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Global and regional importance of the tropical peatland carbon pool

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Abstract

Accurate inventory of tropical peatland is important in order to (a) determine the magnitude of the carbon pool; (b) estimate the scale of transfers of peat-derived greenhouse gases to the atmosphere resulting from land use change; and (c) support carbon emissions reduction policies. We review available information on tropical peatland area and peat thickness and calculate peat volume and carbon content in order to determine their best estimates and ranges of variation globally, regionally and nationally. Our best estimate of tropical peatland area is 439,238 km^2 (~11% of global peatland area) of which 247,778 km^2 (57%) is in Southeast Asia. We estimate the volume of tropical peat to be 1,756 Gm^3 (~22-33% of global peat volume) with the highest share in Southeast Asia (77%). This new assessment reveals a larger tropical peatland carbon pool than previous estimates, with a best estimate of 88.5 Gt (range 81.5-91.8 Gt) equal to 17-19% of the global peat carbon pool. Of this, 68.5 Gt (77%) is in Southeast Asia. A single country, Indonesia, holds the largest share (57.4 Gt, 65%), followed by Malaysia (9.1 Gt, 10%). These data are used to provide revised estimates for Indonesian and Malaysian forest soil carbon pools of 77 Gt and 15 Gt, respectively, and total forest carbon pools (biomass plus soil) of 97 Gt and 19 Gt. Peat carbon comprises 60% of the total soil carbon pool in Malaysia and 74% in Indonesia. These results emphasise the prominent global and regional role played by the Southeast Asian peat carbon pool and the importance of including peat carbon in national and regional assessments of terrestrial carbon stocks. This information is essential given current interest in greenhouse gas emissions from developed and degraded peatlands and the need to predict future trends under the influence of land use and climate change.

Introduction

Peatlands are globally important terrestrial carbon pools and vital components of carbon soil-atmosphere exchange processes (Immirzi *et al.,* 1992; Strack, 2008). By area, peatlands have their greatest extent of 3,570,000 km^2 in boreal and temperate zones (Immirzi *et al.*, 1992) but tropical peatlands, which are located in Southeast Asia, Africa, the Caribbean, Central and South America, are also an important component of the global peatland resource, contributing to terrestrial carbon storage in both their above-ground biomass and underlying thick deposits of peat (Rieley *et al.,* 1996; Page *et al.,* 1999; Page *et al.,* 2004). Most tropical peatlands are located at low altitude, although a proportion occurs at high altitude in the mountains of Africa, South America and Papua New Guinea.

There is growing recognition of the importance of carbon storage in, and carbon gas emissions from, tropical peatlands and their role in global environmental change processes. Degradation of tropical peatlands leads to release of carbon and a reduction in the size of their carbon stores (Page *et al.,* 2002; Jauhiainen *et al.,* 2005, 2008; Hooijer *et al.,* 2006, 2009; Rieley *et al.,* 2008). The most rapid degradation of tropical peatland is currently taking place in Southeast Asia where there are strong economic and social pressures for timber, land for agriculture and plantations of oil palm and pulp trees (Koh *et al.*, 2009). As a consequence, this region's peatlands have undergone rapid deforestation in the last two decades (Langner *et al.*, 2007, Langner & Siegert, 2009), widespread drainage (Hooijer *et al.,* 2006, 2009), and frequent and intensive fires (Page *et al.,* 2002, 2009a; Langner *et al.*, 2007; Langner & Siegert, 2009). These have caused high levels of carbon gas emissions to the atmosphere through loss of biomass, peat oxidation and combustion (Hooijer *et al.,* 2006, 2009; Page *et al*., 2002; van der Werf *et al.,* 2004, 2008). Tropical peatlands are also sensitive to changes in temperature and precipitation and evidence shows that prolonged periods of drought can change them from carbon sinks to carbon sources (Suzuki *et al*., 1999; Hirano *et al*., 2007).

As a consequence of these impacts, tropical peatlands are areas of high carbon density, which play an important role in carbon-gas land-atmosphere interactions (Canadell *et al*., 2004; Gruber *et al*., 2004). This updated and improved inventory is important in order to determine the global area of tropical peatland and the magnitude of its carbon pool, estimate the likely scale of transfers of peat-derived greenhouse gases to the atmosphere resulting from changes in tropical peatland use both now and in coming decades, and predict what is likely to happen to the peatland carbon sink and store under the influence of future climate change. These data are also necessary for improving global climate-carbon models and supporting initiatives to improve peatland management planning and policy for climate change mitigation and carbon accounting. For example, new policy initiatives to reduce greenhouse gas emissions through avoided deforestation in developing countries (REDD and the voluntary carbon market) have emphasised the potential for conserving tropical peatlands by negotiating carbon offset and trading agreements (Murdiyarso *et al*., 2008).

This paper augments other recent regional studies of carbon pools in peat accumulating ecosystems (e.g. North American wetlands (Bridgham *et al.,* 2006), west Siberian peatlands (Yefremov & Yefremova, 2001) and the northern permafrost region (Tarnocai *et al.,* 2009)) by re-evaluating the status of tropical peatlands in regional and global peatland and soil carbon pools. Several previous peatland inventories (e.g. Immirzi *et al*., 1992; Lappalainen, 1996) presented the area and volume of tropical peatland on a country by country basis, but were hampered by a lack of reliable data and knowledge of their accuracy and provenance. Our study builds upon these inventories and incorporates new published and unpublished information, assesses the reliability of the data and, where possible, provides an evaluation of their uncertainty by giving ranges of estimates.

The specific objectives of this paper are to (1) present best estimates of the important attributes of tropical peatland (area, thickness, volume, bulk density and carbon content) by country and region in order to provide improved knowledge and certainty of the amount of peat in tropical countries and the magnitude of the carbon pools, and (2) assess the contribution of tropical peatland to national, regional and global peatland inventories and soil carbon stocks.

MATERIALS AND METHODS

In carrying out this assessment, we constrained the data in several ways: firstly, by including only those countries that lie between the Tropics of Cancer and Capricorn (23.5°N and 23.5°S, respectively), which excludes some peatland in the sub-tropics (e.g. Florida Everglades) but includes high altitude peatlands, some of which bear greater resemblance to temperate than lowland tropical peatland and, secondly, by defining peat as the surface layer of soil, consisting mostly of partially decomposed vegetation, with an organic content of at least 65% in a minimum thickness of 30 cm (Andriesse, 1988; Rieley & Page, 2005). Not all tropical peatland inventories follow this definition, or define the resource, and there are inconsistencies in the data available for assessment.

We encountered anomalies and mistakes in some estimates of tropical country peatland areas that had been incorporated into subsequent reports and publications. For example, the highest published estimate of peatland area in Indonesia (270,000 km^2) provided by Jansen *et al.* (1985) is cited by several other authors. This area is based on a definition of peat as a cumulative layer of 40 cm or more containing greater than 30% organic matter and therefore is for the total area of Histosols that includes both non-peat organic soil and true peat according to our definition. The lowest reported value for Indonesia of 160,000 km^2 is also given by Jansen *et al.* (1985), although its origin is probably Polak (1952), who considered peat as soils with more than 65% organic matter in a cumulative layer of at least 1 metre. The definitions of peat used to obtain these area values are, therefore, different and illustrate the importance of using a standardised approach. In addition, we believe that this lower value of 160,000 km^2, which is cited frequently, applies only to Kalimantan and Sumatra since Indonesia did not acquire Irian Jaya (now West Papua) until 1963 and its peatland area was not included in earlier inventories.

Data sources, assessment and components

Data Sources

The principal sources of information consulted were global (Kivinen & Pakarinen, 1980, 1981; Bord na Mona, 1984; Immirzi *et al.,* 1992; Lappalainen, 1996; Joosten & Clarke, 2002; GPD, 2004; World Energy Council, 2004) and tropical peatland inventories (Shier, 1985; Andriesse, 1988; Rieley *et al.,* 1996; Rieley & Page, 2005). Where possible, primary reports and published papers, from which these inventories were derived, were consulted. Later inventories tend to quote data from earlier ones and the trail leads mostly to the same origins, namely Bord na Mona (1984) and Kivinen & Pakarinen (1980, 1981); the former obtained information from official government sources and both derived data from various proceedings of and surveys undertaken by members of the International Peat Society (e.g. IPS, 1985). A few sources of information for peatland area in Indonesia could not be checked owing to their unavailability in a consultancy report (Jansen *et al.*, 1985), symposium proceedings (Soepraptohardjo & Driessen, 1976) and an old issue of a Dutch scientific journal (Polak, 1952).

