OPINION

MEDIA KONSERVASI
SCIENTIFIC JOURNAL IN CONSERVATION OF NATURAL RESOURCES AND ENVIRONMENT

Lowland Tropical Peatlands – A Brief Review of Their Important Role in the Global Carbon Cycle and Biodiversity Support

Susan E Page

School of Geography, Geology and the Environment, University of Leicester, Leicester, LE1 7RH, United Kingdom

Article Info:
Received 07 April 2024,
Revised 16 April 2024,
Accepted 20 April 2024

Corresponding Author:
Susan E Page
School of Geography, Geology and the Environment, University of Leicester, Leicester, LE1 7RH, United Kingdom
E-mail: sep5@le.ac.uk

Abstract

Tropical peatlands are crucial ecosystems, storing vast carbon reserves and supporting rich biodiversity. Despite covering a small land area, they play significant roles in global carbon cycling and climate regulation. However, these ecosystems face escalating threats from human activities, including agricultural expansion and peatland drainage. This paper provides a concise overview of tropical peatlands, focusing on their distribution, characteristics, and ecological importance in Southeast Asia, Africa, and South America. It highlights the diverse vegetation communities and notable animal species found in peat swamp forests, underscoring their conservation value. Peatland degradation leads to increased greenhouse gas emissions, land subsidence, and loss of traditional livelihoods for local communities. Addressing these challenges requires integrated approaches, including conservation efforts to protect and restore intact peat swamp forests, sustainable land-use practices, and policy interventions to regulate land management. Research collaboration between scientists, policymakers, and local communities is essential for developing evidence-based conservation strategies. By prioritizing the preservation of tropical peatlands, we can mitigate climate change impacts, conserve biodiversity, and safeguard the well-being of local communities.

Keywords: Biodiversity conservation, Carbon sequestration, Climate regulation, Landuse change, Peatlands

1. Opinion

Peatlands are unique ecosystems that play a crucial role in the global carbon cycle, biodiversity support and the provision of other ecosystem services. These areas, which are characterised by the accumulation of partially decayed organic matter under permanent or frequent waterlogged conditions, are found across the globe – from the Arctic to the Equator. Peatlands store a vast amount of carbon, playing a critical role in climate regulation. The peat itself is a carbon sink, sequestering CO_2 (carbon dioxide) from the atmosphere and preventing it from contributing to global warming. However, this delicate balance is under threat due to land use changes and other human activities.

Despite only covering some 3% of the world's land surface, global peatland carbon (C) stocks are estimated to be in the range 600-650 Gt (billion tonnes) [1,2], exceeding the amount of C stored in the world's vegetation (~500 Gt; [3]). The C stocks of undisturbed peatlands are protected from microbial degradation by water saturation and, at northern latitudes, by low temperatures, both of which retard the rate of organic matter decomposition. In forested tropical peatlands, the chemical nature of the plant litter, which is often rich in volatile organic compounds, may also constrain microbial decomposition.

Tropical peatlands are primarily located near the equator, spanning regions in Southeast Asia, Africa, and South America. Notable examples include the peat swamp forests of Indonesia and Malaysia, the Congo Basin in Africa, and the Amazon Basin in South America [4]. In Southeast Asia, the peatlands are typically large domed systems located behind coastal mangroves or further inland on interfluves between major rivers. During their development, the peat surface of these systems became increasingly elevated above the surrounding landscape, with rainwater replacing tidal and riverine flood waters as the principal water source as peat thickness increased. Average peat thickness is 5 to 7 m, but in some locations can exceed 10 or even 18 m [4,5]. In Indonesia, some 74% of the total C stored in the country's forest biomass and soils can be attributed to peatland ecosystems [4] emphasising the critical importance of C-dense peatlands in national C stocks and C accounting. Similar domed peatlands have been described from other parts of the humid tropics, including in Central and South America [6], and Central Africa [7]. Peatlands along the Caribbean coast have developed behind mangrove systems [8], while inland peatlands have developed in river floodplains under the influence of regular seasonal river flooding. On the African continent, extensive peatlands are a feature of the central Congo River basin where they cover a considerable land area estimated at 146,000 km^2. These flat, rain-fed, nutrient-poor peatland systems occupy large, shallow basins between rivers and store an estimated 30 Gt C [1,9]. A further setting for tropical peat formation is in coastal mangroves where there is limited supply of mineral material into the ecosystem, for example on oceanic islands. Here the sediments are derived entirely from the remains of the mangrove vegetation. Along the Central American and Caribbean coastlines, these peats have accrued to depths of 10 m or more [10].

