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New map reveals more peat in the tropics

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Key messages

- A new global wetlands map, which uses a multisource approach (satellite, climatic and topographic data) and is underpinned by an expert system model with high spatial detail (232 x 232 m^2), is now available. The map suggests that much more peat exists in the tropics than was previously reported.
- Unprecedented areas and volumes of peatlands, three times the size of previous estimates, are identified in the tropics, mainly outside Asia.
- Brazil emerges to be the main host of peat areas and volumes, closely followed by Indonesia.
- Tropical and sub-tropical peatland-hosting countries in all continents can use the map to direct, locate and prioritize conservation and management of wetlands and peatlands in the context of climate change mitigation and adaptation.
- Scientific engagement should be continued through intensive field campaigns to validate these new peat hotspots; the interactive map will facilitate this process.

Mapping global wetlands and peatlands

Wetlands and peatlands are global hotspots of biodiversity, ecosystem productivity, greenhouse gas (GHG) emissions, and economic activity (aquaculture, tourism, agriculture, and timber). They are key regulators of biogeochemical cycles, such as carbon and nitrogen cycling, and also play important regulating functions in water flows, coastal erosion and coastal land stabilization.

Wetlands and peatlands have fundamental roles in climate change regulation and mitigation. Unmanaged wetlands are the largest and most precarious natural sources of methane; they also accumulate organic carbon in their soils, acting as long-term soil carbon reservoirs that date back to the Holocene. As a result, drainage, fire and conversion to agriculture and agroforestry turn them into net GHG sources.

The need to conserve wetlands is widely recognized, and conventions such as Ramsarsupport this aim[1]. However, conservation objectives have long been challenged by national development policies, global markets and short-term economic priorities.

Global rates of wetland loss and deterioration have accelerated, affecting up to 50% of wetlands during the 20th century (Davidson 2014). Estimates are, however, imprecise because there is considerable uncertainty about fundamental information, such as their global distribution, spatial extent and temporal dynamics.

Given the importance of global wetlands in climate mitigation and ecosystem regulation, and the threats they face in the tropics, there is an urgent need to develop robust, comparable and detailed maps of tropical wetlands and peatlands.

This is the challenge that the Sustainable Wetlands Adaptation and Mitigation Program (SWAMP) has addressed, as part of a collaborative effort between CIFOR and the US Forest Service, supported by USAID. The Global Wetlands Map is based on an expert system model which, unlike artificial networks or machine learning techniques, relies on the experience of the modeler to define complex 'if–

1 The Convention on Wetlands, called the Ramsar Convention, is an intergovernmental treaty that provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources.

then' rules as decision-making processes (Gumbricht et al. 2017). The map shows the global distribution of wetlands, peatlands, and peat depths on a pixel basis.

The need for new models

Numerous efforts have been made to assess the extent of global wetlands. However, current estimates vary four-fold in modeled area simulations (7.1–26.9 million km^2), and three-fold (4.3–12.9 million km^2) in observational mapping (Melton et al. 2013).

Part of this variability relates to the unstandardized definition of wetlands and the temporality of their inundation patterns. We define wetlands as areas that maintain a wet soil surface over a certain period of time. The level of wetness can range from permanently inundated, such as a water body, to an area that is periodically drained and rewetted. In short, wetlands are not always flooded.

The other reason for this variability is a lack of ground data to validate mapping efforts. The new map now needs extensive work to confirm its estimates.

Difficulties mapping the extent of wetlands and peatlands revolve around three main issues:

1. pre-assessment choices, including unstandardized definitions of wetlands and peatlands, variations in mapping resolutions and timing of monitoring
2. assessment constraints, including choices of methodology (e.g. inclusion of land cover, hydrology and/or topography), remote sensing types, and technical constraints
3. post-assessment limitations, such as the lack of ground truthing of datasets to validate the location area and carbon stocks.

The new wetlands map, developed by the SWAMP scientists, is based on three properties of wetland formation:

1. water excess: long-term water supply exceeds atmospheric water demand (evapotranspiration)
2. soil moisture content: annually or seasonally water-logged soils
3. geomorphology: allowing for water accumulation and wetland development.

