Age, extent, and carbon storage of the central Congo Basin peatland complex

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Abstract/ First paragraph

Peatlands are carbon-rich ecosystems that cover just 3% of Earth's land surface[1], but store one-third of soil carbon[2]. Peat soils are formed by the build-up of partially decomposed organic matter (OM) under waterlogged anoxic conditions. Most peat is found in cool climatic regions where unimpeded decomposition is slower, but deposits

are also found under some tropical swamp forests[2,3]. Here we present field measurements from one of the world's most extensive regions of swamp forest, the Cuvette Centrale depression in the central Congo Basin[4]. We find extensive peat deposits (OM ≥65%, ≥0.3 m deep) beneath the swamp forest vegetation. Radiocarbon dates indicate that peat began accumulating from 10,600 cal yr BP (Before Present, AD 1950), coincident with more humid conditions at the beginning of the Holocene in Central Africa[5]. The peatlands occupy large interfluvial basins, and appear to be a largely rain-fed, ombrotrophic-like system. Although the peat layer is relatively shallow (maximum depth 5.9 m; median 2.0 m), combining *in situ* and remotely sensed data, we estimate the area of peat to be 145,500 km^2 (95% CI: 131,900–156,400 km^2), making this the most extensive peatland complex in the tropics. This area is greater than five times the 'maximum possible' area reported for the Congo Basin in a recent synthesis of pantropical peat extent[2]. We estimate these peatlands store 30.6 Pg C below-ground (95% CI: 6.3–46.8), which is similar to the aboveground carbon stocks of the tropical forests of the entire ~3.7 million km^2 Congo Basin[6]. Our Cuvette Centrale result increases the best estimate of global tropical peatland carbon stocks by 36%, to 104.7 Pg C (minimum estimate: 69.6 Pg C; maximum estimate: 129.8 Pg C, *sensu* Ref. 2). This stored carbon is vulnerable to land-use change and any future reduction in precipitation[7,8].

Main text

The Congo Basin drains ~3.7 million km^2, within which lies a central shallow depression overlain by swamp forest, known as the Cuvette Centrale, French for 'Central Basin'[9]. Over this region the Congo River drops just 115 m over 1,740 km, with year-round waterlogging[9], thus we hypothesised that the second largest wetland in the tropics may contain extensive peat deposits. A few little-known grey literature sources since the 1950s briefly mention peat occurring in central Congo, but geolocations or other details were not reported[10-13]. Recently published estimates of tropical peatland area and carbon storage still rely on this scant unverifiable information[2,14]. Thus, here we assess whether the Cuvette Centrale contains significant peat deposits, and if so, estimate its extent and total carbon storage.

We combined a digital elevation model (DEM, from the Shuttle Radar Topography Mission, SRTM) to exclude high ground and steep slopes, radar backscatter (from the Advanced Land Observation Satellite Phased Array type L-band Synthetic Aperture Radar, ALOS PALSAR) to detect standing surface water under forest, and optical data (from Landsat Enhanced Thematic Mapper, ETM+) to categorise likely swamp vegetation, to identify areas to prospect for peat (Extended Data Table 1). We identified nine transects (2.5 to 20 km long) within a ~40,000 km^2 area of northern Republic of Congo (RoC), each traversing more than one vegetation type within waterlogged regions, and collectively spanning the range of non-waterlogged vegetation types (Fig. 1). We confirmed the presence of peat (definition: ≥0.3 m depth; OM content ≥65%) in all eight expected areas (four perpendicular to a low-nutrient black-water river, pH 3.8, three perpendicular to a more nutrient-rich white-water river, pH 7.4, which has high banks and likely does not contribute water to the swamp, and one transect at the midpoint of the two rivers), and no peat in the abandoned meanders of the white-water river where higher nutrient levels likely increase dry-season decomposition, thereby preventing peat formation.

Peat thickness, measured at least every 250 m along each transect, increased with increasing distance from peatland edges, to a maximum depth of 5.9 m near the mid-point between the two rivers (mean depth, 2.4 m, 95% CI 2.2–2.6; *n*=211; Fig. 2). Such peat thicknesses are shallower than in many other parts of the tropics (Table 1). Radiocarbon dating of basal peat samples returned ages ranging from 10,554 to 7,137 cal yrs BP (calibrated ^{14}C years Before Present [1950], at 2 σ; Extended Data Table 2). These dates are consistent with peat initiation and carbon accumulation being linked to a well-documented increase in humidity across the Congo Basin during the early Holocene, between ~11,000 and ~8,000 cal yr BP, the onset of the African Humid Period[5] (Extended Data Table 3). Additional radiocarbon dates show 0.57–0.80 m of peat accumulation over the past 1,464 to 2,623 cal yrs BP (Extended Data Table 2), indicating that peat has continued to accumulate since the end of the African Humid Period at ~3,000 cal yr BP at the low latitude of the Cuvette Centrale swamps[15].

