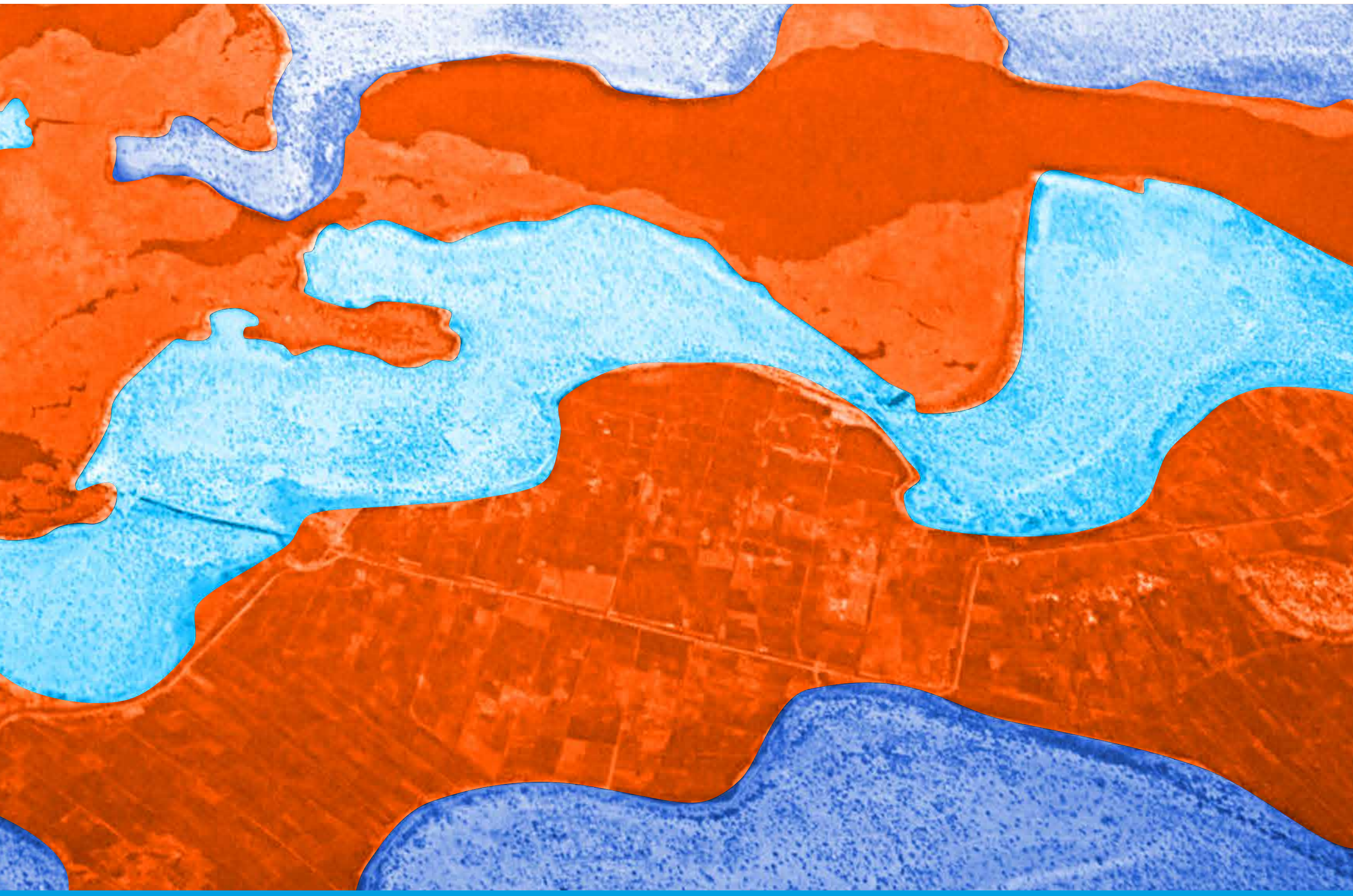
UN environment programme

Global Peatland Hotspot Atlas: The State of the World's Peatlands in Maps

Visualizing global threats and opportunities for peatland conservation, restoration, and sustainable management



Global Peatlands Initiative

ISBN: 978-92-807-4197-1
Job Number: DEP/2684/NA
DOI: https://doi.org/10.59117/20.500.11822/46635

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Suggested Citation
United Nations Environment Programme (2024). Global Peatland Hotspot Atlas: The State of the World's Peatlands in Maps. Visualizing global threats and opportunities for peatland conservation, restoration, and sustainable management. Nairobi.

Production
United Nations Environment Programme (UNEP).
https://www.unep.org/resources/report/global-peatland-hotspot-atlas-2024

Supported by:
The Global Peatland Hotspot Atlas is a product produced under the umbrella of the Global Peatlands Initiative: Assessing, Measuring and Preserving Peat Carbon project (GPI project) which is funded by the International Climate Initiative (IKI) of Germany.

Acknowledgements
The United Nations Environment Programme (UNEP) would like to thank the Greifswald Mire Centre (GMC) and the Michael Succow Foundation (MSF) for compiling the Global Peatland Database and for the production of the Global Peatland Map and all Thematic Maps.

UNEP would also like to thank the Global Peatlands Initiative (GPI) Team for the overall coordination of this Atlas.

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Thanks also to:
Caroline Borowski, Martha Burckhardt, the Global Peatland Database mapping team, the contributors of the UNEP 2022 Global Peatland Assessment, Susan Gardner, Jane Muriithi, Mónica López Conlon, Cisca Devereux, and Fabrice Inkonkoy

GREIFSWALD MIRE CENTRE

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Supported by:

Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection

IKI INTERNATIONAL CLIMATE INITIATIVE

based on a decision of the German Bundestag

Glossary

Biodiversity
The variability among living organisms from all sources including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part. This includes variation in genetic, phenotypic, phylogenetic, and functional attributes, as well as changes in abundance and distribution over time and space within and among species, biological communities, and ecosystems [2].

Biome
A set of naturally occurring communities of plants and animals occupying an environmental and/or climatic domain, defined on a global scale. IPBES biomes (e.g., tropical and subtropical forests, shelf ecosystems, inland waters) are broader and more aggregated than many purely biological classification systems. Where biomes are transformed into anthromes, the pre-impact range of the biome may still be relevant for analysis. 'Natural biome' may be used to distinguish from 'anthropogenic biome' or 'anthrome' [1].

Blanket bog
Ombrotrophic mire type occurring in regions with excessive rainfall globally. The surface relief of blanket bogs largely follows the underlying mineral soil like a 'blanket' [3].

Bog
A type of peatland which is rainwater fed and therefore acidic and nutrient poor [4].

Climate Change
Climate change refers to a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcing such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or inland use. Note that the Framework Convention on Climate Change (UNFCCC), in its Article 1, defines climate change as: 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.' The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition and climate variability attributable to natural causes [5, 1].

CO_2 equivalent (CO_2e) emission
The amount of carbon dioxide (CO_2) emission that would cause the same integrated radiative forcing or temperature change, over a given time horizon, as an emitted amount of a greenhouse gas (GHG) or a mixture of GHGs [5].

Degraded lands
Land in a state that results from persistent decline or loss of biodiversity and ecosystem functions and services that cannot fully recover unaided within decadal timescales [1].
Drivers of Change: All those external factors that affect nature, and consequently, also affect the supply of nature's contributions to people. The IPBES conceptual framework includes drivers of change as two of its main elements: indirect drivers, which are all anthropogenic, and direct drivers, both natural and anthropogenic [1].

Ecosystem
A dynamic complex of plant, animal and microorganism communities and their non-living environment interacting as a functional unit [6, 1].

Ecosystem degradation
A long-term reduction in an ecosystem's structure, functionality, or capacity to provide benefits to people [7].

Ecosystem services
The benefits people obtain from ecosystems. According to the original formulation of the Millennium Ecosystem Assessment (MEA), ecosystem services were divided into supporting, regulating, provisioning and cultural. After the MEA, the Common International Classification for Ecosystem Services (CICES) distinguishes three main categories of ecosystem services: regulating, provisioning and cultural. The "ecosystem services" classification, however, is superseded in IPBES assessments by the system used under "nature's contributions to people". This is because IPBES recognizes that many services fit into more than one of the four categories [8, 1].

Endemism
The ecological state of a species being unique to a defined geographic location, such as an island, nation, country or other defined zone, or habitat type [5].

Fen
A type of peatland which is additionally to rainwater also fed by water that has been in contact with the mineral soil/bedrock and thus generally less acidic and more nutrient-rich than bogs [4].

Flark
Elongated lowered area of a fen or mixed mire, with sparse vegetation, bordered by strings, and arranged perpendicular to the slope, occurring in String-Flark-Fens [4].

Greenhouse gases (GHGs)
Gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of terrestrial radiation emitted by the Earth's surface, the atmosphere itself and by clouds. This property causes the greenhouse effect. Water vapor (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary GHGs in the Earth's atmosphere. Moreover, there are a number of entirely humanmade GHGs in the atmosphere, such as the halocarbons and other chlorine- and bromine-containing substances, dealt with under the Montreal Protocol. Beside CO_2, N_2O and CH_4, the Kyoto Protocol deals with the GHGs sulphure hexafluoride (SF_6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs [5]).

Hotspot
A general term used across disciplines to describe a region or value that is higher relative to its surroundings [9].

Kernel Density
Calculates a magnitude-per-unit area from point or polyline features using a kernel function to fit a smoothly tapered surface to each point or polyline [10].

Marsh
Wetland frequently or continually inundated with water; hosting soft-stemmed, often grassy vegetation. Marshes can be dryland potholes or coastal to inland, freshwater to saltwater environments. Marshes develop on both, organic (‚peat') and mineral soil.

Mire
A peatland with active peat accumulation [3].
Nature-based solutions: Actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services, resilience and biodiversity benefits [1].

Paludiculture
The cultivation of biomass on wet and rewetted peatlands, so that subsidence is stopped and greenhouse gas emissions minimized [definition informed by the one appearing in the Ramsar COP13 Resolution XIII.12. (2018) Guidance on identifying peatlands as Wetlands of International Importance (Ramsar Sites) for global climate change regulation as an additional argument to existing Ramsar criteria [4].

Palsas
Perennial mounds found in peat bogs in areas with discontinuous and sporadic permafrost and occasionally also in continuous permafrost areas [11].

Peat
Consists of dead, partly decomposed plant remains (but still macroscopically recognizable) that have accumulated and have been conserved on the spot where they have been produced (in situ). Peat forms in waterlogged areas where microbial decomposition of the dead organic matter is slowed by anoxic conditions or very low [12].

Peatland
Land with a naturally accumulated layer of peat near the surface. Peatlands include both ecosystems that are actively accumulating peat and degraded peatlands that no longer accumulate but in contrast lose peat [13, 14]. They are found in a wide variety of climatic zones and under many different landcover types. Peatland ecosystems are typically classified using hydrological, botanical and physiognomic characteristics. These features disappear or are altered if peatlands are drained or intensively used [1].

Peatscapes
Landscapes that are dominated by peatlands.

Permafrost
Ground (soil or rock and included ice and organic material) that remains at or below 0°C for at least two consecutive years [15, 1].

Polygon mire
A permafrost mire characterised by a polygon pattern caused by ice-wedge formation. Two types are distinguished: low center polygon mire and high center polygon mire [3].

Polygonal tundra
A primary landscape type in Arctic systems consisting of ice wedge polygons that form when freeze-thaw cycles physically move the soil [16, 17, 18].

Raised bogs
Peatland with its surface and water level clearly raised above that of the surrounding mineral soil and groundwater, and that receives water and nutrients from the atmosphere only [3].

Seepage mire
A mire that is mainly confined to flat basins and to seepage area where the peat is kept wet by seepage water trickling downslope from thawing permafrost upslope [3].

Soil organic carbon (SOC)
A summarizing parameter including all of the carbon forms for dissolved (DOC: Dissolved Organic Carbon) and total organic compounds (TOC: Total Organic Carbon) in soils [19, 20].

Soil organic matter (SOM)
Matter consisting of plant and/or animal organic materials, and the conversion products of those materials in soils [19, 20].

String
An elongated and elevated area (ridge) perpendicular to the slope of a mire, occurring in String-Flark-Fens [3].

Swamp
Wetland on water-logged organic or mineral soil. They are dominated by water-tolerant woody vegetation such as shrubs, palms or trees.

Wetland
Area of marsh, fen, peatland, or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters [21].

List of acronyms

CH_4	Methane
CO_2	Carbon Dioxide
DOC	Dissolved Organic Carbon
DRC	Democratic Republic of the Congo
EU	European Union
GHG	Greenhouse Gas
GMC	Greifswald Mire Centre
GPA	Global Peatlands Assessment
GPD	Global Peatlands Database
GPI	Global Peatlands Initiative
GPM	Global Peatland Map
IPCC	Intergovernmental Panel on Climate Change
LAC	Latin America and the Caribbean
MSF	Michael Succow Foundation
NbS	Nature-based Solutions
N_2O	Nitrous oxide
PSF	Peat Swamp Forest
UNEP	United Nations Environment Programme

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Foreword

Peatlands play an important global role, far beyond what their size might suggest. Covering just 3% of our Earth's surface, these dense, ancient ecosystems have a profound impact on our planet, storing more carbon than all the world's forests combined. Peatlands are not only essential for climate change mitigation, they also play a vital role in regulating and purifying water for human consumption, wildlife habitats, and socio-economic development. These rich ecosystems act as safe havens for rare and threatened species of flora and fauna that support local livelihoods. Furthermore, peatlands serve as natural archives of archaeological and cultural heritage. Despite being relatively under-recognized, peatlands are found all over the world, present in 177 of 193 UN member states, providing critical ecosystem services that sustain millions of people and their livelihoods. Investing in the protection and restoration of peatlands is one of the most cost-effective strategies to deliver multiple benefits to people, nature, and climate. As the world confronts the severe crisis of climate change, biodiversity loss, and pollution, the conservation, restoration, and sustainable management of peatlands have become more important than ever.

Peatlands are under threat, and yet are often neglected in global environmental discussions. They face widespread exploitation from agriculture, urban development, deforestation, and industrial activities worldwide. Peatland drainage drastically reduces their ability to deliver ecosystem services that support climate adaptation and ecological resilience. Damaged peatlands emit vast amounts of greenhouse gases, intensifying climate change, with devastating effects for both nature and people. Many peatlands are located close to populated areas, making their degradation a direct threat to the livelihoods, health, and safety of millions of people. The loss of these ecosystems can trigger environmental catastrophes including floodings, droughts, soil subsidence, fires and subsequent haze pollution, all of which compromise human health and development, while incurring substantial economic costs.

UNEP's Global Peatlands Initiative (GPI) is at the forefront of advancing strategies for peatlands conservation, restoration, and sustainable management worldwide. The GPI aims to effectively safeguard peatlands by ensuring that policies and action plans are aligned with shared objectives and backed by the most up-to-date science. As a flagship product of the GPI, the Global Peatland Hotspot Atlas serves as a valuable tool for decision-makers, providing data, evidence, and clear insights into the global state of peatlands. By presenting a comprehensive overview of peatland hotspots, the Atlas aims to bridge the gap between science and policy, identifying peatland threats and opportunities, and enabling informed decisions that prioritize their sustainable management. In line with international efforts, including the Rio Conventions and other Multilateral Environmental Agreements, peatlands must be central to discussions about achieving global objectives such as the Kunming-Montreal Global Biodiversity Framework 2030 targets, the Paris Agreement, and the Sustainable Development Goals.

The Global Peatland Hotspot Atlas is a call to action. It is not only about saving an ecosystem, but about acknowledging the human dimension and understanding how the fate of peatlands is intrinsically linked to the future of our planet and its people. It positions peatlands where they belong: at the heart of the global environmental agenda. The time to act is now, and the Atlas is a crucial step forward in ensuring these ecosystems continue to benefit future generations.

Susan Gardner
Ecosystems Division Director
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Key Messages

1. Peatlands play a critical role in climate change mitigation and provide essential ecosystem services, yet they face significant threats and remain among the least understood and monitored ecosystems globally.

2. The Global Peatland Hotspot Atlas builds on the Global Peatlands Assessment and accompanying Global Peatland Map 2.0, both flagship products of the UNEP Global Peatlands Initiative. This Atlas introduces updated and newly designed hotspot maps, offering a clearer visualization of peatland distribution and the threats they face, setting a new standard for global peatland mapping, research, and policy development.

3. Global peatland distribution is shaped by atmospheric circulation patterns and varying climatic conditions, resulting in a high diversity of peatland types, with greater concentrations in boreal regions and the tropics.

4. Major threats to peatlands include drainage for agriculture, forestry, and peat extraction, intensified by industrial activities and infrastructure development. Climate change further exacerbates these issues, leading to significant degradation, loss of ecosystem functions, and increased greenhouse gas emissions, representing currently 4% of global anthropogenic emissions.

5. Peatlands are vital habitats for rare and threatened species, supporting unique flora and fauna. However, human encroachment is driving significant biodiversity loss, with 303 plant and 767 animal species threatened globally. Protecting peatlands is critical for safeguarding these vulnerable species and maintaining ecosystem health.

6. Peatlands exist in various landscapes, from tropical and temperate forests to mountains, tundra, and drylands. In polar and boreal regions, permafrost shapes peatland dynamics, but climate change is thawing the frozen ground and potentially promoting degradation. Peatlands are vital water sources, including in the mountains with high-altitude conditions leading to slower decomposition and greater carbon accumulation. Meanwhile, peatlands in arid regions are increasingly at risk of shrinking as climate extremes intensify.

7. Rapid urban and infrastructure development, including road and railway construction, along with industrial activities such as mining and oil and gas exploitation, cause peatland degradation, habitat fragmentation, pollution, and increased greenhouse gas emissions, posing a global threat to peatlands.

8. In temperate, tropical, and subtropical climates, drainage for agriculture, livestock farming, and oil palm plantations are the primary drivers of peatland degradation, yet ongoing research on paludiculture (sustainable wet agriculture) may offer promising sustainable alternatives.

9. Peatland drainage leads to peat subsidence (land loss and shrinkage) and increases flood risk, particularly in regions where peatlands are already vulnerable to floods, along major rivers, coastlines, and at the base of mountains.

10. Drained peatlands are highly vulnerable to smoldering fires during dry seasons, releasing significant greenhouse gas emissions and hazardous haze detrimental to human health. In contrast, undrained peatlands may only experience surface fires that do not penetrate the peat soil.

11. Effective protection of peatlands requires holistic water management and a landscape approach to conserve the entire hydrological catchment and preserve its valuable ecosystem services for both people and for nature.

1.1 Aim and purpose of the Atlas

Objective:
The Global Peatland Hotspot Atlas, hereafter referred to as the "Atlas", is developed as an accompanying resource to the UNEP-published Global Peatlands Assessment – the state of the World's peatlands: Evidence for action toward the conservation, restoration, and sustainable management of peatlands [1]. Building on the findings of the Global Peatlands Assessment (GPA), the Atlas reveals the status of global peatlands through a series of maps that highlight their distribution and features on a continental scale, identifying hotspots and illustrating the current threats to these ecosystems due to infrastructure, urbanization, resource extraction, land use, and climate change. It achieves this by intersecting the Global Peatland Map 2.0 with global, spatial datasets on land use, biodiversity, protection status, and climate change-intensified events such as peat fires and floods. The objectives are to highlight peatland diversity across the globe and identify where current and future impacts could jeopardize ecosystem functionality, including the provision of essential ecosystem services, resilience towards climate change, water provision and purification, and biodiversity protection. Furthermore, the Atlas highlights the global potential for peatland protection, conservation, restoration, and sustainable management, while spotlighting regions of particular vulnerability for future planning and development.

Status and degradation:
Status: The extent of peatlands worldwide is approximately 488 million hectares, equivalent to 3.8% of the total global surface area, with a carbon stock of about 600,000 Mt. Nearly 12% of global peatlands are degraded to the extent that peat is no longer actively forming, and the accumulated peat is disappearing. Around the world, around 19% of peatlands are found within protected areas. Yet 500,000 hectares (~ 0.1%) of intact peatlands are destroyed annually by human activities. This is 10 times faster than the average rate of peatland expansion during the Holocene [2]. This results in annual GHG emissions from peatlands of 1,941 Mt CO_2e per year [1].

Intact peatlands are primarily found in remote regions, distant from international markets, within the (sub)arctic, boreal, and tropical zones. In contrast, modified or degraded peatlands predominate in temperate and (sub)tropical regions, within areas with significant industrialization, urban development, and intensive agricultural and forestry activities.

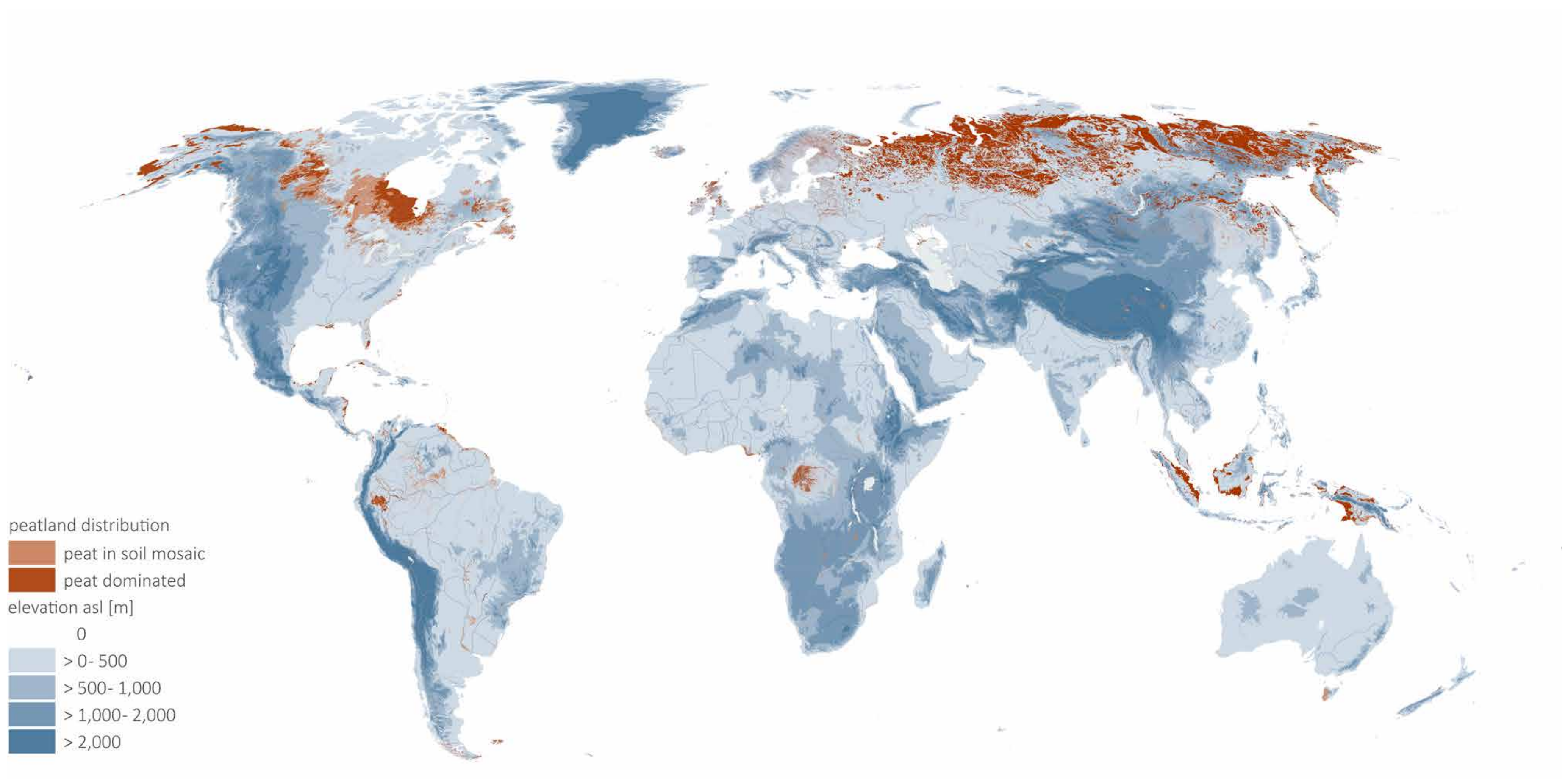
Degradation:
The main direct anthropogenic driver of change in peatlands is drainage for agriculture and afforestation, linked to urbanization and infrastructure development [1]. Other threats to peatlands include deforestation, road and railway construction, mining, oil and gas exploration and exploitation, drought, overgrazing, and pollution. Europe and parts of Asia are global peatland degradation hotspots, because of widespread and long-term land use change to agriculture, forestry, and peat extraction.

Effects of changes in peatland ecosystems addressed in the Atlas:
Drainage, the removal of peatland vegetation, and other land use changes have impacted many nature's contributions to people (NCPs) provided by peatlands. These changes have led to the loss of peatland-specific biota and biodiversity [3, 4], reduced their capacity for water supply and regulation [5], and halted carbon sequestration while depleting drained peat stores, resulting in net GHG emissions [6].

Furthermore, the lowering of water levels leads to an immediate reduction in landscape cooling through evapotranspiration and contributes to the loss of peatland-specific biodiversity. Nitrogen mineralization, induced by peat oxidation, leads to nitrate emissions and eutrophication in downstream rivers, lakes, and ultimately seas and oceans [7]. Peatland subsidence - following peatland drainage - increases the risks of saltwater intrusion in coastal areas, and the risk of severe flooding generally through both land sinking and land loss. This, in combination with rising sea levels due to global warming, poses a particular threat to low-lying coastal cities and other densely populated areas located nearby or even built directly on coastal peatlands and Small Island Developing States (SIDS).

1.2 Global Peatland Map 2.0

The Global Peatland Map 2.0 (GPM 2.0) was produced through the Global Peatlands Assessment (GPA) to compile the most up-to-date data on peatlands location and extent globally. It shows peatland occurrences divided into two classes: '1'=peat dominated, and '2'=peat in soil mosaic. The assignment of these two classes was informed by ancillary peat occurrence information, satellite imagery and Digital Elevation Model (DEM) inspection, and multiple expert knowledge. The GPM 2.0 allows decision-makers to scope potential regions for conservation, restoration, and sustainable management of peatlands. However, it does not permit a direct 1:1 comparison with ground conditions and is unsuitable for detailed, high-resolution land use planning at the local level.

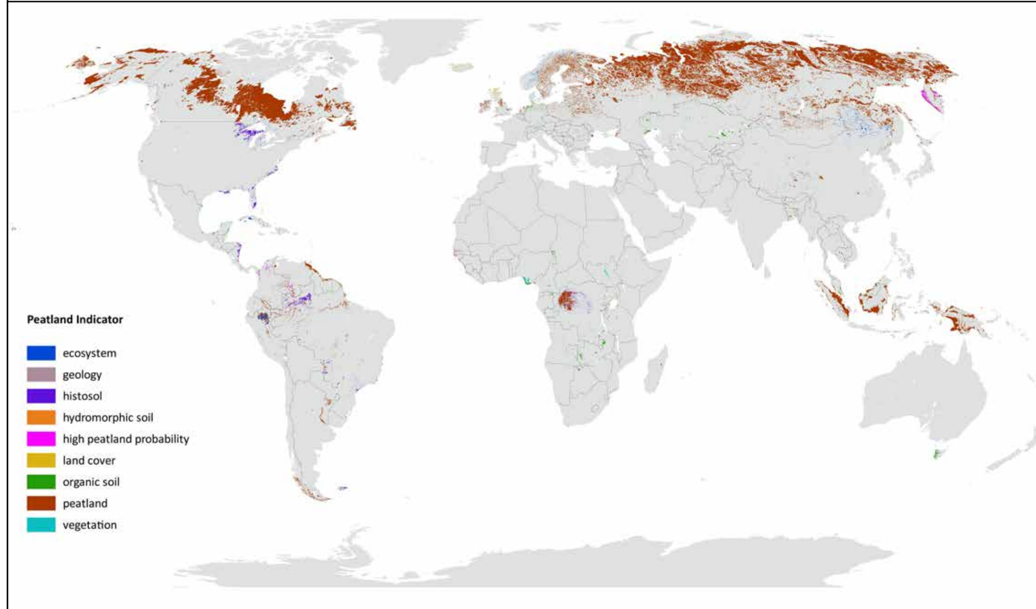


Map 1.2.1 Global peatland distribution [1, 22]

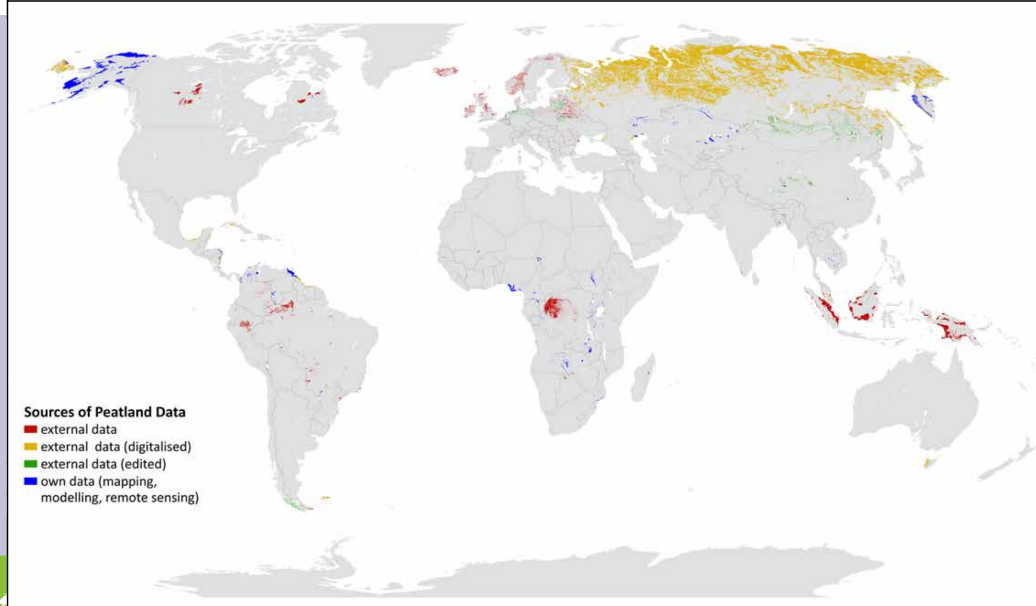
The GPM 2.0 [1, 22] has been compiled by merging over 200 individual datasets of varying scales, which describe the extent of peatlands, organic soils, histosols, and include suitable proxy data indicating permanent water surplus. Following the Intergovernmental Panel on Climate Change (IPCC), no minimum thickness for the organic layer was specified to account for the often historically determined, country-specific definitions of peat and peatland. However, where such information was available, a threshold of >12% Soil Organic Carbon (SOC) was applied to account for the relevant datasets. The input data for the GPM 2.0 were sourced from the Global Peatland Database (GPD) and accessed from the World Wide Web. Most of the spatial data included represent 'peatlands', 'organic soils', or 'histosols' (Map 1.2.2) and were obtained from external sources such as scientific publications on soil and peatland research, national agencies, online repositories, or directly from researchers (Map 1.2.3). To fill gaps in the coverage of these 'external data', additional peatland mapping was conducted using several methods (Map 1.2.3).

Users of the GPM 2.0 should note that this map does not yet cover all global peatlands and will be updated in future versions. Smaller peatlands, which can be numerous within certain regions, are not covered comprehensively. Moreover, the map includes 'probable' peatland areas where, based on ancillary data, landscape position, and remote sensing signal, peatlands can be expected but have not been confirmed on the ground [23]. These areas are included to raise awareness and encourage more comprehensive mapping and assessment in regions where peatlands have been underrepresented or previously overlooked. For more detailed information on the methods, input data origin, and references used for the GPM 2.0, see Annex III of the Global Peatland Map 2.0 of the Global Peatlands Assessment.

The Atlas builds on the Global Peatlands Assessment and accompanying Global Peatland Map 2.0. It provides the most relevant hotspot maps in a redesigned format and introduces several new maps.



Map 1.2.2 Peatland indicator data [1, 22]



Map 1.2.3 Sources of peatland data [1, 22]

1.3 Global peatland distribution

The **global distribution of peatlands** [1, 22] aligns with atmospheric circulation patterns, characterized by three zones of rising air masses and high precipitation. These zones are located near the equator and around the 60° latitudes in both hemispheres (as illustrated in Map 1.3.1). The southern zone is less significant in terms of peatland distribution due to the limited landmass at these latitudes. In contrast, the northern zone is abundant in peatlands, attributed to cooler temperatures, reduced evapotranspiration, and flat topography. Closer to the poles, permafrost hinders subsurface drainage, promoting peatland formation even under conditions of extremely low precipitation. Flat landscapes with poor drainage have supported the development of the world's largest peatland regions, such as West Siberia (Asia), the Hudson Bay Lowland and Mackenzie River Basin (North America), Southeast Asia, the Congo Basin (Africa), and Western Amazonia (South America [1, 22]).

Additionally, peatlands may occur anywhere where the local climate, substrate, topography, and hydrology create conditions for permanently wet soils. However, they are less common and extensive in subtropical regions around 30° N and 30° S, where descending dry air caused by global atmospheric circulation limits their formation. In these areas, peat development is influenced by moist air masses resulting from ocean currents and the Earth's rotation. Peatlands are also found on the windward sides of mountains, where ascending air cools and condenses vapor, leading to increased rainfall (such as on the western side of the Cordillera Mountains in South America) and in floodplains that receive substantial water flow from rain-fed mountain rivers (like the Brahmaputra, Mississippi, and Rio Paraná [1, 22]).

This results in peatlands being found in at least 177 out of the 193 UN member states (Maps below).

Global peatland distribution is influenced by atmospheric circulation patterns - movements of air driven by temperature and pressure differences - resulting in a higher prevalence of peatlands in boreal regions and the tropics.