To measure these properties, the model develops three biophysical indices that are parameterized with empirical data:

1. a hydrological index (wTCI) that runs water balances using mean monthly precipitation (1950–2000) from the WorldClim's global dataset and evapotranspiration from Climate Research Unit (CRU) – East Anglia.
2. a soil moisture (soil wetness phenology) index (TWI) that monitors the duration of wet and inundated soil conditions using bi-weekly Moderate Resolution Imaging Spectroradiometer (MODIS) spectral data (MCD43A4) for the year 2011 (2010–2012)
3. a topographic index that defines geomorphological features that promote or exclude water accumulation. This relies on data from the Shuttle Radar Topographic Mission (SRTM).

Using these three indices, the model predicts the presence of wetlands and peatlands in the tropics and sub-tropics, and their depths.

A new understanding of wetlands and peatlands distribution

The map estimates wetland areas of 4.7 million km^2, which is toward the high end of previous databases. This value matches the Global Lakes and Wetlands Database (GLWD), which relies on a multisource approach and has been reported to better capture reality in Amazonian wetland assessments (Hess et al. 2015).

Peat is defined as any soil that has at least 30 cm of decomposed or semi-decomposed organic material with at least 50% organic matter. With a transformation factor of 1.72, this corresponds to 29% carbon content.

Following this definition, the model suggests unprecedented areas and volumes of peatlands in the tropics (at least three times larger than previously reported), mainly outside Asia. A total of 1.7 million km^2 of peatlands are identified by the map, with an associated volume of 7,268 km^3 and a mean tropical peat depth of 1.8 m.

The map estimates that tropical peat area and volume are three times larger than those predicted by previous studies (Page et al. 2011). South America (contributing 46%) holds larger areas of tropical peatlands than Asia (36%), while Brazil, not Indonesia, leads in national contributions to tropical peatland area. South America and Africa are also found to have almost ten times more peat volume than previously reported. South America holds the largest peat volume (42%), compared to Asia (39%). A detailed breakdown and comparison are shown in Table 1.

There are several reasons behind the new map's higher estimates of wetland and peatland areas: it captures seasonally inundated wetlands as well as permanently inundated areas; it estimates soil wetness and topographic

Table 1. Median figures for total area, volume and depth of peatlands in three regions and hot spot countries found by Page et al. (2011), compared with Gumbricht et al. (2017).

Region	Country	Total area (km^2)		Volume (km^3)		Depth (m)	
		Page	Gumbricht	Page	Gumbricht	Page	Gumbricht
Asia	Indonesia	206,950	225,420	1,138	1,388	5.5	3.4
	Malaysia	25,889	29,649	181	180	7.0	3.4
	Papua New Guinea	10,986	45,018	27	220	2.5	3.2
South America	Brazil	25,000	312,250	50	1,489	2.0	3.1
	Colombia	5,043	74,950	3	327	0.5	2.9
	Peru	50,000	74,644	88	449	1.8	2.8
Africa	Congo DRC	2,800	115,690	11	747	4.0	3.1
	Congo	6,219	43,769	47	345	7.5	3.3
	Nigeria	1,840	21,685	9	114	5.0	3.1

conditions that favor waterlogging in the absence of flooding; it works at a finer spatial resolution, capturing smaller wetland features that add up to significantly larger areas than previously reported; and it does not exclude wetlands based on their land uses (e.g. agricultural paddy rice).

The map and derived data must be interpreted with some caution. Intensive fieldwork will be needed to validate the map's estimates. The model offers predictive values but does not necessarily correspond to reality. Fire and erosion effects on peat loss have not been considered, and areas with the hydro-geomorphological capacity to form peat do not always do so. The need for ground data to validate this (and any) wetland/peatland map is clear and urgent.

As an initial validation process, the research team compiled 275 geopositioned peatland points from the literature and contrasted them against the peatland area map. Pantropical agreement was 65% (74% for Indonesia). Large known peatlands in the tropics were also contrasted against the map's results as a qualitative validation. The need for ground data is clear.

Known errors and future improvements

Discrepancies and errors are known to remain in the current estimates. Improvements are needed in various aspects, including the number and density of hydrometeorological stations, and georeferenced points to validate peat depth. Priorities may be given to the following issues:

- **Overestimation of depths:** when contrasting the map's peatland depths with ground depth data (using the 275 points collected from the literature), the map overestimates depths. This affects country volume estimates. While depths have been corrected to minimize this bias, some overestimation is expected in depth and corresponding volumes. No biases are detected for area extent, and comparison with local large deposits and literature reviews suggest the area data are robust. The reasons behind the observed peatland depth biases are diverse, but they mainly relate to erroneous topographic SRTM source data that lead to errors over dense canopies (artificially heightened) and water bodies (artificially lowered). This results in the overestimation of soil depths, especially in forested swamps. Improved parameterization is needed for future versions of the map.
- **Climatic anomaly in 2011:** the MODIS-derived soil moisture index relies on data from one year only, 2011. This year may have captured anomalous, wet La Niña conditions, leading to overestimations of peatland area. Extending the temporal threshold to a longer period would offer clues about the effect of this time selection, and minimize biases.
- **Weather stations:** the hydrological balances suffer from inaccurate source data for the tropics, and areas such as the Amazon and the Congo Basin have too sparse a density of stations. The hydrological index would benefit from regional climate data, model development and calibration.

The Global Wetlands Map

The Global Wetlands Map makes the results of the expert system model available to expert and non-specialist users. It offers the first global, online database of wetland and peatland areas and depths. Figure 1 shows the highlights

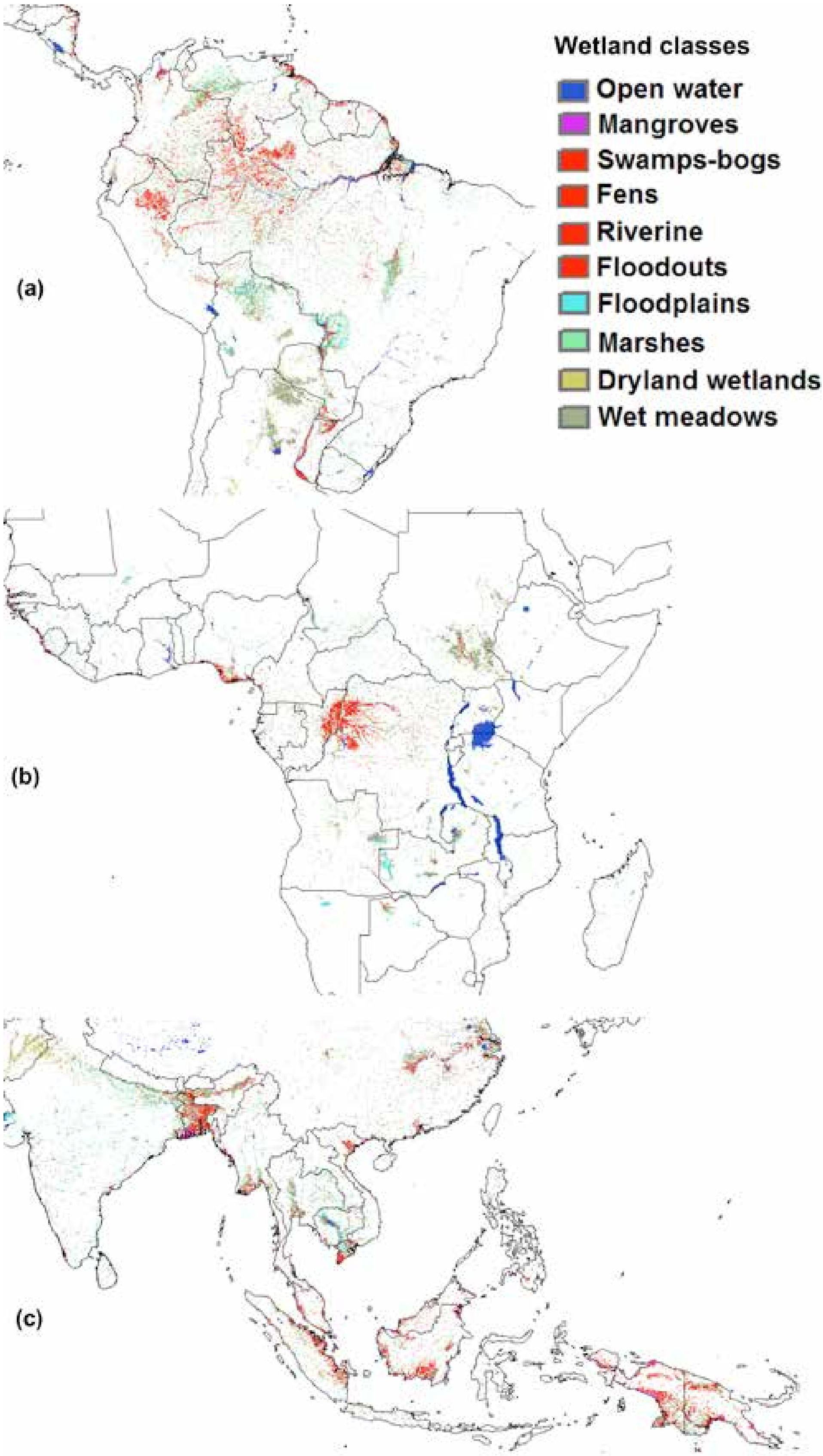

Figure 1. Continental zooming of the modeled wetland classes in the tropics and subtropics (232 m): (a) South America, (b) Africa, (c) South-East Asia. Colors represent different wetland types. Wetlands that form peat are shown in red.

