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Review

Research Progress in the Field of Peatlands in 1990–2022: A Systematic Analysis Based on Bibliometrics

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Abstract: Peatlands are major natural carbon pool in terrestrial ecosystems globally and are essential to a variety of fields, including global ecology, hydrology, and ecosystem services. Under the context of climate change, the management and conservation of peatlands has become a topic of international concern. Nevertheless, few studies have yet systematized the overall international dynamics of existing peatland research. In this study, based on an approach integrating bibliometrics and a literature review, we systematically analyzed peatland research from a literature perspective. Alongside traditional bibliometric analyses (e.g., number of publications, research impact, and hot areas), recent top keywords in peatland research were found, including 'oil palm', 'tropical peatland', 'permafrost', and so on. Furthermore, six hot topics of peatland research were identified: (1) peatland development and the impacts and degradations, (2) the history of peatland development and factors of formation, (3) chemical element contaminants in peatlands, (4) tropical peatlands, (5) peat adsorption and its humic acids, and (6) the influence of peatland conservation on the ecosystem. In addition, this review found that the adverse consequences of peatland degradation in the context of climate change merit greater attention, that peatland-mapping techniques suitable for all regions are lacking, that a unified global assessment of carbon stocks in peatlands urgently needs to be established, spanning all countries, and that a reliable system for assessing peatland-ecosystem services needs to be implemented expeditiously. In this study, we argued that enhanced integration in research will bridge knowledge gaps and facilitate the systematic synthesis of peatlands as complex systems, which is an imperative need.

Keywords: peatland(s); carbon cycle; water balance; land use; climate change

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1. Introduction

Peatlands constitute the Earth's major natural terrestrial carbon pool [1–4]. Despite potential deviations from actual conditions, a recent assessment indicates that the global peatland area is about 4.23 million km^2, mainly distributed within the latitude range of 45° to 65° N. Worldwide, Asia, North America, Latin America and the Caribbean, and Europe account for about 33.01%, 32.43%, 12.99%, and 12.05% of the peatland area, respectively [5]. Peatlands are formed by the continuous natural accumulation and development of peat soils in environments where the soil surface is waterlogged or excessively wet and geologically stable for a long period of time, where abundant plant residues have accumulated, and where microbial decomposition is inhibited under the influence of prolonged waterlogging and/or low temperatures [3,6–8]. Although there is no unified definition of a peatland in present academic circles, the typical characteristics that are widely accepted are a peat layer thickness of at least 30–40 cm with a soil organic matter content of above 30%, which usually reaches a threshold of 50–65% or more [5,9]. Peatlands, with large organic carbon stocks and high carbon densities, are the terrestrial ecosystems with the largest carbon stocks per unit area and the fastest rate of carbon accumulation [10,11].

Peatlands are essential to a variety of areas of study, including global ecology, hydrology, and ecosystem services. Although peatlands cover only approximately 3% of the Earth's terrestrial area, they contain one-third of the world's soil carbon and twice as much carbon as that contained in the biomass of all the Earth's forests, and the sustainable development of humanity is tied to their conservation and management [12–14]. Other recent evaluations have revealed that peatlands store 455–612 Pg (1 Pg = 1015 g, 1 Pg is 1 billion tons) of organic carbon, which is equivalent to 5–20% of the global soil carbon stock, 15–72% of the atmospheric carbon stock, and 18–89% of the global terrestrial carbon stock [15,16]. Thus, peatland dynamics play an influential role in global climate change and carbon cycling [13]. In addition, freshwater resources in peatlands account for 10% of global terrestrial freshwater [14,17], and peatlands have a high capacity for runoff regulation and flood and drought mitigation [18,19]. In many regions, peatland vegetation also supplies human food and other resources directly, supporting the economic development of local communities [5,20,21]. In brief, peatlands are of great value for regional and global climate regulation, water conservation, biodiversity protection, soil and water conservation, and carbon cycling [22].

Peatlands are globally significant wetland ecosystems, known for their diversity, ecological functions, and carbon-storage capabilities. Their diversity is influenced by factors such as climate, hydrology, vegetation composition, and terrain. Tropical peatlands, situated near the equator, are predominantly moss-dominated and exhibit rapid formation [23]. Temperate peatlands are common in high-latitude areas with cooler climates [24], diverse vegetation types, and relatively slower formation rates. Peatlands based on sphagnum moss possess robust water-retention [25] properties, while fen-based peatlands are mainly composed of herbaceous and woody plants [26]. Besides these main types, there are other forms of peatlands, such as mountainous peatlands, forested peatlands, etc. While peatlands serve important roles in agriculture and energy sectors, their development and utilization often lead to environmental challenges. Contemporary strategies prioritize their protection and sustainable management [27].