The location, extent and thickness of tropical peatlands is still subject to uncertainty. For example, the massive peatlands of the Congo Basin have only recently been mapped and their C stocks determined [1,9]. Likewise, we have limited knowledge of the full extent of tropical peatlands in South America, particularly in more remote parts of the Amazon basin. In Southeast Asia, the uncertainty around peatland C stocks is compounded by rapid land use change and wildfires, both of which result in a reduction in peat thickness or total loss of peat C stocks [11].

Across all lowland tropical peatlands, the peat forming vegetation is characteristically some type of peat swamp forest. There may be a zonation of plant communities across the peat dome: in Southeast Asia, marginal, tall mixed swamp forest at the edge of the dome is replaced by increasingly smaller stature pole forest communities towards the dome centre [12]. Despite the stressful environmental conditions (waterlogging, anoxia, acidity and low nutrient availability) Southeast Asian peat swamp forests have a relatively high tree species diversity (Figure 1). In Peru, plant communities differ between nutrient-rich to nutrient-poor systems. Some of the youngest peatlands are regularly inundated by river flood waters, whilst the thickest peatlands, up to 8 m deep, have developed into nutrient poor, rain-fed, shallowly-domed forms [6]. This diversity of environmental conditions is reflected in the vegetation, which varies from palm-dominated (*Mauritia flexuosa*) and open swamp communities to mixed hardwood swamp forests on rain-fed peats, with distinct vegetation zones on larger domes [13]. There has been limited investigation of the floristic diversity of Amazonian peatlands, but initial findings indicate a low tree species diversity and lack of endemic species [14]. In the Congo basin the peatland vegetation cover is either a mixed-species hardwood swamp forest or palm swamp, dominated by *Raphia laurentii* [1]. Elsewhere in tropical Africa, lowland peat-forming systems are more limited in extent and usually associated with *Papyrus* swamps fringing lake basins and rivers.

Lowland tropical peatlands are important habitats for faunal diversity. Southeast Asian peat swamp forests are noteworthy for populations of orang utan (*Pongo pygmaeus*), Sunda clouded leopard (*Neofelis diardi*) and, in the peat-stained river waters, specialised blackwater fish (Figure 2). Amongst smaller mammals there is a high diversity of bats including several regionally rare and threatened species [15]. Whilst none of the mammals recorded from peat swamp forest can be considered true habitat endemics, the loss of forested habitat elsewhere in the tropical lowlands of Southeast Asia has given the remaining peat swamp forests an increased conservation importance for these species. In South America, peatlands also support a diverse fauna including monkeys, macaws, tapirs (*Tapirus terrestris*), white-lipped peccaries (*Tayassu pecarí*), agouti (*Dasyprocta spp*.), as well as a variety of fish [16]. Similarly, the Congo Basin peatlands support thriving populations of several threatened animal species including the western lowland gorilla (*Gorilla gorilla*), chimpanzee (*Pan troglodytes*) and bonobo (*Pan paniscus*), along with large populations of the African forest elephant (*Loxodonta cyclotis*) and the African dwarf crocodile (*Osteolaemus tetraspis*) [17].

Figure 1. View inside low pole forest on the main dome of the Kampar Peninsula peatland, Riau, Sumatra, Indonesia (Photo credit: S.E. Page)

Figure 2. Young orang utan (*Pongo pygmaeus*) in the Sebangau peat swamp forest, Central Kalimantan, Indonesia (Photo credit: S.E. Page)

Despite providing important ecosystem services such as C sequestration and storage and biodiversity support, tropical peatlands have been subject to forest disturbance or loss and peatland drainage. One of the primary drivers of land-use change is agriculture, particularly the conversion of peat swamp forests into plantations (oil palm and pulpwood for paper production) and small-scale farming (Figure 3). Around 50% of the peatlands in Southeast Asia are now under some form of agricultural production. Elsewhere in the world, peatland degradation has not proceeded so fast. Nevertheless, disturbance by logging or over-exploitation of the forest for natural resource extraction and exploration for inland oil reserves do pose significant threats [16,18].