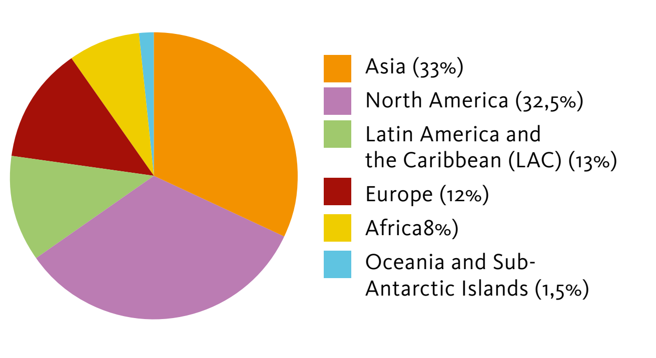
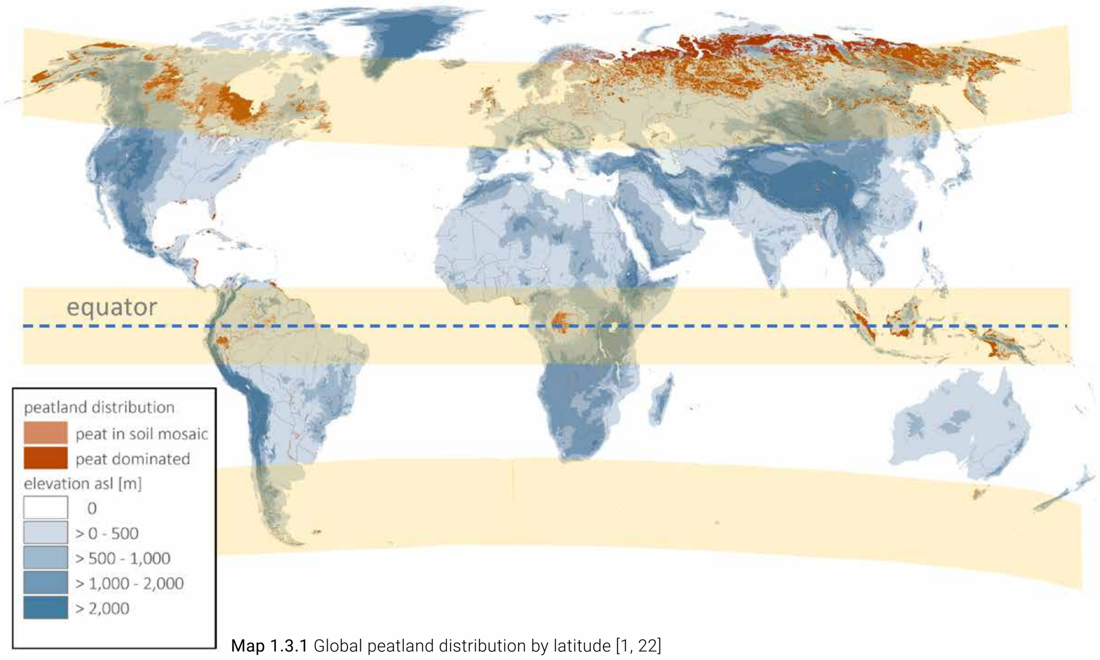


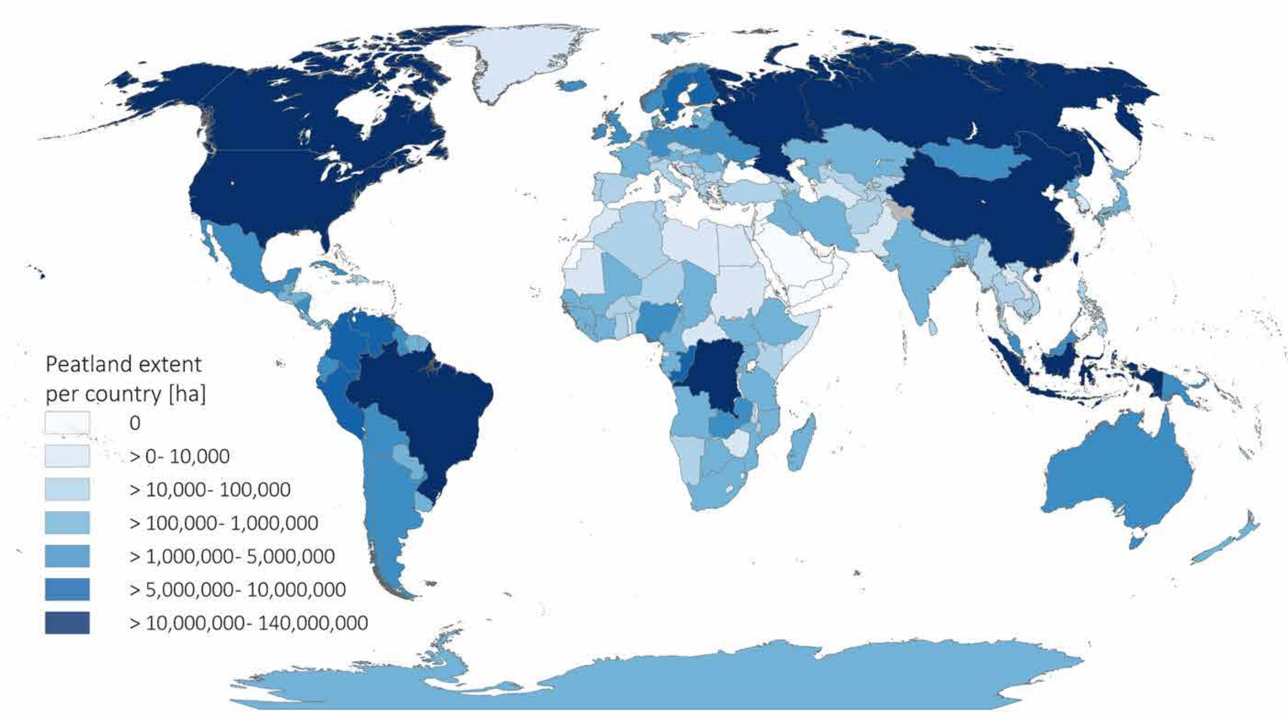
Figure 1.3.1 Global Peatland Area [1, 23]



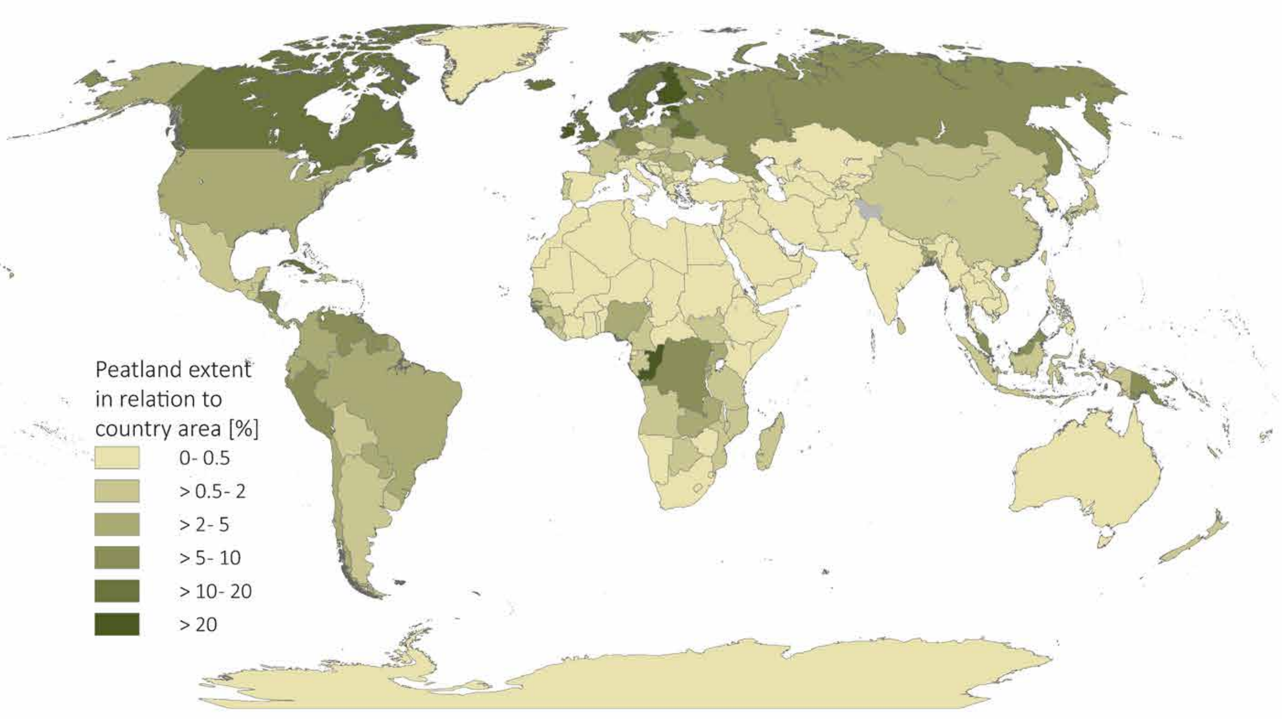
Map 1.3.1 Global peatland distribution by latitude [1, 22]

Table 1.3.1 Top 5 countries with largest peatland area per region

ASIA	NORTH AMERICA	LATIN AMERICA	EUROPE	AFRICA	AUSTRALASIA
1. Asian Russia (118,500,000 ha)	1. Canada (119,377,000 ha)	1. Brazil (26,019,489 ha)	1. European Russia (20,800,000 ha)	1. Democratic Republic of the Congo (18,157,111 ha)	1. Papua New Guinea (4,469,008 ha)
2. Indonesia (20,949,000 ha)	2. United States (38,813,000 ha)	2. Peru (7,651,400 ha)	2. Finland (8,313,381 ha)	2. Republic of the Congo (9,540,799 ha)	2. Australia (2,500,000 ha)
3. China (12,885,443 ha)	3. Greenland (8,000 ha)	3. Colombia (5,407,898 ha)	3. Sweden (6,797,032 ha)	3. Nigeria (2,155,663 ha)	3. Australian Alps (269,363 ha)
4. Mongolia (2,700,000 ha)	4. Saint Pierre and Miquelon (2,800 ha)	4. Venezuela (5,307,400 ha)	4. Norway (4,865,000 ha)	4. Zambia (1,565,696 ha)	4. New Caledonia (20,000 ha)
5. Malaysia (2,530,100 ha)	5. Bermuda (25 ha)	5. Argentinia (3,031,659 ha)	5. Belarus (3,014,298 ha)	5. Angola (891,630 ha)	5. Solomon Islands (10,000 ha)



Map 1.3.2 Peatland extent per country [23]

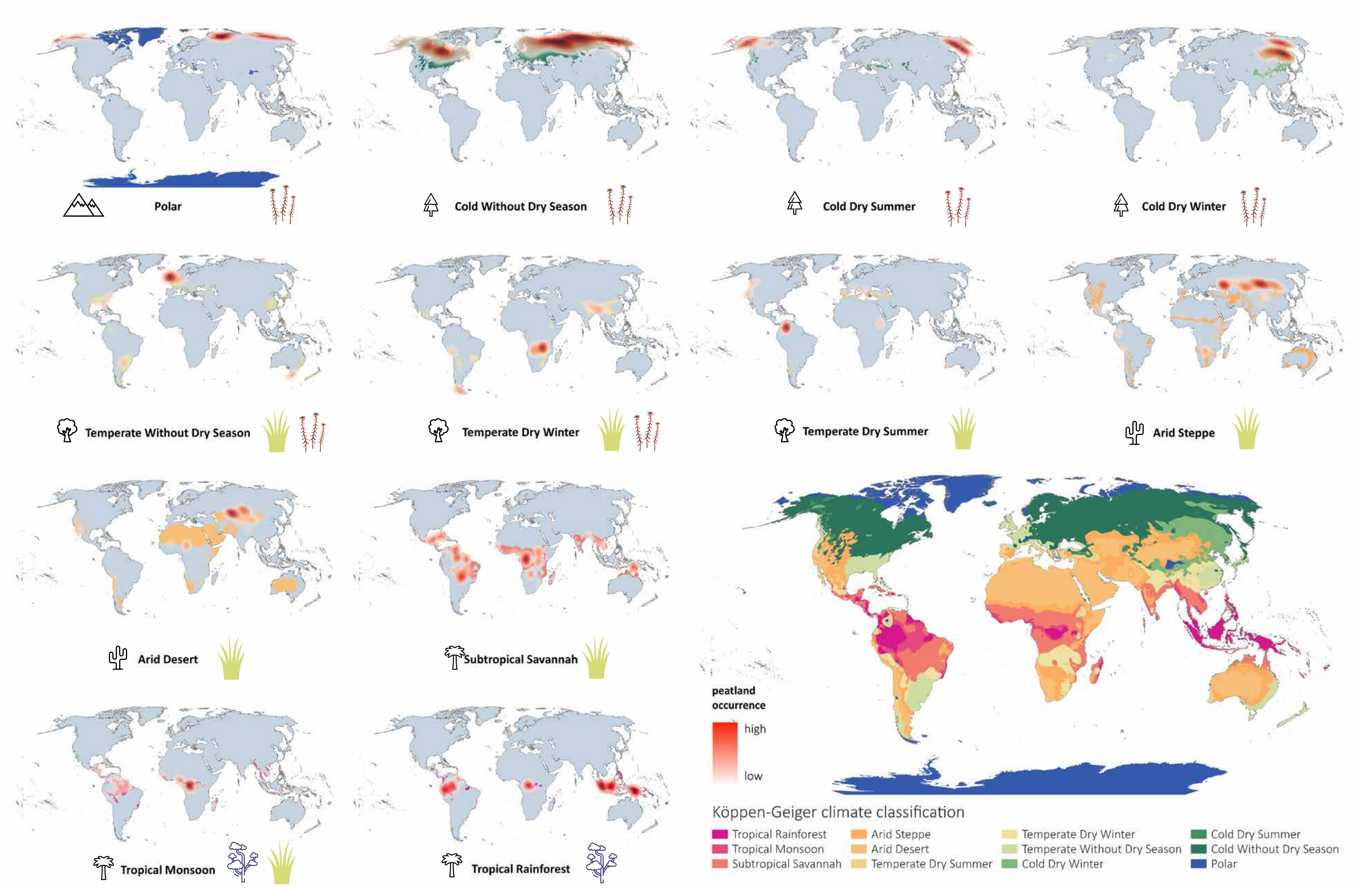


Map 1.3.3 Peatland extent in relation to country area [23]

1.4 Peatland within global climate zones

Regional humidity and temperatures are significant factors influencing the development of peatlands around the world. Since the Köppen-Geiger climate classification system [5] defines climate by patterns of temperature and precipitation, it provides a rough indication of where peatlands occur worldwide. Furthermore, the Köppen-Geiger climate classification highlights that peatlands exhibit similar characteristics in terms of the type of water supply and dominant vegetation across recurring climatic zones on different continents. For instance, and simply put, we see **1) mosses prevailing in arctic, boreal and humid temperate climates, 2) grass-like plants prevailing in more arid temperate and subtropical climates, and 3) trees prevailing in tropical climates.** However, additional ecological peatland types also occur across all climate zones, often exhibiting distinct characteristics along coastal regions and with increasing altitudes. The vast peatlands in the arctic and boreal climates of the north and also of peatlands in the temperate climate zones are widely known. Peatlands of the tropical rainforest and monsoon climates are increasingly receiving attention. **Surprisingly, peatlands are also found in subtropical savannah, steppe and arid climate zones,** particularly in major river floodplains, fed by excess rain in their headwater mountains, or in coastal zones and oases, when they may receive sufficient groundwater from large catchments [1, 22].

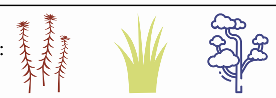
Figure 1.4.1 Images of some representative peatland types to illustrate diversity across the world and their characteristic occurrence. Photos: Hans Joosten: a, d, e, j, l, m, p, q, Steve Zoltai: b, c; Katja Hahne: h; Michael Succow: i; Outi Lähteenoja: k; Rene Dommain: n; Martin Schumann: o; Jennie Whinam: r. Note, that these global peatland regionality maps differ from those in UNEP (2022 [1]), where the FAO Global Ecological Zones were adopted: https://www.fao.org/forest-resources-assessment/remote-sensing/global-ecological-zones-gez-mapping/en/



Map 1.4.2 Peatland distribution in climate zones [1, 22, 24]

Map 1.4.1 Köppen-Geiger climate classifications [24]

Most common plants groups in peatlands under different major climates (simplified):



Differing climatic conditions on Earth play a crucial role in shaping distinct types of peatlands. Each unique set of conditions determines the development of specific peatland types with different hydrological and ecological characteristics.

2.1 Peatland biodiversity

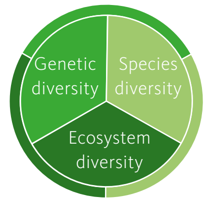
Biodiversity includes species diversity, ecosystem diversity, and genetic diversity, all of which are critical for the health and resilience of our planet, lives, and livelihoods. Peatland ecosystems are found around the world, with each region, elevation, and landscape setting from the arctic to the tropics contributing uniquely to the balance necessary for sustaining biodiversity. Protecting, conserving, and sustainably managing a variety of peatlands across all regions is fundamental for safeguarding species, ecosystem, and genetic diversity. It also helps preserve the vital ecosystem services these landscapes provide, both locally and globally, supporting migratory pathways and regulating the hydrological and carbon cycles.

Peatlands serve as essential habitats for rare, threatened, and endemic flora and fauna species. They also house common species that help maintain ecological balance, enhancing the ecosystem services they provide. Additionally, migratory species rely on peatlands as important nursery and stopover points during their life cycle journey, further connecting peatlands and promoting gene flow and interactions across landscapes. Peatlands in the northern hemisphere, particularly in boreal and arctic regions, exhibit lower species richness compared to tropical regions, but remain crucial for their role in the landscape. They harbor keystone species, such as Sphagnum mosses, which significantly shape peatland structure and functioning by regulating hydrology and playing a key role in carbon cycling through their effects on microbial communities.

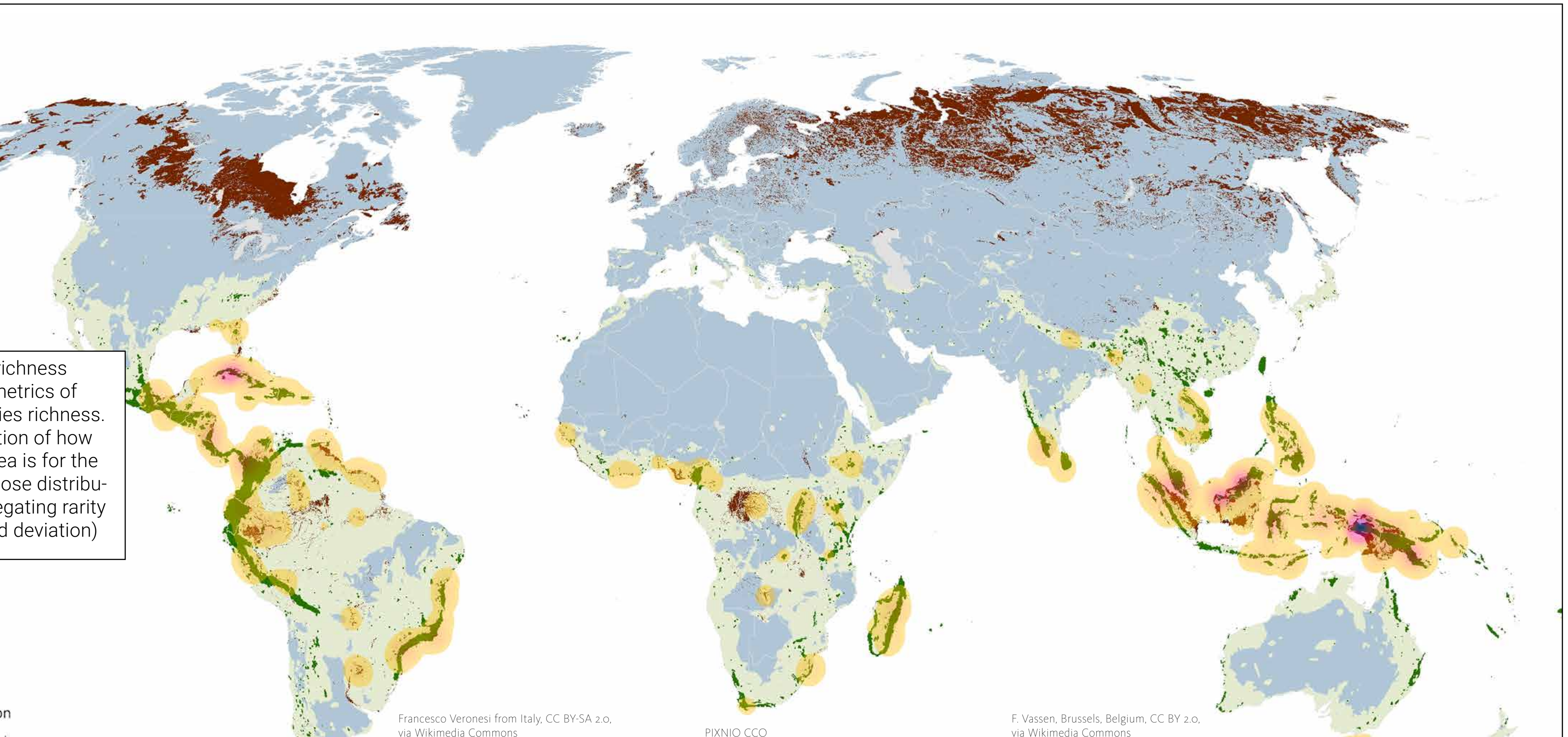
In the northern subtropics and southern hemisphere, peatlands are biodiversity hotspots, exhibiting a very high degree of species richness and diversity while also supporting a complex range of ecological processes and services connected across the basin and across the water continuum.

Biodiversity within peatlands extends beyond individual species and encompasses the ecosystem diversity of various peatland types—such as bogs, fens, coastal marshes and mangroves, or peat swamp forests —which harbor abundant and distinct plant and animal life. However, peatlands face increasing human encroachment, leading to rapid declines in biodiversity. Currently, 303 plant species and 767 animal species within global peatland ecosystems are classified as 'vulnerable,' 'endangered,' or 'critically endangered,' with around 3/4 of these species found in Africa, Asia, and Latin America and the Caribbean (LAC [1, 22]).

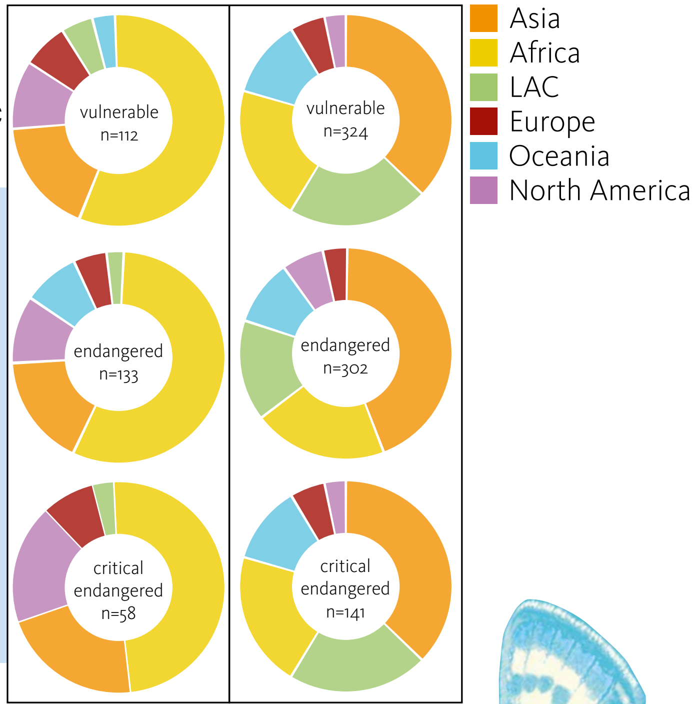
Peatlands are safe havens for rare and threatened species. Protecting them safeguards the habitats of countless unique animals and plants reliant on these vital ecosystems.



The rarity-weighted richness index [3] combines metrics of endemism and species richness. It provides an indication of how important a given area is for the assessed groups whose distribution overlap by aggregating rarity values. (sd= standard deviation)



Map 2.1.1 Rarity-weighted species richness on peatland [22, 25]



Francesco Veronesi from Italy, CC BY-SA 2.0, via Wikimedia Commons

The **Zapata Wren** (*Ferminia cerverai*) is an endangered bird endemic to Cuba, primarily found in the dense, cattail-dominated wetlands and peatlands of the Zapata Swamp.

PIXNIO CCO

The **Bog Turtle** (*Glyptemys muhlenbergii*) is a semi-aquatic endangered turtle native to the eastern United States of America, facing decline due to habitat loss from urbanization and invasive plants.

F. Vassen, Brussels, Belgium, CC BY 2.0, via Wikimedia Commons

The Blue Iridescent Firefly (*Lycaena helle*) occurs in Central, Eastern and Northern Europe, as well as parts of Siberia and Mongolia. It inhabits fens with snake knotweed (Bistorta officinalis), wet tall herbaceous meadows, transitional mires, and sparse peatland forests. Its greatest threat is habitat destruction resulting from the conversion of peatlands through drainage.

Palmiet wetland, South Africa © WWF Zambia

Palmiet (*Prionium serratum*) is an endemic semi-aquatic grass found in the valley bottom fens of South Africa's Western and Eastern Cape. These palmiet dominant peatlands host many rare species, but face threats from draining, agriculture, grazing, afforestation, and infrastructure development.

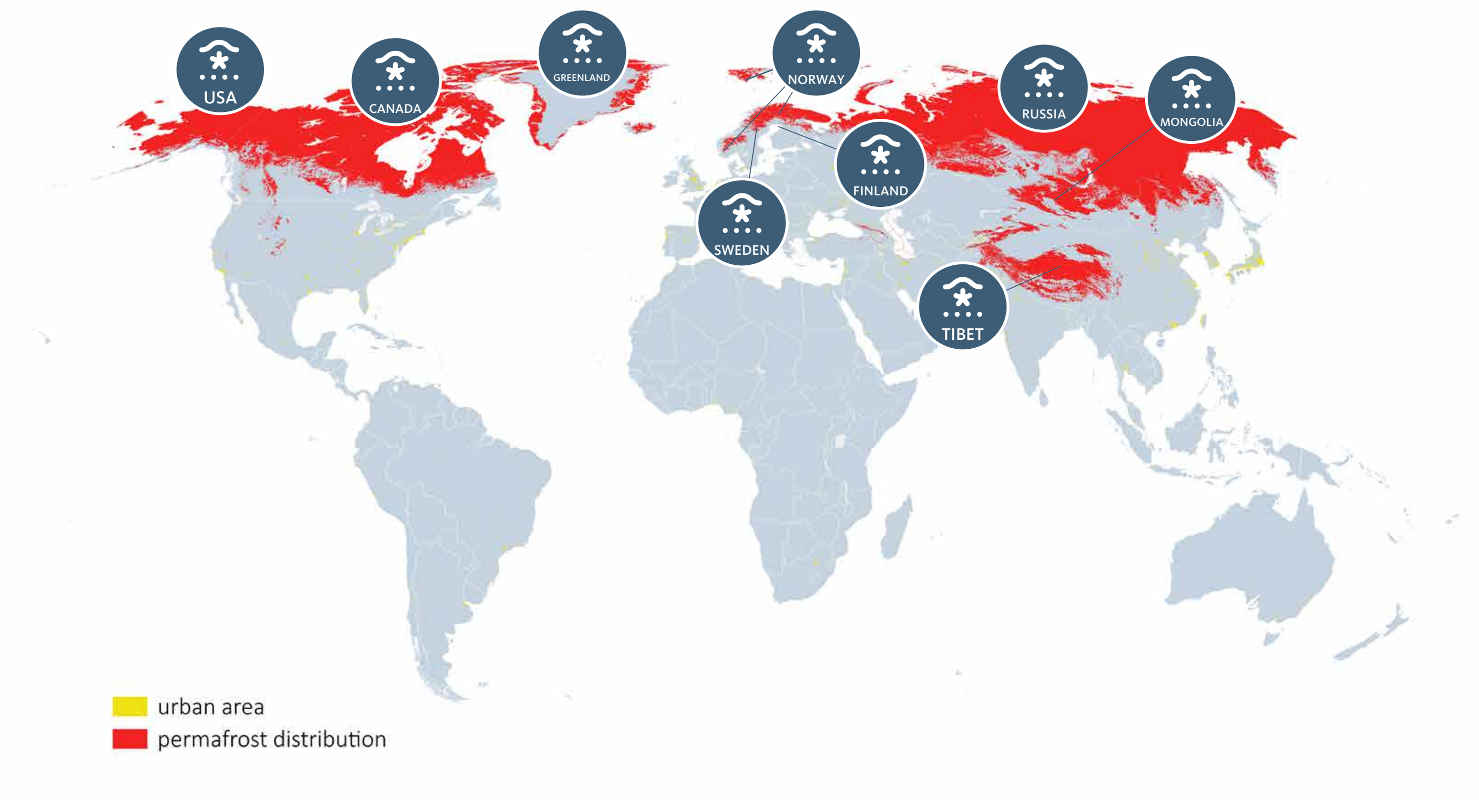
PotMart186, CC BY-SAPIXNIO CCO 4.0, via Wikimedia Commons

The **Eastern Ground Parrot** (*Pezoporus wallicus wallicus*) occurs in western mainland Australia, Tasmania, and some offshore islands. It thrives in marshy coastal plains without trees and in reed beds with low shrubs, relying on naturally occurring fires to reproduce and colonize new areas.

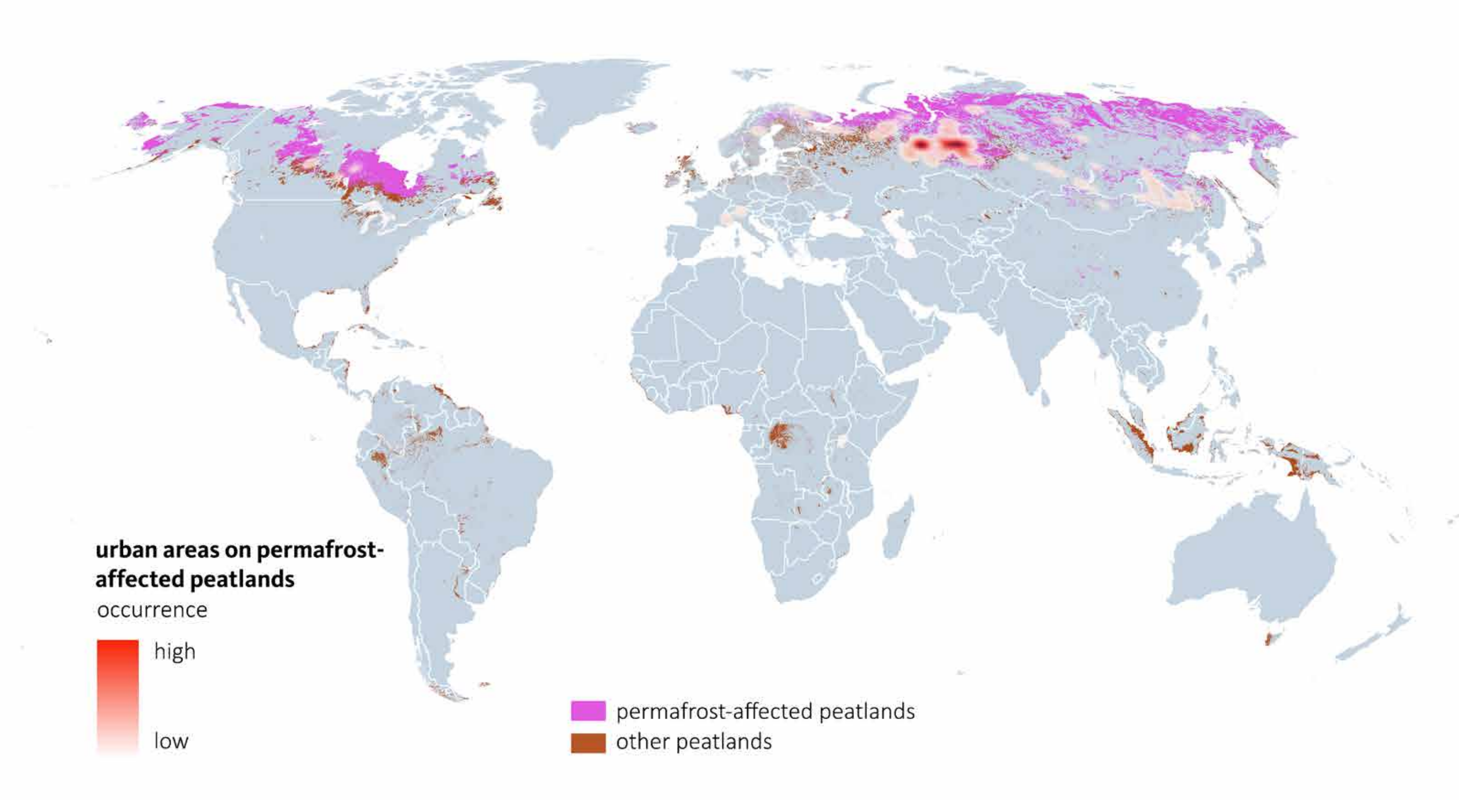
Berbak National Park, cc-by-sa-2.0. via Wikimedia Commons

Tropical peat swamp forests are the most widespread peatland ecosystems in Southeast Asia, home to at least 1,524 plant species, including a large number of mosses, ferns and fungi. They exhibit the highest floristic peatland diversity globally and support a significant portion of the region's fauna, including 123 mammal species, 268 bird species, and 219 freshwater fish species [4].

2.2 Peatland in permafrost



Map 2.2.1 World permafrost distribution [28]



Map 2.2.2 Permafrost-affected peatland [22, 28]

Permafrost peatlands exist within the permafrost zones of several northern hemisphere countries, spanning over 1.4 million square kilometers with a peat layer thicker than 40 centimeters, and encompassing an even larger area with shallower peat [1]. Additionally, extensive permafrost peat deposits can be found far outside the polar and sub-polar regions. For example, they occur in Mongolia and on the Qinghai-Tibetan plateau, where mountain ranges inhibit the inland movement of warm oceanic air and winter temperatures are very low [22]. Hotspots of urban areas on permafrost peatlands occur in the Western Siberian lowland, Yakutia and Mongolia, with weaker occurrences on the Canadian Shield, Northeast China, and the East European Plain. Climate change and permafrost thawing are likely to have a destabilizing effect on the infrastructure in these regions.

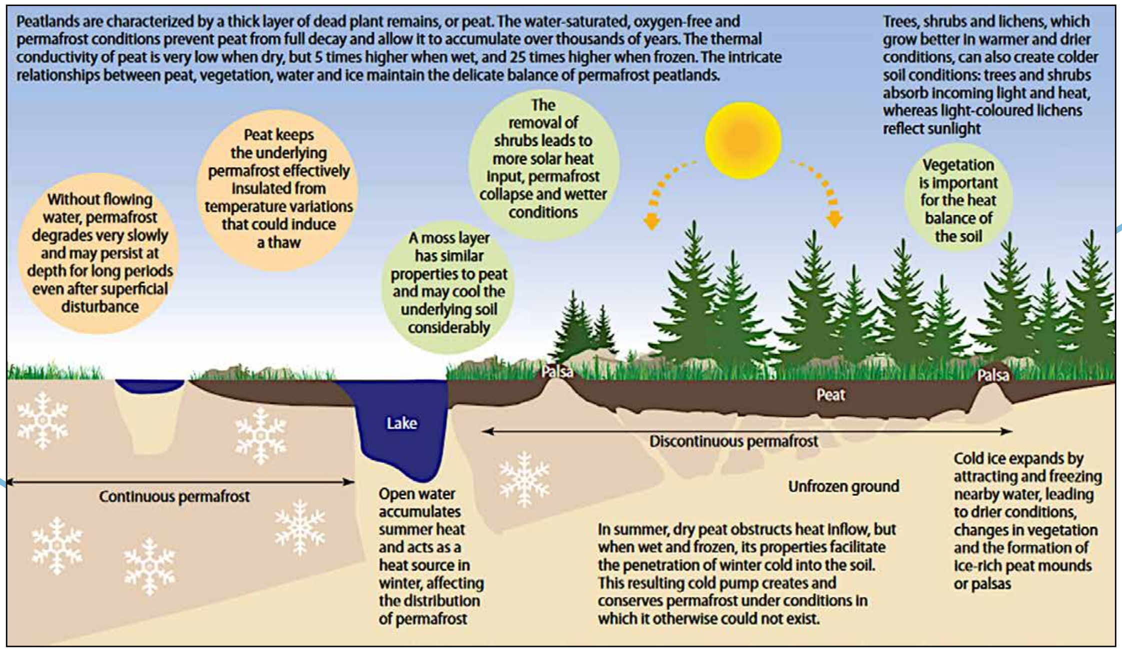


Figure 2.2.1 Relationships between permafrost, peat, plants, and water [27]

Permafrost and the role of peat, plants, and water
The presence of a permanently cold climate with frost, natural thawing, and freezing at the soil surface influences the hydrology, structure, peat formation, and vegetation of peatlands. While peat formation depends on permafrost conditions, it also stabilizes and favors such conditions in the soil. And, the ice within the peat layer provides stability and prevents peat subsidence and erosion (Figure 2.2.1 [27]).