Peatland management and conservation have emerged as important topics of international concern. Peatlands are found in more than 180 countries worldwide [5,28]. Thus, harmonization and coordination at the international level are required to attain peatland protection and restoration. Currently, many countries have realized the significance of peatlands and have taken positive actions to protect and manage them. The United Nations Environment Programme (UNEP) and more than 20 partners are leading the Global Peatland Initiative (GPI), which seeks to collectively achieve the protection of peatlands in all regions, to expand and accelerate peatland restoration, and to develop programs for the sustainable management of peatlands. Furthermore, the fourth United Nations Environment Assembly, held at UNEP headquarters in March 2019, noted that improving peatland management can contribute to the implementation of several important international conventions, such as the Paris Agreement, the United Nations Framework Convention on Climate Change (UNFCCC), the Ramsar Convention on Wetlands, and the Convention on Biological Diversity (CBD). Additionally, the assembly adopted a resolution urging member nations and other stakeholders to prioritize peatland protection and requested that the UNEP coordinate efforts to develop a comprehensive, accurate global inventory of peatlands as an essential basis for identifying appropriate interventions, understanding their value and potential for carbon sequestration, and planning for their sustainable management. At the same time, the assembly urged member nations and other stakeholders to enhance cooperation to advance peatland protection and management [5]. It was evident that the protection of peatlands would be a focus of attention for UNEP in the near future.

Climate change and its impacts are currently a serious threat to the future of peatlands. The global release of CO_2 from peatlands due to warming or degradation is estimated to be about two billion tons per year, which is 5% of the global carbon release flux [29]. However, if effective measures are taken, the protection and restoration of peatlands could reduce global greenhouse gas emissions by 800 million tons per year, nearly 2% of the world's current carbon emissions, and save nearly USD 40 billion in mitigation investments, making it one of the lowest-cost ways to reduce carbon emissions globally [30]. Despite this, the potential of peatlands in global climate change-mitigation strategies is a prominent issue that has been grossly underestimated [31]. Additionally, peatlands have long been uninhabitable areas, considered wastelands, and have only been considered valuable when used for agriculture, forestry, or peat extraction [32]. This view, which focuses on the direct supply value of peatlands, has led to the exploitation of peatlands in many areas and has caused serious damage to local ecosystems, triggering environmental degradation, biodiversity loss, nutrient loss, and a decline in water quality and quantity [33]. Beyond that, a climate change context of rising temperatures and frequent wildfires has led to a greater risk of peatland degradation, especially to those in high-latitude, permafrost regions.

Because of these threats, research deepening the basic knowledge of peatlands is of great significance for their conservation at the international and national levels. There remain, however, two major issues: At the macroscale, few studies have systematically sorted out the entire international peatland research situation, failing to fully capture the development of global research, clarify the current hot research topics, identify the research focuses of different countries and institutions/organizations, and describe the situation of international research cooperation. At the microscale, there is an imminent need to systematically rationalize and summarize the difficult problems and core technical issues prevailing in current global peatland research. For instance, there is still a great deal of uncertainty about changes in the distribution of peatlands at the global scale. The UNEP estimation suggests a global peatland area of about 4.23 million km^2 [5] but is still accompanied by large uncertainties. The primary reason for this was inadequate basic data and relatively few models for distribution simulation, which made it difficult to systematically improve the mapping accuracy. Moreover, there is no optimized technology for peatland mapping in all areas. A key issue of spatial scale in the determination of soil moisture and soil carbon content in peatland mapping has not yet been resolved, and the interactions and differences in complex internal mechanisms between mid- and high-latitude peatlands and permafrost are poorly understood globally. Peatlands are an enormous reservoir of carbon globally, but research on their carbon-stock assessment and emissions needs to be intensified. Peatlands also have vital ecosystem service values, but there is a lack of rational and accurate ecosystem service-valuation methods and tools for them.

The clarification and resolution of these issues will facilitate peatland conservation and restoration and contribute to the smooth implementation of peatland programs at the international and national levels. Therefore, it is necessary to conduct a synthesis study of peatlands. Recently, intelligent research posture-analysis techniques using bibliometric methods have been widely applied in many areas of the earth sciences, and research based on situational analysis has been successfully carried out in a wide range of fields, including ecosystem services, permafrost, and ecological studies [34–36]. Hence, this methodology will be used in this study to analyze the macro dynamics of global peatland research. This paper conducts a systematic literature review and analysis to answer three key scientific questions: (1) What are the international peatland research trends? (2) What are the hot topics in international peatland research? (3) What are the main challenges and characteristics of current international peatland research?

