have to rely on field mapping inventories, because practical remote sensing techniques are not yet available (Virtanen 2008). From a monitoring point of view the latter is not yet a problem, because GHG are emitted (and have to be monitored) as a function of peatland *area*, not of peatland *depth*.
Peat depth is only relevant to estimate the *length of time* over which emission avoidance can be credited, i.e. before the complete peat layer would have disappeared in the baseline situation. In tropical peatlands peat is depleted with a rate of ~0.9 cm/yr for each 10 cm of additional drainage depth, in subtropical peatlands with a rate of ~0.6 cm, and in temperate peatlands with a rate of ~0.4 cm/yr (Couwenberg *et al*. 2009). This means that every present-day drained peatland (defined on the basis of a minimum layer of peat, see Couwenberg 2009) will remain a net GHG emittor for many years to come. In these years the necessary additional information on peat depth distribution can be gathered.

As a general rule, the cost of monitoring is related to the desired precision of the GHG flux estimates. The market value of a ton avoided or sequestered ‘carbon’ will thus determine the level of precision that is cost-effective. Assessing the effect of peatland rewetting by comprehensive, direct flux measurements might currently cost in the order of magnitude of € 10000 per ha per yr.

Fortunately, somewhat less accurate proxies provide much cheaper alternatives:

- Monitoring GHG fluxes using **water levels** requires water level data that are frequent in time and dense in space. This can be brought about by field observations and automatic water level loggers. On the longer run, cheaper (but with higher initial investments) is the option of modelling, using weather data as input in a well calibrated non-stationary, three-dimensional hydrological model. Remote sensing is not yet suited for monitoring water levels of drained peatlands directly.

- **Vegetation** can easily be mapped and monitored in the field. Monitoring by remote sensing has been tested successfully and is very promising, also in financial terms. Certainly when satellite imagery with high spatial and temporal resolution is used it will be possible to reach a high level of accuracy.
- Also **subsidence** can easily be monitored by field observations, but it is practically impossible to do that over large areas in regions where annual height losses are only some millimetres. In tropical peatlands height losses from peatland drainage amount to several centimetres per year (and even substantially more in case of fire). Here the use of LiDAR remote sensing to monitor subsidence looks very promising. This approach is currently being developed in the AusAID – Indonesian Kalimantan project.

All three methodologies allow for immediate baseline setting, because the proxy data for the present-day situation can already now be mapped. They later can be translated into accurate ex-ante GHG flux estimates after improved calibration of the proxies.

6. Conclusions

Globally very significant GHG benefits can accrue by avoiding peatland degradation and by actively restoring peatlands. The practice-oriented proxy methodologies under development in Europe and SE Asia (based on water level, vegetation, and subsidence) look very promising for measuring, reporting and verifying emission reductions. They require further development, however, that is currently being pursued in research and implementation projects. It may be expected that these (and more?) methodologies will be available for cost-effective and reliable baseline setting and monitoring in a post-2012 climate framework. This will allow inclusion of peatland conservation and rewetting in climate policies.

References

Couwenberg, J. 2007. Biomass energy crops on peatlands: on emissions and perversions. IMCG Newsletter 2007/3: 12-14.

Couwenberg, J. 2009. Emission factors for managed peat soils – an analysis of IPCC default values. Wetlands International, Ede. 14pp.

Couwenberg, J., Augustin, J., Michaelis, D. & Joosten, H. 2008. Emission reductions from rewetting of peatlands. Towards a field guide for the assessment of greenhouse gas emissions from Central European peatlands. Duene Greifswald / RSPB Sandy. 28 pp.

Couwenberg, J., Dommain, R. & Joosten; H. 2009. Greenhouse gas fluxes from tropical peatswamps in Southeast Asia. Global Change Biology (accepted).

Dommain, R., Couwenberg, J. & Joosten, H. Holocene development and long-term carbon sequestration of tropical peatswamps in Southeast Asia. Global Change Biology (submitted).

Frolking, S. E., Roulet, N. & Fuglestvedt, J. 2006. How northern peatlands influence the Earth's radiative budget: Sustained methane emission versus sustained carbon sequestration, J. Geophys. Res. -Biogeosciences, 111, D08S03, doi: 10.1029/2005JG000091

Holden, J., Chapman, P.J. & Labadz, J.C. 2004. Artificial drainage of peatlands: hydrological and hydrochemical process and wetland restoration. Progress in Physical Geography 28: 95-123.

Hooijer, A., Silvius, M., Wösten, H. & Page, S. 2006. Peat-CO2 – Assessment of CO2 emissions from drained peatlands in SE Asia. Delft Hydraulics Report Q3943. 36 pp.

IPCC (2006) 2006 IPCC guidelines for national greenhouse gas inventories, prepared by the National Greenhouse Gas Inventories Programme (eds. Eggleston HS, Buendia L, Miwa K, Ngara T, Tanabe K). IGES, Japan. URL: http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html (retrieved 05/2009).