These inventory data were collected and collated for different purposes using a variety of criteria and methods and mostly provide ranges of values, the upper and lower limits of which might have been obtained from different sources. For example, the detailed report prepared by Bord na Mona (Bord na Mona, 1984) for the World Bank focuses on the potential of peat in developing countries for energy and focussed on peat with a minimum thickness of one metre. Detailed inventories and primary reports were available for Southeast Asia, especially Indonesia, where a major proportion of tropical peatland is located and whose peat resources are relatively well documented (e.g. RePPProt, 1988-1990). For most other countries, however, only single inventory values were available giving the impression of precision of survey and accuracy of the data when, in fact, the opposite was the case. We also found that many published estimates had been rounded to tens, hundreds and even thousands of hectares, whilst some inventories focused on the highest available estimates and ignored much lower minimum values (e.g. Joosten & Clarke, 2002).

Data components

Peatland area

The area of tropical peatland is usually included in national soil inventories but those for different countries may not be strictly comparable owing to different definitions of peat and inclusion of non-peat organic soils in the statistics. If, for example, the minimum thickness of the surface organic layer adopted is 50 cm this will provide a smaller estimate of peatland area than if it were 20 cm or less. Many country inventories provide the area of Histosols and organic soils, of which peat is one type, but which is not always separated, and therefore the area of non-peat Histosols (<30 cm) may exceed that of true peat. As far as was possible, non-peat Histosols are included in the maximum estimates and dealt with separately.

The data that we acquired on peatland area revealed large variation, not only between countries and regions but also within countries (minimum compared to maximum). In determining best estimates it is important to treat the maximum estimates with caution since they may include large areas of shallow peat and non-peat Histosols and organic soils. In a few instances they also include other wetlands. In arriving at best estimates, however, it is inappropriate to simply determine the means of the minimum and maximum values, the approach adopted by Immirzi *et al*. (1992) and others. Instead we used a discriminating approach in which we assessed every piece of data to determine its likely accuracy. In doing this we used our expert judgment to accept data (maximum or minimum) as best estimates if the accounts were recent (post 1990) and originated from official sources. This was possible for only a few countries, for example, Indonesia and Malaysia. In those cases for which maximum values exceeded minimum values greatly we subtracted them, calculated 25% of the difference and added this amount to the minimum value. This was done to prevent distortion of best estimates as a result of inflated maximum areas and to provide a conservative evaluation.

Peat thickness

Knowledge of peat thickness, country by country and best estimates for all tropical countries are essential in order to determine as accurately as possible the total volume of tropical peat and hence its carbon content. Data on peat thickness are much fewer than for area because acquisition requires time-consuming direct measurement in the field and the difficulty of sampling peat with a thickness of up to 10 metres or more containing a large proportion of very hard tree remains. Even when values are available, there is usually no information on the sampling methods or means of data evaluation and interpolation. Peat thickness cannot be treated in the same way as peatland area because (a) the minimum is often the lowest value that can qualify as peat (0.3 m), (b) the maximum may relate to only one or a few high values in the literature, and (c) mean peat thicknesses and ranges are seldom available.

A few sources provide maximum peat thickness, others indicate ranges while some give a mean. Default values of 0.3 m and 2 m were applied as minimum and maximum thicknesses, respectively, to those countries for which peat thickness data could not be found. We used mean thicknesses as best estimates where these were available, otherwise we derived them conservatively from 25% of the maximum values in order to derive conservative estimates. We used only best estimate peat thickness values to calculate minimum, maximum and best estimates of peat volume and carbon pools.

Peat volume

This is the product of peatland area and peat thickness.

$$\mathbf{V}_{\boldsymbol{p}} = \mathbf{A}_{\boldsymbol{p}} \times \mathbf{T}_{\boldsymbol{p}} \qquad \mathbf{(1)}$$

Where Vp = peat volume (m^3); Ap = area of tropical peatland (m^2); Tp = mean peat thickness (m)

The minimum mean peat volume in a country is obtained by multiplying the minimum area by the minimum thickness. The best estimate mean volumes are derived in a similar manner. In the determination of maximum peat volumes the areas in excess of the best estimate area values were considered to have thin peat only, with a mean thickness 0.3 m, and these volumes were computed separately and added to the best estimates to provide maximum peat volume values. This was felt necessary in order to maintain the conservative approach used throughout this assessment.

Bulk density and carbon content of tropical peat

Peat bulk density (BD) is the dry mass of a standard volume of field material (solids plus pore space and water) that has been dried to constant weight at 80^{o}C and is usually expressed in grammes per cubic centimetre (g cm^{-3}) or kilogrammes per cubic metre (kg m^{3}). Bulk density depends on the degree of peat compaction, water content, plants from which the peat has formed, degree of peat decomposition, mineral content of the peat and land use. The method used to measure bulk density and the way in which it is expressed (e.g. dry or wet BD) are important considerations when comparing data from different authorities and between countries.

Carbon content of peat is usually expressed as fraction of the dry peat dry weight (50% = 0.5). Carbon contents published in the literature have been determined by different methods that have changed over time and have become more automated and sophisticated. Consequently, differences between carbon contents may be partly a result of these differences in analytical procedures, although the methods used are seldom specified.

Unfortunately, there are few published data on either bulk density or percentage carbon for tropical peatlands and these vary spatially over the surface of tropical peatland and at different depths within peat profiles. Most bulk density values in the literature are for surface or subsurface tropical peats to a maximum depth of 100 cm, but mostly in the upper 50 cm or less. Bulk density is often higher at the surface compared to the rest of the peat profile although the highest values are usually obtained for bottom peat samples, close to the underlying mineral ground, in which the organic matter content is lowest and mineral content highest (Weiss *et al*., 2002; Page *et al*., 2004). It is probably true to say that low bulk densities are associated with high carbon contents (i.e. more organic samples) and *vice versa*; high bulk densities are associated with high mineral and low carbon contents.

Carbon contents of tropical peats are less variable across their surface and down profiles than bulk densities. Lowest values are for samples taken near to the underlying mineral substrate or for very shallow peats in which there is a larger proportion of inorganic material and these do not fit with our definition of peat. The carbon content of surface tropical peat varies depending on vegetation cover and land use and, as with bulk density, may not provide a true representation of entire peat deposits.

As with peat thickness, the most detailed information on bulk density and carbon content was available for Indonesian and Malaysian peat deposits and very few data were found for peat in other tropical countries. In the absence of data, we applied best estimate values for bulk density and carbon content that were derived from our assessment of the literature on peats in these two countries and taking into account values from other countries where available.

Carbon pool

The magnitude of the tropical peatland carbon pool is obtained by multiplying peat volume by bulk density and percentage carbon content (Equation 2).

$$\mathbf{C_{\mathit{p}} = V\mathit{p} \times BD_{\mathit{be}} \times C_{\mathit{c}} / 10^9} \qquad \textbf{(2)}$$

Where C_p is the peatland carbon pool in Gt[1]; V_p is the volume of tropical peat in Gm^3[2]; BD_{be} is best estimate mean dry bulk density determined as explained in the text and expressed in g m^{-3}; C_c is percentage carbon content expressed as a fraction.

Results

Peatland area

Data on the area of peatland in tropical countries and geographical regions together with their maximum, minimum, best estimates and areas of shallow Histosols and organic soils are presented in Table 1.

<<INSERT TABLE 1 NEAR HERE>>

The total area of tropical peatland lies within the range 384,776- 656,430 km^2, with a best estimate of 439,238 km^2. The Southeast Asia region contains the largest share of this resource (247,778 km^2, 57% of the best estimate value), followed by South America (106,363 km^2; 24%), Africa (55,616 km^2; 13%), Central America and the Caribbean (22,956 km^2; 5%), Asia (other) (6,335 km^2; 1%) and the Pacific region (190 km^2; <1%) (Table 1). Within Southeast Asia, Indonesia has the largest area (206,950 km^2, 47% of the total best estimate), followed by Malaysia (25,889 km^2; 6%) and Papua New Guinea (10,986 km^2; 3%) with other countries in this region containing a much smaller amount (1% collectively in Brunei, Myanmar, the Philippines, Thailand and Vietnam).

[1] Gt = Gigatonnes = Billion tonnes = t x 10^9 = g x 10^{15} = Petagrammes
[2] Gm – Giga cubic metres = m^3 x 10^9

In South America the largest peatland area is in Peru (50,000 km^2; 11%) followed by Brazil (23,875 km^2; 5%), Venezuela (10,000 km^2; 2%) and Guyana (8,139 km^2; 2%). In Africa, Zambia contains 12,201 km^2 (3%) of the tropical peatland area, followed by Sudan with 9,068 km^2 (2%) and Uganda 7,300 km^2 (2%). Panama in Central America has a peatland area of 7,870 km^2 (2%). All other tropical countries have smaller areas of peatland equal to 1% or less of the total.

Peat thickness

Those tropical countries for which peat thickness values were available are listed in Table 2 and the best estimates of the means are used in subsequent calculations of peat volumes and carbon pools. For countries without information on peat thickness, default values were applied (see above).