Figure 3. Smallholder agriculture on peatland near Palangkaraya, Central Kalimantan, Indonesia (Photo credit: S.E. Page)

Peatland drainage disrupts the waterlogged conditions essential for peat formation, leading to the release of stored C into the atmosphere through microbial decomposition. This not only contributes to enhanced greenhouse gas emissions to the atmosphere [19,20] but also to subsidence of the land surface. With rates in the range 3 to 5 cm per year, subsidence can, over time, increase flood risk and threaten agricultural productivity [21,22]. Drained peatlands are also at high risk of uncontrolled fire. In undisturbed peat swamp landscapes, the naturally high water table and humid micro-climate ensure a high degree of resistance to ignition. But in the new landscapes of drained peatlands and fragmented forests, the combined effects of a dry peat surface, lower levels of humidity beneath disturbed vegetation canopies and widespread use of fire to clear the land prior to cultivation, have greatly increased the risk of large-scale, uncontrolled fires. Some of the most severe fires of recent years (e.g. in 1997, 2002, 2006, 2015 and 2019) can be linked to droughts driven by the ENSO (El Niño Southern Oscillation) climate anomaly, which results in an extended dry season across western Southeast Asia. Peatland fires involve both flaming and smouldering combustion. Flaming fires occur at and above the peat surface, burning the vegetation along with dead plant litter and passing quite quickly through the landscape. In contrast, smouldering fires burn slowly down into and below the ground, consuming the carbon-rich peat as a fuel source. Because smouldering fires occur in peat that, although drained, is still quite moist, they receive a limited oxygen supply to the fire front, leading to incomplete combustion reactions. These result in a dense, toxic smoke containing a cocktail of gases, including CO_2, carbon monoxide (CO) and methane (CH_4), along with small particulates and aerosols which are not only a source of greenhouse gas emissions but are also harmful to human health ([20]; Figure 4). Peat fires are very difficult to extinguish using conventional fire-fighting techniques and are often only fully put out by a rising ground water table following heavy rain.

Figure 4. Peat fires in the former Mega Rice Project area near Palangkaraya, Central Kalimantan, Indonesia, during the 2002 El Nino event (Photo credit : S.E. Page)

The degradation of tropical peatlands also has socio-economic implications, especially for local communities that depend on these ecosystems for their livelihoods. Peatlands often serve as a source of water, food, and traditional medicines for indigenous populations. The loss of these ecosystems not only threatens the cultural practices of these communities but also jeopardizes their ability to sustain themselves.

Efforts to address the challenges facing tropical peatlands require a multi-faceted approach that combines conservation, sustainable land-use practices, and policy interventions. Conservation initiatives should focus on protecting intact peat swamp forests and rehabilitating or restoring degraded areas, focusing on restoration of both peatland hydrology and the peat swamp forest vegetation. More sustainable land-use practices may be able to help strike a balance between economic development and environmental preservation, but only if water tables can be brought closer to the peat surface in order to reduce microbial degradation, C losses and GHG emissions [23]. Maintaining a high peat moisture content also reduces the rate of land subsidence and the risk of fire. But making agricultural soils wetter brings with it a range of concerns, including trafficability for machinery (heavy machines will sink into softer, wetter soils), a potential increased risk of pathogens (crop diseases) associated with more humid conditions, and the lack of economically viable crops adapted to higher water table conditions. A more radical solution involves re-wetting and the development of new agricultural 'paludiculture' systems that can operate with water levels at the soil surface [24]. This would be very different from most of the agricultural practices on tropical peatlands today which focus on dryland crops, i.e. crops that are not adapted to wetland conditions. Developing productive and economically feasible paludiculture will require trials to test innovative new crops while also developing new products and markets for farmers.

Policy interventions can play a crucial role in safeguarding tropical peatlands (UNEP, 2022). Governments and international organizations need to implement and enforce regulations that prevent the conversion of remaining peat swamp forests, whilst incentives for more sustainable land management practices and penalties for illegal activities can serve as effective tools to promote responsible peatland use. Furthermore, raising awareness about the importance of tropical peatlands is essential for garnering public support and encouraging behavioural change. Education campaigns can highlight the interconnectedness of these ecosystems with climate regulation, biodiversity conservation, and human well-being. Engaging local communities in conservation efforts ensures that initiatives are culturally sensitive and consider the needs and perspectives of those directly affected by peatland management decisions [25,26].

Research, both in the natural and the social sciences, has played and continues to play a pivotal role in advancing our understanding of tropical peatlands and developing effective conservation and management strategies. Ongoing studies on the hydrology, ecology, and carbon dynamics of these ecosystems are contributing valuable insights that can inform policy and management practices. Collaborative efforts between scientists, policymakers and local communities are critical for bridging knowledge gaps and implementation of evidence-based measures.