The waterlogging that inhibits OM decay may be due to poor drainage plus high rainfall (~1,700 mm yr^{-1}) and/or overbank flooding by rivers. One year of continuous peatland water table measurements across four of the transects (Fig. 1) showed no evidence of flood-waves (Extended Data Fig. 1; *cf.* a flood-wave recorded using a similar sensor in a Peruvian peatland[16]). Recorded water table increases were largely consistent with the Tropical Rainfall Monitoring Mission rainfall record (product 3B42, Extended Data Fig. 1). Furthermore, the calcium concentration within surface peats is low, at 0.3 g kg^{-1}, as is pH, at 3.2, similar to other ombrotrophic rainwater-fed tropical peatlands (typically [Ca]<0.4 g kg^{-1} [Refs 17,18]), *cf.* minerotrophic river-fed: typically [Ca], 1-10 g kg^{-1} [Refs 16,17]). We also observed peatland inundation whilst river levels were still well below their banks. While supra-annual river flooding cannot be excluded[19], the peatlands of the Cuvette Central can be considered ombrotrophic-like peatlands due to their low-nutrient status and heavily rainwater dependent water tables. This is consistent with past satellite-only studies suggesting that these wetlands are largely hydrologically independent from regional rivers[20,21], and with our radiocarbon dates suggesting that peat accumulation began with an increase in regional precipitation.

Our transect sampling shows that peat is consistently found under two common vegetation types, hardwood swamp forest (with *Uapaca paludosa, Carapa procera* and *Xylopia rubescens* often common) and a palm-dominated (*Raphia laurentii*) swamp forest. Peat was also usually found under another much rarer palm-dominated (*Raphia hookeri*) swamp forest occupying abandoned black-water river channels. Peat was not found beneath *terra firme* forest, seasonally flooded forest or savanna (Extended Data Table 4). We then used these peat-vegetation associations to estimate peatland extent within the Cuvette Centrale, via remotely sensed mapping of hardwood and palm-dominated swamp forest extent. Field ground truth points of land cover classes, including hardwood swamp ~300 km from our main study region (total 516), were used to train a maximum likelihood classification derived from eight layers (two polarisations and their ratio from ALOS PALSAR; slope and elevation from the SRTM DEM; Landsat ETM+ bands 3, 4 and 5; Extended Data Fig 2; Extended Data Table 5). Running the classification 1,000 times, each time using a random two-thirds sample of ground truth points as training data, generated a peatland probability map with a median area of 145,500 km^2 (Fig. 1; mean 145,200 km^2; 95% CI 131,900–156,400 km^2; median overall classification accuracy against independent test data 88%: Extended Data Table 6). This is greater than five times the ‘maximum possible’ area reported for this region in a recent synthesis of pantropical peat storage[2]. Comparing our estimated area of swamp vegetation that overlies peat with other remotely sensed estimates of the total regional wetland extent, including seasons wetlands[22], suggests that peatlands account for ~40% of the total regional wetland extent.

While further measurements will be required to improve our first estimate of the area of peat within the Cuvette Centrale, it is very likely the largest peatland complex in the tropics. Peatlands on the tropical Asian islands of New Guinea, Borneo, and Sumatra cover 101,000 km^2, 73,000 km^2, and 69,000 km^2 respectively, but today ~30%, ~40% and ~50% of the area has undergone land-use change and drainage[23]. Each of these estimates is below our lower confidence interval of peat extent within the Cuvette Centrale.

Combining the peatland area estimates with our measurements of peat depth, bulk density, and carbon concentration values, using a resampling approach, we find that the median total peat carbon storage within the Cuvette Centrale is 30.6 Pg C (mean, 29.8 Pg C; 95% CI 6.3–46.8 Pg C; Extended Data Figs 3 and 4). Uncertainty, while absolutely large, is proportionately smaller than initial estimates of other extensive peatlands[3]. Additional peat depth measurements, guided by our map, should reduce the uncertainty on our first estimate. Peat C stocks dwarf those stored in living vegetation overlying the peatland, based on *in situ* sample plots (median, 1.4 Pg C; 95% CI 0.6–2.5 Pg C; n=60). Total below-ground carbon storage is likely to be greater than peat-only estimates suggest, as beneath the true peat a layer of OM- and carbon-rich material occurs, but is outside our definition of peat (OM ≥65%; Extended Data Fig. 3).

The most recent synthesis of tropical peat carbon storage[2] suggested that total peat carbon storage across the African continent is 7 Pg C, which rises to 34.4 Pg C after taking into account our new Cuvette Centrale estimate. Total tropical peat carbon stocks were also estimated, at 89 Pg, which after accounting for losses from extensive ongoing land-use change and peat fires in Asia in the ~23 years since the data was collected[2], at ~0.5 Pg C yr^{-1} [Ref. 24], and combining with our new Cuvette Centrale data, yields a total contemporary tropical peat carbon stock of 104.7 Pg C, 29% within the Cuvette Centrale (with a minimum estimate of 69.6 Pg C and a maximum of 129.8 Pg C, see Ref. 2). In terms of both peat area and peat carbon stocks DRC (90,800 km^2 peat; 19.1 Pg C) and RoC (54,700 km^2 peat; 11.5 Pg C) become the second and third most important countries in the tropics for peat areas and C stocks[2]. Globally they are the fifth and ninth most important for peat area and the fifth and sixth most important in terms of C stocks[25], and together account for ~5% of the estimated global peat C stock[2]. Translating the long-term C sink in peat into contemporary CO_2 fluxes is challenging, likely requiring an integrated multi-sensor monitoring programme. Combining contemporary CO_2 flux estimates with CH_4 emissions (large, but poorly constrained[26]), would then improve our understanding of the role of the wetland within the global carbon cycle and climate system.