The thickest peat deposits in this assessment are in Africa with best estimates of mean peat thickness of 11 m in Rwanda, 8 m in Burundi, 7.5 m in Congo, 5 m in Nigeria and 4 m in both Democratic Republic of Congo and Uganda. In Southeast Asia the thickest peat is in Malaysia (7 m) followed by Indonesia (5.5 m). In Central America and the Caribbean peat is thickest in Panama with a best estimate of 6 m, followed by Cuba (1.8 m) and Trinidad and Tobago (1.3 m). There is no information on peat thickness for most other countries in this region and the default best estimate of 0.5 m has been applied to them. South American peats are shallower with a mean thickness of 4 m in Venezuela, 2 m in Brazil and 1.75 m in Peru.

<< INSERT TABLE 2 NEAR HERE >>

Peat volume

The maximum, minimum and best estimates of peatland volume by country and by region are given in Table 3. The total volume of tropical peat is in the range 1,618 to 1,822 Gm^3 with a best estimate of 1,756 Gm^3. Southeast Asia has the largest share of the tropical peatland resource by volume (1,359 Gm^3; 77% of the best estimate), followed by South America (190 Gm^3; 11%), Africa (136 x 10^9 m^3; 8%), Central America and the Caribbean (62 x Gm^3; 4%), with Asia (other) and the Pacific region together containing only 9 Gm^3 (1%) (Table 3).

<<INSERT TABLE 3 NEAR HERE>>

Within Southeast Asia, as with area, Indonesia has the largest share of the tropical peatland resource by volume (1,138 Gm^3; equivalent to 65% of the best estimate global total), followed by Malaysia (181 Gm^3; 10%) and Papua New Guinea (27 Gm^3; 2%) (Table 3). All other countries in this region have less than 1% and contribute very little to the overall global tropical peat resource. In South America, Peru has 88 G m^3 (5%), followed by Brazil (48 G m^3; 3%) and Venezuela (40 x 10^9 Gm^3; 2%). Congo has the largest volume in Africa with 47 Gm^3 (3%), followed by Uganda (29 Gm^3; 2%). In Central America and the Caribbean, Panama has a peat volume of 47 Gm^3 (3%). All other countries contain 1% or less of the tropical peat volume.

Peat bulk density

Virtually all of the bulk density data available in the literature are for Southeast Asia, especially Sarawak, Malaysia and Kalimantan and Sumatra in Indonesia, although a few values were found for some other countries (Table 4). It is difficult to obtain primary data for bulk density and most published information provides ranges only; there are few individual values, means or standard deviations. For surface peats the bulk density values represent the spatial variation while, for peat cores, the ranges indicate upper and lower extremes only and do not provide detail of the variation in bulk density throughout the peat profile. If surface values only are used the bulk density will be higher than if the lower values in the rest of the profile are taken into account. Similarly, in peatland converted to agriculture the high bulk densities in the upper one metre or so of the peat soil following compaction do not indicate the much lower values in the permanently waterlogged peat beneath. In the absence of sufficient information on peat bulk density across the tropics we used a single best estimate of 0.09 g cm^{-3} that is a combination of the weighted means of 0.08 g cm^{-3} (Page *et al.*, 2004) for peatland in Central Kalimantan, Indonesia and 0.13 g cm^{-3} for Central Kalimantan, 0.08-0.13 g cm^{-3} for Sumatra and 0.09-0.13 g cm^{-3} for West Kalimantan (Neuzil, 1997). The bulk densities obtained for a few other countries are in accordance with these.

<<INSERT TABLE 4 ABOUT HERE>>

Peat carbon content

Published values of carbon content of Southeast Asian peats range from 41.6% (Sajarwan *et al.*, 2002) to 62.0% in Central Kalimantan (Neuzil, 1997; Page *et al.*, 2004) (Table 4). The much lower values that appear in some studies, e.g. 23.8% (Jaya, 2007) and 26.0% (Sajarwan *et al.*, 2002), are for samples taken near to the underlying mineral substrate or for non-peat organic soils in which there is a large proportion of inorganic material and these do not fit with our definition of peat. For the purposes of this assessment, the mean carbon content in peat from the Sabangau catchment, Central Kalimantan (Page *et al.,* 2004) of 56±3% was adopted for calculation of tropical peat carbon content. This value is virtually the same as the value of 57±3% obtained by Neuzil (1997) for several cores from Central Kalimantan, West Kalimantan and Sumatra and is similar to the peat carbon content values that could be found for a few other countries.

Peat carbon pool

The values for global, regional and national tropical peatland carbon pools follow a similar pattern to peat volume. The total tropical peatland carbon pool is in the range 82-92 Gt with a best estimate of 89 Gt. The largest pool is in Southeast Asia (69 Gt, 77% of the best estimate total), followed by South America (10 Gt; 11%), Africa (7 Gt; 8%), Central America and the Caribbean (3 Gt; 4%) and Asia (other) and the Pacific region (<1 Gt; 1% combined) (Table 5). Within Southeast Asia, Indonesia has by far the largest share of the tropical peatland carbon pool (57 Gt, 65%), followed by Malaysia (9 Gt, 10%), with Brunei, Myanmar, Papua New Guinea, the Philippines, Thailand and Vietnam, collectively, containing a smaller proportion of the total (2%).

<<PUT TABLE 5 NEAR HERE>>

Discussion

There have been several previous evaluations of the global area of peatlands and estimates of their carbon store but these differ widely owing to a lack of detailed information from many countries and differences in definitions of peat and estimates of peat thickness (e.g. Moore & Bellamy, 1974; Bord na Mona, 1984; Armentano & Menges, 1986; Andriesse, 1988; Gorham, 1991; Immirzi *et al.,* 1992). We used the evaluation by Immirzi *et al.* (1992) as the most comprehensive estimate of the area of boreal and temperate peatlands and added to this our updated tropical peatland area to arrive at an improved global total (Table 6).

<<PUT TABLE 6 NEAR HERE>>

Tropical peatlands, with a best estimate area from this assessment of 439,238 (384,773 – 656,430) km^2, make up 10 to 16% of the global peatland extent. The peatlands of Southeast Asia, with a best estimate area of 247,778 km^2, represent between 6% and 8% of the global peatland area. South America has a peatland area of 106,363 (3% of the global peatland area), Africa has 55,616 km^2 (1%) and Central America and the Caribbean have 22,956 km^2 (<1%).

According to Immirzi *et al.* (1992), the total global peat volume (mean=best estimate) is 5,958 Gm^3, based on an average peat thickness of 1.5 m. This underestimates the greater thickness of tropical peat compared to boreal and temperate peat. By combining the non-tropical peat volume of 5,335 Gm^3 (Immirzi *et al*., 1992) with our best estimate of 1,756 Gm^3 for the volume of tropical peat provides a larger global estimate of 7,091 Gm^3 showing that tropical peatlands contain 25% of the global peatland volume (Table 7), making a much larger contribution than their area suggests. By using a higher mean peat thickness value of 2.3 m for boreal and temperate peat, as suggested by Gorham (1991), produces a peat volume of 8,180 Gm^3 which, when combined by our assessment of the tropical peat volume, produces a global estimate of 9,936 Gm^3, of which tropical peat comprises 17-18% and Southeast Asian peat 14%.

<<INSERT TABLE 7 AROUND HERE>>

Immirzi *et al.* (1992) conclude that the amount of carbon stored within peatlands globally is in the range 329 to 525 Gt with a mean value of 462 Gt, although other published values range from 234 to 679 Gt (Gorham, 1991; Eswaran *et al.,* 1993; Batjes, 1996; Lappalainen, 1996; Joosten & Clarke, 2002). Using the minimum, maximum and mean estimates of non-tropical peatland area from Immirzi *et al.* (1992), multiplying these by their peat carbon density (1099.5 t C ha^{-1}) in a mean global peat thickness of 1.5 m, and adding the new tropical peat carbon store values obtained in this assessment, provides a new overall global estimate of 469 – 486 Gt with a best estimate of 480 Gt (Table 8). Using the greater mean thickness value of 2.3 m for boreal and sub-arctic peat (Gorham, 1991) and thus a higher carbon density value of 1466 t C ha^{-1}, results in a larger estimate of the global peat carbon store of between 598 to 618 Gt with a best estimate of 610 Gt (Table 8). On this basis of these assessments, the tropical peat carbon pool is between 11 and 14% of the global peat carbon pool.

The Southeast Asian region contains the largest proportion of the tropical peat carbon store with between 66.4-69.8 Gt C (best estimate 68.5 Gt C). We found that

Indonesian peatlands alone store 57.4 Gt compared to 42 Gt used by Hooijer *et al.* (2006, 2009) in their assessment of CO_2 emissions from drained peatlands in Southeast Asia but close to the value of 55 Gt C calculated for the Indonesian peatland carbon pool by Jaenicke *et al.* (2008) using a combination of 3D modelling and satellite imagery.