Jaenicke, J., Rieley, J.O., Mott, C., Kimman, P. & Siegert, F. 2008. Determination of the amount of carbon stored in Indonesian peatlands. Geoderma 147: 151-158.

Joosten, H. & Augustin, J. 2006. Peatland restoration and climate: on possible fluxes of gases and money. In: Bambalov, N.N. (ed.): Peat in solution of energy, agriculture and ecology problems. Tonpik, Minsk, pp. 412 - 417.

Joosten, H. & Couwenberg, J. 2008. Peatlands and Carbon. In: Parish, F. *et al*. Assessment on peatlands, biodiversity and climate change. Global Environment Centre, Kuala Lumpur and Wetlands International Wageningen, pp. 99-117.

Koska, I., Succow, M. & Clausnitzer, U. 2001. Vegetation als Komponente landschaftsökologischer Naturraumkennzeichnung. In: Succow, M. & Joosten, H. (eds.) Landschaftsökologische Moorkunde. Schweizerbart, Stuttgart, pp. 112-128.

Lindsay, R.A. 1992. Peatland conservation: the Cinderella syndrome - keynote address. In: Bragg, O.M., Hulme, P.D., Ingram, H.A.P. & Robertson, R.A. (eds.): Peatland ecosystems and Man: an impact assessment. University of Dundee/International Peat Society, Dundee, pp. 331-344.

Parish, F., Sirin, A., Charman, D., Joosten, H., Minaeva, T. & Silvius, M. (eds) 2008. Assessment on peatlands, biodiversity and climate change. Global Environment Centre, Kuala Lumpur and Wetlands International Wageningen, 179 p.

Raymond, P.A. & Bauer, J.E. 2001. Riverine export of aged terrestrial organic matter to the North Atlantic Ocean. Nature 409: 497-500.

Schumann, M., Thevs, N. & Joosten, H. 2008. Extent and degradation of peatlands on the Ruoergai Plateau (Tibet, China) assessed by remote sensing. In. Farrell, C. & Feehan, J. (eds.): After Wise Use – the Future of Peatlands. Int. Peat Society, Jyväskylä, pp. 77-80.

Tanneberger, F., Thiele, A., Minke, M., Couwenberg, J., Augustin, J., Wichtmann, W. & Joosten, H. 2009. Climate and biodiversity benefits of peatland restoration in Belarus. In: Progress and problems in wetland science - with a particular focus upon wetland restoration in Europe. 4th Annual meeting of the European Chapter of the Society of Wetland Scientists (SWS), Programme & Abstracts. Leibniz Institute of Freshwater Ecology and Inland Fisheries, Berlin, pp. 20-21.

Verhagen, J., van den Akker, J., Blok, C., Diemont, H., Joosten, H., Schouten, M., Schrijver, R., den Uyl, R., Verweij, P. & Wösten, H. 2009. Peatlands and carbon flows. Outlook and importance for the Netherlands. Netherlands Environmental Assessment Agency, Bilthoven. Report 500102 022, 52 pp.

Virtanen, K. 2008. Geological study of mires. In: Korhonen, R., Korpela, L. & Sarkkhola, S. (eds.): Finland – Fenland. Research and sustainable utilisation of mires and peat. Finnish Peatland Society, Maahenki, pp. 21-28.

Wichtmann, W. & Joosten, H. 2007. Paludiculture: peat formation and renewable resources from rewetted peatlands. IMCG Newsletter 2007/3: 24-28.

Mission:

To sustain and restore wetlands, their resources and biodiversity for future generations.

HEADQUARTERS
PO Box 471
6700 AL Wageningen
The Netherlands
Tel.: +318-660910
Fax: + 31 318-660950
E-mail: post@wetlands.org
Website: http://www.wetlands.org

AFRICA

Senegal
Rue 111, Zone B, Villa N° 39B
BP 25 581 Dakar - Fann, Senegal
Tel.: +221 33 869 1681
Fax: +221 33 825 1292
E-mail: wetlands@orange.sn
Website: http://Afrique.wetlands.org

Mali
PO Box 97
Mopti/Sévaré, Mali
Tel.: +223 21 420 122, Fax: +223 21 420 242
E-mail: malipin@afribone.net.ml
Website: http://Afrique.wetlands.org

Guinea-Bissau
c/o Gabinete de Planificação Costeira (GPC)
(Coastal Planning Office)
CP 23, 1031 Bissau-Codex
Guinea-Bissau
Tel.: +245 20 12 30 / Mobile: +245 72 00 562
Fax: +245 20 11 68
E-mail: gpc@sol.gtelecom.gw /
joaosa2003@hotmail.com
Website: http://Afrique.wetlands.org

Kenya
ICIPE Campus, Kasarani Road
P.O. Box 3502-00100 Nairobi, Kenya
Tel.: +254 20 8562246
Fax: +254 20 8562259
E-mail: Oliver.Nasirwa@Birdlife.or.ke
Website: http://Afrique.wetlands.org