Palsa permafrost mire, Russia
© F. Tanneberger

Palsa in Pokhodsk, Yakutia
© H. Joosten

Polygonal tundra landscapes (Bylot Island, Nunavut) © L. Rochefort

Thermokarst from permafrost thawing in Russia
© H. Joosten

Permafrost conditions significantly influence the dynamics and structures of peatlands in polar/arctic and boreal regions, with climate change strongly degrading or altering them by thawing permafrost.

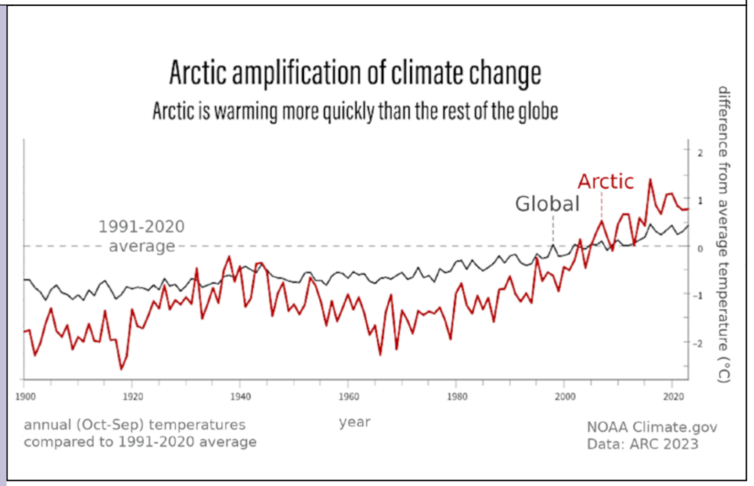
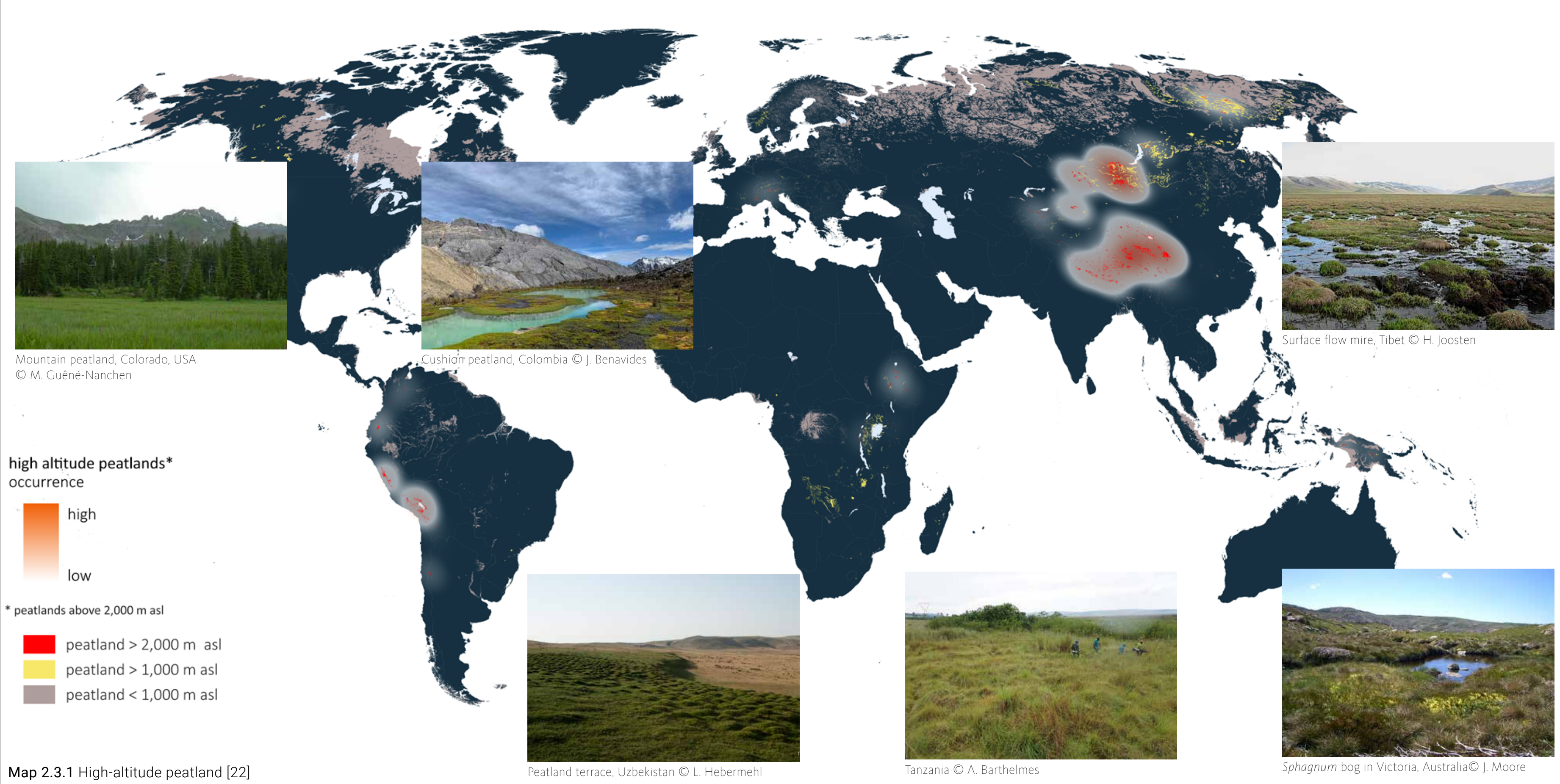


Figure 2.2.2 Temperature rise globally and in the arctic zone [28]

With global warming and the consequent rise in temperature (Figure 2.2.2 [28]), permafrost soils and peatlands are thawing at an increasing rate. This could lead to waterlogging, changes in water flow patterns, drainage, and eventually the decomposition of peat, which would release vast amounts of greenhouse gases.

2.3 Mountain peatland and water supply

Mountain peatlands differ in both structure and function from lowland peatlands. While mountain peatlands are typically smaller with relatively lower carbon storage capacity, they occur in the headwaters of many rivers, making them crucial for water supply. As islands of wet habitat amidst steep slopes and well-drained surroundings, these peatlands play a vital role as water sources for local biodiversity, migrating species, and human communities alike [1, 3].



Map 2.3.1 High-altitude peatland [22]

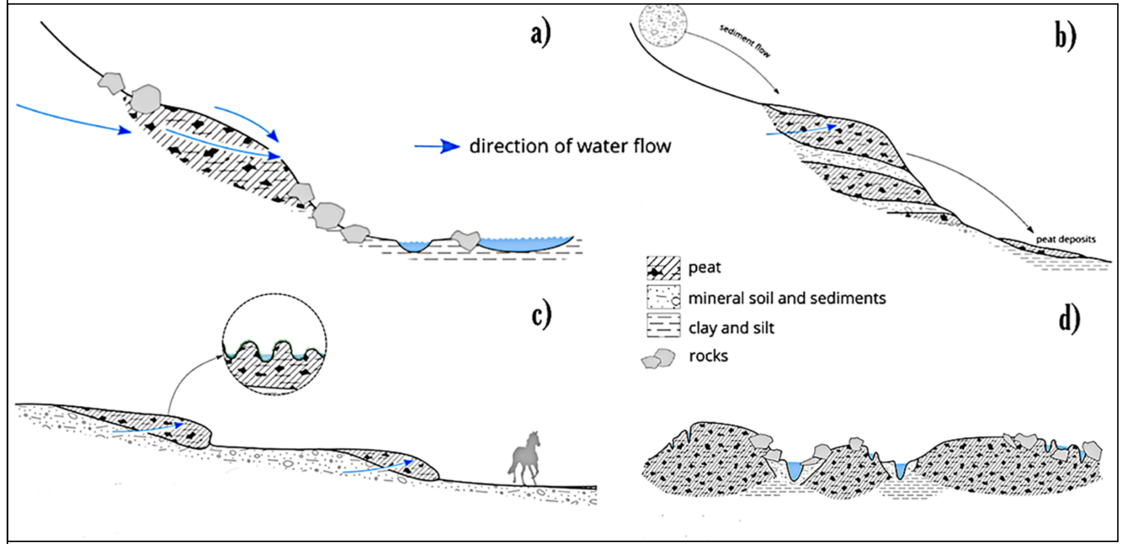
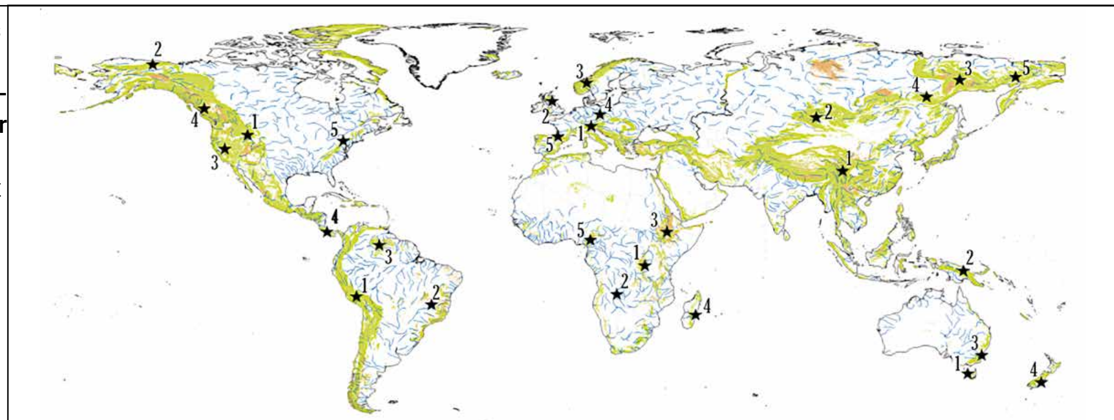


Figure 2.3.1 Stratigraphy of typical high altitude mires in Uzbekistan: a) sloping mire, b) sloping spring mire, c) spring mire, d) sloping mire with peat hills erodet by intersecting water channels [8]

Mountain peatlands are vital headwaters for rivers and water bodies, essential for supplying water to both biodiversity and humans. Altitude influences temperature and precipitation, resulting in slowed organic matter decomposition and increased carbon accumulation at higher elevations in these ecosystems.

Mountains are characterized by extreme spatial heterogeneity. The combination of altitude, climate, topography and land cover creates complex, nested mosaics of habitat conditions across various spatial scales. Globally, higher elevations receive more precipitation and experience lower temperatures, and the **slowed down organic matter decomposition eventually leads to peat and carbon accumulation in very wet terrain depressions, valley bottoms, plateaus, or as blankets in alpine climates.** However, the climate of different mountain ranges varies significantly worldwide, as mountain climates are regional variations of broader climatic conditions in higher altitudes [1, 29].



Map 2.3.2 Key mountain ranges for peatland occurrence [33, 34]

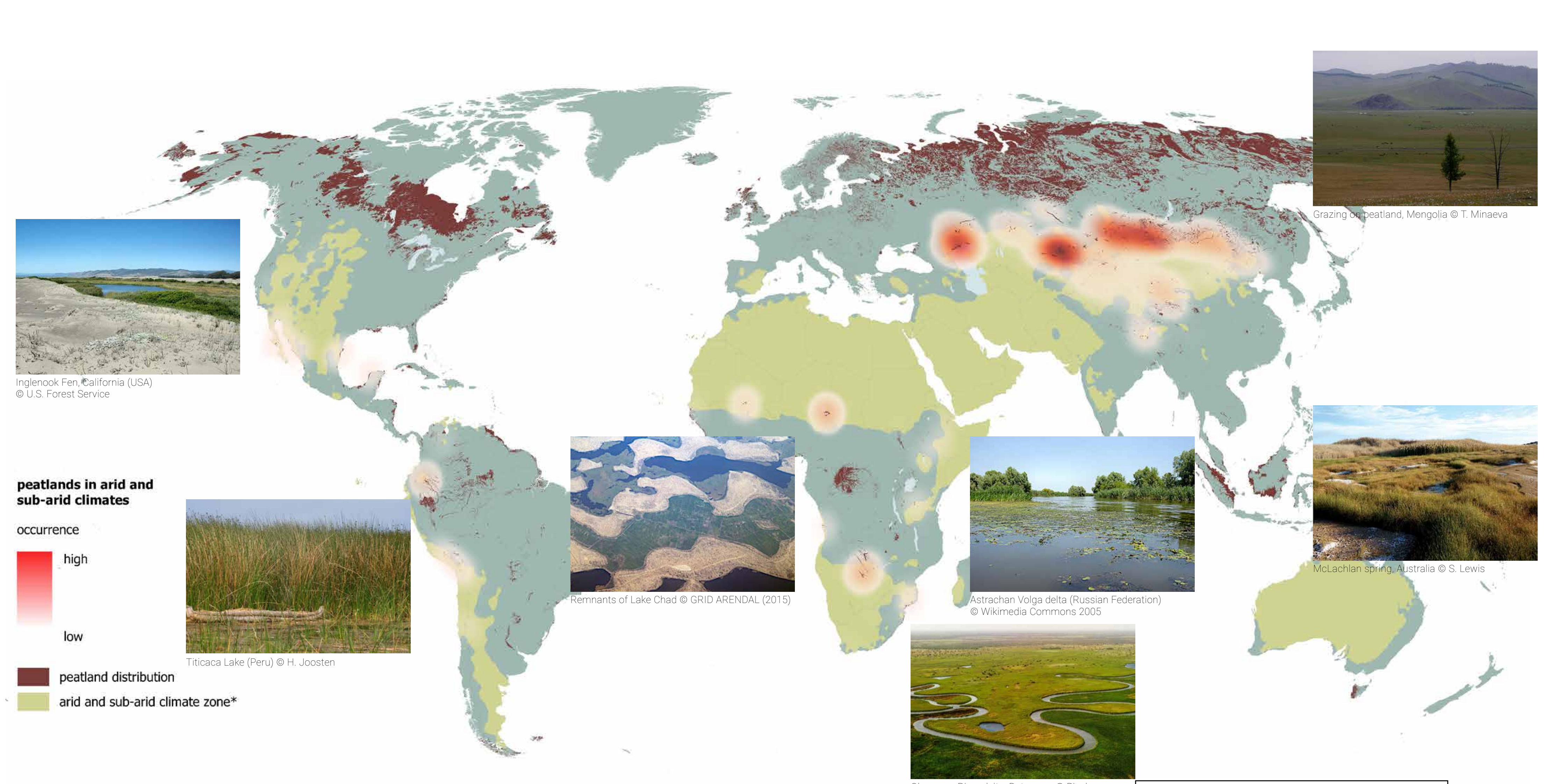
The most important mountain ranges for the occurrence of peatlands per continent and their connection to large rivers (GRDCv2 2020) as their source area/head waters [1, 22, 33, 34]. For numbers see Table 2.3.1 (left). Mountain distribution after Snethlage et al. (2022); green >1000 m.a.s.l. and orange >2000 m.a.s.l.

Table 2.3.1 The most important mountain ranges for the occurrence of peatlands per continent (Map 2.3.2 [1, 22, 33]). Please note that the GPM 2.0 does not provide adequate coverage for all these mountain ranges yet.

ASIA	NORTH AMERICA	LATIN AMERICA	EUROPE	AFRICA	AUSTRALASIA
1. Himalaya (IND, CHN, PAK)	1. Rocky Mountains (USA, CAN)	1. Andes (PER, COL, ECU, CHL, ARG)	1. Alps (GER, AUT, CHE, ITA, FRA)	1. Albertine Rift Valley	1. West Coast Range (Tasmania, AUS)
2. Altai Mountains & Mongolian Highlands (MNG, TJK, RUS, KAZ)	2. Brooks Range of Alaska (USA , Canada)	2. Brazilian Highlands (BRA)	2. Grampian Mountains (Scotland, GBR)	2. Angola Highlands (AGO)	2. New Guinea Highlands (PNG)
3. Verkhoyansk Mountain System (RUS)	3. Sierra Nevada (USA)	3. Guiana Highlands (BRA, VEN)	3. SW Scandinavian Mountains (NOR)	3. Ethiopian Highlands (ETH)	3. Australian Alps (AUS)
4. Aldan Mountains (RUS)	4. Coast and Cascade Ranges (W-USA, W-CAN)	4. Cordillera Central (PAN, CRI)	4. Central European Uplands (GER, FRA, CZE, SVK, POL)	4. Ankaratra Massif (MDG)	4. Southern Alps (NZL)
5. Kolyma Mountains (RUS)	5. Appalachian Mountains (USA)		5. Pyrenees (FRA, ESP)	5. Cameroone Line (CMR)	

Mountains are highly significant regions in the context of climate change and sustainable development, situated at the crossroads of accelerated global warming and significant human dependence. As highly fragile and vulnerable environments, mountains are hotspots of climate-related losses in ecosystems and habitability, often accompanied by challenging socioeconomic circumstances for the rural communities residing within them [5, 6].

2.4 Peatland in dryland



Map 2.4.1 Peatland in arid and sub-arid climate [22, 24]

Peatland in dryland, whether in hot or cold steppe and desert climates, face significant regional shrinkage risks that will worsen as climate extremes intensify.

Aridity characterizes drylands that severely lack available water, hindering or preventing the growth and development of plant and animal life. There are two subtypes: 1) hot or cold arid-**desert climates**, showing severe excess of evaporation over precipitation, and 2) hot or cold sub-arid or steppe climates, being intermediates between desert and humid climates. Drylands occur on every continent in the world [24], covering 33 % of the Earth's land surface, including 57 % of Africa, 69 % of Australia, and 84 % of the Middle East. **The largest peatland extents in such drylands occur under cold steppe and desert climates in Central Asia, parts of the Andes, and the Volga-Delta region in Kazakhstan,** where they are potentially related to permafrost or water discharge from connected mountain ranges. **Peatlands under hot steppe and desert climates occur primarily in sub-Saharan Africa** (Lake Chad, Barotse Floodplain, and the Okavango Delta), **as well as in coastal areas of the Gulf of California and the Gulf of Mexico.** Arid swamps vary from fresh to saline waters as they dry out, supporting grass, sedge, herb, shrub or tree vegetation [1, 22].

There are numerous significant impacts on wetlands and peatlands in drylands, including drainage, agriculture, overgrazing, pollution (including runoff from agricultural areas), erosion, and climate change, all of which disrupt flooding patterns. Among these, the most serious impact comes from large-scale water abstraction, severely affecting wetland ecosystems in the world's arid zones. The fate of the Aral Sea starkly underscores the urgent need to preserve the wetlands. Its significant drying has resulted in fragmentation, ecosystem degradation, and severe impacts on local economies and livelihoods. **The risk of wetland shrinkage in drylands is pronounced at the regional level and is expected to worsen with increasing climate extremes** [36]. There are many examples of these wetlands' decline (including peatlands): Lake Chad in Africa has experienced lowering water levels, adversely impacting fish populations and other wildlife, and leading to the desertification of former wetlands and the loss of arable land [38]. In China's dry inland areas, wetlands have declined by about 70,000 hectares over the past 40 years [37, 39]. The substantial ecological degradation of wetlands in southeastern Australia during the millennial drought (2001–2009) highlights their vulnerability to climate change [40, 41]. **Accelerated by climate change, it is projected that at least 6,000 dryland wetlands worldwide will disappear by 2100** [36].

Figure 2.4.2 Wetland loss in the Hammar marshes (Iraq) from 1984-2020 due to drainage, dam construction, and agriculture (Satellite images by Google Earth).

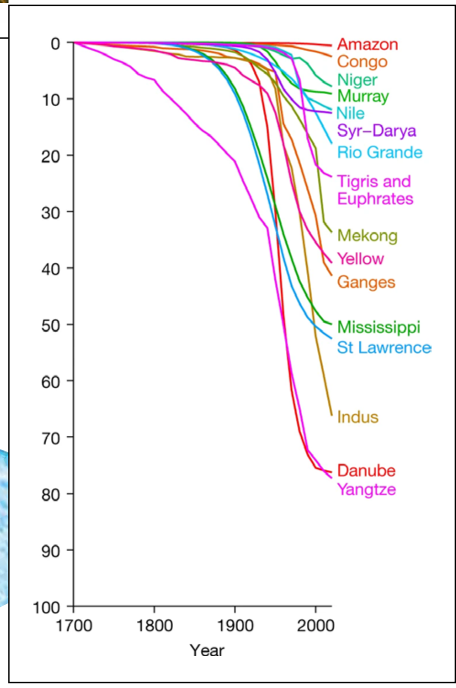


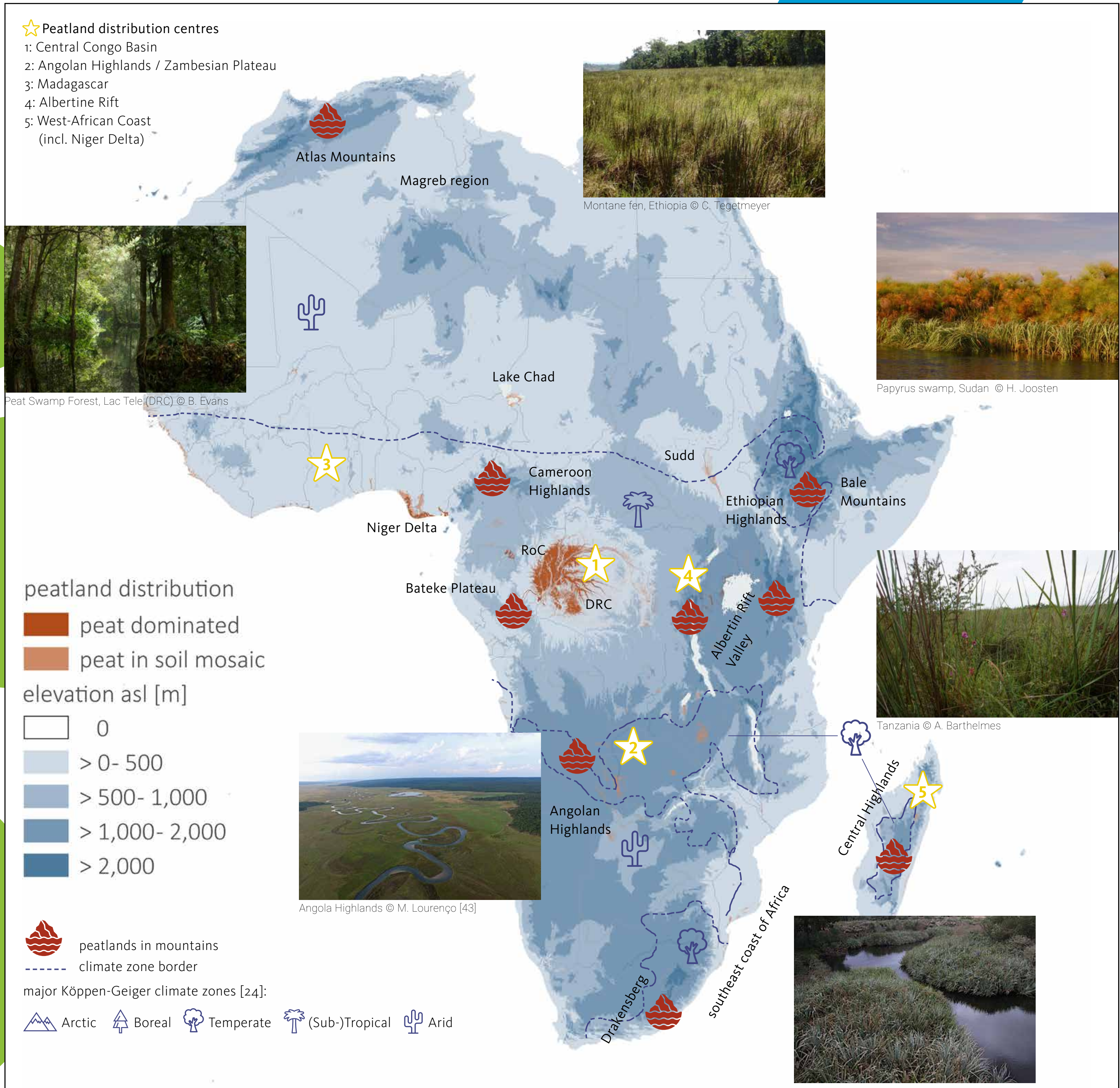
Figure 2.4.1 Regional wetland loss in major river basins since 1700. Considerable wetland loss has been recorded for several large river catchments in arid climates, e.g., for the Indus, Tigris and Euphrat, Syr-Darja, Nile, and the Niger river. These catchments partially include peatlands [35]

3.1 Peatlands of Africa

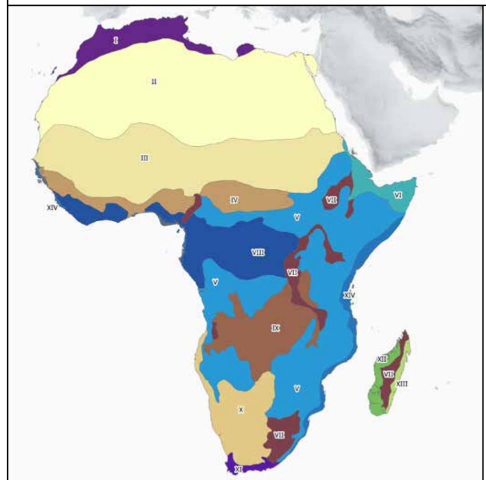
- **Total peatland area: 39 million ha**
- **Distribution: Congo Basin, Albertine Rift, Madagascar, Highlands of Zambia and Angola, West-African coast**
- **Peatland cover over total regional surface area: 1 %**
- **Share of global peatland area: 8 %**
- **Degraded peatlands: 8 %**
- **Annual GHG emissions from peatlands: 130 Mt CO_2e / yr**
- **Share of global GHG emissions from peatlands: 7 %**
- **Peatlands within protected areas: 35 %**
- **Top 5 countries with largest peatland area:**
  1. **Democratic Republic of the Congo (18,157,111 ha)**
  2. **Republic of the Congo (9,540,799 ha)**
  3. **Nigeria (2,155,663 ha)**
  4. **Zambia (1,565,696 ha)**
  5. **Angola (891,630 ha)**
- **Total peatland carbon stock: 36,896 Mt C [77]**
- **Threatened peatland species: Flora: 66 VU, 80 EN, 30 CR; Fauna: 81 VU, 66 EN, 31 CR [79]**
- **Ramsar Wetlands of International Importance with peat: 31 sites (7.3 % of total Ramsar sites in Africa [78])**

Africa, the second-largest landmass on Earth, boasts a diverse range of peatland types. They prevail in various regions, including the tropical zone, in mountains and on plateaus, along the coast, and in river floodplains and deltas (Map 3.1.1). The Central Congo Basin is home to the world's second-largest tropical peatland complex, including hardwood swamp forests and palm-dominated swamp forests. This region features three wetlands of international importance (Ramsar sites): the Grands Affluents and Lac Télé/Likouala-Aux-Herbes in the Republic of Congo, and the Ngiri-Tumba-Maindombe in the Democratic Republic of Congo. In 2017, both countries agreed to jointly manage these sites, creating the largest transboundary Ramsar site in the world, covering over 129,000 square kilometers of highly diverse peatland ecosystems. Many peatlands in sub-Saharan Africa are associated with large river systems such as the **Sahelian** and **Zambezian floodplains, as well as flooded savannahs**, where mineral and organic soils are closely intertwined and **organic-rich floating mats** occur. Recently, larger peatlands have been identified in West Africa, specifically in Côte d'Ivoire and Nigeria, situated in **river floodplains dominated by *Raphia* peat swamp forests** and mangroves. Moreover, the mountains and equatorial lakes of the Great Rift Valley in East Africa host open peatlands dominated by ***Papyrus*, grasses, and sedges, as well as *Raphia*-dominated peat swamp forests. Afromontane and Afroalpine peatlands featuring Sphagnum, Lobelia** and, ***Dendrosenecio*** can be found above 2,000 meters above sea level in Ethiopia, Tanzania, Kenya, Rwanda, Lesotho, and South Africa [1, 22].

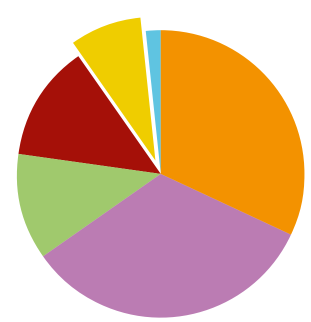
In the South African region, peatlands are the best explored on the continent and are predominantly located along the east coast where they include **forested peatlands and mangroves,** such as those found in the Maputaland coastal plain. In the Maghreb region of North Africa, peatlands are generally small and host **alder swamps, *Sphagnum* fens** and **peaty heaths with *Erica scoparia*. Although only about 8% of Africa's peatlands are degraded on a continental scale, several countries already report that more than 50% of their peatlands are degraded** [1]. Peatlands of South Africa, Burundi, Rwanda and Madagascar are heavily overused in both highlands and lowlands, mainly for agriculture. Peatlands in the Nile Basin are degrading at an alarming rate caused by agriculture, extraction, infrastructure development, and climate change, which severely impacts livelihoods, especially by affecting the provision of clean water. However, there are still large intact peatlands in Africa, such as the Sudd in South Sudan, the Angola Highlands, the Peat Swamp Forests along the coast of Côte d'Ivoire and the Cuvette Central in the Congo Basin [1, 22]. Unfortunately, recent initiatives have been announced that involve logging, oil and gas exploration, dam building, and infrastructure development in the Congo Basin putting these peatlands at significant risk.