The soil is the largest terrestrial pool of organic carbon, with global estimates ranging between 1395 Gt (Adams *et al.,* 1990), 1462-1548 Gt (Batjes, 1996) and 1600-1800 Gt (Bouwman, 1990). Compared to a median value of 1500 Gt C in soils, tropical peatland represents between 5-6% of the global soil carbon pool. The size of the carbon pool in tropical soils generally is poorly known (Batjes, 1996), but in countries where peatland occupies a significant proportion of the land area, e.g. Indonesia (10.8%) and Malaysia (7.9%), this ecosystem holds a major proportion of the national soil carbon stock. Brown *et al.* (1993) estimated that the carbon pool in Indonesia's forest soils (to 100 cm depth) and vegetation was 40 Gt, of which soil carbon accounted for 50% (i.e. 20 Gt); values for Malaysia were 10 Gt C (6 Gt in soil plus 4 Gt in biomass). Including our values for peat carbon pools could increase the Indonesian forest soil carbon pool to about 77 Gt (even allowing for the fact that Brown *et al.* (1993) included 100 cm thickness of peat swamp forest soil carbon in their estimate), producing a total forest carbon pool value of 97 Gt, of which the soil component is 79% and the peat 58%. Likewise the Malaysian forest soil carbon store increases to 15 Gt, with a total forest store of 19 Gt. Of this total value, soil carbon makes up 79% and the peat carbon proportion is 47%. Thus in these two countries, peat carbon comprises 60% of the total soil carbon pool in Malaysia and 74% in Indonesia. Forests across the entire tropical Asian region are estimated to have a total soil carbon pool of 43 Gt with an additional 42 Gt in biomass (Brown *et al.*, 1993); including our best estimate of the tropical Asian peatland carbon pool (i.e. Southeast Asia plus Asia (other)) increases the value of this region's forest soil carbon pool to ~130 Gt, 68% of which is in peat. This new data assessment draws attention to the large contribution of Southeast Asian peatlands to both national and regional forest soil carbon and emphasises the importance of considering peat carbon stores in assessments of emissions from tropical land use change and fire.

Our assessment highlights countries for which there is a lack of primary data on peatland area, thickness, bulk density and carbon content, leading to uncertainty in the calculation of peat volumes and carbon pools. Some inventories include organic soils and shallow non-peat Histosols in peatland inventories. This applies to peatland area but it is a much greater problem for peat thickness, bulk density and carbon content which have been inadequately determined in many countries. Further detailed field surveys would undoubtedly contribute to more precise and better constrained estimates of tropical peatland carbon pools, particularly in Africa, Central and South America where there is still relatively little spatial information on peat thickness.

Even in Southeast Asia, where the peatlands of Indonesia and Malaysia have been relatively well studied, there is still a lack of knowledge of the aerial extent and volume of peatlands in some locations. In West Papua (Irian Jaya), for example, there are at least 70,000 km^2 of thick peat deposits that have received very little study. This is also the case in Papua New Guinea, where the difference between non-peat and peat-forming wetlands is ill defined. In this assessment we have used a best estimate peatland area of 16,971 km^2 for Papua New Guinea, whilst Joosten and Clarke (2002) provide a higher value of 28,900 km^2. Their original data source (Wayi and Freyne, 1992) indicates that this is the extent of Histosols (i.e. organic soils associated with a wide range of wetlands, not all of which conform to our definition of peat), thus the best estimate value we have used could underestimate the true extent of the resource. This uncertainty regarding classification of wetlands and wetland soils is not confined to Southeast Asia. For example, our best estimates of peatland areas in Sudan and Zambia are 9,068 and 11,060 km^2, whilst the extent of Histosols and non-peat organic soils (according to our definition of peat) is 33,270 and 15,645 km^2, respectively (GPD, 2004); again, we may have underestimated the true extent of peatland in these and several other countries.

In other cases, the lack of precise information is because of limited field survey in remote locations. Ruokalainen *et al.* (2001) have suggested that Amazonian peatlands could have a total area of 150,000 km^2. They do not provide verifiable evidence for their assertions and these data should be treated with care until they are confirmed. Most of these are small, topogenous (as opposed to ombrogenous) wetlands associated with *Mauritia flexuosa* (aguaje palm) swamps that are predominantly riverine or flood plain wetlands interspersed amongst dryland forest types (Lähteenoja *et al.*, 2009; Phillips *et al.*, 1997). There is no general agreement that these are peat forming in all situations, although they may accumulate plant litter to a thickness in excess of 0.5 m that could be classified as peat. Undoubtedly, Amazonian peatlands warrant further more detailed investigation and assessment, although, owing to their shallow nature (average depth 1.75 m, according to data presented for 12 peat cores in Peru (Lähteenoja *et al.* (2009)) they will likely make only a small additional contribution to the tropical peatland carbon pool unless extensive thick, ombrogenous deposits are described. Tropical mountain peatlands also warrant further investigation. These are mostly small in area, occurring primarily in basins and on slopes, but they can be numerous and, collectively, could make a substantial contribution to regional peat resources, particularly in Andean countries (Chimner & Karberg, 2008).

African peatlands are also under investigated. Some peatlands have thick peat deposits with maximum recorded thickness in excess of 30 m (Table 2) in Burundi, Congo and Democratic Republic of Congo. At present it is difficult to carry out field investigations in these countries owing to their political situation, but if it were, our best estimates of peatland areas might be increased with implications for the size of their carbon pools.

Improved knowledge and understanding of the tropical peatland resource is vital given the current rapid rate of peatland development occurring across the tropics and specifically in Southeast Asia where the vast majority of the resource is located. Consideration of the scale of carbon flux from deforestation or degradation of tropical peatland should take into account the high below-ground carbon storage, which will typically be an order of magnitude greater than that in the above-ground biomass. For example, our best estimate of carbon density in Indonesian peatland is 2,772 t C ha^{-1} (based on a best estimate peat thickness of 5.5 m), which is much higher than typical values for above ground peat swamp forest biomass of 100 to 150 t C ha^{-1} (Page *et al.*, 2006). Deforestation of Southeast Asian peatlands is proceeding at rates as high as 2.2% yr^{-1} across Borneo (2002 to 2005; Langner et al., 2007) and 9.0% yr^{-1} for some specific locations (former Mega Rice Project, Central Kalimantan, 1997 to 2005;

Hoscilo *et al.*, submitted). Relatively few studies (e.g. Page *et al.,* 2002; van der Werf *et al.*, 2004, 2008; Hooijer *et al.,* 2006, 2009; Fargione *et al.,* 2008) have explicitly recognised the scale of carbon emissions arising from disturbance of tropical peatlands where the flux from the below-ground carbon pool can be several orders of magnitude greater than that from the above-ground pool and extend over a much longer time period. For the year 2000, Hooijer *et al.* (2006) estimated that some 106,000 km^2 (43%) of the tropical peatland resource across Southeast Asia had been deforested, drained and converted to some other form of land use. Based on our best estimate of the regional peatland carbon pool, this renders ~29 Gt C vulnerable to release to the atmosphere as a result of peat oxidation and fire over coming decades. Even with improved land management, the magnitude of emissions from tropical peatland is unlikely to be reduced, since climate modelling studies have shown that peatland areas of equatorial Southeast Asia and Amazonia will experience reduced rainfall and greater seasonality (IPCC, 2007; Li *et al.*, 2007; Mahli *et al.*, 2008), which will lead to lower peatland water tables, enhanced peat decomposition and an increased likelihood of fire.

New policy initiatives to reduce greenhouse gas emissions through avoided deforestation in developing countries (REDD and the voluntary market) are likely to become a dominant component of land-based carbon mitigation in the future (Agus, 2008; Murdiyarso *et al.*, 2008). This study emphasises that tropical peatlands have one of the highest carbon densities of all terrestrial ecosystems. Tropical peatlands, particularly in Southeast Asia, combine a large carbon forest sink with an even larger peat carbon store, thus policies that promote avoided deforestation and degradation as well as peatland rehabilitation (Page *et al.*, 2009b) would yield high benefits per hectare if applied to tropical peat swamp forest.

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Tables

Table 1: Area of tropical peatland on a country and regional basis expressed as best estimate, maximum and minimum area values (km^2) (see notes for details).

Table 2: Thickness of tropical peat on a country and regional basis expressed as maximum, range, mean and best estimate (m) (see notes for details).

Table 3: Volume of tropical peatland on a country and regional basis expressed as best estimate, maximum and minimum values (m^3 x 10^6) (calculated from area in Table 1 and peat thickness in Table 2).

Table 4: Bulk density and carbon concentration of tropical peat obtained from the literature (psf: peat swamp forest; BD: bulk density) with some values for temperate peat for comparison.

Table 5: Carbon store in tropical peatland on a country and regional basis expressed as best estimate, maximum and minimum values (Gigatonne) (calculated from volume in Table 1, bulk density of 0.09 g cm^{-3} and carbon concentration of 56% (0.56))

Table 6: Updated estimates of global and tropical peatland areas derived from Immirzi *et al.* (1992) and this assessment.