of different classes of wetlands in three regions. Marshes are the most abundant wetland class (59%) followed by swamps (21%). Mangroves occupy 4% of the total wetland area.

The data behind the map are freely available for download in a GeoTIFF format that can be used on GIS programs such as ArcGIS. As countries with large amounts of wetlands seek to define, manage and report on these areas, the Global Wetlands Map will provide an indispensable tool to do so.

While soil scientists, hydrologists and climate experts will doubtless use and contribute to improving the map, it will also serve the needs of other users including policy makers, conservationists, and land and infrastructure developers.

Rethinking peatlands distribution

The new analysis has identified massive areas of peatlands in Latin America and Africa. The interactive online map makes this information available to scientists and policy makers. While isolation and inaccessibility have largely protected the peatlands of Latin America and Africa so far, new climatic stresses such as increased drought and fire frequencies, could bring new challenges to these regions.

The Intergovernmental Panel on Climate Change (IPCC) recently published guidelines on how to conduct GHG inventories in wetlands. Countries now seek to identify where those areas are, and how to report them. The Global Wetlands Map will greatly facilitate this process.

Understanding the spatial distribution of carbon stocks allows decision makers to identify potential areas for climate change mitigation, by conserving existing carbon-rich pools and enhancing carbon sequestration and storage. The map is also a useful tool to locate and prioritize restoration activities, such as rewetting and revegetating, as measures for climate change adaptation.

Next steps

The model has produced some unexpected results, and highlights the misconception of previous estimates around the distribution of tropical peatland areas, volumes and depths. Further research will be needed to:

- validate the peatlands data, in locations where the model predicts peatlands that have not previously been mapped, and assess key properties such as depth, carbon content and bulk density;
- address the aforementioned weaknesses on overestimation of peatland depths, expand the timeline for the soil moisture index, and improve regional climate data input for the Amazon and Congo basin;
- use multi-temporal phenology data to better capture climate variability effects and changes over time;
- develop a model for montane wetland regions, which are currently not captured by the model;
- develop regionally or locally adjusted thresholds of the indices, to improve classification;
- investigate how climate variations could affect wetland area and volume estimates, which would provide information on the non-linear responses between climate, wetland areas and GHG emissions;
- monitor temporal trends in peatland degradation, thereby contributing to restoration efforts;
- explore the use of novel remote sensing technologies, such as the European Copernicus Sentinel satellites, to increase detail and accuracy in mapping peatlands and their dynamics.

Recommendations

Based on the research and dialogue with stakeholders, we offer the following recommendations:

- Like-minded initiatives should use the map to help re-orient global efforts to address climate change mitigation and adaptation. Wetlands and peatlands in remote areas could be protected for their contributions to climate change mitigation, while recognizing and valuing the other ecosystem services they provide to people.
- The scientific community should refine the map and model, by parameterizing them for different regions. The resulting reference and field data would improve regional estimates.
- The new map should be used as a benchmark for updating estimates of carbon stocks in organic soils in the tropics and for assessing changes in peatlands as a result of land-use change, and emissions from both the biomass and soil carbon pools.
- National governments should use the map to locate carbon assets, and plan how to protect and manage wetlands and peatlands wisely.
- Additional open source tools to facilitate the exploitation of higher resolution satellite observations for the conservation, wise-use and effective management of wetlands should be developed, supporting national and regional wetland observatories (e.g. GlobWetland Africa - http://globwetland-africa.org/).
- Capacity building initiatives should promote the use of the map and tools in training courses, to empower government bodies and local communities in taking ownership in the protection and wise use of their wetlands.
- Development agencies, including NGOs, should use the map to support the achievement of sustainability goals, as well as meeting economic objectives.

The map is publicly available and interactive, and can be accessed at http://www.cifor.org/global-wetlands/.

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