2. Conclusions

In conclusion, tropical peatlands are vital ecosystems with far-reaching implications for climate regulation, biodiversity conservation, and human well-being. The threats they face from agriculture, logging, and other human activities necessitate urgent and concerted efforts to protect and restore these invaluable environments. Through a combination of conservation, sustainable land-use practices, policy interventions, and public awareness, we can work towards ensuring the long-term health and resilience of these tropical ecosystems, preserving their unique biodiversity and their critical contribution to mitigating the impacts of climate change.

Conflicts of interest

There are no conflicts to declare.

References

1. Dargie, G.C.; Lewis, S.L.; Lawson, I.T.; Mitchard, E.T.A.; Page, S.E.; Bocko, Y.E.; Ifo, S.A. Age, extent and carbon storage of the central Congo Basin peatland complex. *Nature* **2017**, *542*, 86–90.
2. Yu, Z.; Loisel, J.; Brosseau, D.P.; Beilman, D.W.; Hunt, S.J. Global peatland dynamics since the Last Glacial Maximum. *Geophys. Res. Lett.* **2010**, *37*.
3. Pan, Y.; Birdsey, R.A.; Fang, J.; Houghton, R.; Kauppi, P.E.; Kurz, W.A.; Phillips, O.L.; Shvidenko, A.; Lewis, S.L.; Canadell, J.G.; et al. A large and persistent carbon sink in the world's forests. *Science (80-.).* **2011**, *333*, 988–993.
4. Page, S.E.; Rieley, J.O.; Banks, C.J. Global and regional importance of the tropical peatland carbon pool. *Glob. Chang. Biol.* **2011**, *17*, 798–818, doi:10.1111/j.1365-2486.2010.02279.x.
5. Ruwaimana, M.; Anshari, G.Z.; Silva, L.C.R.; Gavin, D.G. The oldest extant tropical peatland in the world: a major carbon reservoir for at least 47,000 years. *Environ. Res. Lett.* **2020**, *15*, 114027.
6. Lähteenoja, O.; Page, S. High diversity of tropical peatland ecosystem types in the Pastaza-Marañón basin, Peruvian Amazonia. *J. Geophys. Res.* **2011**, *116*, G02025.
7. Davenport, I.J.; McNicol, I.; Mitchard, E.T.A.; Dargie, G.; Suspense, I.; Milongo, B.; Bocko, Y.E.; Hawthorne, D.; Lawson, I.; Baird, A.J.; et al. First Evidence of Peat Domes in the Congo Basin using LiDAR from a Fixed-Wing Drone. *Remote Sens.* **2020**, *12*, 2196.
8. Phillips, S.; Rouse, G.E.; Bustin, R.M. Vegetation zones and diagnostic pollen profiles of a coastal peat swamp, Bocas del Toro, Panamá. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **1997**, *128*, 301–338.
9. Crezee, B.; Dargie, G.; Ewango, C.; Mitchard, E.; Emba, O.B.; Kanyama, J.T.; Bola, P.; Ndjango, J.-B.; Girkin, N.; Bocko, Y.; et al. Mapping peat thickness and carbon stocks of the central Congo Basin using field data. *Nat. Geosci.* **2022**, *15*, 639–644.
10. Middleton, B.A.; McKee, K.L. Degradation of mangrove tissues and implications for peat formation in Belizean island forests. *J. Ecol.* **2001**, *89*, 818–828.
11. Miettinen, J.; Hooijer, A.; Vernimmen, R.; Liew, S.C.; Page, S.E. From carbon sink to carbon source: extensive peat oxidation in insular Southeast Asia since 1990. *Environ. Res. Lett.* **2017**, *12*, 24014.
12. Page, S.E.; Rieley, J.O.; Shotyk, W.; Weiss, D. Interdependence of peat and vegetation in a tropical peat swamp forest. *Philos. Trans. R. Soc. Lond. B. Biol. Sci.* **1999**, *354*, 1885–1897, doi:10.1098/rstb.1999.0529.
13. Draper, F.C.; Roucoux, K.H.; Lawson, I.T.; Mitchard, E.T.A.; Coronado, E.N.H.; Lähteenoja, O.; Montenegro, L.T.; Sandoval, E. V; Zaráte, R.; Baker, T.R. The distribution and amount of carbon in the largest peatland complex in Amazonia. *Environ. Res. Lett.* **2014**, *9*, 124017.
14. Draper, F.C.; Honorio Coronado, E.N.; Roucoux, K.H.; Lawson, I.T.; Pitman, N.C.A.; Fine, P.V.A.; Phillips, O.L.; Torres Montenegro, L.A.; Valderrama Sandoval, E.; Mesones, I.; et al. Peatland forests are the least diverse tree communities