Table 7: Updated estimates of global and tropical peat volumes derived from Immirzi *et al.* (1992) and this assessment.

Table 8: Updated estimates of global and tropical peatland carbon pools derived from Immirzi *et al.* (1992) and this assessment.

Table 1: Area of tropical peatland on a country and regional basis expressed as best estimate, maximum and minimum area values (km^2) (see notes for details).

Region	Country	Minimum area (km^2)	%	Best estimate of area (km^2)	%	Shallow Histosols and organic soils (km^2)	%	Maximum area (km^2)	%	Notes
AFRICA	Angola	100	0	2640	1	7621	4	10,261	2	Min from Andriesse (1988). WSM[3] in GDB (2004) gives 10,261 km^2 as max for Histosols.
	Botswana	2500	1	2625	1	375	0	3000	0	Max and Min from Sliva (pers. comm.) mentioned in GPD (2004).
	Burundi	140	0	323	0	555	0	878	0	Min from Bord na Mona (1984). WSM in GPD (2004) gives 878 km^2 as max for Histosols.
	Cameroon	100	0	1077	0	2930	1	4007	1	Min from Joosten & Clarke (2002) but source not given; Max from WSM in GPD (2004).
	Congo	2900	1	6220	1	9957	5	16177	2	Min from Bord na Mona (1984); WSM in GPD (2004) gives 16,177 km^2 as max for Histosols.
	Democratic Republic of Congo	400	0	2800	1	7,200	3	10000	2	Most inventories give the 400 km^2 cited in Shier (1985); Andriesse (1988) and GPD (2004) give higher value.
	Gabon	80	0	548	0	1,403	1	1951	0	Min from Joosten & Clarke (2002) but source not given; Max from WSM in GPD (2004).
	Ghana	49	0	59	0	41	0	100	0	Min from WSM in GPD (2004); Max from Joosten & Clarke (2002)
	Guinea	853	0	1952	0	3,298	2	5250	1	Min from WSM in GPD (2004); Max from Bord na Mona (1984) but includes mangroves.
	Ivory Coast	300	0	725	0	1,275	1	2000	0	Min from Bord na Mona (1984); Max from Markov (1988) in GPD (2004).
	Kenya	1600	0	2440	1	2,519	1	4959	1	Min from Lappaleinen & Zurek (1996), source credited to Markov (1988) in GPD (2004); Max from WSM in GPD (2004).
	Liberia	26	0	120	0	280	0	400	0	Min from WSM in GPD (2004); Max from Bord na Mona (1984).
	Madagascar	1903	0	1920	0	50	0	1970	0	Min from WSM in GPD (2004); Max and Best Estimates from Bord na Mona (1984).
	Malawi	353	0	492	0	418	0	910	0	Min from WSM in GPD (2004); Max from Bord na Mona (1984).
	Mauritania	60	0	60	0	0	0	60	0	Joosten & Clarke (2002); source not given.
	Mauritius	1	0	1	0	0	0	1	0	Joosten & Clarke (2002); source not given.
	Mozambique	100	0	575	0	1,425	1	2000	0	Min from Andriesse (1988); Max fom Grunding (pers. comm.) in GBD (2004).
	Nigeria	120	0	1600	0	5,400	2	7000	1	Min from Joosten & Clarke (2002) but cannot be verified. Max from Lappaleinen & Zurek (1996) but cannot be verified, mostly mangrove and other wetland.
	Reunion	1	0	1	0	0	0	1	0	Joosten & Clarke (2002); source not given.
	Rwanda	800	0	830	0	90	0	920	0	Min from Bord na Mona (1984); Max from WSM in GPD (2004).

	Senegal	15	0	36	0	64	0	100	0	Min from Bord na Mona (1984); Max given by Markov (1988) in GPD (2004).
	Sierra Leone	3	0	3	0	0	0	3	0	Joosten & Clarke (2002); source not given.
	Sudan	1000	0	9068	2	24,202	11	33270	5	Min Lappaleinen & Zurek (1996); Max WSM in GPD (2004); mostly non-peat wetlands.
	Uganda	5000	1	7300	2	6,900	3	14200	2	Min by Markov in GPD (2004); Max from Bord na Mona (1984) referring to Kivinen & Pakarinen (1981).
	Zambia	11060	3	12201	3	3,424	2	15625	2	Min from Markov (1988) in GPD (2004); Max from WSM in GPD (2004) for Histosols.
SUB-TOTAL		**29464**	**8**	**55616**	**13**	**79,427**	**37**	**135043**	**21**	
ASIA (SOUTH EAST)	Brunei	909	0	909	0	75	0	984	0	Max from Anderson (1964); Min from Anderson and Marsden (1984).
	Indonesia	206950	54	206950	47	63,680	29	270630	41	Min and Best Estimate are from REPPPROT (1988-1990) soil survey; Max from Pusat Penelitian Tanah (1981) quoted in Pamungkas & Soepardi (1997).
	Malaysia	22490	6	25889	6	1,392	1	27281	4	Min from Anderson (1983); Max. from GPD (2004); Best Estimate from Mutalib *et al,* (1992).
	Myanmar (Burma)	500	0	1228	0	2,182	1	3410	1	Min from Markov (1988) in GBD (2004); Max is Histosols from WSM in GBD (2004).
	Papua New Guinea	5000	1	10986	3	17,956	8	28942	4	Min from Andriesse (1988); Max from Wayi & Freyne (1992).
	Philippines	60	0	645	0	1,755	1	2400	0	Min from Bord na Mona (1984); Ma. from Oravainen *et al.* (1989, 1992) quoted in Klemetti *et al.*(1996).
	Thailand	638	0	638	0	0	0	638	0	Gov. statistics quoted in Urapeepatanapong & Pitayakajornwute (1996).
	Vietnam	100	0	533	0	1,297	1	1830	0	Min from Markov *et al.* (1988); Max from Bord na Mona (1984) for Histosols.
SUB-TOTAL		**236722**	**62**	**247778**	**56**	**88,337**	**41**	**336115**	**51**	
ASIA (OTHER)	Bangladesh	300	0	375	0	225	0	600	0	Min from Joosten & Clarke (2002) but without the source; Max from Bord na Mona (1984).
	China	4159	1	5312	1	3,459	2	8771	1	Min is based on total area of 41,590 km^2 from Bord na Mona (1984); Max is based on total Histosols of 87,711 km^2 from WSM in GPD (2004). (Assuming 10% of China's peatland is in the tropical zone.)
	India	320	0	490	0	510	0	1000	0	Min from Bord na Mona (1984); Max from Markov (1988) in Lappalainen & Zurek (1996).
	Sri Lanka	25	0	158	0	407	0	565	0	Min from Bord na Mona (1984); Max is WSM in IMCG (2004).
SUB-TOTAL		**4804**	**1**	**6335**	**1**	**4,601**	**2**	**10936**	**2**	
CENTRAL AMERICA & CARIBBEAN	Belize	680	0	735	0	165	0	900	0	Min from Andriesse (1988) based on FAO World Soil Map; Max from Bord na Mona (1984).
	Costa Rica	370	0	370	0	0	0	370	0	From Bord na Mona (1984).
	Cuba	2300	1	5293	1	2,377	1	7670	1	Min from Casanova (1986); Max from Bord na Mona (1984).
	El Salvador	90	0	90	0	0	0	90	0	From Bord na Mona (1984).
	Haiti	1	0	120	0	4,630	2	4750	1	Min from Joosten & Clarke (2002), source unknown; Max from Lappalainen & Zurek (1996) quoting Scott (1991).
	Honduras	4530	1	4530	1	0	0	4530	1	From Bord na Mona (1984) based on FAO World Soil Map.
	Jamaica	100	0	128	0	82	0	210	0	Min from Joosten & Clarke (2002), source unspecified; Max from Bord na Mona (1984).
	Nicaragua	3710	1	3710	1	0	0	3710	1	From Bord na Mona (1984).
	Panama	7870	2	7870	2	0	0	7870	1	From Bord na Mona (1984).