The world's three major regions of lowland tropical peat, in the Cuvette Centrale, tropical Asia islands, and Western Amazonia, appear to strongly differ (Table 1). Surface topography assessments, using either SRTM or ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer), did not reveal clear domes, where the peat surface increases from the edge to interior of the peatland, as expected from a poorly draining rain-fed system ('raised bogs')[27], unlike those seen in many, but not all, Western Amazonian[17], and tropical Asian[18,28] peatlands (Fig. 2). However, our surface topography detection limits are likely 2–3 m, and independent satellite altimetry data suggests that water levels in the interfluvial wetlands are always 0.5–3m higher than adjacent rivers[26], consistent with very small domes. Overall, our results imply that within the Cuvette Centrale large-scale shallow interfluvial basins have filled with peat, which gradually increases in thickness away from the river margins (Fig. 2), having accumulated, on average, slowly over the Holocene (Table 1). By contrast, in a typical tropical Asian system, high precipitation and the persistence of climatic conditions suitable for peat accumulation since the early Holocene, and often before the Last Glacial Maximum, has allowed peat to accumulate to greater thickness, and form clear domes[29,30]. Lowland Western Amazonia differs again: high precipitation levels during the Holocene have permitted relatively rapid peat accumulation since at least 8,900 cal yrs BP in places, and domes to form, but their location on dynamic river floodplains means that peatlands rarely survive long enough to accumulate to great thickness[31]. Such differences extend to peat properties, with Cuvette Centrale peats having much higher bulk density, and slightly higher C concentration, likely reflecting enhanced decomposition than is typical in other lowland tropical peatlands, thereby increasing C storage per unit volume of peat (Table 1).

The Cuvette Centrale peatlands are relatively undisturbed at present, due to difficult access and distance from markets. However, they face two threats: changes in land-use, particularly drainage for agricultural use, as is occurring extensively across tropical Asia; and a regional reduction in precipitation via a changing climate, which may already be occurring[32]. While modelled projections of Central African rainfall are not consistent, some suggest declining annual precipitation[7] and more intense dry seasons[8]. The existence of large carbon stocks in peat – potentially equivalent to 20 years of current fossil fuel emissions from the United States of America – increases the importance of improving climate model projections for Central Africa, a long neglected region.

The Cuvette Centrale swamps are refuges for remaining megafauna populations, including lowland gorillas and forest elephants. Our findings suggest that they are also the world's most extensive tropical peatland complex and amongst the most carbon-dense ecosystems on Earth, on average storing 2,186 Mg C ha^{-1}. The existence of such large and previously unquantified components of the national carbon stocks of both RoC and DRC provides an additional imperative for governments, alongside conservation, development and scientific communities, to work with the people of the Cuvette Centrale to pursue development pathways that radically improve local livelihoods without compromising the integrity of this globally significant region of Earth.

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Author Contributions

S.L.L. conceived the study. G.C.D., S.L.L., I.T.L., S.A.I and S.E.P. developed the study. G.C.D. collected most of the data, assisted by B.E.Y., S.L.L., and I.T.L. Laboratory analyses were by G.C.D. G.C.D. and E.T.A.M. analysed the remotely sensed data. G.C.D., S.L.L., I.T.L., E.T.A.M. and S.E.P. interpreted the data. G.C.D. and S.L.L. wrote the paper, with input from all co-authors.

In text tables:

Table 1. Cuvette Centrale, Southeast Asian and South American peatland properties.

Region and references	**Peatland Area (km^2)**	**Basal Peat Age (cal k yrs BP)**	**Peat Depth (m)**	**Peat Bulk Density (g cm^{-3})**	**Carbon (%)**	**Carbon Density (g C cm^{-3})**	**Peat Accumulation Rate (mm yr^{-1})**	**LORCA (g C m^{-2} yr^{-1})**
	Best Estimate (95% CI)	**Mean±1 S.D. (Oldest)**	**Mean±1 S.D. (Max)**	**Mean±1 S.D. (Min; Max)**	**Mean±1 S.D. (Min; Max)**	**Mean±1 S.D. (Min; Max)**	**Mean±1 S.D. (Min; Max)**	**Mean±1 S.D. (Min; Max)**
Central Congo Basin, this study	145,500 (131,900-156,400)	8.9±1.2 (10.6[*])	2.4±1.6[†] (5.9)	0.19±0.06[§] (0.1; 0.32)	59±3[#] (53; 63)	0.11±0.028[††] (0.06; 0.15)	0.21±0.05 (0.16; 0.29)	23.9±5.8 (18.3; 33.1)
Central Kalimantan, Borneo[28-30,33]	30,100 (NR)	14.1±7.0 (~26.0)	4.7±0.9 (9.4[‡])	0.11±0.03[‖] (NR)	57±2[‖] (NR)	0.061±0.015 (0.046; 0.075)	0.54 (NR)	31.3 (16.6; 73.2)
Pastaza-Marañon Basin, Western Amazonia[3,16,31]	35,600 (33,500-37,700)	3.5±2.8 (8.9)	2.5±0.7 (7.5[‡])	0.11±0.06[¶] (0.05; 0.24)	46±8[**] (30; 54)	0.033±0.011 (0.021; 0.050)	1.74±0.72 (0.72; 2.56)	52±22 (36; 85)

Table title and footnotes:

Table 1. Cuvette Centrale, Southeast Asian and South American peatland properties.