Map 3.1.1 Peatland distribution in Africa [1, 22]


Map 3.1.2 Africa's peatland regionality map [42]

I N-African Mediterranean marsh, II N-African dryland grassy marsh, III N-African flooded grassland, IV W-African wooded savannah marsh, V (Sub-)tropical savanna marsh, VI Horn of Africa dryland marsh, VII African mountain compound fen and bog, VIII African lowland (peat) swamp, IX Zambesi and Okavango flooded grassland, X S-African dryland grassy marsh, XI S-African Mediterranean marsh, XII W-Madagascar coastal and upland marsh, XIII E-Madagascar mangrove, coastal marsh and (peat) swamp, XIV African mangrove, coastal marsh and (peat) swamp


Share of global peatland area (8% [1, 23])

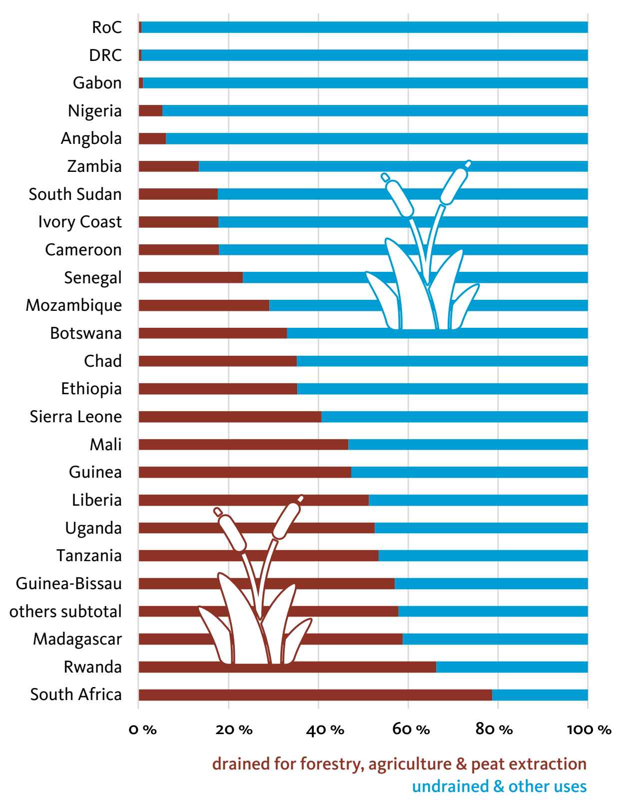
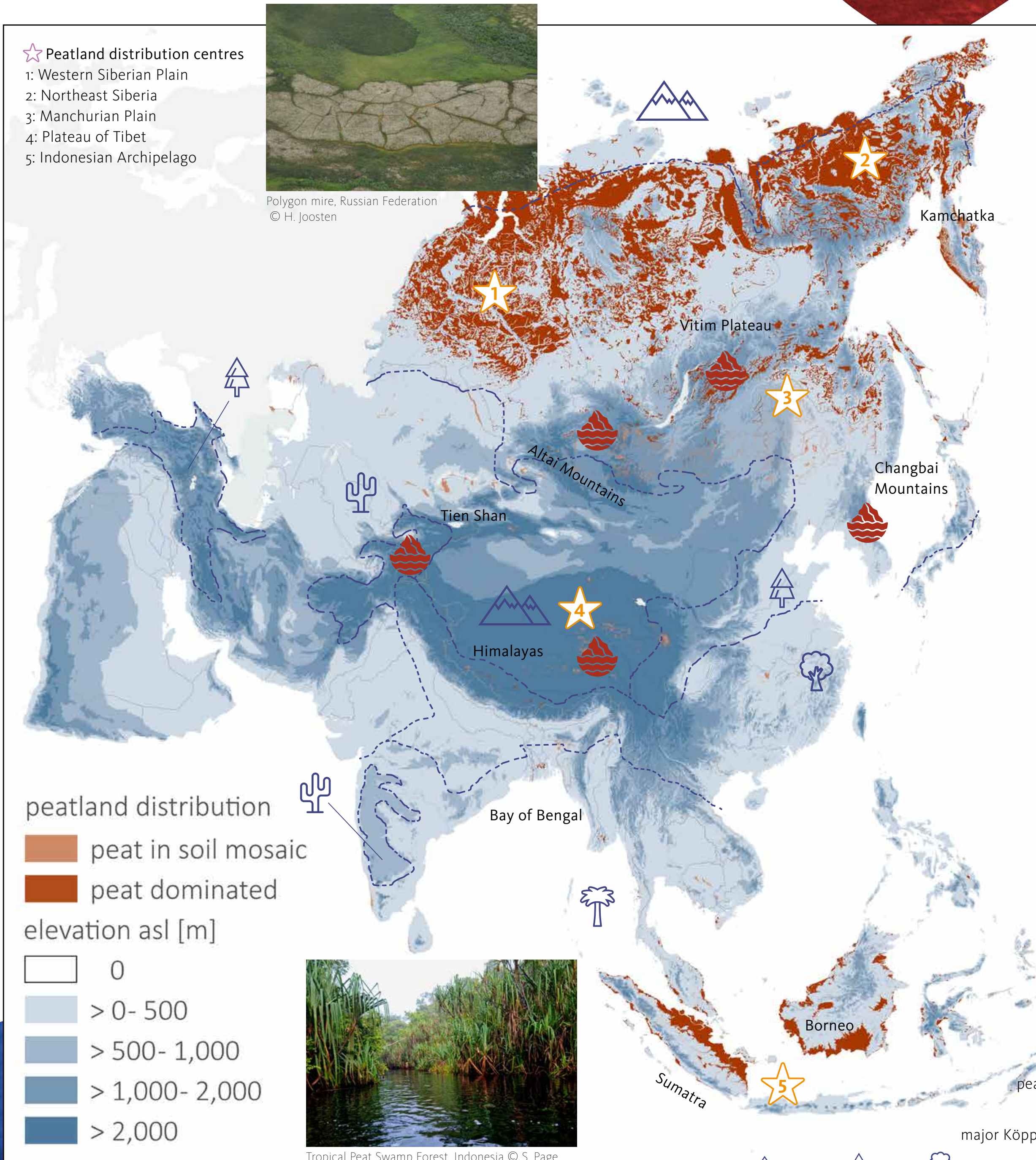


Figure 3.1.1 Status of peatlands (% [1, 23])

3.2 Peatlands of Asia



Polygon mire, Russian Federation © H. Joosten

Tropical Peat Swamp Forest, Indonesia © S. Page

Map 3.2.1 Peatland distribution in Asia [1, 22]


Yakutsk, Russian Federation © H. Joosten


Mongolia © H. Joosten


Tibet © H. Joosten

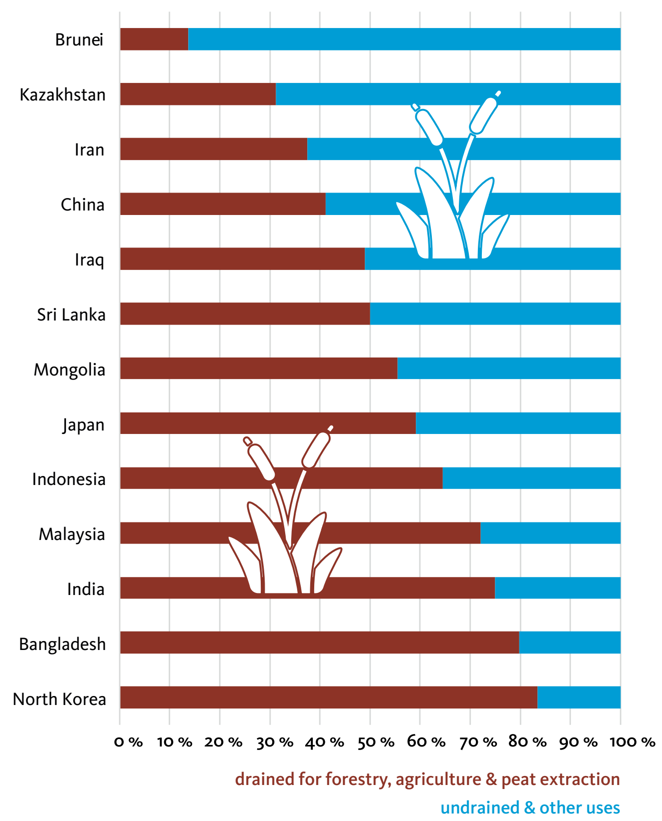
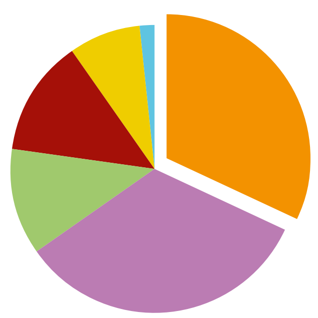
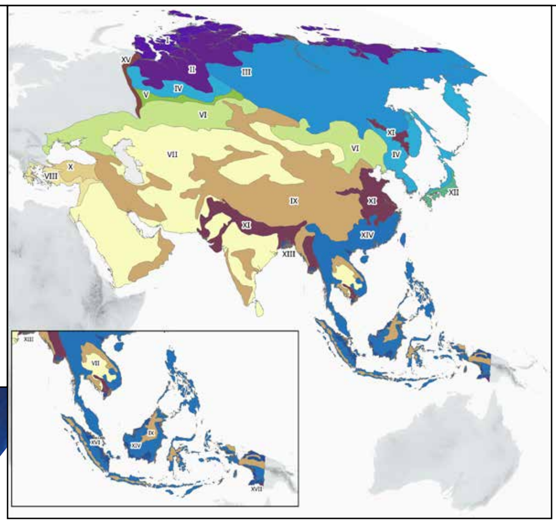


Figure 3.2.1 Status of peatlands (% [1, 23])


Share of global peatland area (33% [1, 23])

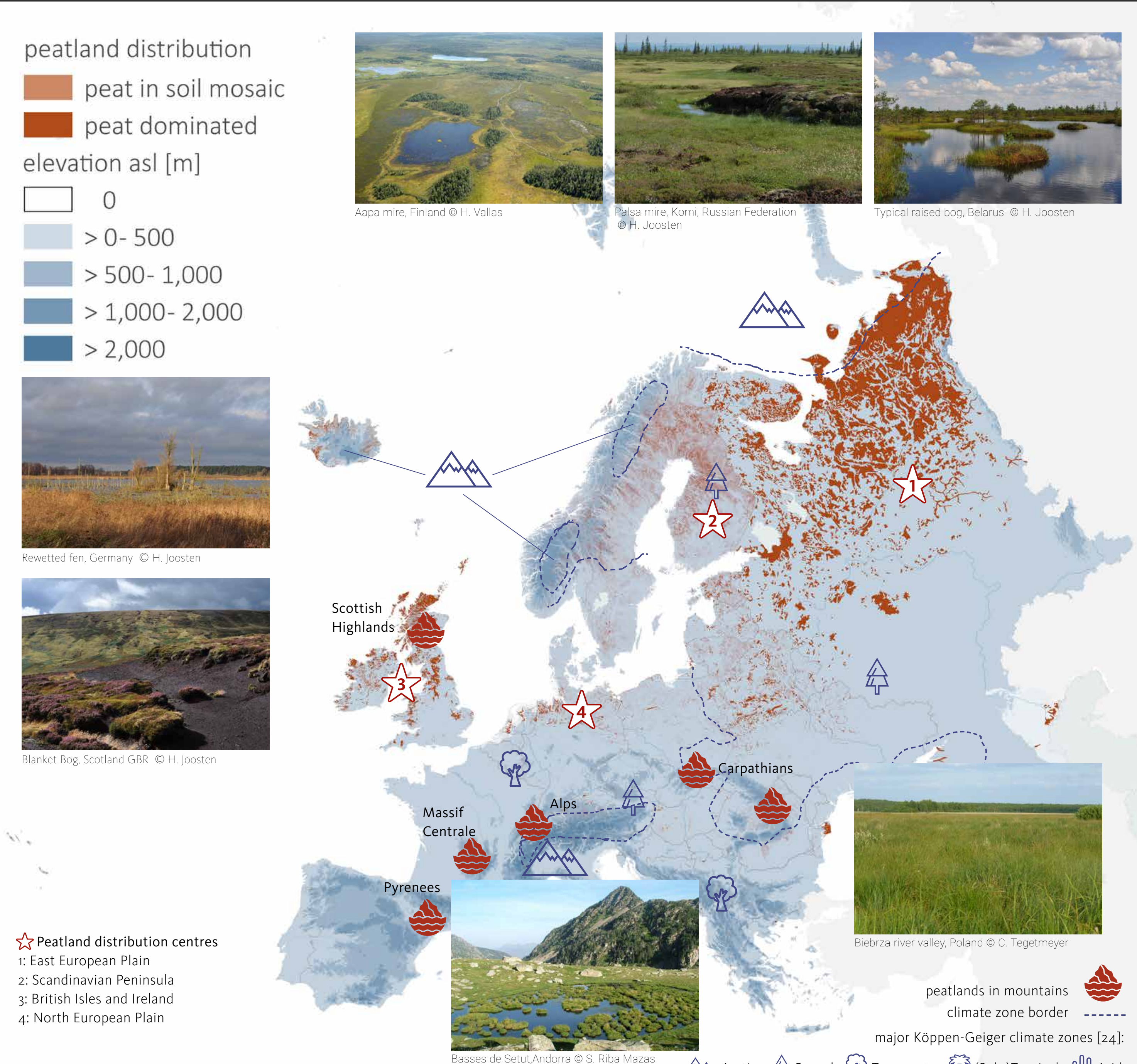

Map 3.2.2 Asia's peatland regionality map [42]

I Arctic seepage and polygon mire, **II** N-Siberian palsa mires, **III** C- and E-Siberian fen and bog, **IV** Typical raised bog, **V** Temperate fen, **VI** Grassy valley bottom and depression marsh, **VII** Drylands grassy marsh, VIII Mediterranean marsh, **IX** Asian mountain compound fen and bog, **X** Temperate grassy marsh, **XI** Floodplain fen and marsh, **XII** Temperate depression marsh, **XIII** Asian mangroves and coastal marsh, **XIV** Asian (sub-)tropical marsh, **XV** Ural mountain fen, **XVI** S-Asian (peat) swamp, **XVII** Trans Fly savanna marsh and swamp

- **Total peatland area: 161 million ha**
- **Distribution: Western Siberian Plain, Northeast Siberia, Manchurian Plain, Plateau of Tibet, Indonesian Archipelago**
- **Peatland cover over total regional surface area: 3.7 %**
- **Share of global peatland area: 33 %**
- **Degraded peatlands: 13 %**
- **Annual GHG emissions from peatlands: 1,021 Mt CO_2e / yr**
- **Share of global GHG emissions from peatlands: 53 %**
- **Peatlands within protected areas: 10 %**
- **Top 5 countries with largest peatland area:**
  1. **Asian Russia (118.5 million ha)**
  2. **Indonesia (21 million ha)**
  3. **China (13 million ha)**
  4. **Mongolia (2.7 million ha)**
  5. **Malaysia (2.5 million ha)**
- **Total peatland carbon stock: 182,417 Mt C [77]**
- **Threatened peatland species: Flora: 20 VU, 25 EN, 13 CR; Fauna: 135 VU, 144 EN, 56 CR [79]**
- **Ramsar Wetlands of International Importance with peat: 71 sites (18.2 % of total Ramsar sites in Asia [78])**

Asia is the largest continent and also holds the largest area of peatlands worldwide [1, 22]. As the continent extends from the Arctic to the tropics, it hosts a wide variety of peatland types shaped by diverse climates, ranging from polar to tropical, and from wet to arid conditions [24]. Accordingly, peatlands differ largely in their water supply, vegetational composition and peat accumulation rates. Nearly half of the peatlands are located in the arctic and boreal zones, while about a quarter occur in the temperate zone and another quarter in the tropics. **Polygonal peatlands** occur in the arctic permafrost and are mainly dominated by peat mosses (Sphagnum), brown mosses, dwarf shrubs and sedge (Cyperaceae) species. Arctic peatland vegetation is not diverse, but represents unique ecosystem types. **Palsa and Aapa mires** in the subarctic and boreal zones maintain complex patterns of drier hummocks with dwarf shrubs, mosses and lichen, and wet hollows dominated by sedges, cotton-grass, and Sphagnum communities. Sedges (Cyperaceae), grasses (Poaceae) and mosses play a greater role in **peatlands of the continental temperate and subtropical zone**, whereas in the tropical zone, extensive **Peat Swamp Forests (PSFs)** and mangroves are most prominent on peatlands, especially in SE Asia. Here, PSFs have the highest floral diversity in peatlands globally (at least 1,524 vascular plant species). Besides SE Asia, (sub-)tropical peatlands extend from coastal areas of the Bay of Bengal to the foothills of the Himalayas in Bangladesh, India, and Pakistan, as well as in coastal Sri Lanka and Kerala (India). **Plateau and mountain peatlands** prevail in the cold and arid climates of the Central Asian mountains (e.g. Himalaya, Tien Shan, Altai), and the Changbai Mountains (NE China). In the tropical zone, peat accumulation began earlier than in the temperate and polar regions. This was sustained by continuous large, mainly belowground litter inputs mainly from evergreen trees, in contrast to sedge, dwarf shrubs, and mosses, which are the peat-forming vegetation in temperate and boreal biomes. **Despite this available knowledge, data on peatlands distribution need to be improved across all of Asia** [1]. **The peatlands of temperate, arid, and tropical Asia face severe drainage and overexploitation, leading to significant greenhouse gas emissions, with SE Asia being the largest peatland emission hotspot globally.** Key drivers of peatland degradation across the continent include permafrost thawing in the north, overgrazing by livestock and arable farming in Central Asia, and deforestation and drainage for oil palm, pulp wood and food crops in the tropics. **The peatlands of Bangladesh, India, Malaysia and Indonesia are more than 60% degraded in each country** [1]. Moreover, climate change poses a major risk for northern peatlands due to widespread permafrost thawing. Peatlands here are affected by road and infrastructure construction for oil and gas production too.

3.3 Peatlands of Europe



Map 3.3.1 Peatland distribution in Europe [1, 22]

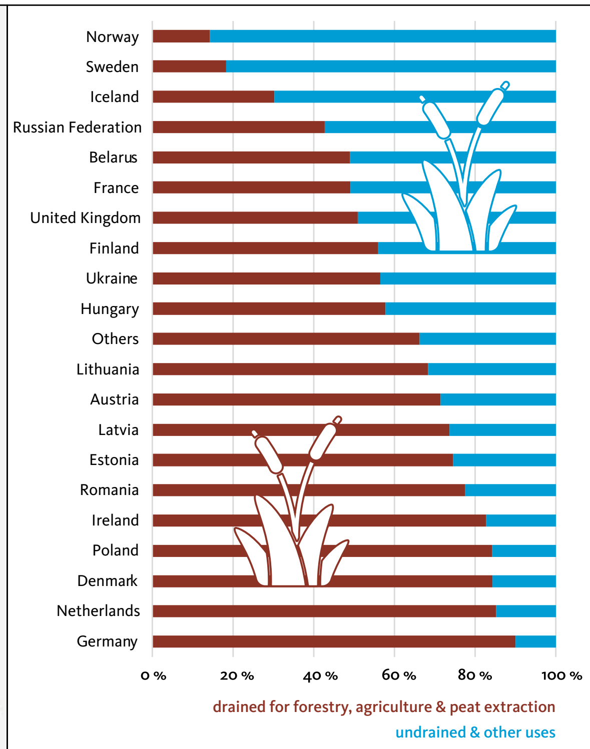
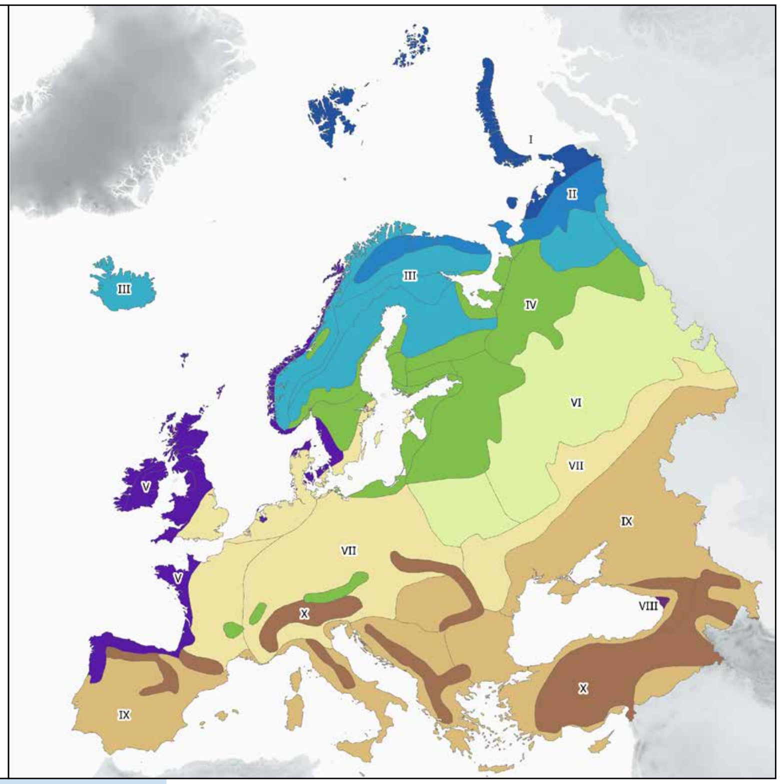


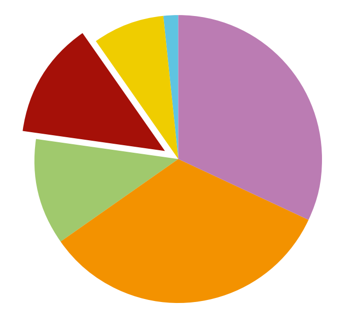
Figure 3.3.1 Status of peatlands (% [1, 23])



Map 3.3.2 Europe's peatland regionality map [42]

I Arctic seepage and polygon mire, **II** Palsa mire, **III** Northern fen (aapa mires s.l.), **IV** Typical raised bog, **V** Atlantic bog, **VI** Continental fen and bog, **VII** Nemoral-submeridional fen, **VIII** Colchis mire, **IX** Southern European marsh, **X** Central and southern European mountain compound

- **Total peatland area: 59 million ha**
- **Distribution: Easernt European Plain, Scandinavian Peninsula, British Isles, North European Plain**
- **Peatland cover over total regional surface area: 6 %**
- **Share of global peatland area: 12 %**
- **Degraded peatlands: 46 %**
- **Annual GHG emissions from peatlands: 582 Mt CO_2e / yr**
- **Share of global GHG emissions from peatlands: 30 %**
- **Peatlands within protected areas: 20 %**
- **Top 5 countries with largest peatland area:**
  European Russia (20,800,000 ha)
  Finland (8,313,381 ha)
  Sweden (6,797,032 ha)
  Norway (4,865,000 ha)
  Belarus (3,014,298 ha)
- **Total peatland carbon stock: 43,620 Mt C [77]**
- **Threatened peatland species: Flora: 6 VU, 10 EN, 5 CR; Fauna: 32 VU, 12 EN, 8 CR [79]**
- **Ramsar Wetlands of International Importance with peat: 456 sites (40.5 % of total Ramsar sites in Europe [78])**

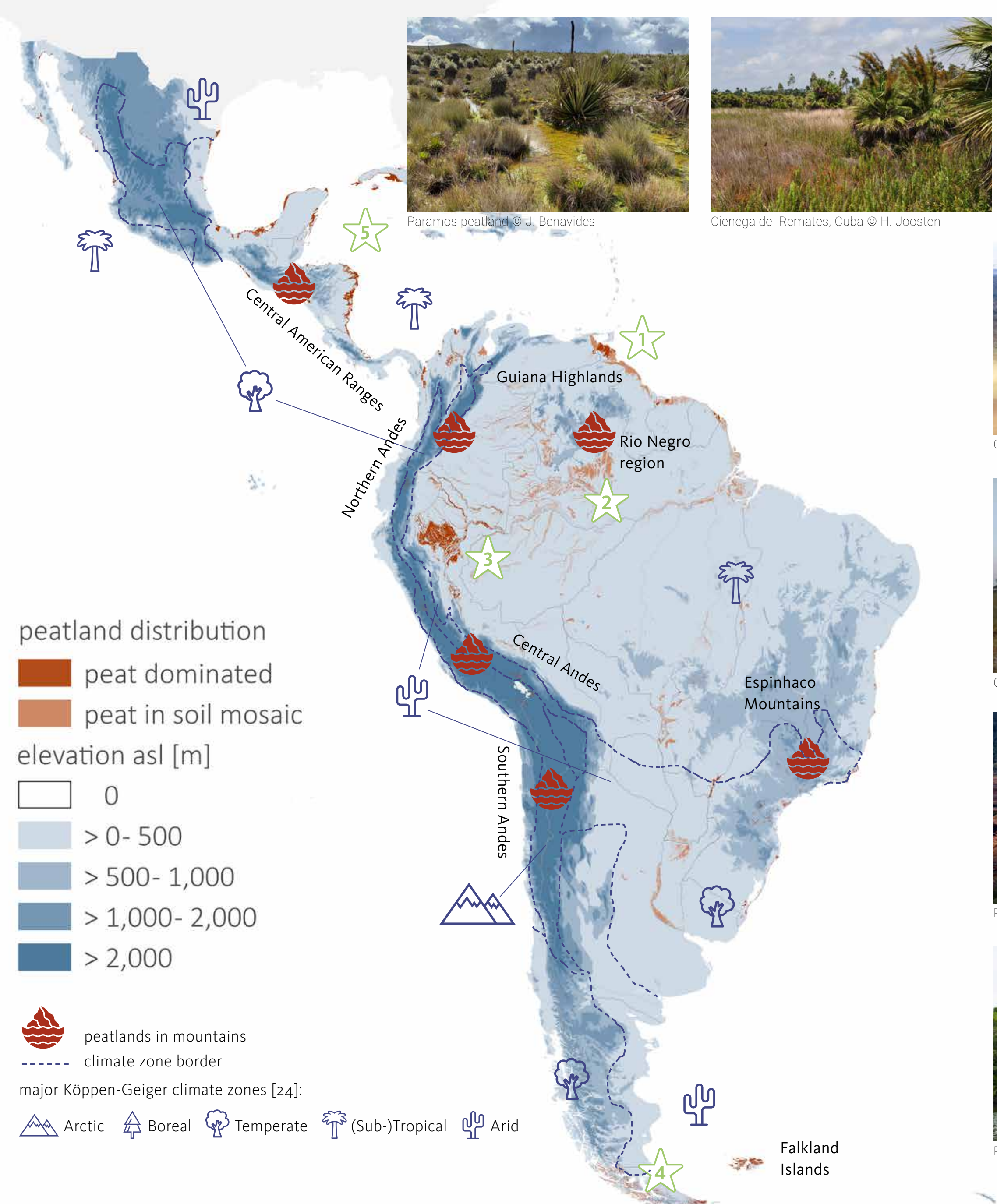


Share of global peatland area (12% [1, 23])

In Europe, peatlands are unevenly distributed, with a greater concentration in northern regions, highlands, and coastal areas (Map 3.3.1). They are sparsely distributed in steppe and broadleaf forest zones. Among all continents, Europe has experienced the highest proportional losses of actively accumulating peatlands ('mires' [1]). Nevertheless, it still harbors significant mire diversity. The **Arctic Seepage and Polygonal Mire Region**, covering the northernmost part of Europe, is characterized by the wide occurrence of tundra seepage and polygonal bogs. The **Palsa Mire Region** encompasses large areas in the Russian Federation, northern Finland, Sweden and Norway. The **Northern Fen Region**, covering the boreal vegetation zones in northern Europe, is characterized by fens and hillside bogs. The **Typical Raised Bog Region** is characterized by typical raised bogs and wooded raised bogs. The **Atlantic Bog Region** along the western European coast is defined by the wide occurrence of Atlantic raised bogs, blanket bogs and fens, and the **Continental Fen and Bog Region** is characterized by a mosaic of fens and bogs. The **Nemoral-Submeridional-Fen Region** covers large parts of England, France and Germany. Flat fens are the most characteristic mire type, alongside plane bogs and percolation bogs [3].

Approximately 10% of the former European peatland area has been entirely lost due to drainage for agriculture, forestry, and peat extraction, while around 46% of the remaining peatland area in Europe is classified as degraded; in the EU, this figure rises to 50% [1]. As a result, Europe is the second-largest emitter of GHG from drained peatlands globally. Additionally, climate change is contributing to peat loss in undrained peatlands through severe droughts and heatwaves, fires, changes in vegetation, and permafrost degradation. The significant and rapid loss of old permafrost driven by climate change has only just begun [44].

3.4 Peatlands of Latin America and the Caribbean



Paramos peatland © J. Benavides

Cienega de Remates, Cuba © H. Joosten


Canaima, Venezuela © C. Malpica


Cerrado fen, Brazil © F. Beer


Raised bog, Tierra del Fuego, Argentinia © H. Joosten


Peat Swamp Forest (Peru) © K. Hergoualc'h

Map 3.4.1 Peatland distribution in Latin America and the Caribbean [1, 22]

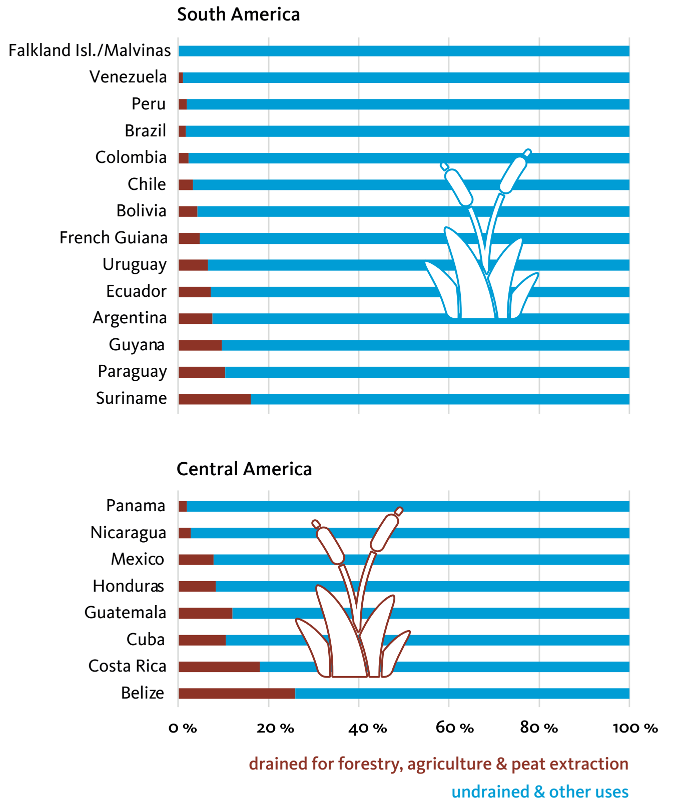
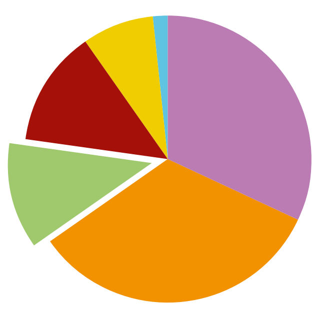
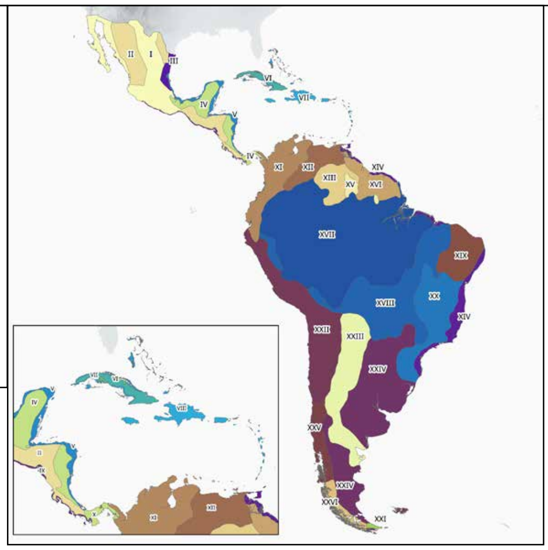


Figure 3.4.1 Status of peatlands (% [1, 23])


Share of global peatland area (13% [1, 23])



Map 3.4.2 Latin America and the Caribbean's peatland regionality map [42]

I Dryland grassy marsh, **II** C-American mountain compound fen and Paramo, **III** Western Gulf coastal marsh, **IV** C-American lowland marsh and (peat) swamp, **V** W-Caribbean coastal marsh and (peat) swamp, **VI** Caribbean Island inland marsh, **VII** Cuban peatlands, **VIII** Caribbean Islands mangrove and coastal marsh, **IX** Pacific mangrove and coastal marsh, **XI** N-Andes open fen (incl. Paramo) and swamp, **XII** Riverine palm swamp and grassy marsh, **XIII** Guiana Plateau (peat) swamp and grassy marsh, **XIV** S-American mangroves, coastal marsh and (peat) swamp, **XV** Guiana highland compound fen, **XVI** Orinoco-Guiana lowland (peat) swamp and grassy marsh, **XVII** Amazon lowland palm and (peat) swamp, **XVIII** Southern dryland grassy marsh, **XIX** Shallow depression marsh, **XX** Eastern mountain compound fen and bog, **XXII** Central Andes Paramo and Puna, **XXIII** (Sub-)tropical savanna marsh and palm swamp, **XXIV** SE-Patagonian grassy marsh, **XXV** N-Patagonian mountain fens and lowland riverine (peat) swamp, **XXVI** S-Patagonian cushion fen and Sphagnum bog, **XXI**, Tierra del Fuego raised and blanket bog

Peatlands occur across all of the region and therefore, in a diverse range of climates and ecological zones spanning from Central America to Patagonia, various types of peatlands are found within three main ecological zones: **(sub)tropical lowlands, (sub)tropical mountains, and temperate systems in Patagonia** [1, 22, 24].

The (sub)tropical lowlands of the Amazon Basin harbor a great variety of peatland vegetation with e.g., **pole forests, dominated by *Mauritia flexuosa* palms and herbaceous swamps with *Typha domingensis*. *Mauritia flexuosa*** swamps extend into subtropical savannah climates, accompanied by other **tree species and palms such as *Roystonea dunlapiana* and *Pachira aquatica*. Seasonally flooded forest** and **grassy freshwater swamps** further enrich the vegetation types found in this climate zone.

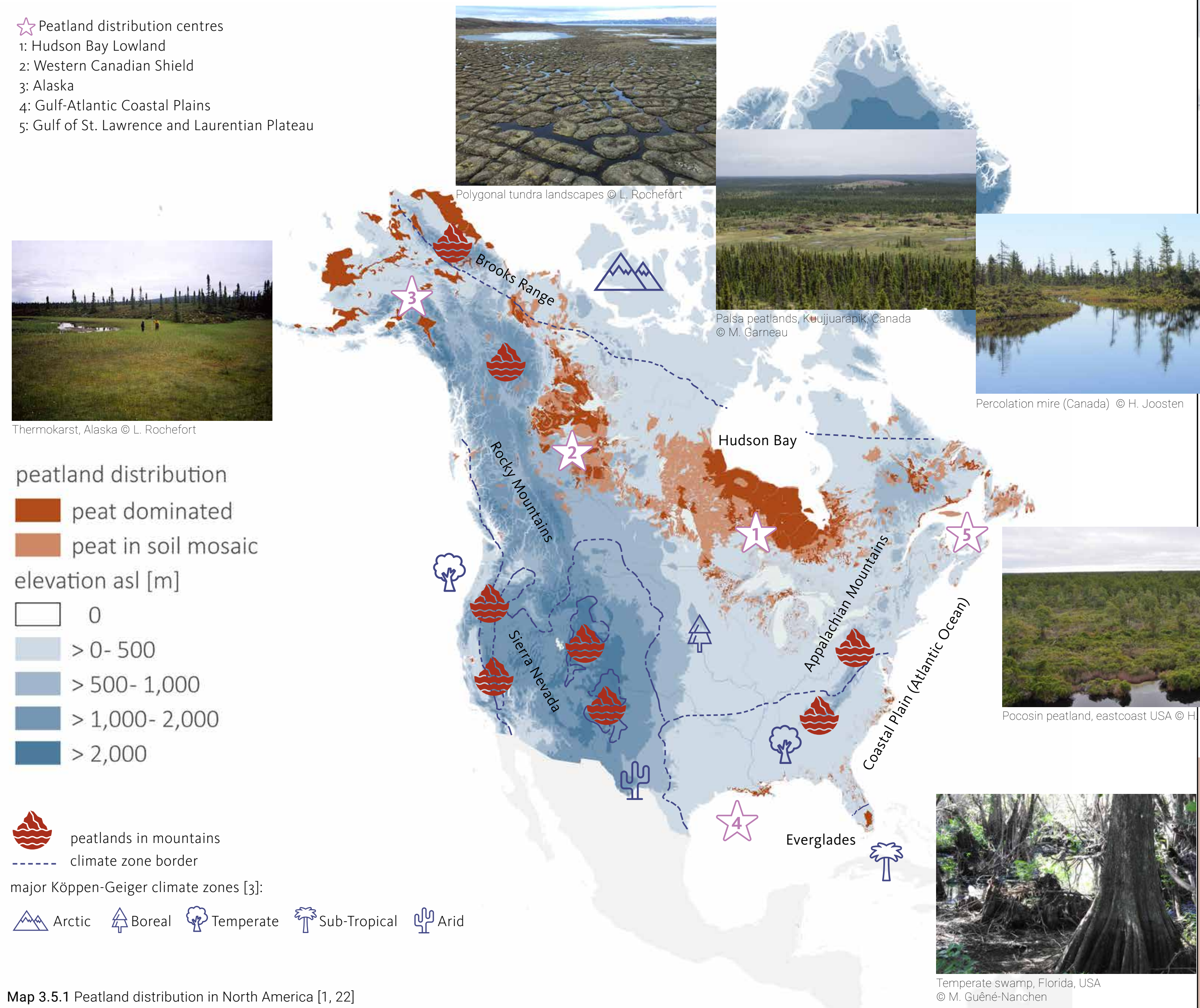
On the Caribbean Sea coast, **mangrove forests, open herbaceous swamps and peatlands dominated by *Raphia* palms** occur.

In the higher altitudes of the Andes, **cushion plant peatlands** and **sedge, grass and *Sphagnum*-dominated peatlands** are found. In the very south of the continent in Patagonia, **ombrotrophic *Sphagnum magellanicum* bogs and minerotrophic fens** dominate. In the Guayana Shield, peatlands occur atop rocky surfaces, in depressions, floodplains, and on slopes [22].