	Puerto Rico	100	0	100	0	0	0	100	0	From Bord na Mona (1984).
	Trinidad and Tobago	10	0	10	0	0	0	10	0	From Bord na Mona (1984).
SUB-TOTAL		**19761**	**5**	**22956**	**5**	**7,254**	**3**	**30210**	**5**	
PACIFIC	Australia (Queensland)	150	0	150	0	0	0	150	0	From Kivinen & Pakarinen (1980) based on a survey carried out by the International Peat Society in 1979.
	Fiji	40	0	40	0	0	0	40	0	From Bord na Mona (1984).
SUB-TOTAL		**190**	**0**	**190**	**0**	**0**	**0**	**190**	**0**	
SOUTH AMERICA	Bolivia	9	0	509	0	1,491	1	2000	0	Min from Bord na Mona (1984); Max from Ruokalainen *et al.* (2001), source not given.
	Brazil	13500	4	23875	5	31,125	14	55000	8	Min from Bord na Mona (1984); Max from Ruokoleinen *et al.* (2001), source not given.
	Chile	1047	0	1047	0	0	0	1047	0	Total area from Bord na Mona (1984) is 10,470 km^2 of which 10% is in tropical zone.
	Colombia	3390	1	5043	1	4,957	2	10000	2	Min from Bord na Mona (1984); Max from Ruokalainen *et al.* (2001), source not given.
	Ecuador	5000	1	5000	1	0	0	5000	1	From Ruokalainen *et al.*, (2001), source not given.
	French Guyana	1620	0	1620	0	0	0	1620	0	From Bord na Mona (1984) but may be mostly freshwater swamp.
	Guyana	8139	2	8139	2	0	0	8139	1	From Bord na Mona (1984).
	Peru	50000	13	50000	11	0	0	50000	8	From Ruokalainen *et al.* (2001), source not given.
	Surinam	1130	0	1130	0	0	0	1130	0	From Bord na Mona (1984).
	Venezuela	10000	3	10000	2	0	0	10000	2	From Bord na Mona (1984) citing geological survey data.
SUB-TOTAL		**93835**	**24**	**106363**	**24**	**37,573**	**17**	**143936**	**22**	
TOTAL		**384776**	**100**	**439238**	**100**	**217,192**	**100**	**656430**	**100**	

Table 2: Thickness of tropical peat on a country and regional basis expressed as maximum, range, mean and best estimate (m) (see notes for details).

Region	Country	Maximum peat thickness (m)	Peat thickness range (m)	Peat thickness mean (m)	Best estimate Peat thickness (m)	Notes
AFRICA	Angola	N.I.	N.I.	N.I.	0.5	No information available.
	Botswana	4	N.I.	N.I.	1	Sliva (pers. comm.) in GPD (2004).
	Burundi	32.7	N.I.	N.I.	8	Pajunen (1985).
	Cameroon	N.I.	N.I.	N.I.	0.5	No information available.
	Congo	30	N.I.	N.I.	7.5	Markov (1988) in GPD (2004).
	Democratic Republic of Congo	30-60	1-15	N.I.	4	Shier (1985); Bord na Mona (1985).
	Gabon	N.I.	N.I.	N.I.	0.5	No information available.
	Ghana	N.I.	N.I.	N.I.	0.5	No information available.
	Guinea	N.I.	N.I.	N.I.	0.5	According to Bord na Mona (1984) all peats are shallow.
	Ivory Coast	5-7	N.I.	N.I.	1.5	Markov (1988) in GPD (2004).
	Kenya	N.I.	N.I.	N.I.	0.5	No information available.
	Liberia	0.5	N.I.	N.I.	0.5	Bord na Mona (1984); Shier (1985).
	Madagascar	10.5	2-10.5	N.I.	2.5	Markov (1988) in GPD (2004); Straka (1960) in GPD (2004).
	Malawi	3.2	N.I.	N.I.	1	GPD (2004).
	Mauritania	N.I.	N.I.	N.I.	0.5	No information available.
	Mauritius	1.9	N.I.	N.I.	0.5	Markov (1988) in GPD (2004).
	Mozambique	5	0.4-3	N.I.	1.5	Markov (1988) in GPD (2004).
	Nigeria	1.2-20	1.2-20	N.I.	5	
	Reunion	3.6	N.I.	N.I.	1	Markov (1988) in GPD (2004).
	Rwanda	20	3-20	11	11	Bord na Mona (1984); Shier (1985).
	Senegal	10	7.7-10	3.5	3.5	Bord na Mona (1984); Shier (1985); Korpijaakko (1985); Lézine & Chateauneuf (1991).
	Sierra Leone	N.I.	N.I.	N.I.	0.5	No information available.
	Sudan	3	N.I.	N.I.	1	GPD (2004).
	Uganda	16	1-10-16	N.I.	4	Bord na Mona (1984).
	Zambia	N.I.	N.I.	N.I.	0.5	No information available.
ASIA (SOUTHEAST)*	Brunei	10	10-15	N.I.	3	James (1984); Jali (2002); Stoneman (1997).
	Indonesia	20	4-6	N.I.	5.5	Derived from values from Neuzil (1997); Page *et al.* (1999); Jaya (2007); Jaenicke *et al.* (2008).
	Malaysia	20	4-10	N.I.	7	Based on peat profiles in Anderson (1961) and Sayok *et al.* (2008).
	Myanmar (Burma)	2	1-2	N.I.	1.5	From Markov *et al.* (1988) quoted in GPD (2004).
	Papua New Guinea	10	1-10	N.I.	2.5	Wayi & Freyne (1992).
	Philippines	12	0.5-12	5.3	5.3	Bord na Mona (1984).
	Thailand	3	1-3	0.6-1	1	Urapeepatanapong & Pitayakajornwute (1996).
	Vietnam	2	N.I.	N.I.	0.5	GPD (2004).
ASIA (OTHER)*	Bangladesh	0.3-4 Av. 1.5	0.3-4	1.5	1.5	Max mean value from GPD (2004); mean from Bord na Mona (1984).
	China	30	1-2-30	N.I.	1	Ma & Wang (1992); mostly buried by marine sediments; peat layers are generally less than 1 m.
	India	9	N.I.	4	4	Markov (1985) in GPD (2004).
	Sri Lanka	6.5	N.I.	4	4	Bord na Mona (1984).

CENTRAL AMERICA & CARIBBEAN	Belize	8	N.I.	N.I.	0.5	Shier (1985); Wooler *et al.* (2007); Monacci *et al.* (2009).
	Costa Rica	3.5	1.5-3.5	N.I.	1	Cohen *et al.* (1985).
	Cuba	3	1-3	1.8	1.8	Lappaleinen & Zurek (1996b).
	El Salvador	N.I.	N.I.	N.I.	0.5	No information available.
	Haiti	N.I.	N.I.	N.I.	0.5	No information available.
	Honduras	N.I.	N.I.	N.I.	0.5	No information available.
	Jamaica	16	0.3-15	4-7	5	Bord na Mona (1985); Shier (1985); Wade & Reeson (1985).
	Nicaragua	N.I.	N.I.	N.I.	0.5	No information available.
	Panama	12	N.I.	6	6	Phillips *et al.* (1997).
	Puerto Rico	N.I.	N.I.	N.I.	0.5	No information available.
	Trinidad and Tobago	N.I.	N.I.	1.3.	1.3	Shier (1985) but without source.
PACIFIC	Australia (Queensland)	N.I.	N.I.	N.I.	0.5	No information available.
	Fiji	5	N.I.	N.I.	1.5	Bord na Mona (1984).
SOUTH AMERICA	Bolivia	N.I.	N.I.	N.I.	0.5	No information available.
	Brazil	13	0.3-13	2	2	Bord na Mona (1984); Garcia *et al.* (2004).
	Chile	N.I.	N.I.	N.I.	0.5	No information available.
	Colombia	1.15	0.5-1.15	N.I.	0.5	No information available.
	French Guiana	N.I.	N.I.	N.I.	1	No information available.
	Ecuador	4	N.I.	N.I.	1	Chimner & Karberg (2008).
	Guyana	2	0.3-2	N.I.	0.5	Bord na Mona (1984).
	Peru	5.9	0.3-5.9	1.75	1.75	Ruokalainen *et al.* (2001); Lähteenoja *et al.* (2008).
	Surinam	9	N.I.	1	1	Shier (1985).
	Venezuela	10	N.I.	4	4	Bord na Mona (1984); Shier (1985).

N.I. = No information found

Table 3: Volume of tropical peatland on a country and regional basis expressed as best estimate, maximum and minimum values ($m^3 \times 10^6$) (calculated from area in Table 1 and peat thickness in Table 2).