NR, Not Reported; LORCA, Long-term rate of carbon accumulation; [†]Median: 2.0 m, n=211; [§]Median: 0.19 g cm^{-3}, n=44 cores, total 372 samples; [#] Median: 59%, n=12 cores, total 181 samples; [††]Median: 0.10 g C cm^{-3}, 12 cores, 181 samples; [‖]n=20 cores, total 173 samples; [¶]n=9 cores, total 134 samples; [**]n=9 cores, total 101 samples; [*]Last ~0.25 m of peat of deepest and oldest basal sample could not be recovered from the ground, thus applying an average peat accumulation rate for this core indicates that peat initiation may be ~980 years earlier than stated, at ~11,500 cal yrs BP (Extended Data Tables 2 and 3); [‡]Deeper values have been reported from other regions within South East Asia and Amazonia[2].

Figure legends:

Figure 1. Location of the Cuvette Centrale wetlands (a), study sites (b), and the peatland probability map (c). (a) Africa, country outlines, and Cuvette Centrale wetland shaded green; (b) ALOS PALSAR radar imagery showing transect locations numbered, 1. Bondoki, 2. Bondzale, 3. Center, 4. Ekolongouma, 5. Ekondzo, 6. Itanga, 7. Makodi, 8. Mbala, 9. Moungouma (yellow), basal peat samples (red) and water table measurements (blue); meandering black-water Likouala-aux-Herbes River on the left, straighter white-water Ubangi River on the right; Green is related to vegetation density, i.e. dark areas are savannas/water and bright areas have tree and palm-dominated vegetation (cross-polarised HV data); Magenta shows palm-dominated swamp, due to the strong double bounce from

stems and wet soil (single-polarised HH data); (c) Probability map of vegetation types derived from 1,000 runs of a maximum likelihood classification using eight remote sensing products (three ALOS PALSAR; two SRTM-derived variables; three Landsat ETM+ bands) and jackknifed selections of training data; black box shows area in (b). Field observations show that peat underlies both hardwood and palm-dominated swamp forest.

Figure 2. Tree height (a), estimated peatland surface derived from two satellite products (b, c), and peat depth (d) along 24 km of transects extending from the peatland edge to the interfluvial centre. (a) Maximum (light green) and mean (dark green) tree height measured *in situ*. (b) ASTER-derived estimated peatland surface (grey; ASTER DEM minus maximum tree height), plus linear trend line (grey dashed line; slope, 0.04 m km^{-1}, 95% CI 0–0.08 m km^{-1}, not significant) and a running mean of the estimated peatland surface using 20 data points before and 20 points following the focal data point (red). (c) SRTM-derived estimated peatland surface (light blue; SRTM DEM minus mean tree height), plus linear trend line (blue dashed line; slope, -0.12 m km^{-1}, 95% CI -0.14 – -0.11 m km^{-1}, $p<0.001$) and running mean (red). (d) Peat depth, measures *in situ*, every 250m (brown). The two transects, Itanga (perpendicular to the Likouala-aux-herbes river; No.6 in Fig 1b) and Center (running from the end of the Itanga transect to the mid-point of the interfluvial region between the Likouala-aux-herbes and Ubangui rivers; No.3 in Fig 1b), are contiguous, but follow different bearings (077° and 102° respectively).

Methods

Site Description

For logistical reasons the search for possible peat deposits was restricted to the Likouala Department, northern RoC. The Department covers 66,000 km^2 with most of the 154,000 population[34] living along the two main rivers of the region, the Likouala-aux-herbes, a black water river, and the Ubangui River, a white water river[35]. The region is almost entirely forested, of which the vast majority is swamp forest[9]. *Terra firme* forest is confined to narrow strips along river levees and the north-west of the region; savanna is found bordering the Likouala-aux-herbes River and surrounding villages and towns[9]. The underlying geology is Quaternary alluvium[35], and relief very gently sloping[35]. Rainfall is determined by the migration of the Inter-Tropical Convergence Zone, creating two wet and two dry seasons (major wet season, September to November, minor wet season, March to May[36]). The mean annual precipitation from the department capital, Impfondo, is 1,723 mm yr^{-1} (measured 1932-2007[36]) and the mean annual temperature, is 25.6°C (measured 1950-1998[37]).

Prospecting for Peat

We searched for published records identifying locations of peat accumulation anywhere in the Cuvette Centrale. While peat presence was noted by several sources, none provided geo-references or other identifying landscape features to allow us to confirm peat presence[10-13]. We therefore used theory and remotely sensed data to guide our search. Seven remote sensing products were used to identify likely locations of peat accumulation, i.e. with year-round waterlogging and overlying vegetation to provide OM inputs, detailed in Extended Data Table 1, with detailed information in the Supplementary Information.