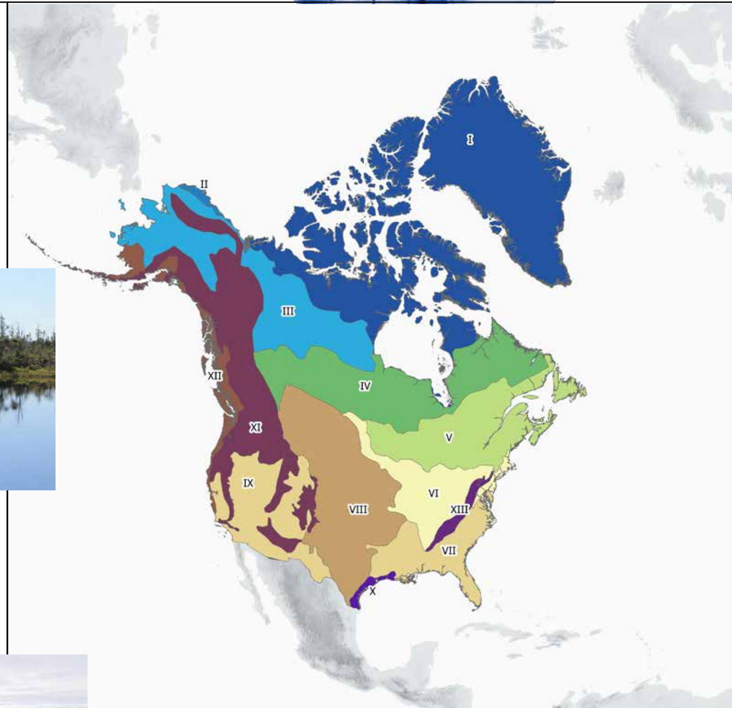
A notable share of the peatlands in Central America and the Caribbean have been drained for agriculture (e.g., banana, sugar cane, and oil palm cultivation), although the exact extent of peatland conversion remains unknown. Large peatlands in South America, particularly in the Amazon Basin, still appear to be intact due to their remote locations. However, peatlands in savannah climates have undergone significant alterations due to agriculture. In general, peatlands across the continent face increasing threats such as agriculture, overgrazing, drainage, mining, oil exploration and exploitation, dam building, and climate change. **Future mapping efforts focused on peatland drainage and land use are likely to reveal larger degraded areas across several countries.**

- **Total peatland area: 63 million ha**
- **Distribution: Orinoco Plains and Delta, Northern Amazon Basin, Western Amazon Basin, Tierra de Fuego (Patagonia), Caribbean Sea coast**
- **Peatland cover over total regional surface area: 3.2 %**
- **Share of global peatland area: 13 %**
- **Degraded peatlands: 3 %**
- **Annual GHG emissions from peatlands: 91 Mt CO_2e / yr**
- **Share of global GHG emissions from peatlands: 5 %**
- **Peatlands within protected areas: 26 %**
- **Top 5 countries with largest peatland area:**
  1. **Brazil (26,019,489 ha)**
  2. **Peru (7,651,400 ha)**
  3. **Colombia (5,407,898 ha)**
  4. **Venezuela (5,307,400 ha)**
  5. **Argentina (3,031,659 ha)**
- **Total peatland carbon stock: 20,846 Mt C [77]**
- **Threatened peatland species: Flora: 3 VU, 7 EN, 2 CR; Fauna: 68 VU, 49 EN, 32 CR [79]**
- **Ramsar Wetlands of International Importance with peat: 45 sites (21.2 % of total Ramsar sites in Latin America and the Caribbean [78])**

3.5 Peatlands of North America



Map 3.5.1 Peatland distribution in North America [1, 22]



Map 3.5.2 North America's peatland regionality map [42]

I Arctic fen of unknown extent, **II** Polygon and palsa mire, **III** Arctic fen, **IV** Sphagnum and Spruce bog, **V** Atlantic (raised) bog, **VI** Eastern forested fen, **VII** Southeastern forested and grassy fen (incl. Pocosin), **VIII** Prairie grassy marsh, **IX** Dryland grassy marsh, **X** Western Gulf coastal marsh, **XI** N-America Western mountain compound fen and bog, **XII** Pacific (raised) bog, **XIII** N-America Eastern mountain compound fen and bog

- **Total peatland area: 158 million ha**
- **Distribution: Hudson Bay Lowland, Canadian Shield, Alaska, Coastal Plain (Gulf of Mexico), Labrador Peninsula / Newfoundland**
- **Peatland cover over total regional surface area: 8.5 %**
- **Share of global peatland area: 32 %**
- **Degraded peatlands: 2 %**
- **Annual GHG emissions from peatlands: 89 Mt CO_2e / yr**
- **Share of global GHG emissions from peatlands: 5 %**
- **Peatlands within protected areas: 20 %**
- **Top 5 countries with largest peatland area:**
  1. **Canada (119,377,000 ha)**
  2. **United States (38,813,000 ha)**
  3. **Greenland (8,000 ha)**
- **Total peatland carbon stock: 184,151 Mt C [77]**
- **Threatened peatland species: Flora: 12 VU, 15 EN, 11 CR; Fauna: 30 VU, 21 EN, 5 CR [79]**
- **Ramsar Wetlands of International Importance with peat: 36 sites (16.4 % of total Ramsar sites in North America [78])**

In North America, **peatlands are widespread in the cold low arctic climate zone,** becoming rarer towards the middle and high Arctic [1, 24]. **Arctic peatlands (Pingos, Polygonal Peatlands, Palsas,** in Alaska, Northwest Territories, Yukon Territory, Nunavut, northern Alberta, Saskatchewan, Greenland) often have a low peat thickness and the transition between peatlands and wet tundra is difficult to distinguish. The vegetation of **arctic fens** consists mainly of brownmosses (e.g., *Scorpidium*, *Aulacomnium*), sedges (e.g., *Carex aquatilis*, *Eriophorum scheuchzeri*), and grasses (e.g., *Arctagrostis latifolia*, *Dupontia fisheri* [1]).

From Alaska to Newfoundland, Labrador, and north of the prairies, **peatlands cover about 25–30% of the boreal forest biome.** They are shaped by latitudinal and longitudinal climate gradients, as well as the geological formations on which they lie [22, 24]. They occur as ***Sphagnum* moss and spruce bogs** which exhibit a variety of Sphagnum species and dwarf shrubs, whereas **fens** are dominated by Cyperaceae species such as *Carex aquatilis*, *C. lasiocarpa*, *Trichophorum cespitosum*, and wooded swamps feature trees such as *Acer rubrum*, *Abies balsamea*, *Fraxinus nigra*, or *Alnus*.

***Sphagnum* bogs, fens, kettle hole mires** and **wooded swamps** are also found in temperate regions, such as along the east coast of the U.S. and Canada, and in the Great Lakes region, often with forest or high shrub cover. The diversity of peatlands here is determined by peat thickness, water table fluctuations, and tree density [1].

In the southeastern U.S. coast and coastal plains from Virginia southward to the Everglades of South Florida and westward along the Gulf of Mexico, **swamps and 'pocosins' are common. Swamps** are dominated by tree species like *Pinus*, *Chamaecyparis*, *Taxodium*, *Acer*, *Nyssa*, or *Persea*, while fens are characterized by Cyperaceae and Poaceae. Typical **Pocosin** vegetation is very acidic and dominated by pine woodlands or cedar forest. These communities occur on peatlands of poorly drained interstream flats, and peat-filled bay depressions. The wettest sites (or the center of bays) may contain only low shrubs and stunted pond pine, with beds of *Sphagnum*, pitcher plants (*Nepenthes*), and cranberry (*Vaccinium* [45]).

The sub-tropical shorelines can host **mangrove forests** with *Rhizophora mangle*, *Avicennia germinans*, and *Laguncularia racemosa*. Boreal, temperate and sub-tropical mountain systems host **fens** dominated by Cyperaceae, and **blanket bogs** dominated by Sphagnum, Cyperaceae and dwarf shrubs in the Rocky Mountains, Brooks Range (Alaska), Sierra Nevada (California), and eastern North American Mountains. Only about 2% of North America's vast peatlands are degraded, because many are located in arctic and boreal climates unsuitable for agriculture or forestry and sparsely populated. However, peatlands have suffered from intensive land-use-related drainage and degradation, mainly for agriculture, in temperate and subtropical climates and from oil, gas and oil sand exploration and extraction also in the boreal and the arctic. Climate change is expected to affect all peatlands in North America in the future, including the vast permafrost peatlands and boreal areas [46, 47], which are threatened by permafrost thaw and increased fire frequency and intensity [1].

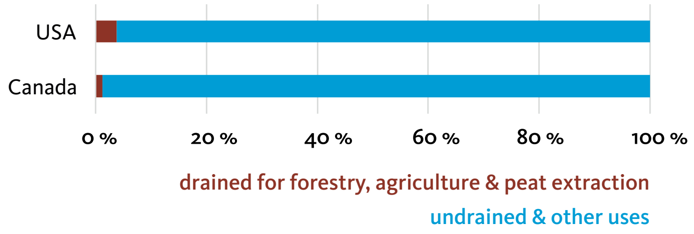
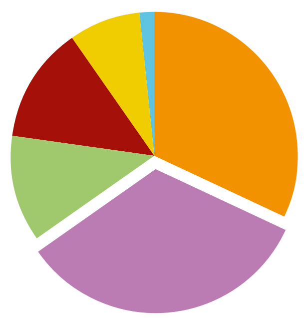
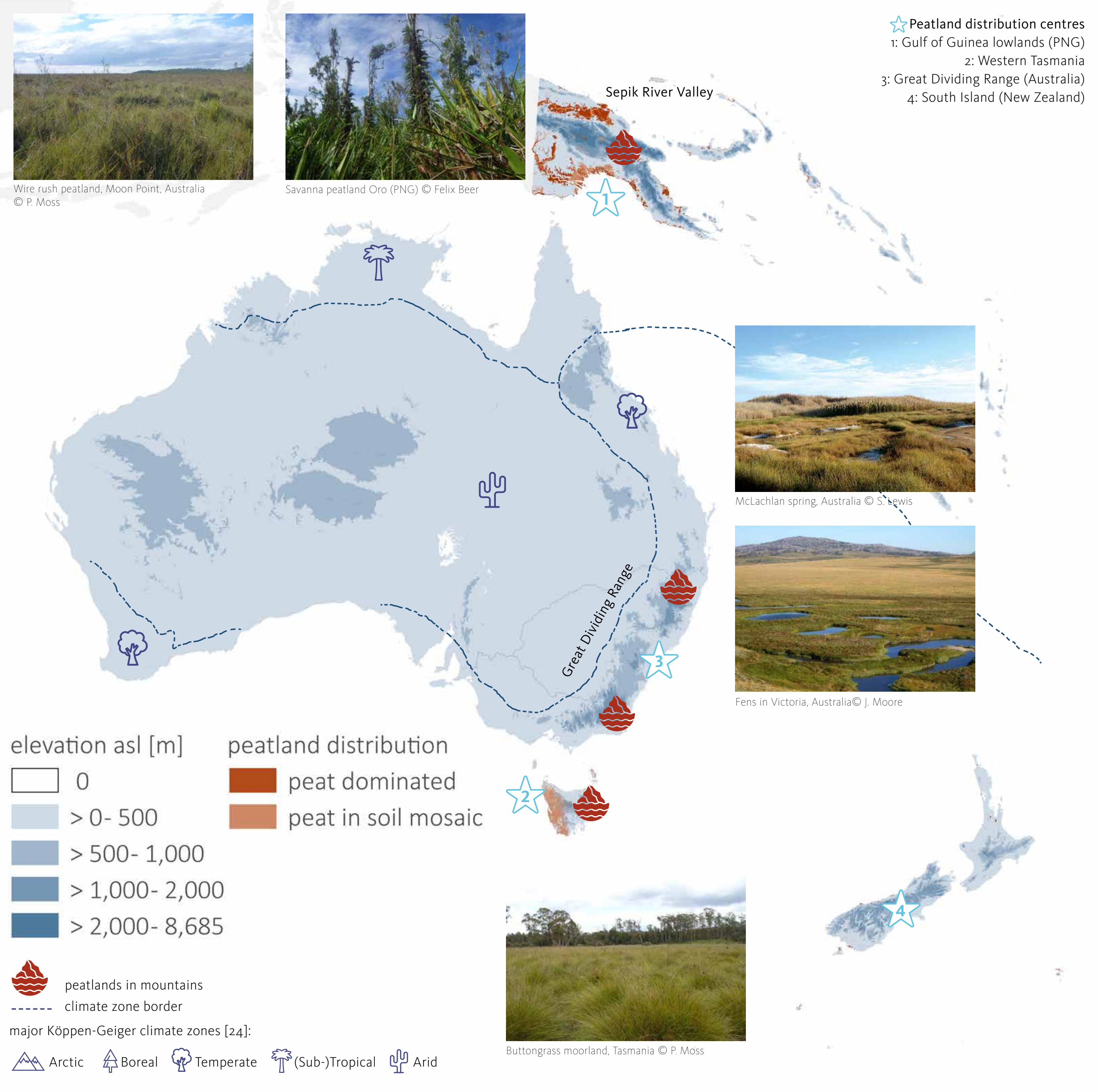


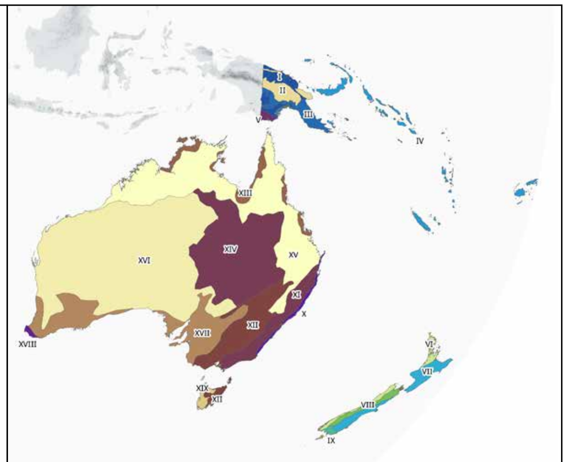
Figure 3.5.1 Status of peatlands (% [1, 23])


Share of global peatland area (32.5% [1, 23])

3.6 Peatlands of Oceania



Map 3.6.1 Peatland distribution in Oceania [1, 22]



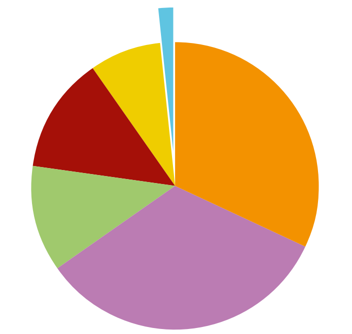
Map 3.6.2 Oceania's peatland regionality map [42]

I New Guinea peat swamp forest and grassy marsh, **II** Central Range blanket and cushion bog, **III** New Guinea swamp forest and grassy marsh, **IV** Pacific Islands lowland and mountain swamp and marsh, **V** Trans Fly savannah marsh, **VI** N- and W-New Zealand marsh, **VII** New Zealand lowland restiad bog, fen and swamp, **VIII** New Zealand mountain compound fen and bog, **IX** - Tasmania button-grass blanket and cushion bog, **X** E- Australian mangrove and coastal marsh, **XI** E-Australian mountain compound fen and bog, **XII** SE-Australian temperate marsh, **XIII** N-Australian mangrove and coastal marsh, **XIV** C-Australian artesian spring mound, **XV** Australian (sub-)tropical marsh, **XVI** Dryland grassy marsh, **XVII** S-Mediterranean marsh, **XVIII** SW-Australian wire rush fen.

- **Total peatland area: 7 million ha**
- **Distribution: Gulf of Guinea lowlands (Papua New Guinea), Western Tasmania, Great Dividing Range (Australia), South Island (New Zealand)**
- **Peatland cover over total regional surface area: 1 %**
- **Share of global peatland area: 1.5 %**
- **Degraded peatlands: 10 %**
- **Annual GHG emissions from peatlands: 28 Mt CO_2e / yr**
- **Share of global GHG emissions from peatlands: 1 %**
- **Peatlands within protected areas: 26 %**
- **Top 5 countries with largest peatland area:**
  1. **Papua New Guinea (4,469,008 ha)**
  2. **Australia (2,500,000 ha)**
  3. **New Zealand (269,363 ha)**
  4. **New Caledonia (20,000 ha)**
  5. **Solomon Islands (10,000 ha)**
- **Total peatland carbon stock: 6,733 Mt C [77]**
- **Threatened peatland species: Flora: 10 VU, 5 EN, 0 CR; Fauna: 34 VU, 32 EN, 18 CR [79]**
- **Ramsar Wetlands of International Importance with peat: 18 sites (21.4 % of total Ramsar sites in Oceania [78])**

Oceania is a diverse region spanning continental landmasses and climate zones, large islands, and small islands, supporting a wide variety of peatland ecosystems [1, 3]. The majority of Oceanian peatlands are dominated by the **Restionaceae, Cyperaceae, Ericaceae and Myrtaceae** plant families. Unique and important peat-forming ecosystems in this region include buttongrass moorlands (dominated by the Cyperaceae Gymnoschoenus sphaerocephalus) found in western Tasmania, and **paper bark forests (*Melaleuca*)**, particularly found in lowland areas throughout Oceania. Moreover, **sedge and rush-dominated coastal peatlands** extend from subtropical Australia to Tasmania. ***Empodisma*** is another key peat-building genus of the Restionaceae family found in South Australia and on New Zealand. Peatlands in mainland Australia occur with a limited spatial extent in mountains, along the coasts and rarely in artesian springs. In Papua New Guinea, a wide range of peatland types is found in valley bottoms, behind river levees, along the coast, at lake margins and in the high mountains. They are dominated by **montane and lowland swamp forests, tall grass fens, short grass fens, mixed sedge-grass fens, and tall sedge fens.** While montane peatlands are mostly groundwater-fed fens, sub-alpine peatland types are mainly rainwater-fed bogs [1, 48, 49, 50].

Peatlands also occur on Pacific Island Countries and Territories on raised atolls [2], dominated by ***Acrostichum* and *Cyclosorus* ferns, palms, and by Eleocharis, *Scirpus*, *Schoenoplectus* or *Pandanus*.** Additionally, peatlands are found in several volcanic calderas filled with peat from **Cyperaceae (sedges), *Scirpus* rushes, *Schoenoplectus* rushes, or extensive floating peat-forming mats of sedges and rushes.** Antarctic peatlands located on small islands north of the Antarctic Peninsula are formed by Chorisodontium aciphyllum and Polytrichum strictum mosses. In this region, peat layers can reach depths of up to 2 meters and be 6,000 years old, while those located farther south are typically shallower and younger. Sub-Antarctic peatlands exhibit greater plant diversity and are characterized by a predominance of vascular plants as the peat-forming species. Peat in these regions is formed from the partly decomposed litter of **small trees, shrubs, grassland, megaherbs, and tundra vegetation.** On Campbell Island, peat covers nearly the entire 11,300 hectare land surface, hosting numerous oligotrophic bogs reaching depths of up to 6 meters [1, 51].



Share on global peatland area (1.5% [1, 23])

Around 10% of the peatlands in Oceania are degraded, with New Zealand standing out where more than 70% of its peatlands have been drained for forestry, agriculture, and peat extraction. For all other countries, the estimated proportion of drained peatlands is less than 15% [1]. Across most tropical islands, coastal peatlands have been modified for agriculture. Key drivers of change in Oceania's peatlands include drainage, agricultural conversion, altered catchment hydrology, climate change, and fire. Specific regions also face challenges from peat extraction, invasive alien species, and pollution. In Antarctica, fluctuations in seal and penguin populations linked to climate change act as potential drivers affecting moss peat banks [1].

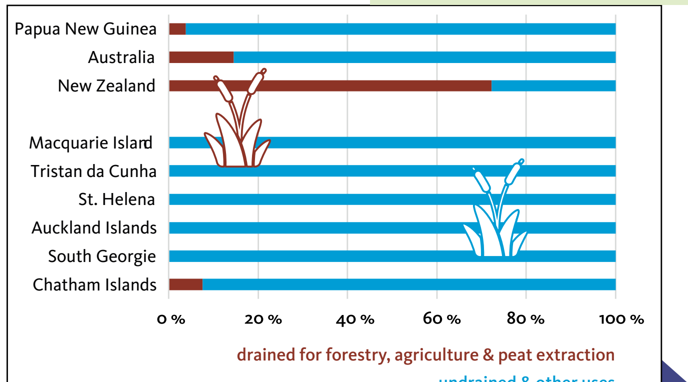
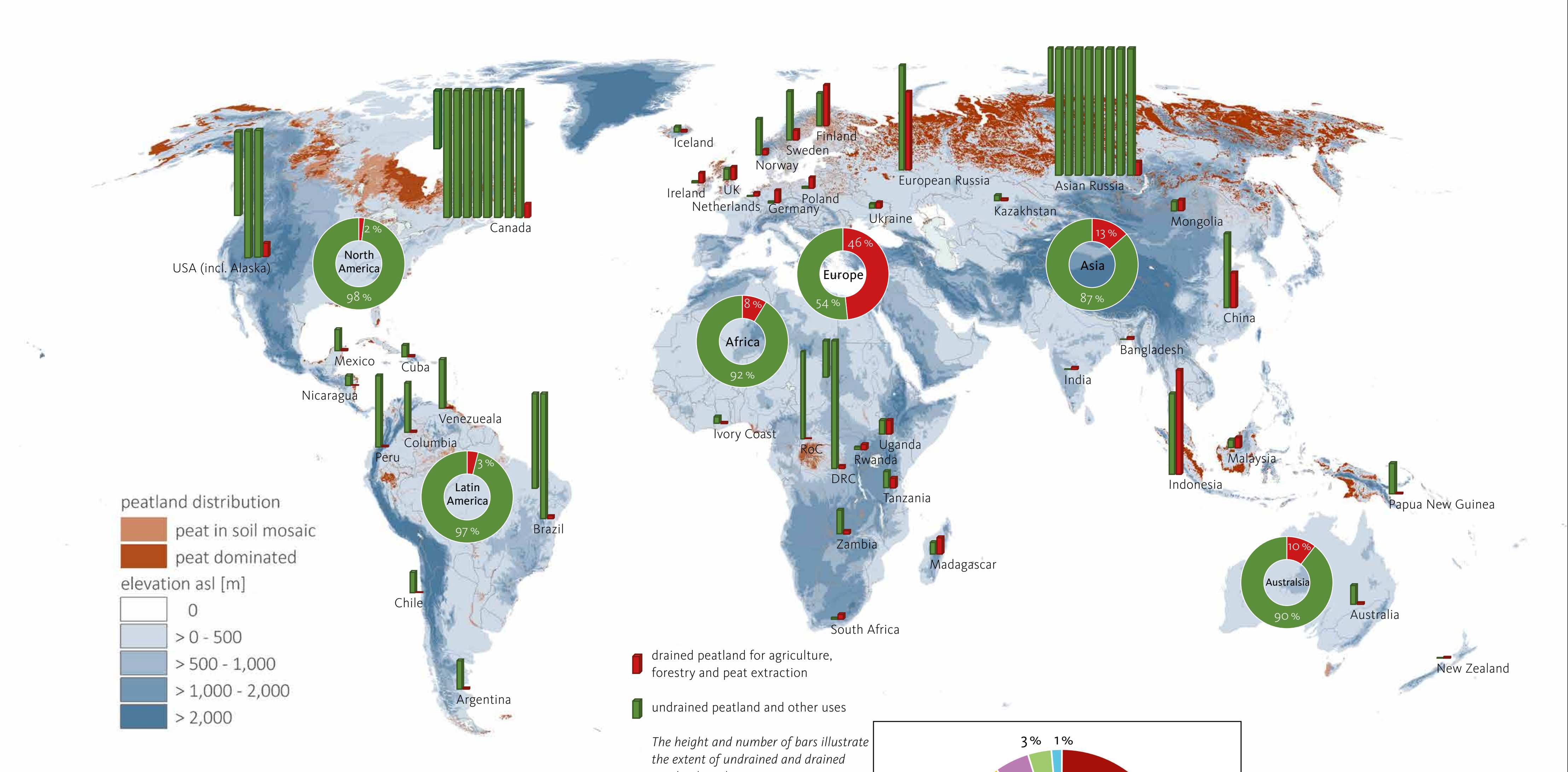


Figure 3.6.1 Status of peatlands (% [1, 23])

4.1 Global peatland drainage



Map 4.1.1 Global peatland drainage distribution [1, 22, 23]

Artificial drainage is the most common cause of peatland degradation, leading to the deterioration of their ecological functions and ecosystem services, subsidence, and greater susceptibility to flooding and fire. Peatlands exist where a high groundwater table hampers the decomposition of organic material. As a result production of organic matter is larger than decomposition, leading to the formation and accumulation of peat. However, drainage transforms peatlands from CO_2 sinks to CO_2 sources, where the intensity of GHG emissions depends on drainage depth and ditch density.

Temperate Europe and tropical Asia, particularly Southeast Asia, account for 85% of the world's drained peatlands (Figure 4.1.1). The vast, untouched 'peatscapes' of the boreal and arctic regions have largely survived due to their harsh climates, which limit agriculture, forestry, and human settlement. Future mapping and assessments are likely to reveal more drained peatlands in South America, Africa, southeastern Europe, and central and northern Asia [1, 22].

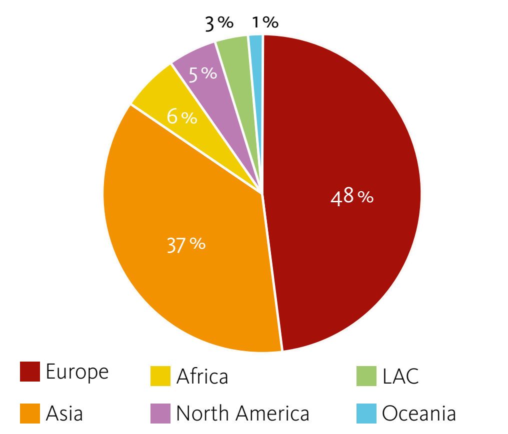


Figure 4.1.1 Global distribution of drained peatlands (% [1, 23])

Deep artificial drainage is a common prerequisite for using peatlands for intensive agriculture, forestry, peat extraction, or infrastructure. This practice reduces landscape-level water availability, disturbs the ecological functions of peatlands, and transforms them from CO_2 sinks to CO_2 sources.

1) Drained bog, Scotland, UK © H. Joosten 2) Drained Peat Swamp Forest, Indonesia © K. van Lohuizen/NOOR 3) Drainage for peat extraction, Rwanda © S. Elshehawi 4) drainage for mushroom production, China © H. Joosten 5) Drained Pocosin peatland, USA © H. Joosten 6) Drainage for forestry, Finland © S. Vei (Wikimedia Commons) 7) Drainage for oil palm plantation, Indonesia © F.A. Aziz (CIFOR)

4.2 Global peatland degradation

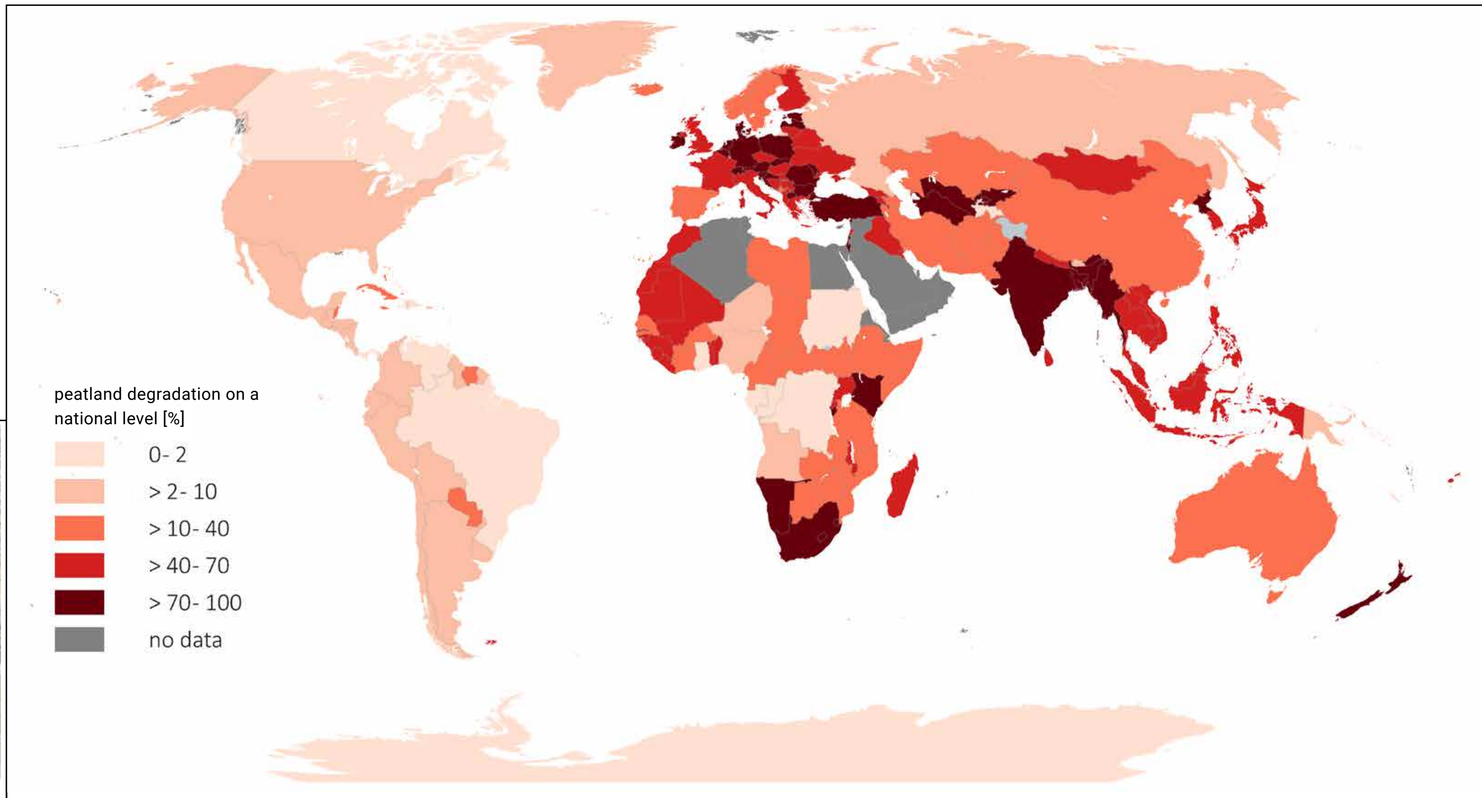
Peatland degradation has multiple causes and a wide range of effects. Heavily degraded peatlands have lost crucial functions such as carbon sequestration and storage, provision of habitat for rare species, cleaning, regulating and storing water, and local climate cooling. In healthy peatlands, functional relationships exist between plants, water, and peat, with changes in one component affecting eventually all others: vegetation changes first, followed by hydrology, and later the peat body itself. Table 4.2.1 illustrates various stages of peatland degradation, with components of increasing being affected. When more inert components are degraded (e.g., the peat itself), full restoration often requires more complex and labor-intensive efforts or even becomes impossible [52].

Figure 4.2.1 undegraded peat [53 A]

Figure 4.2.2 degraded peat [53 B]

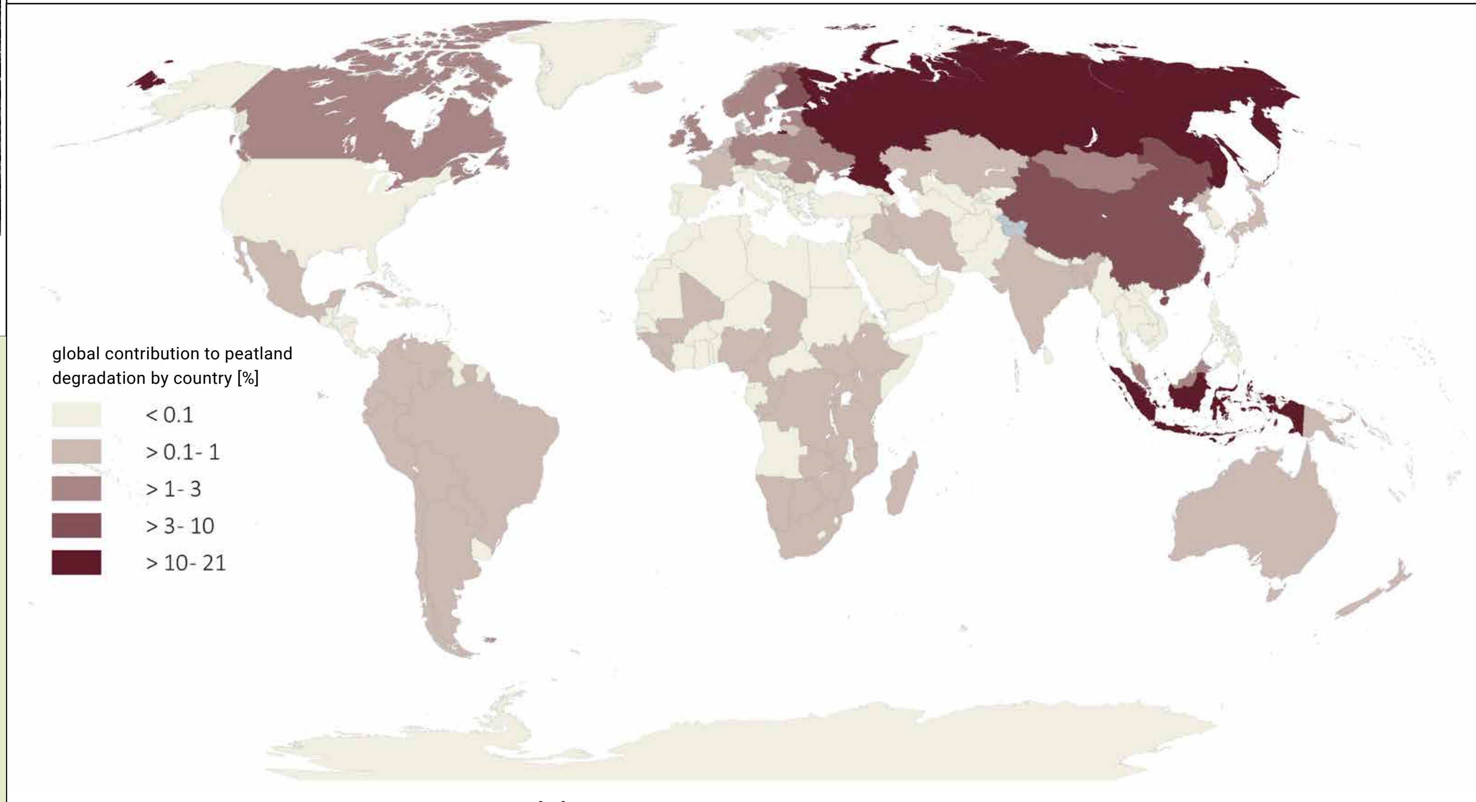
increasing peat degradation

Peatland degradation often begins with artificial drainage, but may also result from overgrazing and trampling, oil spills and burning, waste dumping, and infrastructure development, with climate change further intensifying the degradation.