Region	Country	Minimum peat volume ($m^3 \times 10^6$)	%	Best estimate peat volume ($m^3 \times 10^6$)	%	Volume of shallow Histosols and organic soils ($m^3 \times 10^6$)	%	Maximum peat volume ($m^3 \times 10^6$)	%
AFRICA	Angola	50	0	1320	0	2286	4	3606	0
	Botswana	2500	0	2625	0	113	0	2738	0
	Burundi	1120	0	2584	0	167	0	2751	0
	Cameroon	50	0	539	0	879	1	1418	0
	Congo	21750	1	46650	3	2987	5	49637	3
	Democratic Republic of Congo	1600	0	11200	1	2160	3	13360	1
	Gabon	40	0	274	0	421	1	695	0
	Ghana	25	0	30	0	12	0	42	0
	Guinea	427	0	976	0	989	2	1965	0
	Ivory Coast	450	0	1088	0	383	1	1471	0
	Kenya	800	0	1220	0	756	1	1976	0
	Liberia	13	0	60	0	84	0	144	0
	Madagascar	4758	0	4800	0	15	0	4815	0
	Malawi	353	0	492	0	125	0	617	0
	Mauritania	30	0	30	0	0	0	30	0
	Mauritius	1	0	1	0	0	0	1	0
	Mozambique	150	0	863	0	428	1	1291	0
	Nigeria	600	0	8000	0	1620	2	9620	1
	Reunion	1	0	1	0	0	0	1	0
	Rwanda	8800	1	9130	1	27	0	9157	1
	Senegal	53	0	126	0	19	0	145	0
	Sierra Leone	2	0	2	0	0	0	2	0
	Sudan	1000	0	9068	1	7261	11	16329	1
	Uganda	20000	1	29200	2	2070	3	31270	2
	Zambia	5530	0	6101	0	1027	2	7128	0
SUB-TOTAL		**70103**	**4**	**136380**	**8**	**23829**	**37**	**160209**	**9**

ASIA (SOUTHEAST)*	Brunei	6888	0	6363	0	23	0	6386	0
	Indonesia	1138225	70	1138225	65	19104	29	1157329	64
	Malaysia	157430	10	181223	10	418	1	181641	10
	Myanmar (Burma)	750	0	1842	0	655	1	2497	0
	Papua New Guinea	12500	1	27465	2	5387	8	32852	2
	Philippines	318	0	3419	0	527	1	3946	0
	Thailand	638	0	638	0	0	0	638	0
	Vietnam	50	0	267	0	389	1	656	0
SUB-TOTAL		**1316799**	**81**	**1359442**	**77**	**26503**	**41**	**1385945**	**76**
ASIA (OTHER)*	Bangladesh	450	0	563	0	68	0	631	0
	China	4159	0	5312	0	1038	2	6350	0
	India	1280	0	1960	0	153	0	2113	0
	Sri Lanka	100	0	632	0	122	0	754	0
SUB-TOTAL		**5989**	**0**	**8467**	**0**	**1381**	**2**	**9848**	**1**
CENTRAL AMERICA & CARIBBEAN	Belize	340	0	368	0	50	0	418	0
	Costa Rica	370	0	370	0	0	0	370	0
	Cuba	4140	0	9527	1	713	1	10240	1
	El Salvador	45	0	45	0	0	0	45	0
	Haiti	1	0	60	0	1389	2	1449	0
	Honduras	2265	0	2265	0	0	0	2265	0
	Jamaica	500	0	640	0	25	0	665	0
	Nicaragua	1855	0	1855	0	0	0	1855	0
	Panama	47220	3	47220	3	0	0	47220	3
	Puerto Rico	50	0	50	0	0	0	50	0
	Trinidad and Tobago	13	0	13	0	0	0	13	0
SUB-TOTAL		**56799**	**4**	**62413**	**4**	**2177**	**3**	**64590**	**4**
PACIFIC	Australia (Queensland)	75	0	75	0	0	0	75	0
	Fiji	60	0	60	0	0	0	60	0
SUB-TOTAL		**135**	**0**	**135**	**0**	**0**	**0**	**135**	**0**

SOUTH AMERICA	Bolivia	5	0	255	0	447	1	702	0
	Brazil	27000	2	47750	3	9338	14	57088	3
	Chile	524	0	524	0	0	0	524	0
	Colombia	1695	0	2522	0	1487	2	4009	0
	Ecuador	5000	0	5000	0	0	0	5000	0
	French Guiana	810	0	810	0	0	0	810	0
	Guyana	4070	0	4070	0	0	0	4070	0
	Peru	87500	5	87500	5	0	0	87500	5
	Surinam	1130	0	1130	0	0	0	1130	0
	Venezuela	40000	2	40000	2	0	0	40000	2
SUB-TOTAL		**167734**	**10**	**189561**	**11**	**11272**	**17**	**200833**	**11**
TOTAL		**1617559**	**100**	**1756398**	**100**	**65162**	**100**	**1821560**	**100**

Table 4: Bulk density and carbon concentration of tropical peat obtained from the literature (psf: peat swamp forest; BD: bulk density) with some values for temperate peat for comparison.

	Authority	Location	Position in profile	Bulk density ($g\ cm^{-3}$)	Carbon concentration (%)	
Tropical peat	Andriesse (1974)	Sarawak	Surface	0.09 - 0.12		
	Driessen & Rochimah (1976)	Durian-Rasau, West Kalimantan	Surface	0.08 - 0.23		
		Sabangau, Central Kalimantan	Surface	0.11 - 0.14		>0.2 if well hu
	Cohen *et al.*(1985)	Costa Rica	Surface	0.20 – 0.22		
	Korpijaakko (1985)	Senegal	Surface Mean	0.09 – 0.17 0.13		
	Oravainen *et al.* (1992)	Philippines		0.20 – 0.22		
	Vijarnson (1996)	Thailand	Surface	0.1 – 0.32		Shallow Histos
	Anshari (pers.comm.)	Danau Sentarum, West Kalimantan	5 cores	0.08 – 0.12	51-54	Mean BD 0.10 53%
	Brady (1997)	Sarawak	0 - 20 cm	0.10 - 0.19	54.9 - 56.4	
			20 - 40 cm	0.10 - 0.14	56.7 - 59.4	
			below 40 cm	0.05 - 0.07	-	
	Neuzil (1997)	Central Kalimantan	7 m core	0.10 - 0.18	55 - 57	Higher BD valu
		Riau, Sumatra	10 m core	0.07 - 0.10	56 - 62	BD mostly low
		Benkalis, Sumatra	8 m core	0.07 - 0.09	49 - 56	
		West Kalimantan	7 m core	0.08 - 0.12	53 - 57	Higher BD valu
	Shimada (2000)	Central Kalimantan	Several cores	0.08 – 0.12	55.5 – 57.8	
	Kurnain *et al.* (2002)	Central Kalimantan	Surface	0.15 - 0.17		
			Surface (burnt)	0.24 - 0.18		
	Sajarwan *et al.* (2002)	Central Kalimantan	0 - 50 cm	0.20 - 0.24	41.6 - 57.7	
			50 - 100 cm	0.19 - 0.23	57.4 - 58.9	
	Jali (2002)	Brunei	Several cores	0.05 – 0.14	46.1 – 53.9	
	Dradjad *et al.* (2003)	South Kalimantan	0 - 25 cm	0.39 - 0.62		Shallow peat, r 2240 cm
			25 - 50 cm	0.39 - 0.64		
	Page *et al.* (2004)	Central Kalimantan (Sabangau)	10 m core	0.03 - 0.18	48.1 - 62.0	Mean BD 0.08:
	Melling *et al.* (2005)	Sarawak	Surface (drained)	0.15±0.004	47.8±0.87	
			Surface (sago plantation)	0.16±0.006	44.6±0.96	
			Surface (oil palm plantation)	0.20±0.007	44.7±1.09	
	Jaya (2007)	Central Kalimantan (Block C)	5 peat cores	0.02 - 0.70	23.8 - 58.0	Includes non-p BD values are l
			Surface	0.10 - 0.12	56.7 - 57.0	
	Lähteenoja *et al.* (2009)	Peru		0.02 – 0.20	22.0 – 56.0	

Temperate peat	Rayment & Hore (1976)	Newfoundland, Canada	Virgin bog Cultivated bog	0.08 – 0.09 0.11 – 0.13	
	Egglesmann (1976)	Various locations in Europe		0.03 – 0.12	
	Rydin & Jeglum (2006)	Restiad bogs in New Zealand	Surface Surface Surface	0.102±0.024 0.059±0.022 0.065±0.026	Chatham Island Waikato (9 plo Waikato (18 pl
	Franzen (2006)	Sweden	14 peat cores	0.01 – 0.12 0.03 – 0.08	Minimum and Means of simil

Table 5: Carbon store in tropical peatland on a country and regional basis expressed as best estimate, maximum and minimum values (Gigatonne) (calculated from volume in Table 1, bulk density of 0.09 g cm^{-3} and carbon concentration of 56% (0.56))