Sites were selected to fully span the region, have an access point (one of the two major rivers), and traverse more than one vegetation type (Fig. 1). Sites included vegetation thought not to be associated with peat presence, providing ground points from a wide range of vegetation types, which would later be used in the classification of remote sensing imagery. Transects running perpendicular to the white water Ubangui river (Bondzale, Ekolongouma, Mbala and Moungouma) and black water Likouala-aux-herbes river (Bondoki, Ekondzo, Itanga and Makodi) allowed hypotheses about the role of river flooding and nutrient inputs from the two river systems to the peatlands to be tested, firstly whether the Ubangi, with its higher banks, contributes substantial amounts of water to nearby swamps, or not, and if so whether such locations with higher nutrient inputs may have higher decomposition rates and therefore no peat. The transect which reached the mid-point between the two rivers (Center), was chosen to assess whether peatlands extend fully across the large interfluvial area between the two rivers. The Moungouma transect, which crossed a series of old meanders of the Ubangi River, was not predicted to contain peat due to the suspected high nutrient inputs from the Ubangi River, hypothesized to lead to higher rates of OM decomposition. Transects were visited between January 2012 and May 2015.

Data Collection

The length (2.5 km to 20 km) and orientation of each transect were predetermined before arrival in the field, depending on likely logistical constraints and the hypotheses being investigated. Data collection was usually made every 250 m along each transect following either one of two protocols:

1. Rapid Protocol: This was repeated every 250 m along the transect, except every 1,000 m when the full protocol occurred. The following data were collected: peat thickness was measured by inserting metal poles into the ground until the poles were prevented going any further by the underlying mineral layer[29, 32]. Tree height measurements of five trees forming

the canopy (top leaves fully exposed to the sun) were made using a laser hypsometer (Nikon Forestry Laser 550A S). Vegetation type and dominant species were also recorded.

2. Full protocol: This was repeated every 1000 m along each transect (exceptions were the Center transect, every 4 km owing to its length, 20 km; the Makodi transect, every 200 m owing to seemingly high spatial variation in vegetation communities; and the Moungouma transect, where sampling was irregular to ensure sampling captured each ridge and swale). At each location a complete peat core was extracted (52 mm Eijkelkamp Russian-type corer), subsampled in the field to 10 cm length, and sealed in plastic (see "Peat Sample Analysis" below). Ground or surface water pH was measured (Hanna Instruments HI9124 Portable pH Meter), except non-flooded non-peat sites where the water table was not accessible. A 20x40 m plot was installed, with tree diameter and identity recorded for all trees ≥10 cm diameter at 1.3 m along the stem unless stilt roots, buttresses or a deformity was present, then the measurement was taken 30 cm above the non-cylindrical section of stem. Five canopy tree (top leaves fully exposed to the sun) heights, vegetation type and dominant species were also recorded identically to the rapid protocol.

Peat Sample Analysis

Sixty-one complete peat cores were transported to the UK for analyses. The OM content of samples (% by mass) was estimated using loss on ignition (LOI; 4 hours, 550°C). Samples which did not fit our definition of peat, i.e. depth ≥0.3 m, OM ≥65%, were excluded from further analyses. For two of the 61 cores the OM content had an intrusion of non-peat (OM <65%) part-way down the core which was viewed as a mineral intrusion (affecting 20 cm and 30 cm of the two cores respectively) and not the base of the peat profile, which was taken as the point where OM content decreased below 65% and remained so down the core.

To calibrate the metal pole coring (Rapid Protocol) with the LOI method of determining peat depth (Full Protocol), both methods were undertaken at 24 of the 61 locations where a full core was extracted, with locations spanning the minimum to maximum peat depths. Methods were strongly correlated ($p<0.001$, R^2 adjusted=0.97), and used to calibrate all pole-only measurements (Extended Data Fig. 3).

To estimate peat bulk density, samples of a known volume were dried at 105°C for 24 hours. Bulk density (ρ; g cm^{-3}) was then calculated by:

$$\rho = M/V \qquad [1]$$

Where M is the mass (g) of the sample and V is the volume (cm^{-3}; from corer dimensions) of the peat core section.Peat carbon (C) concentration was estimated using an elemental analyser (EuroVector EA3000 Elemental Analyser).

Radiocarbon Dating

Nine basal peat samples were radiocarbon dated (NERC Radiocarbon Facility, East Kilbride, Scotland), one each from the seven peatland sites sampled by end-2013, and two additional basal dates from different cores spanning the Ekolongouma transect (Extended Data Table 2). For two of the three Ekolongouma cores, two additional down-core peat samples were radiocarbon dated and for the third, deepest core, nine additional down-core peat samples were radiocarbon dated (Extended Data Table 2). Further details of the radiocarbon methods are given in the Supplementary Information.

Water-Table Levels

Continuous peatland water table measurements, collected every 20 minutes for at least 12 months, were recorded via 12 below-ground pressure transducers (Solinst Levelogger Edge) installed across the Bondoki, Bondzale, Ekolongouma and Itanga transects. Additionally, above-ground pressure transducers (Solinst Barologger Edge) were installed, no more than 1 km from the below-ground transducers, to measure atmospheric pressure. The below-ground pressure transducers record a combination of water and atmospheric pressure, therefore water pressure and thereby water-table levels were obtained by subtracting atmospheric pressure (using Solinst Levellogger Software, v.4).