Map 4.2.1 Global peatland degradation distribution at a national level [23]

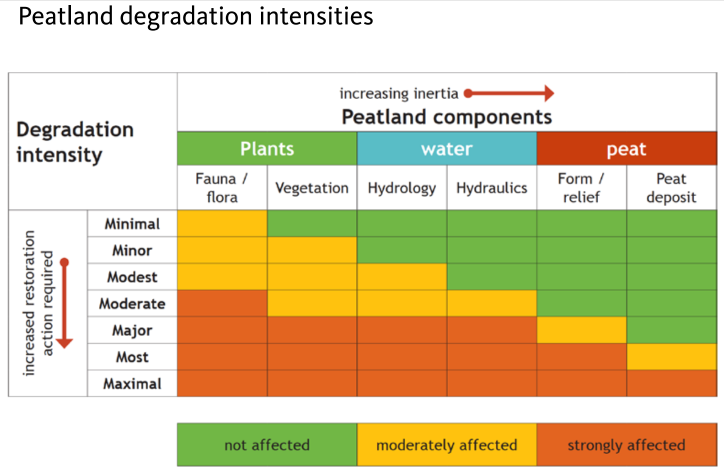
The share of degrading peatlands on a national level.



Map 4.2.2 Global peatland degradation distribution at a global level [23]

The share of countries on the degrading peatlands global level.

Table 4.2.1 Peatland degradation intensities [52]

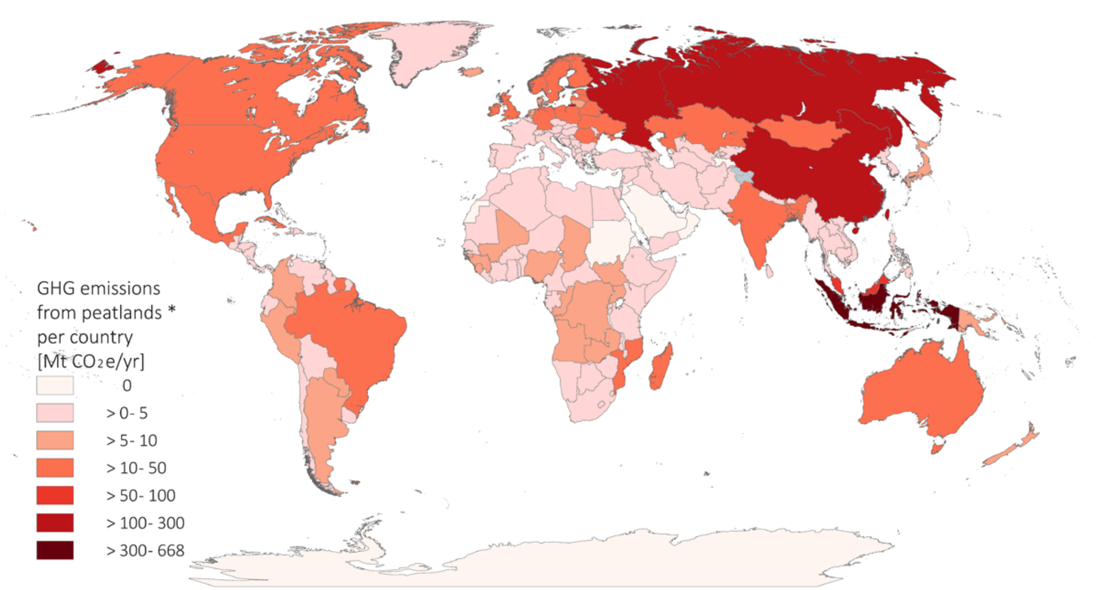


Peatland degradation involves changes in plants, water, and peat qualities over time. The most apparent signs of degradation is vegetation change, the most grave consequences have irreversible changes in the structure and porosity of the peat by decomposition and compaction and its eventual breakdown into a cracked, crumbed, and even powder-like structure (Figures 4.2.1 and 4.2.2). In the initial stages of **minimal** or **minor** degradation, vegetation may be damaged or removed, but the hydrology and the peat remain intact (top right figure). **Modest** degradation involves recent drainage and vegetation change, while **moderate** degradation already shows evident changes in peatland hydraulics, though restoration still remains feasible. **Major** degradation occurs when long-term, deep drainage and destructive use have caused irreversible changes in the structure of the peat, making it compact and much less porous and later also loose and with newly formed macropores. The **most** severe degradation is when the peat body has become completely out of hydrological balance due to subsidence, peat extraction, erosion, fire, or oxidation. Finally, in the **maximal** stage, most or all of the peat has been removed or oxidized, causing the peatland to virtually cease being a peatland [53 A,B].

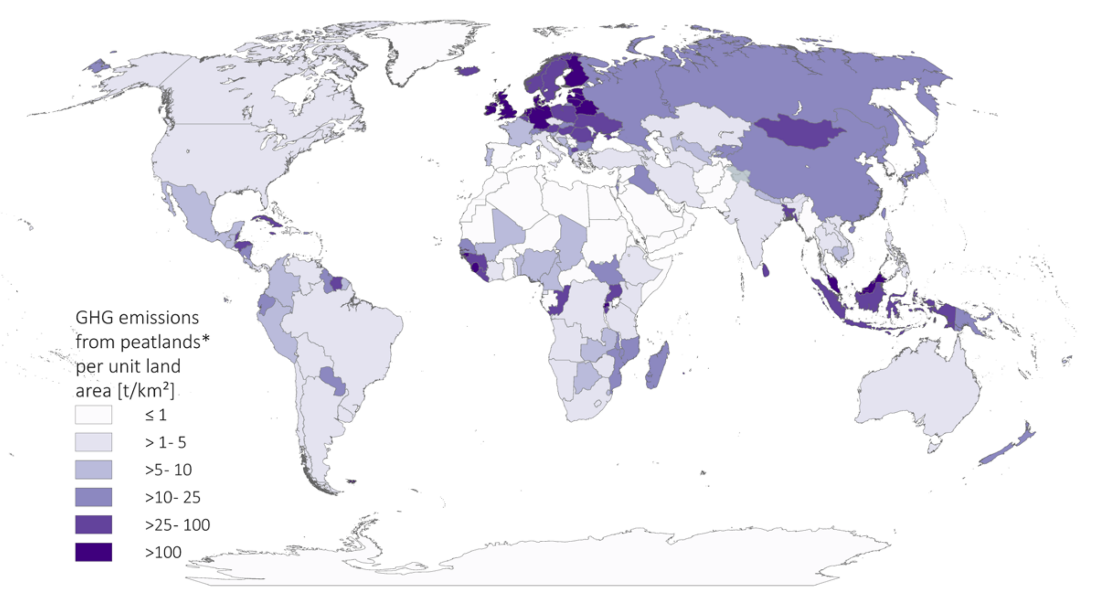
In more than 30 countries, especially in Europe and Asia, where peatlands have long been used for the production of food, fodder, fiber and fuel, over 70% of national peatlands have been degraded (Map 4.2.1 [23]). Notably, only a few countries account for the majority of global peatland degradation, with over 50% attributed to Indonesia, Russia, Finland and China (Map 4.2.2). Among these, only Indonesia is a hotspot of peatland restoration and raising water levels over substantial peatland areas. Overall, future peatland mapping is likely to reveal more degradation in other regions as well.

Marginalized communities, particularly women, who depend on peatlands for water and essential resources, including food security, are significantly affected by peatland degradation. This degradation undermines the ecosystem services these areas provide, disproportionately impacting vulnerable communities that rely on these natural resources to sustain their livelihoods [1].

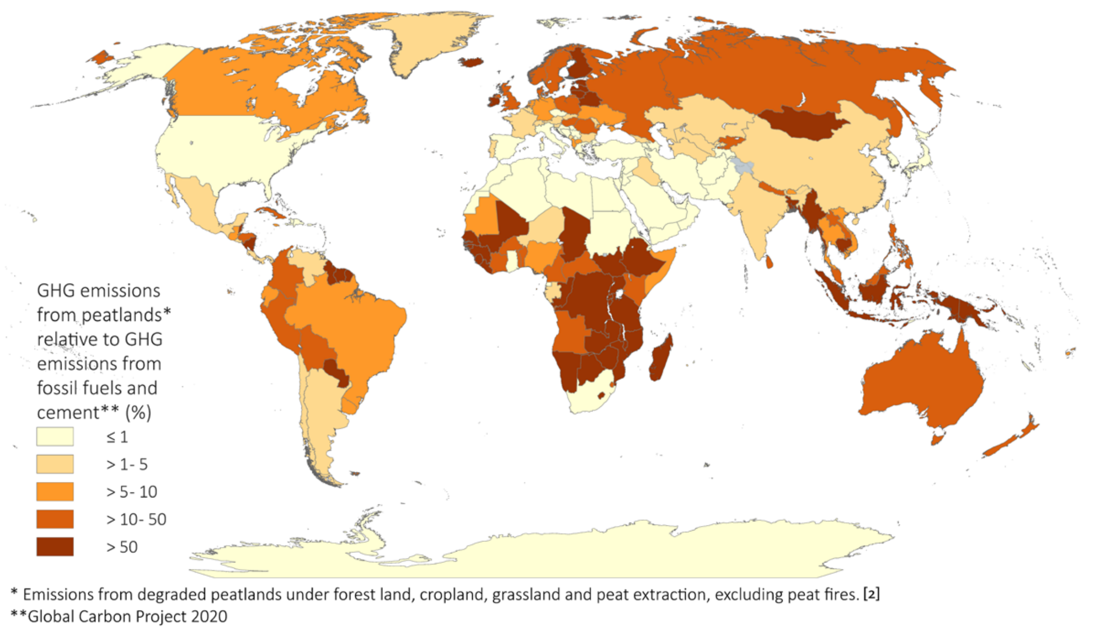
4.3 Global greenhouse gas emissions from peatland



Map 4.3.1 GHG emissions from peatland per country [23]



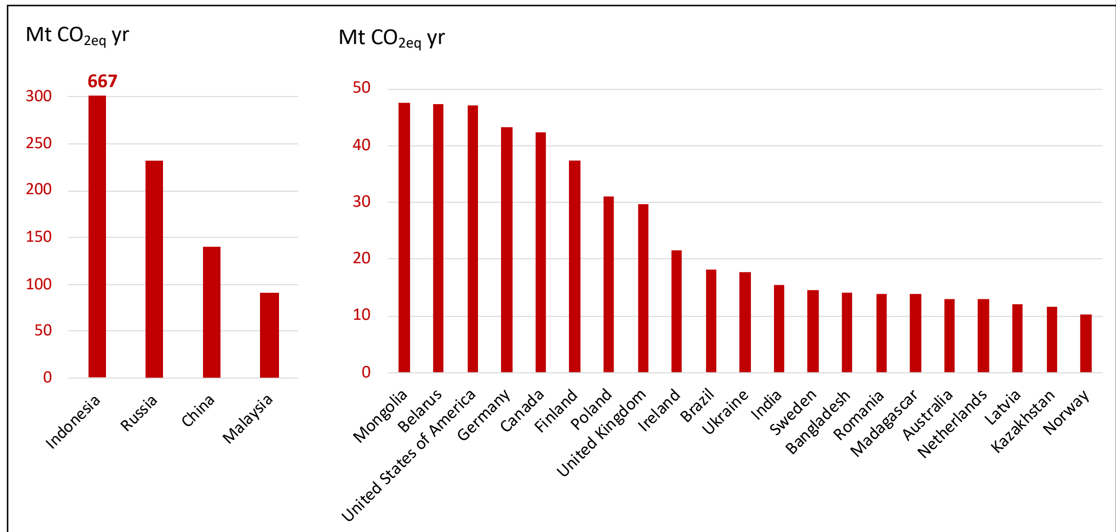
Map 4.3.2 GHG emissions from peatland per unit land area [23]



* Emissions from degraded peatlands under forest land, cropland, grassland and peat extraction, excluding peat fires. [2]
**Global Carbon Project 2020

Map 4.3.3 GHG emissions from peatland relative to emissions from fossil fuels and cement [23]

Figure 4.3.3 Greenhouse Gas Emissions from peatlands: 25 key countries emitting 85 % of GHG emissions from peatlands globally. Calculations are based on drained area for forestry, agriculture, peat extraction, (incl. ditches) using IPCC emission factors for CO_2, CH_4, N_2O, DOC [54].



GHG emissions from degraded peatlands under forest land, cropland, grassland and peat extraction (excluding peat fires) are estimated at around 1,940 Mt CO₂e per year, which is about 4% of total global anthropogenic GHG emissions. Indonesian peatlands emit almost 668 Mt CO₂e per year, followed by the Russian Federation and China with about 230 Mt CO₂e and 140 Mt CO₂e per year, respectively (Figure 4.3.3; Map 4.3.1 [1, 23]. These three countries contribute half of the total annual GHG emissions from drained organic soils. However, Indonesia is making major efforts to rewet peatlands, which is not yet included in the data presented here. 85% of global peat-related GHG emissions are caused by 25 UNFCCC member states that each emit more than 10 million tons of CO₂e per year. These countries are mainly located in Europe, Asia and North America. Madagascar is the only African nation represented, with no countries from South America included. However, this may change with increasing knowledge about peatland distribution and condition increases. Map 4.3.2 shows countries with high emissions per unit total national land area, likely indicating a high density of deeply drained peatlands. Map 4.3.3 compares emissions from peatlands with emissions from fossil fuels and cement. It highlights countries where emissions from peatlands contribute significantly to the national GHG budget and should be considered their NDC strategies. Water plays a crucial role in peatland GHG emissions. There is a clear relationship between mean annual water levels and annual emissions (CO_2, CH_4 and N_2O). The deeper a peatland is drained, the greater the release of greenhouse gases (Figure 4.3.1). In the context of climate change mitigation, the optimal mean annual water level depth ranges between 10 and 0 cm below the surface. At higher levels of flooding, CH_4 emissions increase.

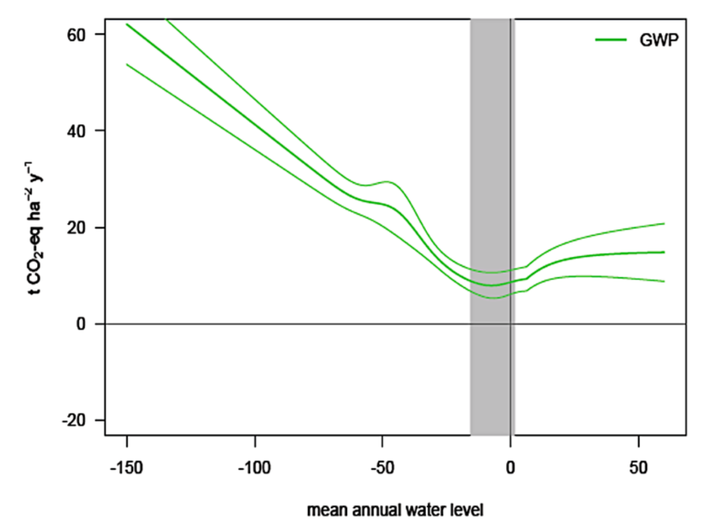


Figure 4.3.1 Relationship between mean annual water level (in cm to surface) and GHG emissions in peatlands in temperate Europe

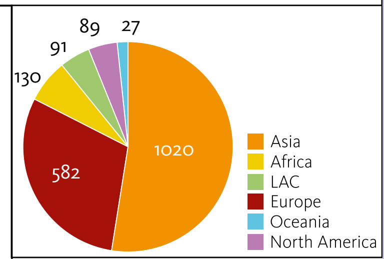


Figure 4.3.2 Global peatland GHG emissions Mt CO₂e. [1, 23]


GHG measurements in peatland, Germany © H. Joosten

GHG emissions from degraded peatland, estimated at around 1,940 Mt CO₂e annually, account for approximately 4 % of global anthropogenic GHG emissions. Water levels play a crucial role, with deeper drainage leading to larger greenhouse gas emissions.


Degraded mountain peatland, UK © H. Joosten


Smallholder farm, Indonesia © S. Page


Degrading peatland, Iceland © H. Joosten


Degrading peatland, North Korea © H. Joosten

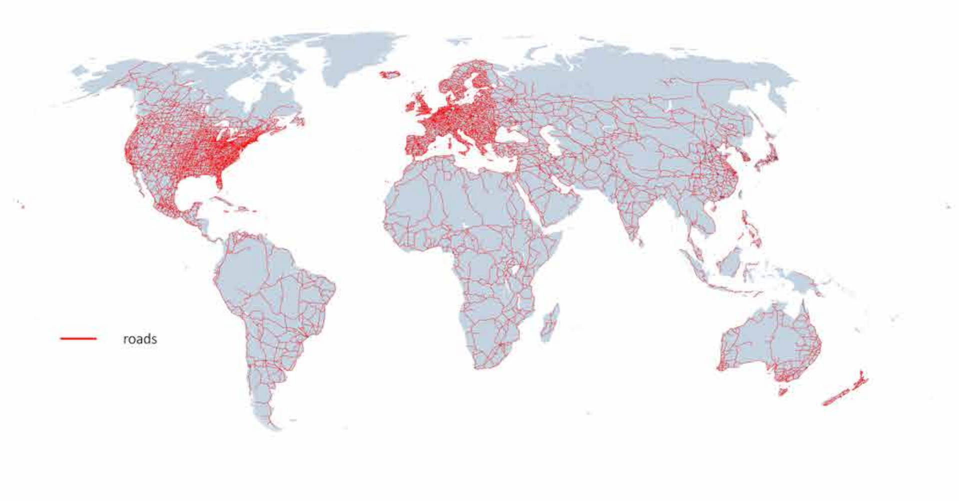

Degrading forested bog, Canada © M. Garneau


Burning peatland, Indonesia © CIFOR

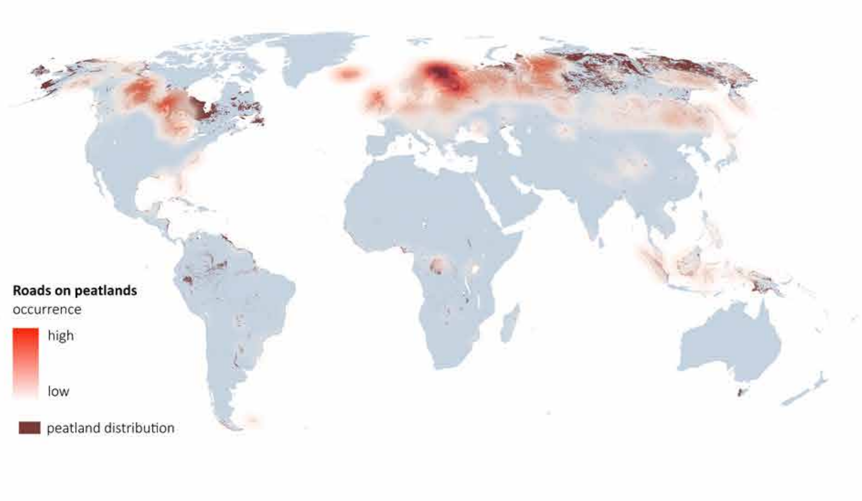

Horticulture on degrading peatland, UK © S. Page

4.4 Transport infrastructure on peatland

Roads on peatland

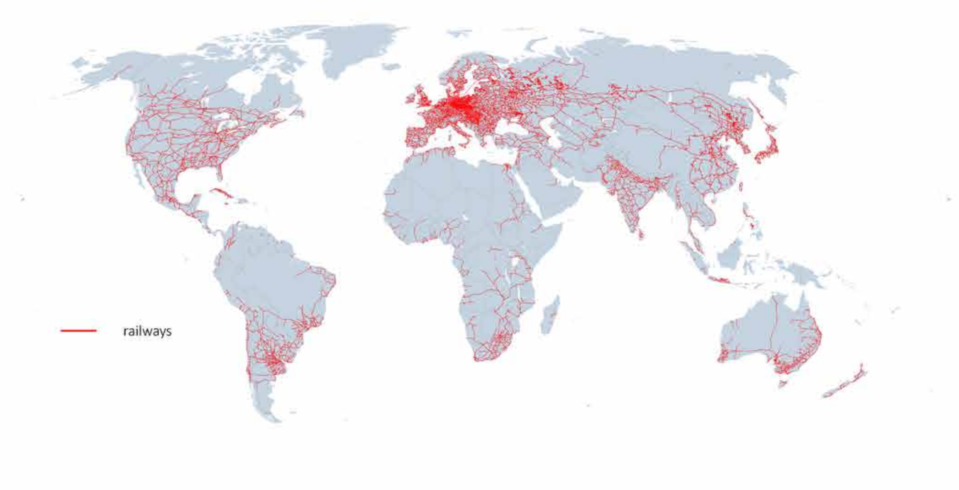


Map 4.4.1 Global distribution of roads [55]

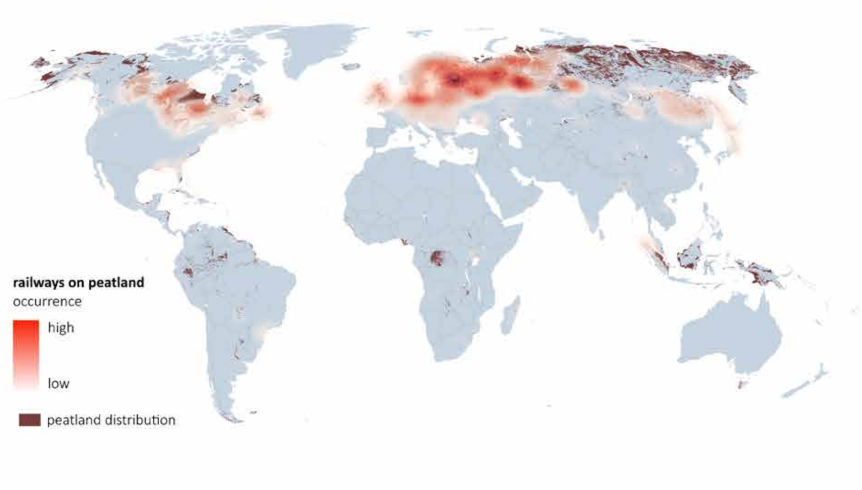


Map 4.2.2 Hotspots of roads on peatland [22, 55]

Railways on peatland

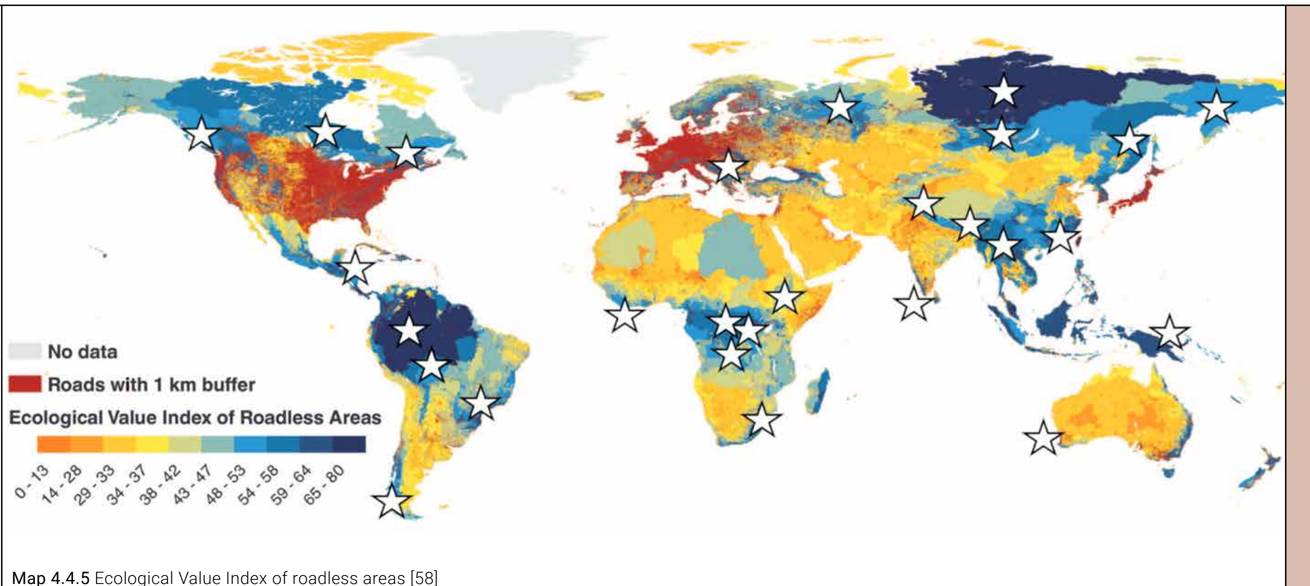


Map 4.4.3 Global distribution of railways [55]



Map 4.4.4 Hotspots of railways on peatland [22, 55]

About 80% of Earth's terrestrial surface remains roadless, but this area is heavily fragmented into approximately 600,000 patches [58]. More than half of these patches are smaller than 1 km², and only 7% are larger than 100 km². The remaining roadless areas on the planet (blue colors in figure left) are crucial for sustaining habitats for biodiversity conservation and for providing globally significant ecosystem services. Intriguingly, many of these remaining roadless areas on the planet also contain - not surprisingly - vast expanses of (partly understudied) peatlands, indicated with the stars in Map 4.4.5.



Map 4.4.5 Ecological Value Index of roadless areas [58]

☆ occurrence of (partly understudied) peatlands in roadless areas [22, 58]

Wherever roads are constructed in previously remote areas, they facilitate human access, exploitation and land cover change. In the case of peatlands, these changes often begin with vegetation removal and drainage. Other direct and indirect environmental impacts include habitat fragmentation, chemical pollution, noise disturbance, increased wildlife mortality due to collisions and poaching, changes in population gene flow, and facilitation of biological invasions. Furthermore, the initial roads open up remote areas to further infrastructure proliferation, including more roads.

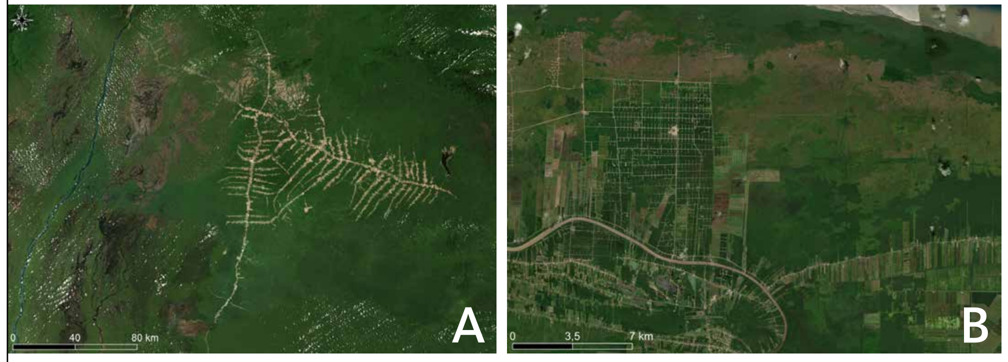


Figure 4.4.1 A) Roads approaching the vast peatlands along the Rio Negro and Rio Branco of Northern Brazil in the Amazon Basin; B) Roads already enabling peatland and wetland exploitation in Suriname (West of Paramaribo; satellite image by BING AERIAL)

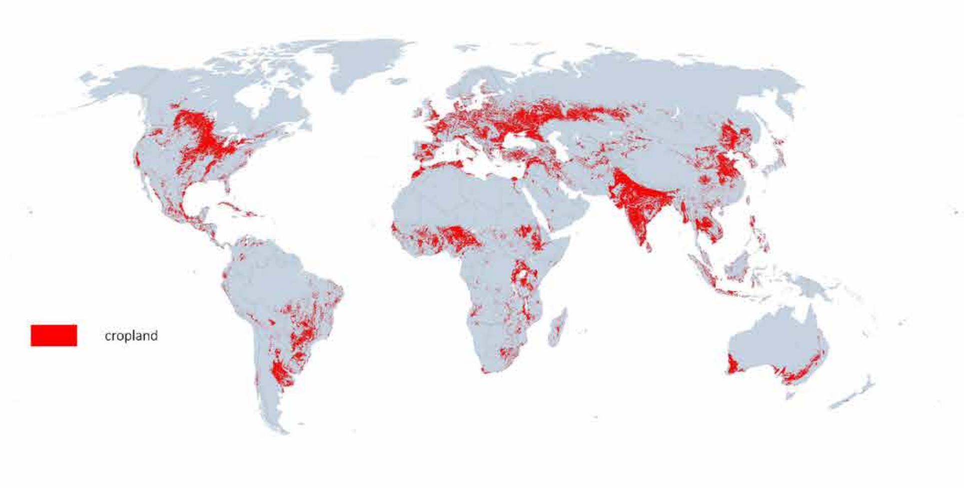
Interestingly, the global hotspots of roads [55] in peatlands are not situated in the intensively built-up areas of Europe and the eastern USA as Map 4.4.1 would indicate, but rather in north-eastern Europe (Finland) and Canada (Map 4.4.2). The abundant presence and cohesion of peatlands in the boreal zone (Map 1.3.1) probably influences this hotspot pattern (cf. Chapter 7) and maybe roads can not be built while avoiding peatlands in those regions.

Railway lines are typical indicators of industrialization and transportation of goods and rawmaterials. A dense rail network is located in Europe and parts of Asia (Map 4.4.3 [55]), with hotspots of their occurrence comparable to the hotspots of roads on peatland – while expanding slightly further towards central Europe (Map 4.4.4).

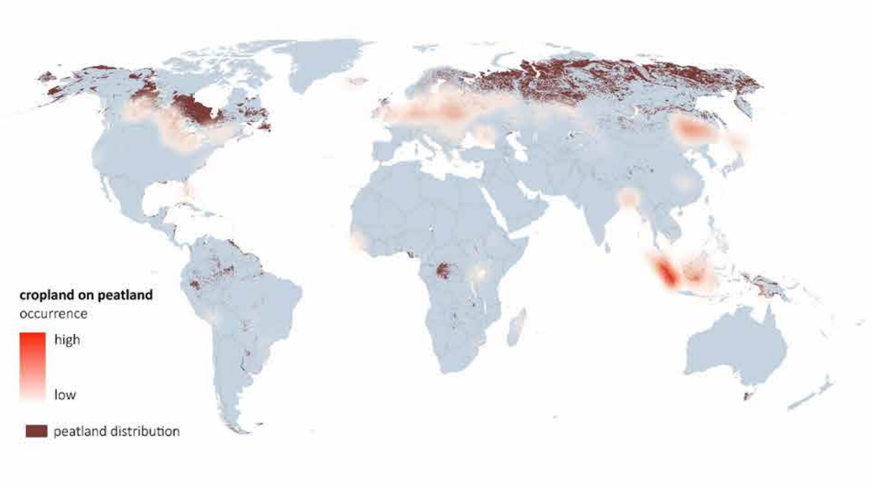
It is anticipated that nearly 25 million km² of paved roads and 335,000 km² of rail tracks will be added by 2050 globally (baseline 2010). In addition, between 45,000 and 77,000 km² of new parking spaces will be added to accommodate passenger vehicle stock growth. Approximately 90% of this infrastructure is expected to be built in developing nations [56]. Given this, some knowledge gaps are evident, particularly considering the rapid and exuberant expansion of traffic routes into remote regions. Research priorities include investigating: 1) the effects of roads on tropical peatlands, 2) the influence of peat erosion and pipe formation processes, 3) the hydrological effects of seismic trails, 4) the ecotoxicological effects of plastic tracks, 5) chemical pollutants on peatlands resulting from vehicular access, and 6) ecological recovery after temporary roads are removed from peatlands [57].

The construction of road, railway, and drainage infrastructure enable exploitation and land use changes, involving soil degradation, habitat fragmentation, pollution, and increased GHG emissions worldwide.

4.5 Agriculture on peatland

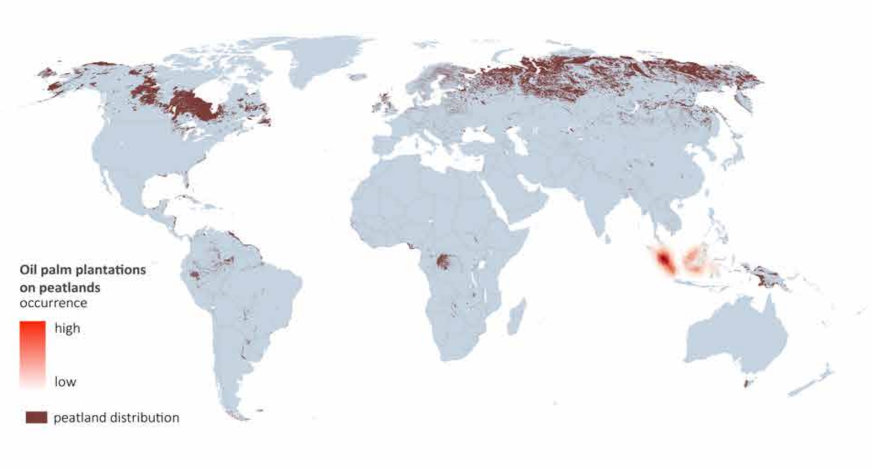


Map 4.5.1 Global distribution of cropland [59]



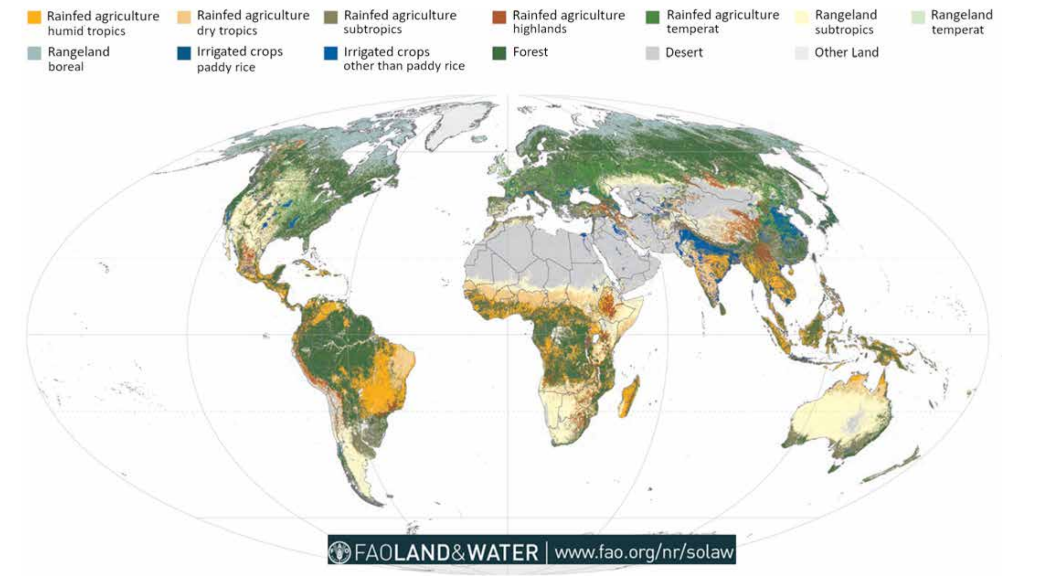
Map 4.5.2 Hotspots of cropland on peatland [22, 59]

Map 4.5.3 Global distribution of oil palm plantations [60]



Map 4.5.4 Hotspots of oil palm plantations on peatland [22, 60]

In temperate, tropical, and subtropical climates, drainage for arable land, livestock farming, and oil palm plantations are the primary drivers of peatland degradation, yet ongoing research on paludiculture offers promising sustainable alternatives.