Region	Country	Minimum carbon store (Gt)	%	Best estimate carbon store (Gt)	%	Carbon store in shallow Histosols and organic soils (Gt)	%	Maximum peat carbon store (Gt)	%
AFRICA	Angola	0.003	0	0.067	0	0.114	4	0.181	0
	Botswana	0.126	0	0.132	0	0.006	0	0.138	0
	Burundi	0.056	0	0.13	0	0.008	0	0.138	0
	Cameroon	0.003	0	0.027	0	0.044	1	0.071	0
	Congo	1.096	1	2.351	3	0.149	5	2.5	3
	Democratic Republic of Congo	0.081	0	0.564	1	0.108	3	0.672	1
	Gabon	0.002	0	0.014	0	0.021	1	0.035	0
	Ghana	0.001	0	0.002	0	0.001	0	0.003	0
	Guinea	0.022	0	0.049	0	0.049	2	0.098	0
	Ivory Coast	0.023	0	0.055	0	0.019	1	0.074	0
	Kenya	0.04	0	0.061	0	0.038	1	0.099	0
	Liberia	0.001	0	0.003	0	0.004	0	0.007	0
	Madagascar	0.24	0	0.242	0	0.001	0	0.243	0
	Malawi	0.018	0	0.025	0	0.006	0	0.031	0
	Mauritania	0.002	0	0.002	0	0	0	0.002	0
	Mauritius	0	0	0	0	0	0	0	0
	Mozambique	0.008	0	0.043	0	0.021	1	0.064	0
	Nigeria	0.03	0	0.403	0	0.081	2	0.484	1
	Reunion	0	0	0	0	0	0	0	0
	Rwanda	0.444	1	0.46	1	0.001	0	0.461	1
	Senegal	0.003	0	0.006	0	0.001	0	0.007	0
	Sierra Leone	0	0	0	0	0	0	0	0
	Sudan	0.05	0	0.457	1	0.363	11	0.82	1
	Uganda	1.008	1	1.472	2	0.104	3	1.576	2
	Zambia	0.279	0	0.307	0	0.051	2	0.358	0
SUB-TOTAL		**3.536**	**4**	**6.872**	**8**	**1.19**	**37**	**8.062**	**9**

ASIA (SOUTHEAST)*	Brunei	0.347	0	0.321	0	0.001	0	0.322	0
	Indonesia	57.367	70	57.367	65	0.955	29	58.322	64
	Malaysia	7.934	10	9.134	10	0.021	1	9.155	10
	Myanmar (Burma)	0.038	0	0.093	0	0.033	1	0.126	0
	Papua New Guinea	0.63	1	1.384	2	0.269	8	1.653	2
	Philippines	0.016	0	0.172	0	0.026	1	0.198	0
	Thailand	0.032	0	0.032	0	0	0	0.032	0
	Vietnam	0.003	0	0.013	0	0.019	1	0.032	0
SUB-TOTAL		**66.367**	**81**	**68.516**	**77**	**1.324**	**41**	**69.84**	**76**
ASIA (OTHER)*	Bangladesh	0.023	0	0.028	0	0.003	0	0.031	0
	China	0.21	0	0.268	0	0.052	2	0.32	0
	India	0.065	0	0.099	0	0.008	0	0.107	0
	Sri Lanka	0.005	0	0.032	0	0.006	0	0.038	0
SUB-TOTAL		**0.303**	**0**	**0.427**	**0**	**0.069**	**2**	**0.496**	**1**
CENTRAL AMERICA & CARIBBEAN	Belize	0.017	0	0.019	0	0.003	0	0.022	0
	Costa Rica	0.019	0	0.019	0	0	0	0.019	0
	Cuba	0.209	0	0.48	1	0.036	1	0.516	1
	El Salvador	0.002	0	0.002	0	0	0	0.002	0
	Haiti	0	0	0.003	0	0.069	2	0.072	0
	Honduras	0.114	0	0.114	0	0	0	0.114	0
	Jamaica	0.025	0	0.032	0	0.001	0	0.033	0
	Nicaragua	0.093	0	0.093	0	0	0	0.093	0
	Panama	2.38	3	2.38	3	0	0	2.38	3
	Puerto Rico	0.003	0	0.003	0	0	0	0.003	0
	Trinidad and Tobago	0.001	0	0.001	0	0	0	0.001	0
SUB-TOTAL		**2.863**	**4**	**3.146**	**4**	**0.109**	**3**	**3.255**	**4**
PACIFIC	Australia (Queensland)	0.004	0	0.004	0	0	0	0.004	0
	Fiji	0.003	0	0.003	0	0	0	0.003	0
SUB-TOTAL		**0.007**	**0**	**0.007**	**0**	**0**	**0**	**0.007**	**0**

SOUTH AMERICA	Bolivia	0	0	0.013	0	0.022	1	0.035	0
	Brazil	1.361	2	2.407	3	0.467	14	2.874	3
	Chile	0.026	0	0.026	0	0	0	0.026	0
	Colombia	0.085	0	0.127	0	0.074	2	0.201	0
	Ecuador	0.252	0	0.252		0	0	0.252	
	French Guiana	0.041	0	0.041	0	0	0	0.041	0
	Guyana	0.205	0	0.205	0	0	0	0.205	0
	Peru	4.41	5	4.41	5	0	0	4.41	5
	Surinam	0.057	0	0.057	0	0	0	0.057	0
	Venezuela	2.016	2	2.016	2	0	0	2.016	2
SUB-TOTAL		**8.453**	**10**	**9.554**	**11**	**0.563**	**17**	**10.117**	**11**
TOTAL		**81.529**	**100**	**88.522**	**100**	**3.255**	**100**	**91.777**	**100**

Table 6: Updated estimates of global and tropical peatland areas derived from Immirzi *et al.* (1992) and this assessment.

Peatland Area	**Minimum (km^2)**	**Best Estimate[1] (km^2)**	**Maximum (km^2)**
Global[2]	3,858,374	3,971,895	4,085,416
Tropical[2]	333,820	415,485	497,119
Boreal and temperate[2]	3,524,554	3,556,410	3,588,297
Revised tropical[3]	384,776	439,238	656,430
Revised global[3]	3,909,330	3,995,648	4,244,727
Tropical (% of revised global area)	9.8	11.0	15.5
Southeast Asia[3]	236,722	247,778	336,115
Southeast Asia (% of revised global area)	6.1	6.2	7.9

[1] Immirzi *et al.* (1992) calculated the mean of the maximum and minimum values without assessing their degree of certainly (i.e. likelihood of being correct); we considered the provenance of the data available and assessed, using criteria described in the text, whether or not data were likely to be correct or not (hence best estimate)
[2] Immirzi *et al.* (1992) estimates of global, boreal/temperate and tropical peatland areas
[3] Area of tropical peatland from this assessment

Table 7: Updated estimates of global and tropical peat volumes derived from Immirzi *et al.* (1992) and this assessment.

	Minimum	Best Estimate	Maximum
Area of boreal and temperate peatland (km^2)[1]	3,524,554	3,556,410	3,588,297
Boreal/temperate peat volume 1 (Gm^3)[2]	5,286	5,335	5,383
Tropical peat volume (Gm^3)[3]	1,618	1,756	1,822
New global peat volume 1 (Gm^3)	6,904	7,091	7,205
Tropical peat volume (% of global 1)	23%	25%	25%
Southeast Asian peat volume (Gm^3)[3]	1,317	1,359	1,386
Southeast Asian peat volume (% of global 1)[2]	19%	19%	19%
Boreal/temperate peat volume 2 (Gm^3)[4]	8,107	8,180	8,253
Tropical peat carbon pool (Gm^3)[3]	1,618	1,756	1,822
New global peat volume 2 (Gm^3)	9,725	9,936	10,075
Tropical peat volume (% of global 2)	17%	18%	18%
Southeast Asian peat volume (Gm^3)	1,317	1,359	1,386
Southeast Asian peat volume (% of global 2)	14%	14%	14%

[1] Immirzi *et al.* (1992)
[2] Based on Boreal/Temperate peat mean thickness of 1.5 m (This is the mean thickness of global peat applied by Immirzi *et al.* (1992)).
[3] This assessment
[4] Based on Boreal/Temperate peat mean thickness of 2.3 m (This is the mean thickness of global peat suggested by Gorham *et al.* (1991) for boreal and sub-arctic peat).

Table 8: Updated estimates of global and tropical peatland carbon pools derived from Immirzi *et al.* (1992) and this assessment.

	Minimum	Best Estimate	Maximum
Area of boreal and temperate peatland (km^2)[1]	3,524,554	3,556,410	3,588,297
Carbon density for peat thickness 1.5 m ($t\ ha^{-1}$)[1]	1099.5	1099.5	1099.5
Boreal/temperate peat carbon pool (Gt[2])[1]	387.5	391.1	394.5
Tropical peat carbon pool (Gt)[3]	81.5	88.5	91.8
Global peat carbon pool (Gt)	469.0	479.6	486.3
Tropical peat carbon pool (% of global)	17%	19%	19%
Southeast Asian peat carbon pool (Gt)	66.4	68.5	69.8
Southeast Asian peat carbon pool (%)	14%	14%	14%
Carbon density of boreal and temperate peatland for peat thickness of 2.3 m ($t\ ha^{-1}$)[1]	1466	1466	1466
Boreal/temperate peat carbon pool (Gt[2])[1]	516.7	521.4	526.1
Tropical peat carbon pool (Gt)[3]	81.5	88.5	91.8
Global peat carbon pool (Gt)	598.2	609.9	617.9
Tropical peat carbon pool (% of global)	14%	15%	15%
Southeast Asian peat carbon pool (Gt)	66.4	68.5	69.8
Southeast Asian peat carbon pool (%)	11%	11%	11%

[1] Immirzi *et al.* (1992)
[2] Gt – Gigatonnes – Billion tonnes = g x 10^9
[3] This assessment