The water table data was inspected for flood events, which were not found (Extended Data Fig. 1), and compared to daily TRMM 3B42 satellite rainfall estimates (Tropical Rainfall Measuring Mission, TRMM, 0.25° resolution, from http://giovanni.gsfc.nasa.gov/giovanni/). Monthly rainfall data comparisons require calculating the monthly cumulative increase in water table (CIWT), with the methods given in the Supplementary Information.

Peatland Surface Topography

We wished to survey the surface topography of our peatlands, specifically to determine if our peatlands are domed. Without aircraft LiDAR, or *in situ* data from a differential GPS, we used satellite Digital Surface Model (DSM) data to create a Digital Terrain Models (DTM) by subtracting our *in situ* tree height data. We selected two transects, Itanga and Center, as they are contiguous (although follow different bearings; 077° and 102° respectively) and extend from the peatland edge to the centre of one of the large interfluvial regions within the Cuvette Centrale. We extracted the surface elevation of all pixels along the two transects from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Map (GDEM v2) 30 m resolution data for 2010[38]. As this measures the top of forest canopies, i.e. it is a DSM, we obtained a ground surface, i.e. a DTM, by subtracting the maximum tree height estimate, i.e. the tallest of our five *in situ* canopy tree height measurements sampled every 250 m along each transect.

The ASTER dataset is known to be noisy and susceptible to artefacts due to cloud cover, as it is created from optical images looking at two angles separated by about a minute, during which time clouds can move[39]. Therefore, we also calculated a second DTM from the Shuttle Radar Topography Mission (SRTM) 1-arc second data, from 2000, for comparison[40]. This product sees a point ~30% into the vegetation, therefore we subtracted the mean tree height of the five canopy trees sampled every 250m along the transects. Neither technique revealed any obvious doming (Fig. 2). Our likely detection limits are domes of 3 m, with 5m domes seen using similar techniques in SE Asia[28]. We also looked for any evidence of domes in the raw DSM data, in the event that ground topography was discernable through the canopy surface topography. None were visible.

Peatland Area Estimates

Peatland area was estimated using a maximum likelihood classification of remote sensing data trained and tested using ground-truth points to give estimates of the extent of vegetation land cover classes across the Cuvette Centrale, some of which are associated with peat. Five land cover classes were used in the classifications: *terra firme*, hardwood swamp, palm-dominated swamp, savanna and water (Extended Data Table 4). These are based on six vegetation land cover classes observed in the field since "*terra firme*" incorporates two vegetation types: seasonally flooded forest and *terra firme* forest, which were not easily distinguishable from each other via remote sensing products (such differentiation was not necessary for this analysis as neither vegetation type overlies peat), while "palm-dominated swamp" also incorporated two vegetation types, one dominated by *Raphia laurrentii* and another rarer type dominated by *R. hookeri,* which were not easily distinguishable from each other via remote sensing products (again such differentiation was not necessary for this analysis as both overlie peat; Extended Data Table 4).

Of the five land-cover classes used, two were observed in the field to be strongly associated with the presence of peat: hardwood swamp forest and palm-dominated swamp forest (Extended Data Table 4). Hardwood swamp forest was consistently found to be associated with the presence of peat. Likewise, *Raphia laurentii* palm-dominated swamp forest was also consistently found to be associated with the presence of peat, while the much rarer *Raphia hookeri* palm-dominated swamp forest was found to be associated with the presence of channels or fluvial features, which often, but not always, contained peat (9 out of 17 *Raphia hookeri* palm-dominated swamp on-the-ground sample points overlay peat). Therefore, although the palm-dominated swamp class is assumed to denote the presence of peat, it will also likely represent very small areas of swamp which do not contain peat. Conversely, we assume that savanna does not generally overlie peat (only one of 12 on-the-ground sample points overlies peat).

Ground truth data to train the classification algorithm, and to assess the accuracy of the output classification, were collected using a GPS (Garmin GPSmap 60CSx) from our study region (250 points from all land cover classes) and far from our study sites in DRC (28 *terra firme* with no peat, 5 for hardwood swamp sites with peat (observed peat depths at these points were 0.9m, 1.6m and > 2 m at three locations), and via Google Earth for unambiguous, non-peat classes only: savanna (59 points), *terra firme* (77 points) and water (69 points).

Eight products, similar to those used to locate the field sites, were used to map the five land cover classes, detailed in Extended Data Table 5, covering three different types of data: L-band radar; optical data and two layers derived from a DEM. Further details of the products are given in the Supplementary Information.