documented in Amazonia, but contribute to high regional beta-diversity. *Ecography (Cop.).* **2018**, *41*, 1256–1269.
15. Page, S.E.; Hooijer, A.; Rieley, J.O.; Banks, C.J.; Hoscilo, A. The Tropical Peat Swamps of Southeast Asia: Human Impacts on Biodiversity, Hydrology and Carbon Dynamics. In *Biotic Evolution and Environmental Change in Southeast Asia*; Gower, D.J., Johnson, K., Richardson, J.E., Rosen, B.R., Rüber, L., Williams, S.T., Ed.; Cambridge University Press, 2012; hal. 406–433.
16. Roucoux, K.H.; Lawson, I.T.; Baker, T.R.; Del Castillo Torres, D.; Draper, F.C.; Lähteenoja, O.; Gilmore, M.P.; Honorio Coronado, E.N.; Kelly, T.J.; Mitchard, E.T.A.; et al. Threats to intact tropical peatlands and opportunities for their conservation. *Conserv. Biol.* **2017**, *31*, 1283–1292.
17. Consortium, C. *Value and Vulnerability of the Central Congo Basin Peatlands*; United Nations Environment Programme World Conservation Monitoring Centre: Cambridge, 2023;
18. Dargie, G.C.; Lawson, I.T.; Rayden, T.J.; Miles, L.; Mitchard, E.T.A.; Page, S.E.; Bocko, Y.E.; Ifo, S.A.; Lewis, S.L. Congo Basin peatlands: threats and conservation priorities. *Mitig. \& Adapt. Strateg. Glob. Chang.* **2019**, *24*, 669–686.
19. Jovani-Sancho, A.J.; O'Reilly, P.; Anshari, G.; Chong, X.Y.; Crout, N.; Evans, C.D.; Evers, S.; Gan, J.Y.; Gibbins, C.N.; Gusmayanti, E.; et al. CH4 and N2O emissions from smallholder agricultural systems on tropical peatlands in SE Asia. *Glob. Chang. Biol.* **2023**, *29*, 4279–4297.
20. Page, S.E.; Mishra, S.; Agus, F.; Anshari, G.; Dargie, G.; Evers, S.; Jauhiainen, J.; Jaya, A.; Jovani-Sancho, A.J.; Lauren, A.; et al. Anthropogenic impacts on lowland tropical peatland biogeochemistry. *Nat. Rev. Earth \& Environ.* **2022**, *3*, 426–443.
21. Evans, C.D.; Williamson, J.M.; Kacaribu, F.; Irawan, D.; Suardiwerianto, Y.; Hidayat, M.F.; Laurén, A.; Page, S.E. Rates and spatial variability of peat subsidence in Acacia plantation and forest landscapes in Sumatra, Indonesia. *Geoderma* **2019**, *338*, 410–421.
22. Hooijer, A.; Page, S.; Jauhiainen, J.; Lee, W.A.; Lu, X.X.; Idris, A.; Anshari, G. Subsidence and carbon loss in drained tropical peatlands. *Biogeosciences* **2012**, *9*, 1053–1071.
23. Evers, S.; Yule, C.M.; Padfield, R.; O'Reilly, P.; Varkkey, H. Keep wetlands wet: the myth of sustainable development of tropical peatlands - implications for policies and management. *Glob. Chang. Biol.* **2017**, *23*, 534–549.
24. Tan, Z.D.; Lupascu, M.; Wijedasa, L.S. Paludiculture as a sustainable land use alternative for tropical peatlands: A review. *Sci. Total Environ.* **2021**, *753*, 142111.
25. Harrison, M.; others Tropical forest and peatland conservation in Indonesia: Challenges and directions. *People \& Nat.* **2019**, *2*, 4–28.
26. Mishra, S.; Page, S.E.; Cobb, A.R.; Lee, J.S.H.; Jovani-Sancho, A.J.; Sjögersten, S.; Jaya, A.; Aswandi; Wardle, D.A. Degradation of Southeast Asian tropical peatlands and integrated strategies for their better management and restoration. *J. Appl. Ecol.* **2021**, *58*, 1370–1387.