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PEATMAP: Refining estimates of global peatland distribution based on a meta-analysis

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ABSTRACT

Peatlands play important ecological, economic and cultural roles in human well-being. Although considered sensitive to climate change and anthropogenic pressures, the spatial extent of peatlands is poorly constrained. We report the development of an improved global peatland map, PEATMAP, based on a meta-analysis of geospatial information collated from a variety of sources at global, regional and national levels. We estimate total global peatland area to be 4.23 million km^2, approximately 2.84% of the world land area. Our results suggest that previous global peatland inventories are likely to underestimate peat extent in the tropics, and to overestimate it in parts of mid- and high-latitudes of the Northern Hemisphere. Global wetland and soil datasets are poorly suited to estimating peatland distribution. For instance, tropical peatland extents are overestimated by Global Lakes and Wetlands Database – Level 3 (GLWD-3) due to the lack of ground-truthing data; and underestimated by the use of histosols to represent peatlands in the Harmonized World Soil Database (HWSD) v1.2, as large areas of swamp forest peat in the humid tropics are omitted. PEATMAP and its underlying data are freely available as a potentially useful tool for scientists and policy makers with interests in peatlands or wetlands. PEATMAP's data format and file structure are intended to allow it to be readily updated when previously undocumented peatlands are found and mapped, and when regional or national land cover maps are updated and refined.

1. Introduction

Peat consists primarily of plant detritus that has accumulated at the Earth's surface due to incomplete decomposition under close to water-saturated conditions. There is no single formal definition of 'peat' and 'peatland', with different interest groups often using their own definitions. For instance, Joosten and Clarke (2002) defined peat as 'sedentarily accumulated material consisting of at least 30% (dry mass) of dead organic material', while Burton and Hodgson (1987) defined peat as a soil with at least 50% organic material, which is determined by measuring the ash left after burning. In addition, histosols, which are regarded as peats in many regions, have been defined as soils which either (1) contain at least 20% organic material or (2) contains at least 18% organic material if the soils have been saturated with water for 30 consecutive days according to the World Reference Base for soil resources (WRB) 2006 (Michéli et al., 2006). Peatlands have been defined as 'an area, with or without vegetation, with a naturally accumulated peat layer at the surface' (Joosten and Clarke, 2002). However, the minimum peat thickness for a site to be classified as a peatland is different depending on local classification schemes, country or even the scientific discipline, ranging from 10 cm to 100 cm (Joosten and Clarke, 2002; Bord na Móna, 1984; Mcmillan and Powell, 1999).

Peatlands represent significant stores of soil carbon and constitute an important component of the global carbon cycle (Page et al., 2011; Scharlemann et al., 2014; Yu, 2012). Pristine peatlands function as long-term carbon reservoirs because the rate of plant production generally exceeds the rate of organic matter decomposition (Frolking et al., 2011; Yu et al., 2011). Despite being large carbon stores, pristine peatlands can still emit sizeable quantities of methane and carbon dioxide, and are sources of water-soluble organic compounds with high interannual variability (e.g. Nilsson et al., 2008). However, peat degradation, which is promoted by climate change (Fenner and Freeman, 2011; Ise et al., 2008; Joosten et al., 2012), peatland drainage (Gibson et al., 2009; Holden et al., 2004; Joosten, 2009), burning (Clay et al., 2012; Page et al., 2002; Turetsky et al., 2015; Yallop and Clutterbuck, 2009) and conversion for agriculture (Carlson et al., 2013) can shift the balance of carbon fluxes so that peatlands become net sources of carbon compounds (Hooijer et al., 2012; van der Werf et al., 2008). Peatlands are not only carbon-dense landscapes but also play important roles in the provision of water resources and habitat. Peatlands provide a range

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of rare, threatened or declining habitats for plants and animals, and represent an important component of global biodiversity (Carroll et al., 2015; Posa et al., 2011). Peatlands contribute to human well-being by providing a range of other nationally and internationally valuable ecosystem services (Reed et al., 2014) including regulating services (e.g. flood regulation) (Gao et al., 2016; Holden, 2005), provisioning services (e.g. agricultural production, sources of energy, habitats for rare species) (Joosten and Clarke, 2002), and cultural services (Bonn et al., 2016).

Current estimates of global peatland cover contain large uncertainties, meaning that the capacities of peatlands to store soil carbon and to provide water and other ecosystem services are poorly constrained. Improving peatland mapping at regional and national scales represents an ongoing effort, and recent advances have been made in the forms of the Tropical and Sub-Tropical Wetland Distribution dataset (Gumbricht, 2015), the Irish National Soils Map (Teagasc, 2014), and refinements to maps of peatlands in the Central Congo Basin (Dargie et al., 2017). However, a high-fidelity, spatially accurate map of global peatland extent based on the best available data in each location is yet to be produced. Existing maps of global peatland extent are typically based on data that are out of date, of coarse spatial resolution, or based on studies from which the methods used to delineate peatlands are not available. For example, the widely cited map by Lappalainen (1996) gives peatland distribution expressed as a coarse proportion of land area at regional and continental scales. Parish et al. (2008) mapped proportional peatland cover by country, providing a national-level choropleth of peatland coverage without subnational detail. The more recent International Mire Conservation Group Global Peatland Database (IMCG-GPD) (Joosten, 2009) estimates were derived from a wide review of the available literature and from expert opinion, and are now widely used (Ciais et al., 2014; Davidson, 2014; Köchy et al., 2015; Smith et al., 2016; Urak et al., 2017). Joosten (2009), however, noted that IMCG-GPD contains large uncertainties, particularly in South America and Africa due to poor availability of source data there. At the time of writing the digital spatial dataset of IMCG-GPD has not been released in its entirety into the public domain.