A supervised maximum likelihood classification was run 1000 times using IDL-ENVI, using a jacknife approach to select different combinations of training and test plots for each run, to produce a consensus classification with a spatial assessment of uncertainty. Maximum likelihood was chosen because the accuracies of initial maximum likelihood classifications were higher than classifications using other commonly-used techniques (we tested Minimum Distance, Mahalanobis Distance, Neural Networks and Support Vector Machine algorithms). To reduce computation time, principal component analysis was used to reduce the eight remote sensing datasets to six uncorrelated principal components which were then used in the maximum likelihood classifications. For each of the 1000 classification iterations, two-thirds of the ground truth points from each class were randomly selected for use as training data. Each iteration produced a land cover classification for each pixel and therefore an area estimate for each land cover class. Thus, there were 1000 estimates for each pixel of its land cover class, which we express as a percentage probability of the most commonly allocated class (Fig. 1). Our best estimate of peatland area is the median value of the combined palm-dominated swamp and hardwood swamp areas from each of the 1000 runs, alongside the 95% CI (2.5th and 97.5th percentile). The random selection of one-third of the points retained as independent test data in each run were then used to estimate the accuracy of that run. This procedure, repeated 1,000 times, gives user and producer accuracy of each land-cover class, and an overall classification accuracy (see Extended Data Table 6).

Below-ground Carbon Stocks

The peatland below-ground C stock (BGC) was assessed by multiplying the peatland area from the maximum likelihood classification with the estimated carbon storage per unit area derived from peat depth, bulk density and carbon concentration measurements. We found no evidence of a difference in peat depth, bulk density or carbon concentration between the palm-dominated swamp and hardwood swamp areas, so we simply sum the two classes. To calculate the C stocks per unit area (core depth x bulk density x carbon concentration), we used 44 cores of known depth for which we had estimates of bulk density and carbon concentration. Estimates of C storage of each 0.1 m depth of each core were summed to provide an estimate of C storage for each core (in Mg C ha^{-1}). Bulk density measurements were usually every other 0.1 m down each core, so interpolation was used for missing data. As bulk density was highly variable down core, only the 44 well-sampled cores were included. For carbon concentration, 12 cores had been sampled every other 0.1 m, for which we interpolated missing values. However, carbon concentration variability was low among cores (Table 1), and a regular pattern with depth was seen: an increase to a depth of ~0.5 m, followed by a long very weak decline, and finally a strong decline over the last ~0.5 m of the core. For the 12 well-sampled cores we used segmented regression (segmented package in R, v 0.5-1.4), to parameterize the three sections of the core, using the means of these relationships to interpolate the carbon concentration for each 0.1 m depth for the remaining 32 cores which had less intensive carbon concentration sampling. We used the relationship of total core depth and per unit area C stocks of the 44 cores (Extended Data Fig. 3), to estimate C stocks from all 211 peat depth measurements across the study area.

We used a resampling approach to estimate uncertainty, by randomly selecting a measured peat depth, calculating the per unit area carbon stocks, including the uncertainty associated with the depth-carbon stocks relationship, and then multiplying this by a randomly selected total peatland area, to give total BGC, expressed in Pg C. We first bootstrapped the peat depth measurements, uncertainty on the depth-carbon stocks relationship, and peatland area, trimming at the 2.5th and 97.5th percentile values[41], then randomly selecting a depth, depth-carbon stock intercept and corresponding slope, and total peatland area, and repeated this, with replacement, 100,000 times, reporting the median as the best estimate and 95% CI as the 2.5th and 97.5th percentiles (Extended Data Fig. 4). The procedure avoids occasional unrealistic (negative) BGC estimates derived from shallow depths combining with the uncertainty associated with the depth-carbon stock relationship. Detailed methods of how we integrated our new estimates into pan-tropical estimates of peat C stocks are given in the Supplementary Information

Above-ground Carbon Stocks

Above-ground carbon (AGC) stocks were estimated using 40 m x 20 m vegetation plots installed every 1 km (Makodi transect: every 200 m, Center transect: every 4 km) along each transect (n=60), using allometric equations[42, 43, 44], including diameter, wood density and tree height[45], assuming 47% carbon content[46]. Wood specific gravity values were from the Global Wood Density Database[47, 48]. Full details are given in the Supplementary Information.

Plot AGC is the sum of each individual stem AGC, expressed as Mg C ha^{-1}. Mean AGC was higher in the hardwood swamp (123.6 Mg C ha^{-1}, BCa 95% CI, 105.5–145.2, n=25) than the palm-dominated swamp (67.0 Mg C ha^{-1}, BCa 95% CI, 51.9–86.4, n=35). Total AGC across the swamps of the Cuvette Centrale was calculated using a resampling method. We randomly sampled, with replacement, one run of the maximum likelihood classification, and extracted the palm-dominated swamp peatland extent and the corresponding hardwood swamp peatland extent from that run. We then randomly selected, with replacement, a palm dominated swamp AGC value and a hardwood swamp AGC value, and multiplied them with their corresponding areas from the single maximum likelihood run, and summed them, to obtain an estimate of the total peatland AGC stocks. We repeated this 10,000 times, reporting the median, mean and 95% CI.

Data Availability

The data that support the findings of this study are available from the corresponding author (G.C.D.) upon request. The peatland probability map for the Cuvette Centrale, Fig. 1c, is publicly available from the African Tropical Rainforest Observation Network (AfriTRON), http://www.afritron.org/en/peatland.