AMERICAS

Argentina
25 de Mayo 758 10 I (1002)
Buenos Aires, Argentina
Tel./Fax: +54 11 4312 0932
E-mail: deblanco@wamani.apc.org
Website: http://LAC.wetlands.org

Panama
Ramsar CREHO
City of Knowledge / Ciudad del Saber
House 131 A
Apdo. Postal 0816 - 03847 Zona 3
Panamá, Rep. de Panamá
Tel.: +507 317 1242
Fax: +507 317 0876
E-mail: julio.montesdeocalugo@wetlands.org
Website: http://LAC.wetlands.org

NORTH ASIA
Room 501, Grand Forest Hotel, No. 3A
Beisanhuan, Zhonglu Road
Beijing 100029, People's Republic of China
Tel.: +86 10 62058405/18 or 62377031
Fax: +86 10 620 77900
E-mail: ckl@wetwonder.org,
zxh@wetwonder.org
Website: http://www.wetwonder.org

Japan
6F NCC Ningyocho Building, 3-7-3 Ningyo-cho,
Nihonbashi, Chuo-ku, Tokyo 103-0013, Japan
Tel: +81 3 5332 3362, Fax: +81 3 5332 3364
E-mail: info@wi-japan.org
Website: http://www.wi-japan.org

OCEANIA

Canberra - Australia
PO Box 4573
Kingston ACT 2604
Australia
Tel.: +61 2 6260 8341, Fax: +61 2 6232 7727
E-mail : doug.watkins@wetlands-oceania.org
Website: http://oceania.wetlands.org

Brisbane - Australia
c/o Queensland Herbarium
Brisbane Botanic Gardens, Mt Coot-tha Road
Toowong, QLD 4066, Australia
Tel.: +61 7 3406 6047, Fax: +61 7 3896 9624
E-mail: roger.jaensch@wetlands-oceania.org
Website: http://oceania.wetlands.org

Fiji
PO Box S6, Superfresh, Tamavua, Suva, Fiji
Mobile: +679 9 255 425, Fax: +679 332 2413
E-mail: apjenkins@wetlands-oceania.org
Website: http://oceania.wetlands.org

SOUTHEAST ASIA

Indonesia
P.O.Box 254 / BOO
16002 Bogor, Indonesia
Tel.: +62 251 8312189
Fax: +62 251 8325755
E-mail: admin@wetlands.or.id
Website: http://www.wetlands.or.id

Project office in Southern Kalimantan
Jl. Menteng 25 No. 31
Palangka Raya 73112
Central Kalimantan, Indonesia
Tel.: +62- (0)536-38268
Fax: +62 (0)536-29058
E-mail: aluedohong@yahoo.com
Website: http://www.wetlands.or.id

Project office in Aceh
Jl. Persatuan 2 No 15, Desa Lambheu
Keutapang Dua, Banda Aceh, Indonesia
Tel.: +62 651 740 1981, Tel.: +62 811167027
Website: http://www.wetlands.id

Malaysia
3A39, Block A, Kelana Centre Point Jalan SS7/19
47301 Petaling Jaya, Selangor, Malaysia
Tel: +60 3 7804 6770, Fax: +60 3 7804 6772
E-mail: malaysia@wetlands.org.my
Website: http://malaysia.wetlands.org

Thailand
Prince of Songkla University
Faculty of Environmental Management
PO Box 95, Kor Hong Post Office
A. Hat Yai, Songkhla Province
90112 Thailand
Tel: +66 74 429307, Fax: +66 74 429307
E-mail: asae-s@psu.ac.th /
asaesayaka@yahoo.com

SOUTH ASIA

India
A-25, 2nd Floor
Defence Colony, New Delhi 110024, India
Tel.: +91 11 24338906, 32927908
Fax: +91 11 24338906
E-mail: wi.southasia@wi-sa.org
Website: http://south-asia.wetlands.org

EUROPE

Black Sea Region
PO Box 82, 01032 Kiev, Ukraine
Tel./Fax: +380 44 2465862
E-mail: kv@wetl.kiev.ua
Website: http://blacksearegion.wetlands.org

Russia
Postal address:
c/o WWF 232, FLIP-Post, Suite 25
176 Finchley Road
London NW3 6BT, United Kingdom
Visiting address:
Nikoloyamskaya Ulitsa, 19, Str. 3
Moscow 109240, Russia
Tel.: +7 495 7270939
Fax: +7 495 7270938
E-mail: oanisimova@wwf.ru
Website: http://russia.wetlands.org

France
Tour du Valat - Centre de recherche pour la conservation des zones humides méditerranéennes
Le Sambuc - 13 200 Arles, France
Tel.: +33 (0)4 90 97 20 13
Fax: +33 (0)4 90 97 20 19
E-mail: bossuet@tourduvalat.org
Website: www.tourduvalat.org

WETLANDS INTERNATIONAL

www.wetlands.org