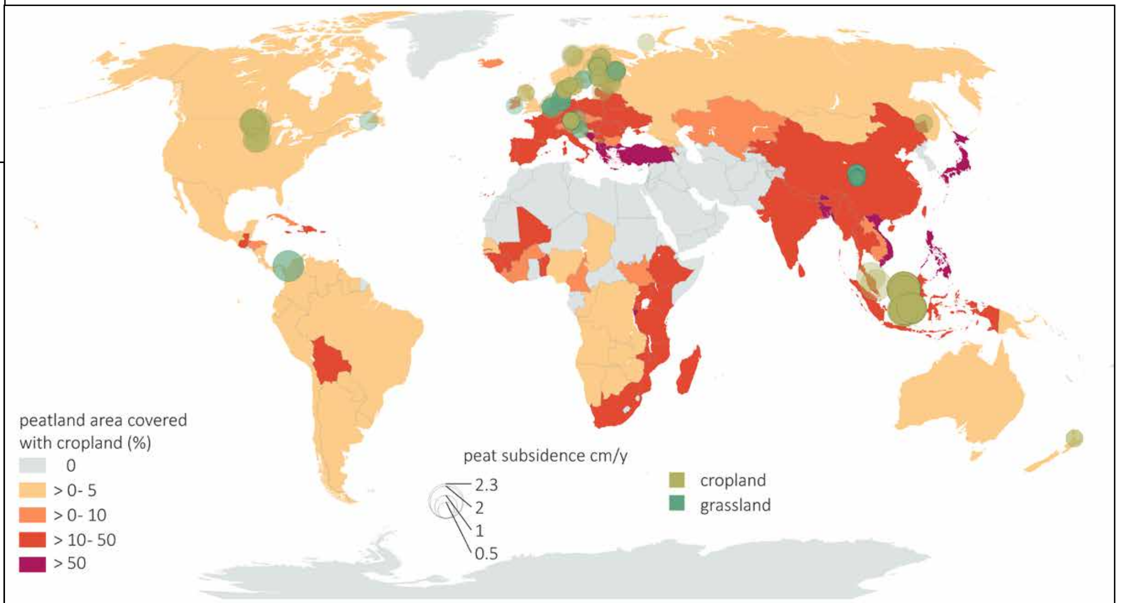
Map 4.5.6 Major agricultural systems globally [44].

Hotspots of cropland and palm oil plantations globally occur in central and eastern Europe, Northeast China, Bangladesh, Indonesia, the Great Lakes region in the USA, and on the Canadian Shield (Map 4.5.2 and Map 4.5.4 [1, 22, 59, 60]). When agriculture is practiced on organic soils, the wetlands are usually deeply drained to provide the necessary conditions for the crops. Map 4.5.6 shows the regional distribution of major agricultural systems globally – of which rainfed agriculture prevails on drained peatland in the temperate and tropical zones, accompanied by irrigated rice.

Deeply drained and regularly plowed peat soils undergo rapid peat oxidation and compaction. Soil degradation and subsidence of the soil surface, make them increasingly susceptible to flooding, land slides and erosion, ultimately resulting in the loss of agricultural land [61]. Ongoing subsidence requires drainage infrastructure to be deepened continuously, literally "bogging the peatland down", which is described as **"the vicious cycle of drained peat soils utilisation"**. Known regions with peatland subsidence and its relation to cropland on peatlands are shown on the Map 4.5.5. Recent research reveals that emissions from organic-rich agricultural ('peaty') soils with soil organic carbon (SOC) contents of 6–18% are likely highly underestimated in peatland-rich countries, as they are often treated as low-emitting mineral soils in national greenhouse gas inventories.

Increasing research on paludiculture (farming on wet and rewetted peatlands) may provide alternatives to the current destructive practices of draining peatlands for agriculture and oil palm plantations. In regions where peatlands are predominantly used for food production, land use strategies could include shifting food production to mineral soils and using the rewetted peatlands for producing biomass for fodder, fiber and fuel (in temperate zones) and restoring degraded mineral soil cropland to reduce pressure on peatlands (e.g., in tropical East Africa and Indonesia).

Shallow-drained peatlands used for subsistence farming are common in certain parts of Africa. They consists of hand-dug shallow ditches surrounding small cropland parcels. The GHG emissions from these cropping systems are still unknown.



Map 4.5.5 Peatland area covered with cropland [22, 23, 59]

Carrot field, Smøla, Norway © H. Joosten

Subsistence agriculture, Kenya © H. Joosten

Aloe vera field, Indonesia © B. Radjaguguk

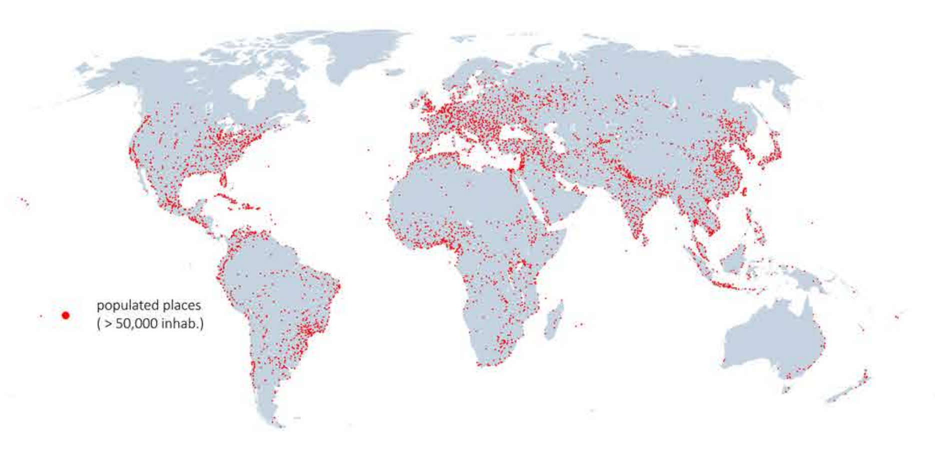
Tilled field, Germany © G. Gaudig

Rice cultivation, Rwanda © S. Elshehawi

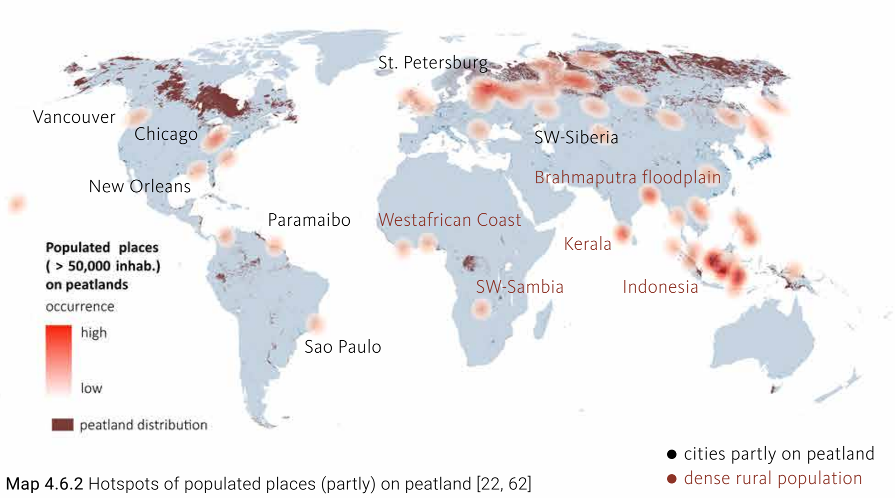
Vegetable growing, Brazil © F. Beer

4.6 Urbanisation on peatland

Populated places on peatland



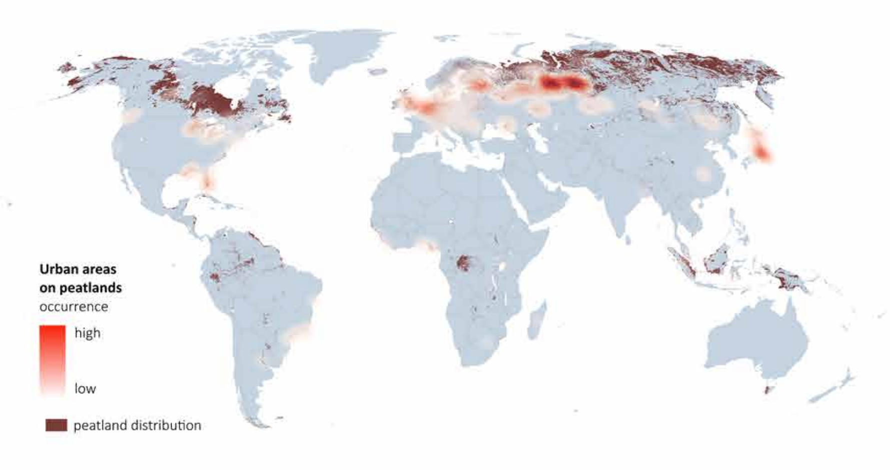
Map 4.6.1 Populated places distribution [62]



Map 4.6.2 Hotspots of populated places (partly) on peatland [22, 62]

Urban areas on peatland

Map 4.6.3 Urban areas distribution [62]



Map 4.6.4 Hotspots of urban areas (partly) on peatland [22, 62]

The overall trend of rapid urbanization poses imminent threats to peatlands in rural areas and those near large cities due to drainage and degradation associated with urban development.


Pixabay 2024

Globally, densely populated areas are located close to the world's oceans, major rivers and their deltas (Map 4.6.1). The most prominent global hotspots of populated places on peatlands are seen in Indonesia, Bangladesh, and the lowlands of Kerala, India (Map 4.6.2). Additionally, the peatland area data aligns with several major cities and densely populated rural areas worldwide. However, comparing these population density hotspots (Map 4.6.2) with urban area hotspots on peatlands (Map 4.6.4) reveals that the densely populated peatland-rich regions, particularly in Asia, have more rural settlements, as Map 4.6.4 does not include rural settlements. Several population density hotspots around specific larger cities (Map 4.6.3) do not appear as strong urban area hotspots (Map 4.6.4), suggesting that these cities may still maintain a rural character with small houses, backyards, shanty towns, and unpaved roads, as seen in the Barotse Floodplain (SW-Zambia), the Brahmaputra Floodplain (Bangladesh) or on Borneo (Indonesia).

The hotspots of urban areas in Western Siberia correspond to very extensive peatland areas in cities with populations ranging from a few tens of thousands to over a million inhabitants (e.g., Chanty Mansysk, Surgut, Nizhnevartovsk), which are characterized as centers of urban development within the context of peatland extension, but which do not represent significant urban area hotspots on a global scale (see Chapter 7. Methods).

Urban areas with high population densities and extensive built infrastructure on or near peatlands are more common in the northern hemisphere (Map 4.6.3) In contrast, highly populated rural regions and less developed large cities on or near peatlands are more prevalent in the global south (Map 4.6.1). In 2009, the world's urban population surpassed the portion of people living in rural areas (Figure 4.6.1). This marks a profound shift towards urbanization, with projections indicating that by 2030, approximately five billion people will live in urban centers, with major increases particularly in Africa and Asia (Figure 4.6.2). Despite occupying less than 5% of the Earth's landmass, urban centers consume over two-thirds of the world's energy and are responsible for over 70% of CO_2 emissions. In addition, cities require huge inputs of resources that impact areas well beyond their immediate boundaries. Therefore, peatlands in formerly rural areas and those adjacent to large cities in Africa and Asia face imminent threats from drainage, construction and pollution associated with urbanization .

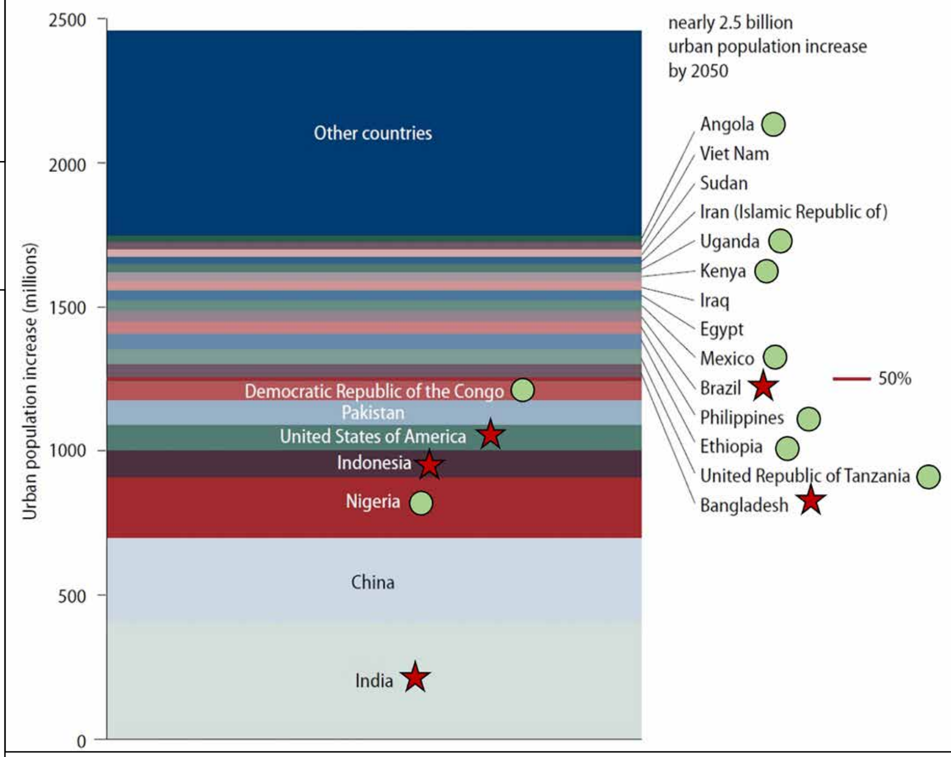


Figure 4.6.2 Contribution to the increase in urban population by country, 2014 to 2050 [63]
★ countries that already belong to the top 25 GHG emitters from drained peatlands primarily due to agricultural use
● countries with a larger extent of pristine peatlands that may be under threat of development for agricultural use (incl. oil palm plantations)

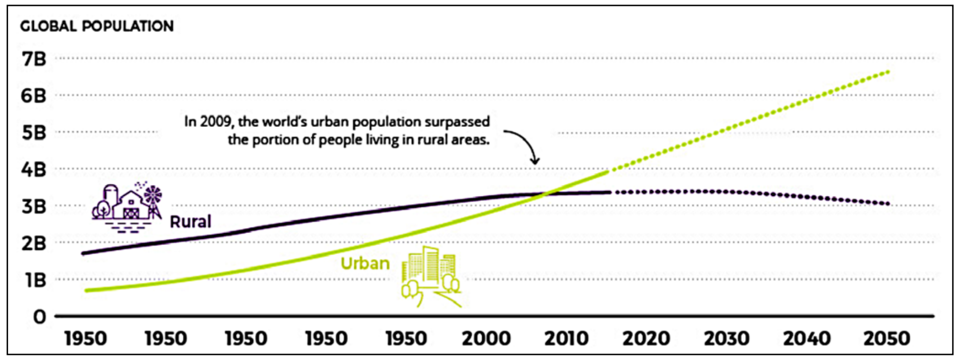
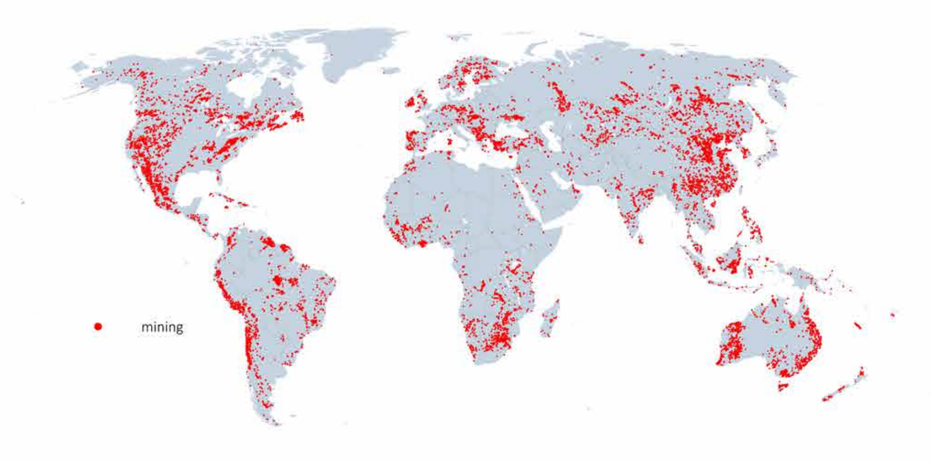


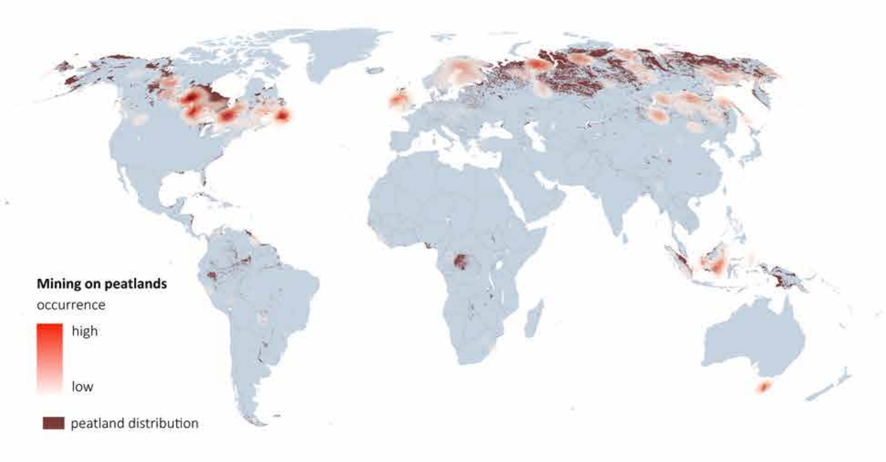
Figure 4.6.1 Global population shift from rural to urban environments [63]

4.7 Mining, oil, and gas deposits on peatland

Mining on peatland



Map 4.7.1 Global mining operations [64]



Map 4.7.2 Hotspots of mining on peatland [22, 64]

The global extraction of minerals, along with oil and gas exploration and exploitation, poses significant threats to peatlands in both boreal and tropical regions.

Global extraction of minerals has grown at an unprecedented pace in the past decades, causing a wide range of environmental impacts around the world. Surface mining involves the removal of all surface vegetation, soils, and near-surface geological deposits, resulting in habitat fragmentation, ecosystem degradation, biodiversity loss, and pollution of rivers and land. Many oil sands deposits are extracted using in situ methods, requiring the construction of production platforms (wells) and associated infrastructure, including access roads, pipelines and processing plants [1].

In the peat-rich boreal regions of North America and Asia, there is a high risk of peatland destruction by mining and oil extraction. For instance, the discovery of extensive mineral deposits in the Hudson Bay Lowlands region has led to numerous active mining sites covering more than 200,000 hectares. The expansion of mining in the peat-rich boreal and subarctic regions of North America could affect large areas of peatlands in the coming decades. Additionally, peatlands in Indonesia, Tasmania, the UK, Ireland, Sweden, Finland, European Russia and Northeast China overlap significantly with ongoing mining activities [22, 64].

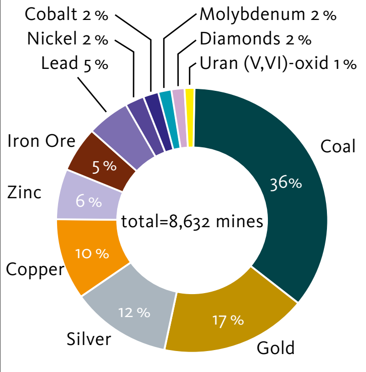
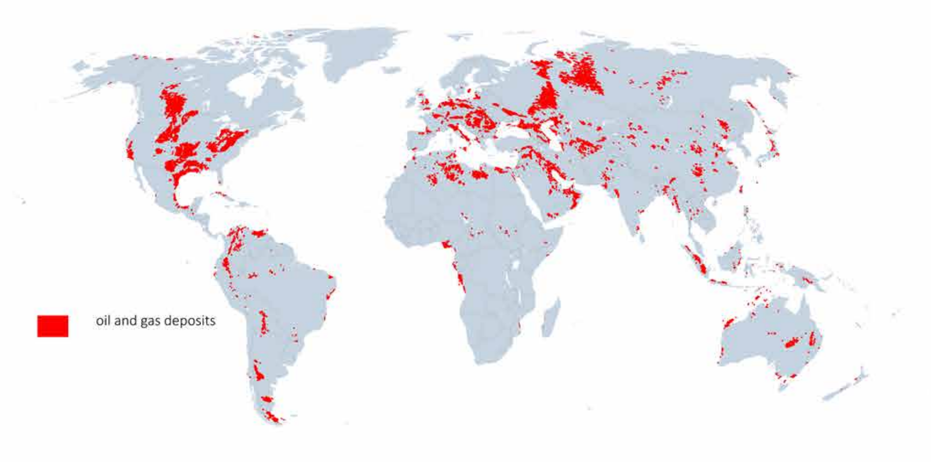
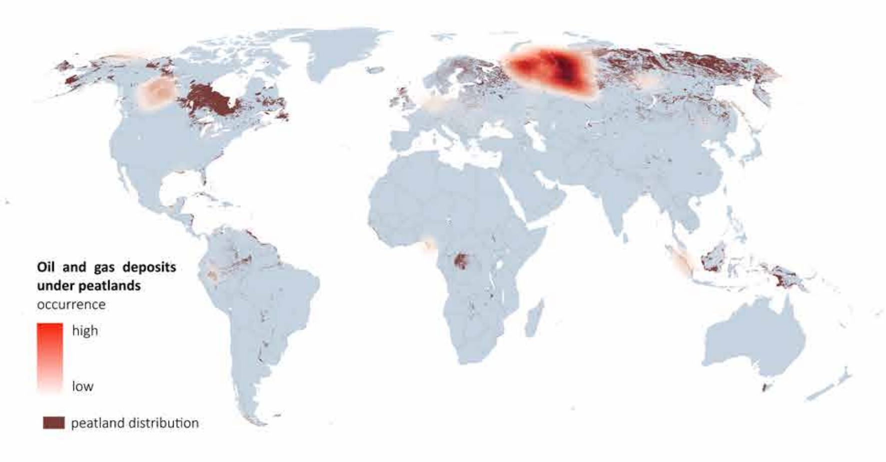


Figure 4.7.1 Commodities with > 100 active mines globally between 2000 and 2017 [after 64]

Oil and Gas deposits on peatland



Map 4.7.3 Global oil and gas deposits [65]



Map 4.7.4 Hotspots of oil and gas deposits under peatland [22, 65]

Oil and gas exploration has historically led to the pollution of peatlands, especially in Canada (370,000 ha affected), and Russian Siberia. Moreover, several regions are currently under threat from oil and gas development, including the Magdalena, Oriente and Marañón River Basins (South America), the Gulf of Mexico, the Great Lakes region (USA), the West African coast, the Central European Plains, the Brahmaputra River Basin, the island of Sumatra, and the northeastern plains of China (Map 4.7.3). In the tropics, oil field exploration and development contribute to deforestation and habitat loss, along with other environmental impacts such as pollution from oil spills and production water (well brine).

Notably, 8.3% (107,000 km²) of the total area of tropical peatlands overlaps with a 30 km buffer zone around oil and gas infrastructure [1, 22, 65].

Figure 4.7.2 Extraction infrastructure and pipe lines on peatlands: A) scheme of an in-situ oil pad built on peatland (Canada [1]); B) foundation of a oil pad on peatland (Canada); C) gas pipeline on peatland in Russian Arctic; D) oil infrastructure and contamination in wetland/peatland of the Pastaz-Marañón Basin in Peru.

4.8 Flood events, flooding risk, subsidence on peatland

Drainage in peatlands causes the peat to shrink by compaction and oxidation and the peat surface to subside, a process exacerbated by fires that burn away the upper peat layers burn. The irreversible reduction in pore space resulting from oxidation and compaction reduces the peat's capacity to store water and regulate water flow. As the peatland lowers, the risk of flooding increases. **Subsidence continues as long as the peatland remains drained** or all peat has disappeared. By subsidence, drained peatlands loose one (in the temperate zone) up to five meters of height (in the tropics) within a century, leading to severe damage to buildings and infrastructure, the necessity to build dykes and pumps to keep the land dry, and near the sea, to increasing salt water intrusion which threating soil productivity [1, 61].

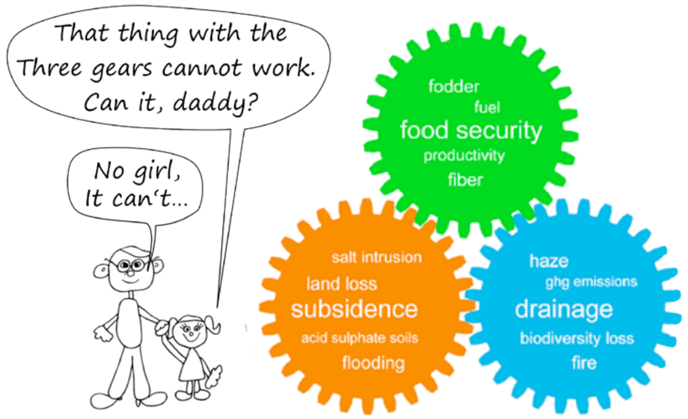
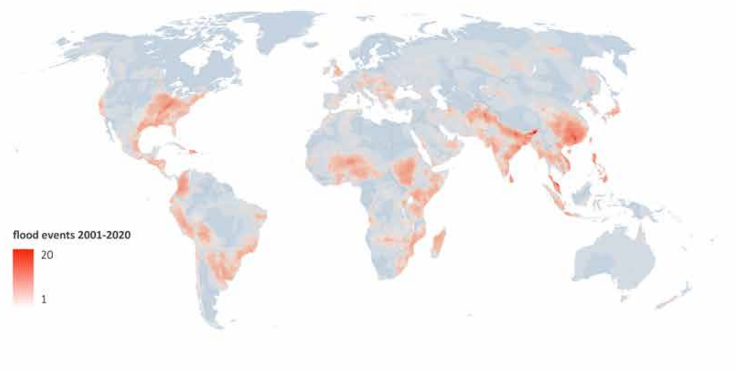


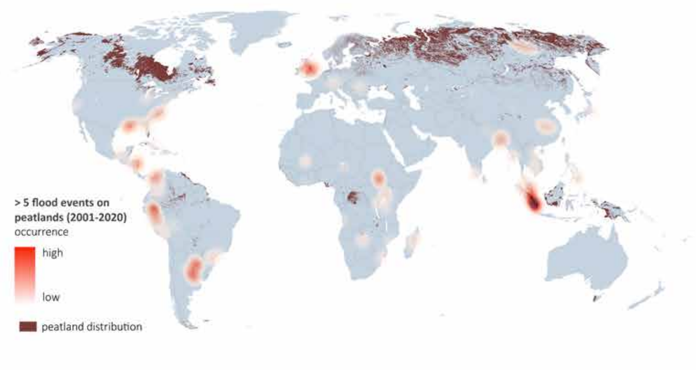
Figure 4.8.2 Drained peatland use destroys its own subsistence base

Peatland drainage leads to peat subsidence and increases flood risk, particularly in regions where peatlands are already vulnerable to floods, along major rivers, coastlines, and at the bases of mountains.

Large, past flood events on peatland



Map 4.8.1 Large flood events (2001–2020 [66])



Map 4.8.2 Hotspots of large flood events on peatland (2001–2020 [22, 66])

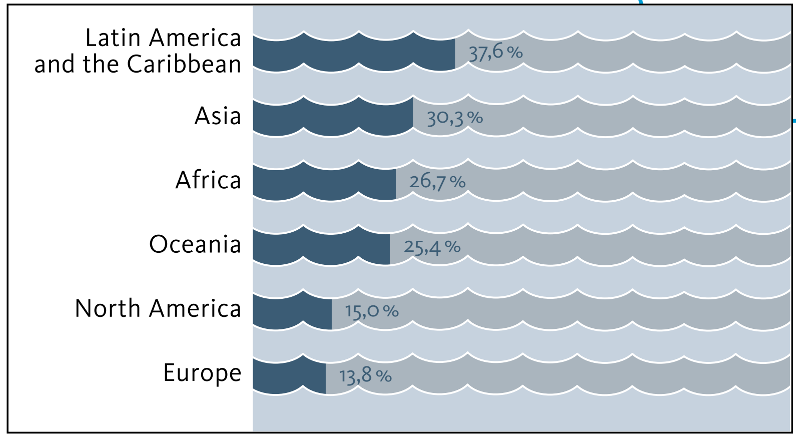
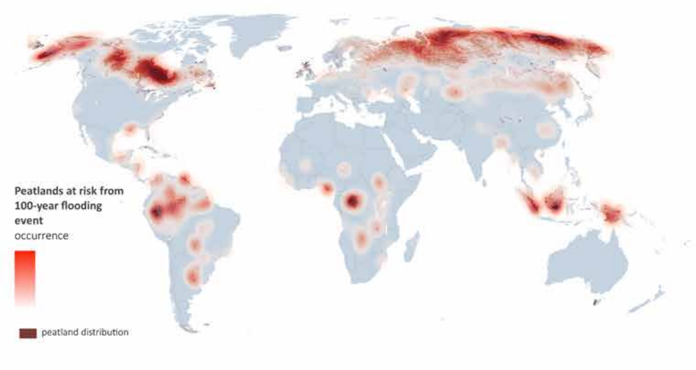


Figure 4.8.1 Cumulative past flood events (Maps 4.8.1 and 4.8.2), 100-year flooding risk (Maps 4.8.3 and 4.8.4), and potential land subsidence (Maps 4.8.5 and 4.8.6), as % of total peatland area

100-year flooding risk on peatland

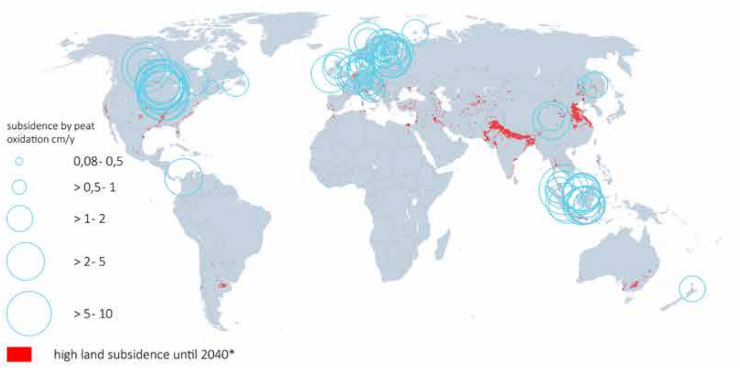
Map 4.8.3 Areas at risk from 100-year flooding [67]



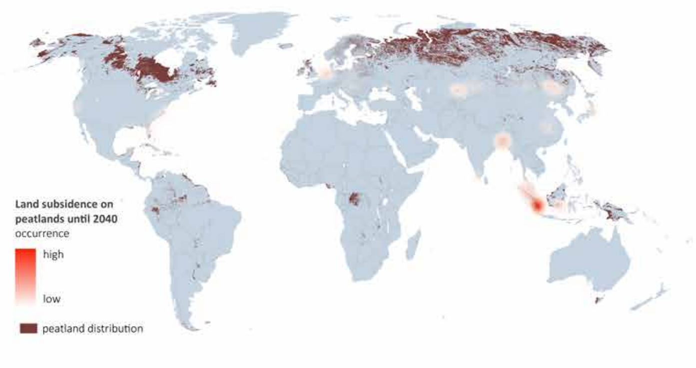
Map 4.8.4 Hotspots of peatland at risk from 100-year flooding [22, 67]

Peat subsidence in the Netherlands © A. Jansen

Potential land subsidence on peatland



Map 4.8.5 Potential land subsidence until 2040 [68]



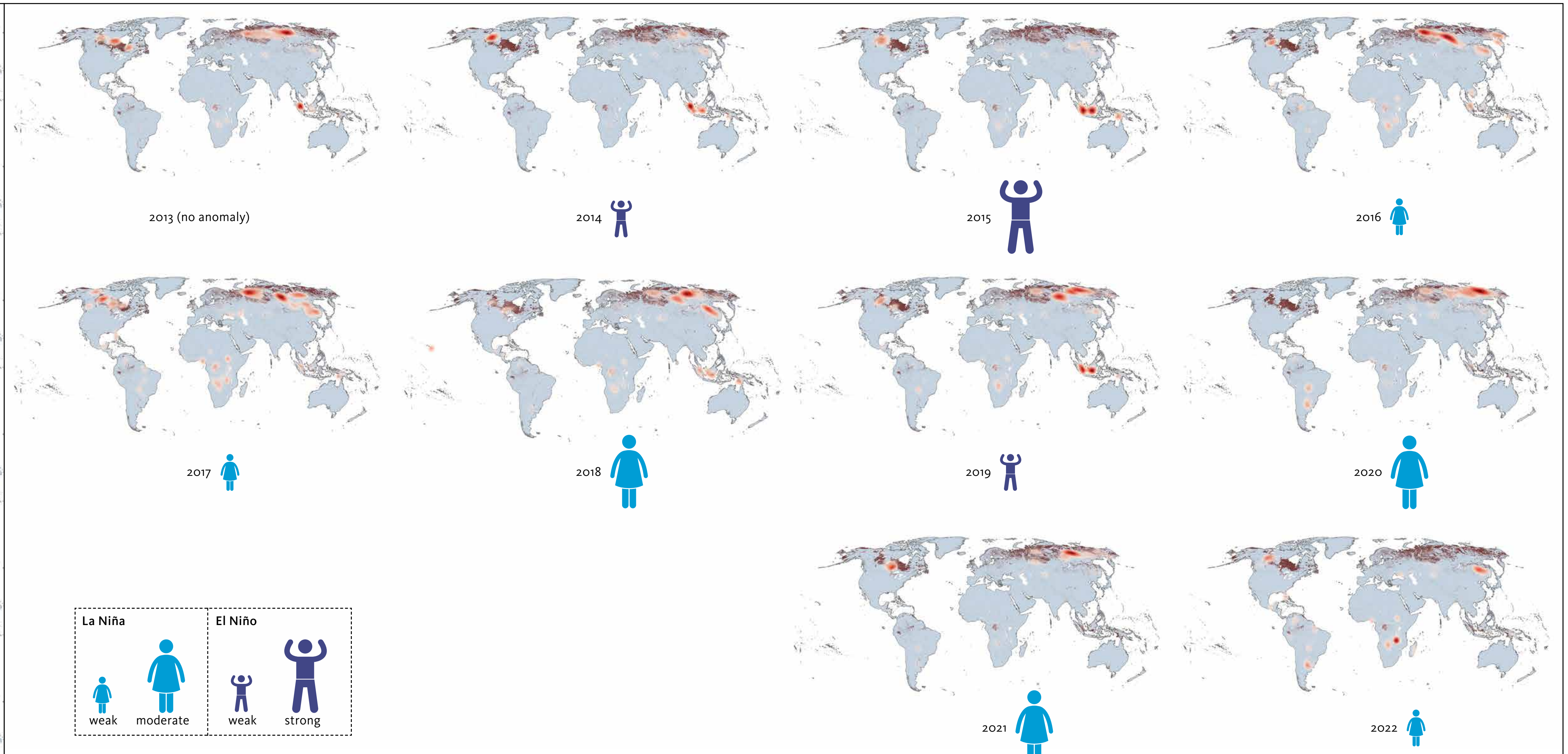
Map 4.8.6 Hotspots of potential land subsidence on peatland until 2040 [22, 68]

* Subsidence probability high or very high (after Herrera-García et al. 2022)

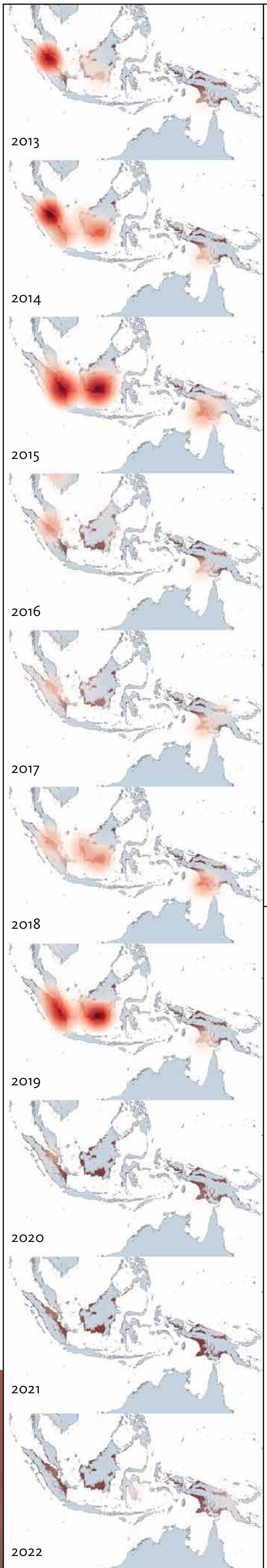
Large flood events [66] in peatlands frequently coincide with floodplains and deltas of major rivers, where peatlands are commonly found (1=Ganges+Brahmaputra, 2=Yangtze, 3=several rivers on Sumatra, 4=Nile, 5=several rivers in the UK, 6=Mississippi, 7=Rio Parana). Additionally, floods occur in peatlands located at the base of mountain ranges (8= Andes, 9=African Rift Valley) (Map 4.8.2 [22]).