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Extended Data Figure legends:

Extended Data Figure 1| Peatland water table time-series data. Time-series of water table levels for (a) Ekolongouma and (b) Itanga transects for the time period March 2013 to May 2014; time-series of water table levels for the wet season month of October 2013 for (c) Ekolongouma and (d) Itanga, when river-caused flood events are more likely, with daily TRMM rainfall estimates plotted, showing the absence of floodwaves; (e) Relationship between the summed monthly CIWT (cumulative increase in water table) from 10 pressure transducers (Itanga, Ekolongouma, Bonzale, Bondoki transects), only for months where CIWT >0, and the summed TRMM-derived monthly rainfall estimates for the equivalent months ($y=0.959x-133$; $R^2=0.90$, $P<0.001$). Months where the water table was not always above the peatland surface (i.e. CIWT ≤0) were excluded from the analysis, owing to large changes in the water table which obscure water table-water input relationships. Data from 10 pressure transducers are included, as two transducers had no months where the water table was consistently above the peat surface.

Extended Data Figure 2| Spatial distribution of the ground truth points across the Cuvette Centrale. ALOS PALSAR imagery, showing the spatial distribution of the ground truth points, derived from both a GPS in the field and Google Earth, used as test and training data in the 1,000 runs of the maximum likelihood classifications across the Cuvette Centrale. The main panel shows the Cuvette Centrale area, with black boxes corresponding to panels (a), showing the main study region, where most fieldwork was undertaken, and (b) and (c) showing, at a larger scale, two regions within the DRC, from which ground truth points, collected in the field using a GPS, were obtained from a separate study.

Extended Data Figure 3| Relationship between (a) peat depth estimates using the field pole method and using peat cores followed by laboratory analysis, and (b) corrected peat depth and total peat carbon stock relationship. (a) Relationship between peat depth, in metres, estimated by the 'rapid method' using a metal pole, and the 'full method', via coring and laboratory analysis (Loss-on-Ignition, LOI; $y = 0.888x - 34.8$; $R^2=0.97$; $p<0.001$). OM must be ≥65% to be classified as peat. Soft carbon-rich material that is <65% OM is captured using the rapid method, which lies beneath peat using our definition, but above the more typical mineral soil. (b) Relationship between core depth, in metres, and total carbon stocks, in Mg C ha^{-1}, for cores from the Cuvette Centrale. Best-fit line is: C stocks = 1374 + 2425(Log_{10} Total Core Depth); $R^2=0.89$; $p<0.0001$.

Extended Data Figure 4| Distribution of Peatland Carbon Stock Estimates. Estimated carbon stocks from 100,000 resamples of peat depth, per unit area carbon storage, and peatland area. Median, 30.6 Pg C, mean 29.8, 95% CI, 6.3–46.8.

Extended data tables titles and footnotes:

Extended Data Table 1| Description of remote sensing products used to identify field sites in the Cuvette Centrale.

*Advanced Land Observation Satellite (ALOS) Phased Array type L-band Synthetic Aperture Radar (PALSAR); †Radar Forest Degradation Index (RFDI); ‡Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM); §Landsat Enhanced Thematic Mapper (ETM+); ‖Radar signal which is transmitted and detected in a horizontal, H, polarisation (HH); ¶Radar signal which is transmitted in a horizontal, H, polarisation but detected in a vertical, V, polarisation (HV).

Extended Data Table 2| Radiocarbon dates from nine peat cores.

*Last ~25 cm of peat profile could not be recovered. This is the deepest sample recovered. Using the average peat accumulation rate for this core (0.26 mm yr^{-1}; Extended Data Table 3) peat initiation could have commenced ca. 960 years earlier at this point i.e. ca. 11,500 cal yrs BP. † The Ekondzo basal sample date is considered an erroneous outlier, due to possible contamination with younger carbon, and not reported in the main text (see Supplementary Information).

Extended Data Table 3| Average peat accumulation rate and long-term rate of carbon accumulation (LORCA) for nine radiocarbon-dated peat cores.

*The much higher accumulation rate and LORCA from the Ekondzo core is considered an error and is not reported in the main text, due to the exceptionally young basal radiocarbon date from this core (see Supplementary Information).

Extended Data Table 4| Vegetation classes encountered in the field, and their associations, or not, with peat.

Extended Data Table 5| Remote sensing products used in the maximum likelihood classification to map peatland extent within the Cuvette Centrale.

*Advanced Land Observation Satellite (ALOS) Phased Array type L-band Synthetic Aperture Radar (PALSAR); † Radar signal which is transmitted and detected in a horizontal, H, polarisation (HH); ‡ Radar signal which is transmitted in a horizontal, H, polarisation but detected in a vertical, V, polarisation (HV); § Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM); ¶Landsat Enhanced Thematic Mapper (ETM+); ‖Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM).

Extended Data Table 6| Land cover classes, ground truth sample sizes, estimated extent of each class from 1000 maximum likelihood model runs, and Producer's, User's and overall accuracy of the classifications.

*Class includes both *terra firme* forest and seasonally flooded forest. See Extended Data Table 4 for descriptions. †Class includes both *Raphia laurentii* and *R. hookeri* palm-dominated swamp. See Extended Data Table 4 for descriptions. ‡Hardwood swamp and Palm-dominated swamp classes combined. §For each of the 1000 classifications an overall classification accuracy was calculated as the percentage of test ground truth points assigned to the correct class in the classification.