The global distribution of peatlands might be estimated from maps of wetland distribution, which are common components of global land cover (GLC) products. Examples of widely used GLC datasets include ISLSCP II (Loveland et al., 2009), MODIS500 (Friedl et al., 2010) and UMD (Hansen et al., 2000), all of which are classified using the IGBP DISCover land cover classification system (Loveland et al., 2000); GLC250 (Wang et al., 2015); FROM-GLC30 (Yu et al., 2014); and GlobeLand30 (Chen et al., 2015). However, none of these GLC products identifies specific subtypes of wetland, meaning that peatlands cannot be distinguished from non-peat forming wetlands. Another potentially useful global wetland database is that of the Ramsar Sites Information Service (https://rsis.ramsar.org/). However, according to Article 2.1 of the Ramsar Convention (Ramsar Convention Secretariat, 2013), Ramsar sites classified as peatlands are likely to include large areas of adjacent non-peat-forming wetlands. Furthermore, only those wetlands which meet at least one of the "Criteria for Identifying Wetlands of International Importance" can be designated by the appropriate national authority to be added to the Ramsar List. There are 596 Ramsar peatland sites globally, covering only approximately 0.5 million km^2. Ramsar data alone therefore represent only a small subset of the world's peatlands. The spatially-explicit, wetland datasets that specify peatlands as one or more subtypes (Table 1) are suitable for mapping peatland distribution. Among these datasets, GLWD-3 (Lehner and Döll, 2004) represents the most detailed, up-to-date wetland database from which global peat distribution might be successfully extracted (Köchy et al., 2015). Another method that has been used to map peatland distribution is to query soil databases for areas of organic-rich soils, such as the histosols (e.g. Köchy et al., 2015).

Our aim was to improve estimates of global peatland distribution compared to coarse, existing peatland maps and national choropleths, by amalgamating the most detailed and up-to-date data available for any given location from a variety of national and regional databases. In doing so, we developed a new global GIS map of peatland distribution. Additionally, we wished to make the new map and its spatially-explicit source data freely available for potential use by others; and to facilitate easy updates to the database in response to the exploration of previously unmapped peatlands (cf. Dargie et al., 2017) and other future refinements to national and regional data sources.

2. Methods

We reviewed candidate data from a wide variety of sources that describe peatland distributions at global, regional and national levels. In areas of overlap between two or more datasets, we determined that the best source data should: contain classifications that are of more direct relevance to peatland extents; possess a higher spatial resolution; and contain products that have been more recently updated in the candidate datasets. We used the following sequence of comparisons to discriminate between overlapping data sources:

(1) Relevance. We determined that the most important criterion was that source data are able to identify peatlands faithfully and to distinguish them from other land cover types, especially non-peat forming wetlands.
(2) Spatial resolution. In areas where two or more overlapping data sources were indistinguishable in terms of their relevance to peatlands, we selected the dataset with the finest spatial resolution.
(3) Age. In any areas where two or more overlapping datasets were indistinguishable based on both their apparent relevance to peatlands and their spatial resolution, we selected the data product that had been most recently updated. Recently updated products commonly contain much older source data, but we use the period over which the latest revision source data were collected as our primary measure of the age of a dataset.

A list of the best source data according to the above criteria is presented in Table A.1. Where source data overlapped the above criteria were applied to select the most appropriate data to use in PEATMAP in order of importance from 1 to 3 with 1 being most important. We combined these data sources to produce a new amalgamated global map of peatland distribution.

For areas where peatland-specific datasets were not available (i.e. Hokkaido, Mongolia and North Korea), we estimated peatland extent based on the distribution of histosols derived from the Harmonized World Soil Database v1.2 (HWSD) (FAO/IIASA/ISRIC/ISSCAS/JRC, 2012), in a manner similar to some previous studies (e.g. Köchy et al., 2015). HWSD is a raster database with a nominal resolution of 30 arc-seconds (corresponding approximately to 1×1 km at the equator) that contains soil data collected over more than 40 years. A map of histosols was derived from HWSD according to the FAO-74 and/or the FAO-90 soil classification. Overall, there are 15,494 km^2 of histosol cover in those areas where no other peatland-specific data are available (i.e. Hokkaido, Mongolia and North Korea).

3. Results and discussion

Our new global peatland map, PEATMAP (Fig. 1), estimates global peatland area as 4.23 million km^2, or approximately 2.84% of the global land area. At a global scale, this estimate corresponds well with existing, oft-cited estimates of approximately 4 million km^2 (e.g. Parish et al., 2008).

Estimated peatland area in Asia accounts for 38.4% of our total estimate of global peatland cover. North American peatlands comprise 31.6%, followed by Europe (12.5%), South America (11.5%), Africa (4.4%), and Australasia and Oceania (1.6%). Estimated peatland area accounts for 5.42% of the land area of North America, followed by

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