100-year flood risk data [67] predicts that the vast northern peatlands of Siberia and North America, as well as the large tropical peatlands in Peru, the Congo Basin and Indonesia, could be severely affected by floods in the next 100 years (Map 4.8.4). This is because peatlands are often located in extensive and shallow depressions connected to large rivers, where devastating 100-year flood waters can accumulate. Smaller hotspots are again related to peatlands occurring in floodplains and deltas of major rivers is triggered by natural (e.g., tectonics) or anthropogenic factors, including peatland drainage and degradation. **Subsidence** [61, 68] permanently reduces the water storage capacity of the peat of the groundwater system, creates sinkholes, damages buildings and infrastructure, and increases vulnerability to flooding. Blue circles indicate global regions where drainage has led to peatland surface lowering of up to 10 cm per year. These areas correspond with hotspots of peatland conversion for agriculture in Europe, Southeast Asia, and North America (Map 4.8.5 and 4.8.6).

4.9 Peatland fires



Map 4.9.1 Hotspots of global peatland fire occurrence from 2013 to 2022 [22, 70]



Map 4.9.2 Hotspots of peatland fire occurrence in Indonesia from 2013 to 2022 [22, 70]

Undrained peatlands in regions where regular fires are part of the natural ecosystem dynamics usually experience rapid burns that affect only the aboveground biomass over a limited area, rather than penetrating into the peat body. Such fire regime is typical for peatlands the boreal and arctic climate zones of North America and Asia, as well as in the flooded savannah landscapes across Africa (Map 4.9.1). However, also there fires are increasing in frequency and intensity in recent years due to prolonged dry periods, triggered by climate change. Human activities such as logging, post-harvest slash-and-burn agriculture, and biomass burning or infrastructure development further exacerbate this trend [1, 69].

Deep and long-term drained peatlands are vulnerable to large-scale, deep-seated, and long-lasting smoldering peat fires fueled by dry peat and dead biomass accumulated after land abandonment. During climate anomalies such as El Niño years in Indonesia, extreme peat and forest fires as may occur, like during the El Niño years of 2014, 2015, and 2019 (Map 4.9.2 [1, 22, 70, 71]). The El Niño Southern Oscillation (ENSO) cycle refers to the climate phenomenon when the sea surface temperatures in the eastern Pacific Ocean become warmer than average, leading to increased rainfall and flooding in the Eastern Pacific, while causing drier-than-normal conditions in the Western Pacific. La Niña is the opposite phase, characterized by cooler-than-average sea surface temperatures in the eastern Pacific, which influences global weather patterns in the opposite direction. As a response to the devastating peat fires in 2015, Indonesia has started an ambitious programme to monitor and rewet drained peatland over currently almost 4 million ha, mainly by legally prescribing that water levels should not drop lower than 40 cm below ground level. Although these 40 cm are not fully secured and insufficient to stop subsidence, emissions and fires completely, this policy has reduced these hazards substantially [72].

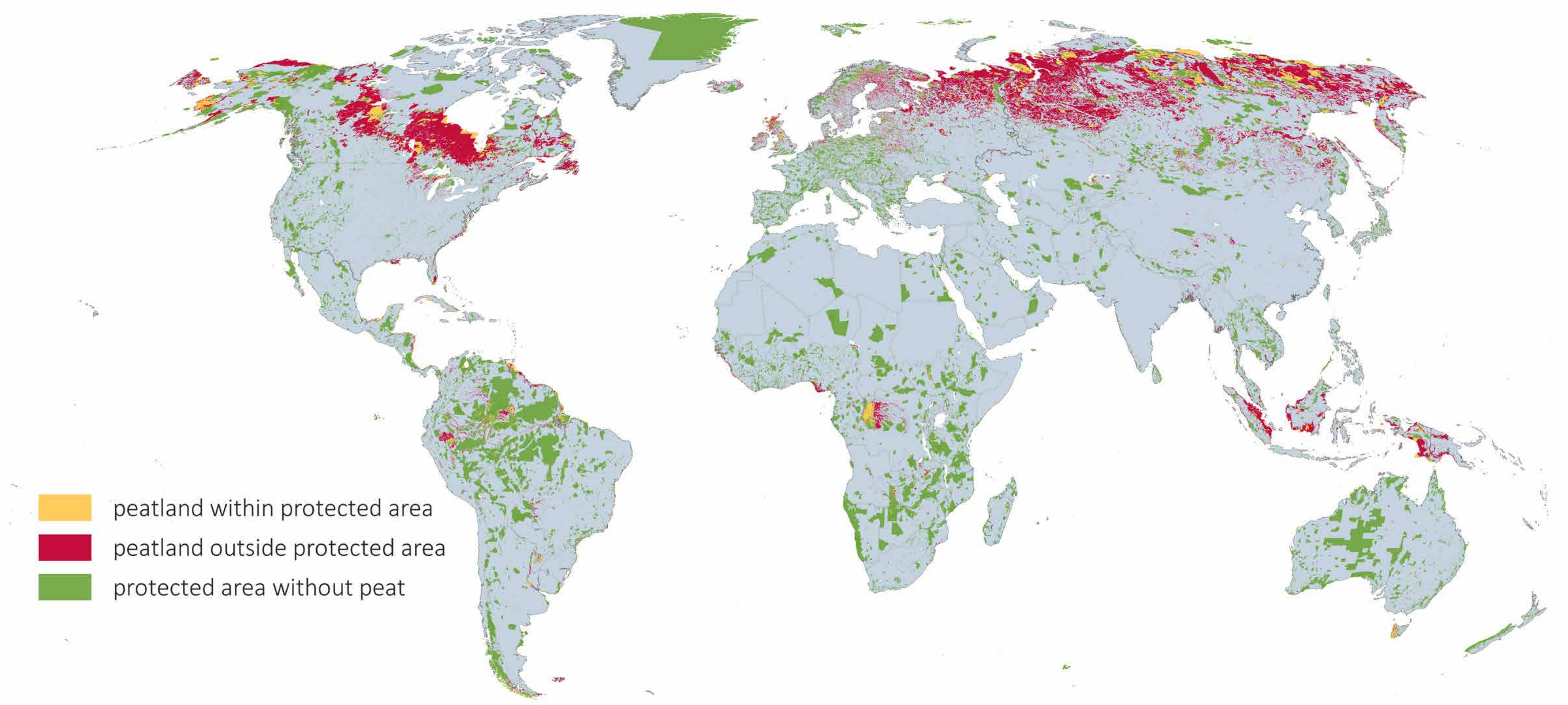
Undrained peatlands do experience surface fires but these do not penetrate into the peat body. In contrast, drained peatlands may suffer prolonged smoldering fires, particularly during El Niño events, resulting in significant GHG emissions and hazardous haze detrimental to human health.

Figure 4.9.1 Peatland vegetation on fire © H. Joosten

Figure 4.9.2 Arctic wildfires consume trees and peat © NPS Climate Change Response/Flickr

Figure 4.9.3 Peatland after peat fire, Brunei Badas © H. Joosten

5.1 Peatland protection

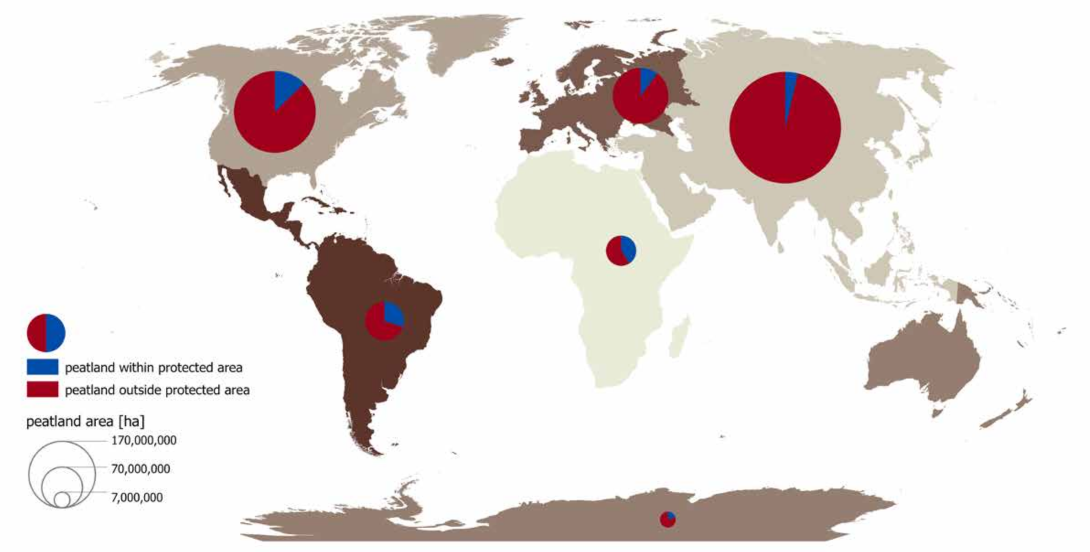


Map 5.1.1 Peatland within and outside protected areas [1, 22, 73]

Only 19% of the total peatland area worldwide is found in protected areas (Figure 5.1.1 [22, 28, 73]). Africa and South America are the continents where proportionally the highest share of peatlands is within protected areas (Map 5.1.1). Effective protection requires legal protection, management planning and implementation, monitoring, and enforcement. However, being located in a protected area does not guarantee that the protected peatlands are pristine or have high ecological and hydrological integrity. Whereas, for example, a large proportion of peatlands in protected areas in northern Asia remain largely pristine, those in protected areas in Europe are partially drained and deteriorating. While the protected status of peatlands is important, it is essential to ensure that protected area regulations are also properly implemented [1].

Peatland conservation faces challenges due to various competing land uses, particularly in regions where they are extensively used for food production, highlighting the need for regionally tailored solutions that enable both protection and sustainable use. Synergies are best achieved through careful and integrated land use planning, stakeholder engagement (including Indigenous Peoples and Local Communities - IPLCs), promotion of gender-responsive approaches, and, most importantly, a solid knowledge of peatlands (including Local and Indigenous Knowledge Systems – LINKS), their functioning and ecosystem services, and the environmental and social costs of degradation.

Additionally, the involvement of both women and men in peatland conservation and management is essential, as their knowledge of local ecosystems can inform sustainable practices. In many regions, women are the primary caretakers of land and resources, and empowering them to engage in peatland conservation efforts can significantly enhance effectiveness. However, women often face barriers such as underrepresentation and limited access to land rights and decision-making processes. Addressing these challenges is crucial for fostering inclusive sustainable management practices and establishing long-term strategies for peatland conservation and restoration.



Map 5.1.2 Peatland within and outside protected areas by region [1, 22]

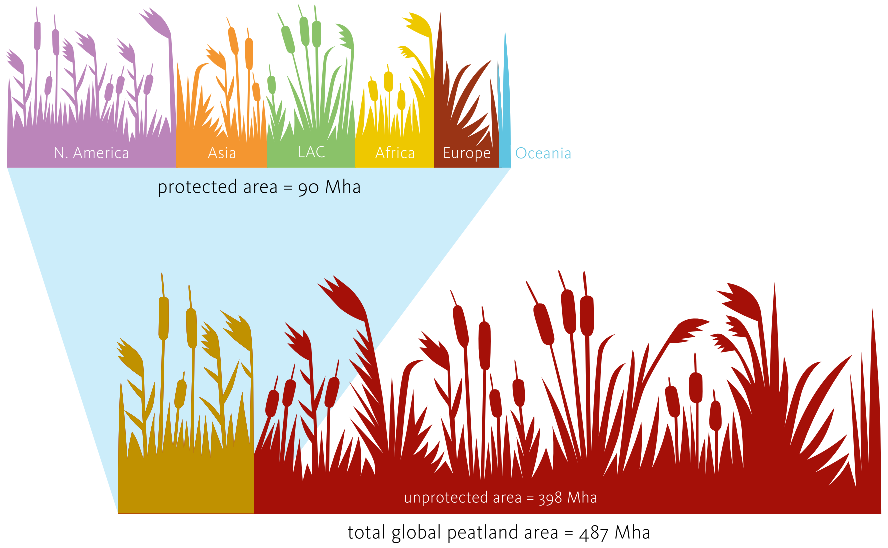


Figure 5.1.1 Protected peatland area global and by region [1, 22]

Effective protection of peatlands requires holistic management and a landscape approach to conserve the entire hydrological catchment and preserve its valuable ecosystem services for both people and nature.

6 Conclusion

The Global Peatland Hotspot Atlas is a crucial tool for understanding and addressing the urgent state of peatlands worldwide. Building on the Global Peatland Map 2.0 and the Global Peatlands Assessment, the Atlas provides a comprehensive view of peatland distribution, their ecological significance, and the increasing threats they face. Peatlands, primarily located in boreal and tropical regions, play a vital role as key Nature-based Solutions and provide essential ecosystem services through carbon storage, water regulation, and biodiversity conservation. However, human activities and climate change are driving rapid degradation, leading to biodiversity loss, heightened greenhouse gas emissions, and compromised ecosystem services.

The Atlas offers Member States and policymakers a series of thematic maps to enhance national climate strategies and make informed decisions about peatland conservation, restoration, and sustainable management. It aligns with the UNEA-4 Resolution on the Conservation and Sustainable Management of Peatlands and significantly contributes to the development of a Global Peatland Inventory, building on the efforts of the Global Peatlands Assessment. By identifying regions most vulnerable to degradation and highlighting the threats faced by peatlands, the Atlas supports the creation of targeted planning and the integration of peatlands into national climate strategies such as Nationally Determined Contributions (NDCs) and National Biodiversity Strategies and Action Plans (NBSAPs). Additionally, the Atlas enables civil society to gain a clearer understanding of peatland distribution and degradation, encouraging greater public awareness and engagement.

This resource also emphasizes the importance of a holistic, landscape-level approach to peatland management. Through its diverse thematic maps, the Atlas reveals that peatland conservation and restoration are global concerns, showing peatlands as complex ecosystems intricately connected to their surrounding landscapes, from tropical and temperate forests to mountains, tundra, and drylands. This highlights the need for comprehensive ecosystem and landscape restoration, integrating the conservation of hydrological catchments and the protection of peatlands within the broader ecosystem. Biodiversity conservation remains a key focus, as the Atlas emphasizes peatlands' critical role in supporting rare and threatened species.

To create these thematic maps on a global scale, the worldwide peatland occurrence (from the Global Peatland Map 2.0) was overlaid with relevant global thematic data. Many maps were designed as "Hotspot Maps", using Kernel Density Estimation to display the density distribution of point clouds with a color gradient, offering a detailed view of peatland density. However, the final quality of these maps is inherently dependent on the resolution and accuracy of the input datasets.

While the Atlas represents a significant advancement in peatland mapping, there remain knowledge gaps in the available data. Support from national governments and local researchers is vital to complement the Global Peatland Database and enhance our understanding of peatland distribution. The next steps involve empowering member states to invest in ground-truthing efforts and encouraging academia to focus on improving mapping methods and research, especially through the use of emerging technologies. Such collaborations are crucial for refining the Global Peatland Map, ensuring that the most accurate and useful data informs effective conservation strategies.

In summary, the Global Peatland Hotspot Atlas marks a significant leap forward in peatland research and management. It offers an advanced visualization of peatland distribution and threats, setting new standards for global mapping and policy development. To address the challenges facing peatlands, immediate and coordinated action is essential to prevent further degradation, restore damaged areas, and protect these vital ecosystems. The Atlas serves as both a warning and a guide, offering actionable insights for sustainable management and biodiversity conservation, ensuring that peatlands continue to provide their invaluable services for both nature and humanity.

7 Methods

Developing hotspot maps

The Global Peatland Map 2.0 (GPM 2.0; see Map 1.2.1) and topic-specific GIS layer were overlaid to visualize global peatland distribution related to 1) human impacts as e.g., land use, infrastructure development, urbanization, resource extraction, or protection, and 2) to the environment as e.g., climate zones and climate (change) impact, biodiversity, permafrost, or altitude (Figure 7.2).

Hotspot maps illustrate the density distribution of data points across overlayed spatial dataset as color gradient. Thus, in a first step the GPM 2.0 and the selected thematic GIS data layers have been individually transferred into point data. From this new point datasets hotspot maps have been calculated with 'Kernel Density Estimation' in QGIS. During this process, the density of points around each output raster cell is calculated and visually displayed as hotspot (Figure 7.1). The defined radius and cell size of the resulting hotspots depends largely on the input data. In this study, radiuses of 10-25 geographical degrees were used.

Hotspot Maps display the complex content of global GIS data in a clear way and help understanding the essential information easily. But, as a derived product, the final quality of the product is dependent on the quality of the input data sets. Note that none of the thematic levels used were developed specifically for peatlands and few global thematic datasets may come with slight biases. However, we carefully selected thematic levels from recent scientific research and widely accepted sources of spatial data. The GPM 2.0 was also used to develop **regional peatland Atlas pages** indicating main distribution centers of peatlands on continents and providing climatic and altitudinal background information, as well as pictures illustrating regional peatlands.

Sometimes, the impact of large peatland density or extent rule over thematic layer input and produces hotspots that do not represent significant hotspots on a global scale, but on a regional level.

One example are the urbanization hotspots around Khanty Mansysk, Surgut, Nizhnevartovsk in Siberian Russia (with few tens of thousands to over a million inhabitants) that area settling within the huge Western Siberian peatlands (Map 4.6.4). Another example is the rather regional hotspot of roads on peatland in the central Congo Basin (Map 4.4.2).

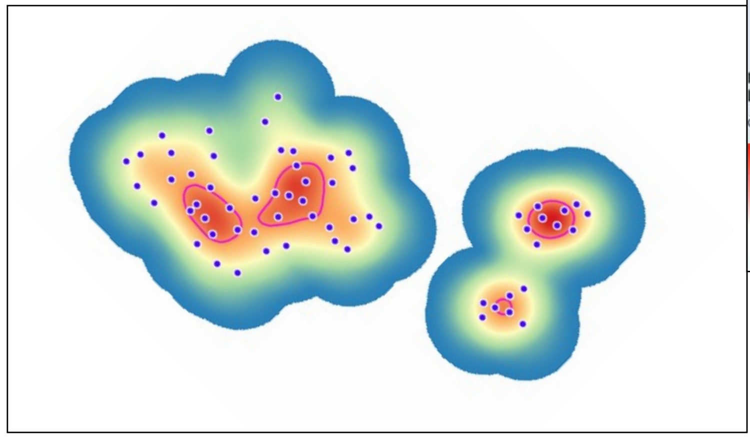


Figure 7.1 Hotspot Maps ('Heat Maps') are graphical representations of the point density distribution of overlaid GIS data layers and the GPM 2.0. (See also: https://plugins.qgis.org/models/19)

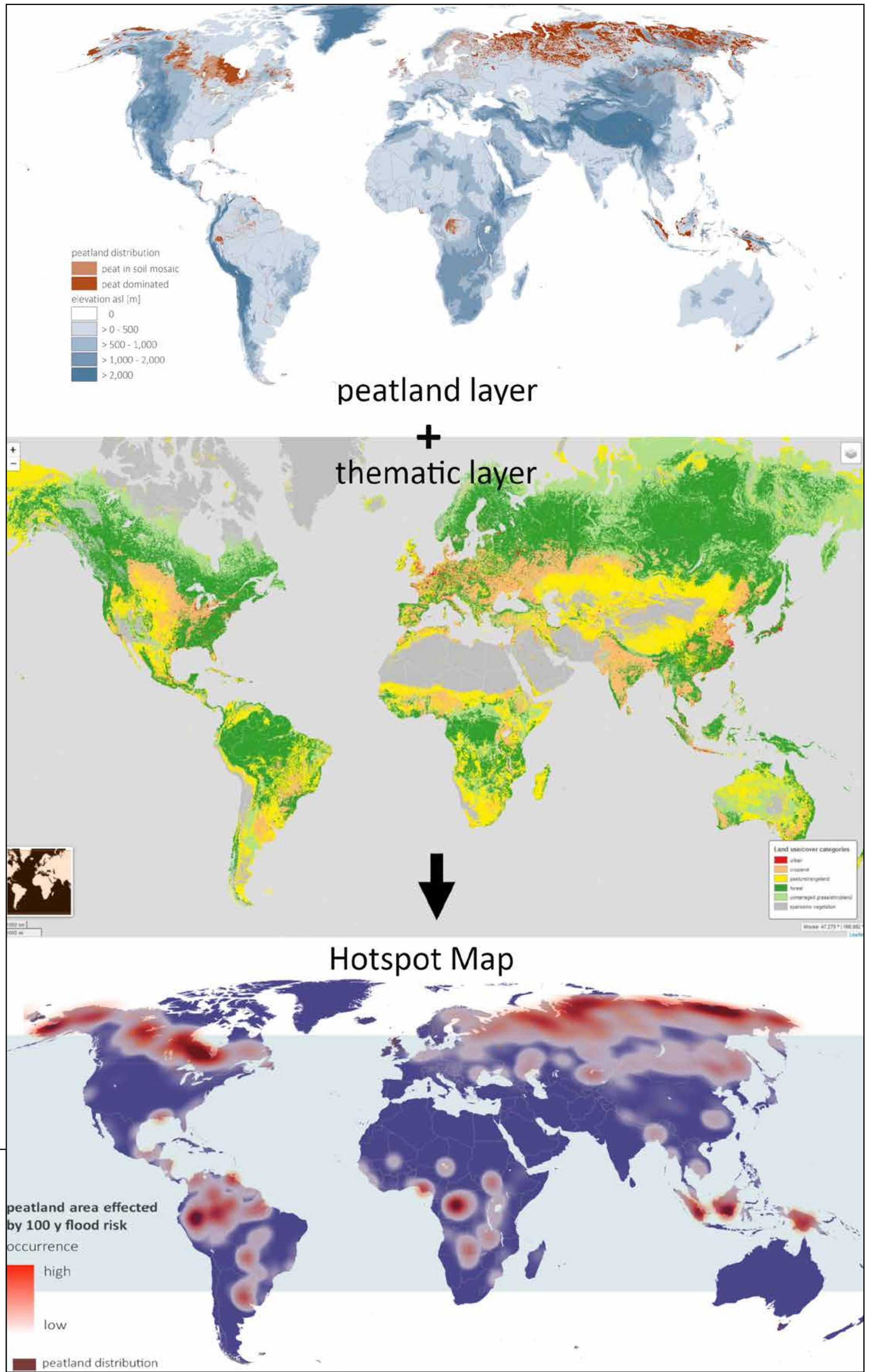


Figure 7.2 Scheme of the intersection process to derive Global Peatland Hotspot maps.

Developing the peatland regionality maps (Chapter 3)
The peatland regionality map were developed in an iterative process mainly using A) the peatland distribution of the Global Peatland Map 2.0 [22], B) the WWF eco-regions [74], C) multiple ancillary information on peatland types and their distribution from the Global Peatland Database [75] and the w.w.w, D) global climate zonation [24], and E) topographical Information [76]. Borders of Global Peatland Regions were manually drawn using the above mentioned input data and an expert knowledge driven, manual approach. Nomenclature of peatland regions include regional names or topographic names (if needed for distinction). They can include specific 'peatland types': e.g., 'bog', 'fen', 'paramos' or 'puna', swamp' or 'palm' (forested peatlands), or 'marsh' (open wetlands with an unclear amount of peatlands included).
Be aware that these peatland regionality maps are preliminary and will undergo further consolidation ('v_01') at Greifswald Mire Centre.

Developing the thematic hotspot maps

Note that extensive information on the background data is available in the Global Peatland Assessment (UNEP 2022 in ANNEX III.3)

Map 1.4.2 Peatland distribution in climate zones
By intersecting the GPM 2.0 [2] with the geographical distribution of global climate zones [24], the occurrence of peatlands in all climate zones globally was mapped and visualized in hotspot maps for peatland occurrence in specific climate zones.
Map 2.1.1 Rarity-weighted species richness on peatland
To show the relation between peatland distribution and biodiversity hot spots, the 'Rarity-weighted species richness index' was used – an index that combines metrics of endemism and species richness as floating points with a resolution of 10 km [25]. The dataset is based on the raw IUCN ranges for amphibians, birds, mammals, reptiles, shrimps, crabs and crayfish. High values of the index indicate high importance of an area for the considered species groups. For a reasonable presentation of the continuous values, we used the mean (0.01578) and standard deviation (0.07515). Values above the mean were considered as 'high' species richness and values above the sum of the mean and the standard deviation (0.0993) as 'very high' species richness in a specific area. Calculations and analyses were carried out with ArcGIS Pro 2.9.0, ArcMap 10.8.1 and QGIS 3.16.16-Hannover. Layouts were essentially created with QGIS 3.16.16.
Map 2.2.2 Permafrost-affected peatland
The GPM 2.0 [22] and the distribution of permafrost [28] were only overlaid graphically to visualize their overlaps.
Map 2.3.1 High-altitude peatland
By intersecting the GPM 2.0 [22] and a global Digital Elevation Model [76], peatland areas above 1,000 m.a.s.l. and above 2,000 m.a.s.l. were visually highlighted in the map and a hotspot map for these high altitude peatlands derived to enhance the visibility of these small peatlands on a global map.
Map 2.4.1 Peatland in arid and sub-arid climate
By intersecting the GPM 2.0 [22] with the global extent of arid climate zones ('arid desert' and 'arid steppe' [24]), the occurrence of peatlands under those climates was determined and visualized in hotspot maps.
Map 4.1.1 Global peatland drainage distribution
Map 4.2.1 Global peatland degradation distribution at a national level
Map 4.3.1 GHG emissions from peatland per country
Map 4.3.2 GHG emissions from peatland relative to emissions from fossil fuels and cement
Map 4.3.3 GHG emissions from peatland per unit land area
This area data has been retrieved from the 2022 update of the country-wise Global Peatland emission Database [23]. This data is partly based on the GPM 2.0 [22] - amended by manifold ancillary data (mainly from national reporting to UNFCCC, national agencies, and peatland and soil scientific papers). This data is compiled for 268 countries and regions in an iterative process. See also ANNEX III of [1] to derive estimates for the drained peatland area under agriculture, forestry and peat extraction. While multiplying these area data with emission factors for CO2, CH4, N2O, DOC and ditch emissions (mainly based on IPCC 2013 Wetland Supplement), annual, country-wise GHG emissions from used peatlands have been calculated and additionally set in relation to the emissions from transport and the cement industry in the respective countries.
Map 4.4.2 Hotspots of roads on peatlands and Map 4.4.4 Hotspots of railways on peatlands
By intersecting the GPM 2.0 [22] with global GIS layers for roads and railway lines [62], a hotspot map was developed to visualize the areas of significant overlap of those layers.
Map 4.5.2 Hotspots of cropland on peatland and Map 4.5.4 Hotspots of oil palm plantations on peatland
By intersecting the GPM 2.0 [22] with the Cropland layer of the 'HILDA+ Global Land Use Change between 1960 and 2019' dataset [59], a hotspot map was developed to visualize the areas globally where peatlands are used for arable farming.
Map 4.6.2 Hotspots of populated places (partly) on peatland and Map 4.6.4 Hotspots of urban areas (partly) on peatland
By intersecting the GPM 2.0 [22] with a global dataset indicating urban areas and populated places [62], a hotspot map was developed to visualize the areas of significant overlap of those layers.
Map 4.7.2 Hotspots of mining on peatland and Map 4.7.4 Hotspots of oil and gas deposits under peatland
By intersecting the GPM 2.0 [22] with datasets indicating mining areas [64] and significant oil and gas deposits [65], a hotspot map was developed to visualize areas with significant impacts of mining or potential exploitation of gas and oil on global peatlands.
Map 4.8.2 Hotspots of large flood events on peatland (2001-2020)
Map 4.8.4 Hotspots of peatland at risk from 100-Year flooding
Map 4.8.6 Hotspots of potential land subsidence on peatland until 2040
To visualize global peatland regions with high overall flooding risks, we developed hotspot maps by intersecting the GPM 2.0 [22] with 1) an archive dataset on large past flood events [66], 2) a global flood hazard map [67], 3) a global dataset on general subsidence during the last 40 years [68] and 4) more specifically peatland related subsidence [61].
Map 4.9.1 Hotspots of global peatland fire occurrence globally from 2013 to 2022 and Map 4.9.2 Hotspots of peatland fire occurrence in Indonesia from 2013 to 2022
To map fire events on peatlands globally, MODIS data from the NASA Fire Information for Resource Management System (FIRMS [70]) has been gathered from 2013 to 2022. All fire pixels with a confidential value below 30 were removed from the fire GIS datasets before its intersection with the GPM 2.0 to derive annual peat fire hotspot maps.
Map 5.1.1 Peatland within and outside protected areas and Map 5.1.2 Peatland within and outside protected areas by region.
The map was created by overlaying the GPM 2.0 [22] with global area data from national and international protected areas [73]. By intersecting the data, the proportion of peatlands located within protected areas per continent was determined.

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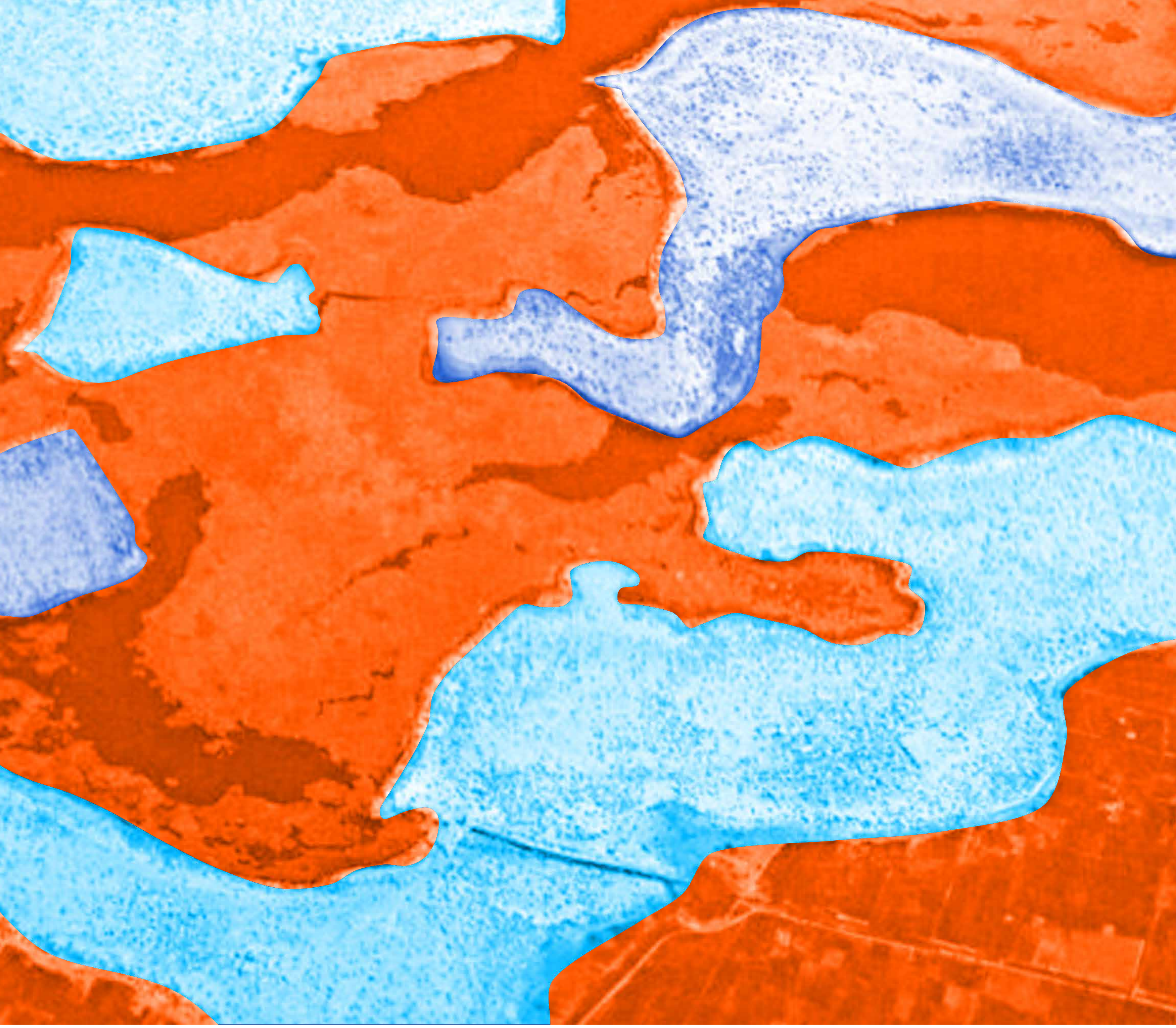

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