2. Data and Methods

The data collected in this paper were retrieved on 11 April 2023 from the Science Citation Index, Science Citation Index Expanded, and Social Science Citation Index databases in the Web of Science (WoS) core data set, which is considered to contain the most extensive collection of journals and the most influential journals. The targeted literature types included dissertations, conference papers, review papers, and conference abstracts. The data were retrieved for the period 1990–2022 by applying a subject search with the search term "TS = Peat Near/0 (bed* or bog OR land* OR Clay OR Soil*)." A total of 5767 papers were obtained, and a final total of 5738 papers were retained for the analysis after cleaning and trimming. The bibliometric methodology used in this study is recognized as an effective method for quickly obtaining and researching publication information. The software and platforms involved in this study include VOSviewer, DDA, and Scimago Graphica. The workflow used in this study is illustrated in Figure 1.

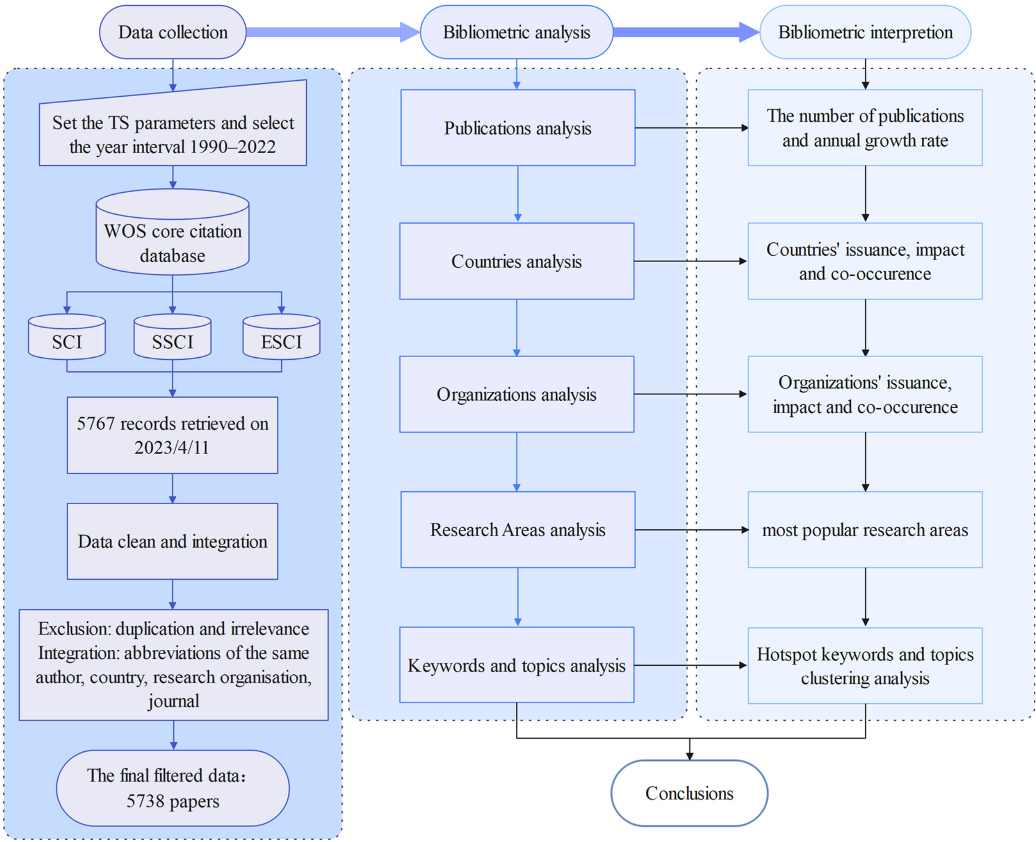

Figure 1. Research workflow of this study.

3. Results

3.1. Trends in the Number of Papers

Global peatland research has received a considerable amount of attention in recent years, a fact well reflected in the record of associated academic publications. As seen in Figure 2, the number of papers per year has increased over 14-fold, from 19 in 1990 up to 268 in 2022. A survey of papers published before 1990 found relatively scarce data, thus we began our analysis in 1990. From 1990 to 2001, the number of publications experienced slow growth, with the total number per year being generally less than 100. In only a few years did the number of papers exceed 100, with 105 and 102 papers in 1997 and 1999, respectively. After 2002, the number of papers per year witnessed rapid growth, reaching 197 by 2009. After 2010, the number of papers per year consistently exceeded 200, peaking at 317 in 2019, followed by a turbulent decline. The publication growth curve indicates a fluctuating process of change in the number of global peatland research papers. Within the last 10 years, an average positive growth trend indicates that peatland research is currently a hot area of international consideration.

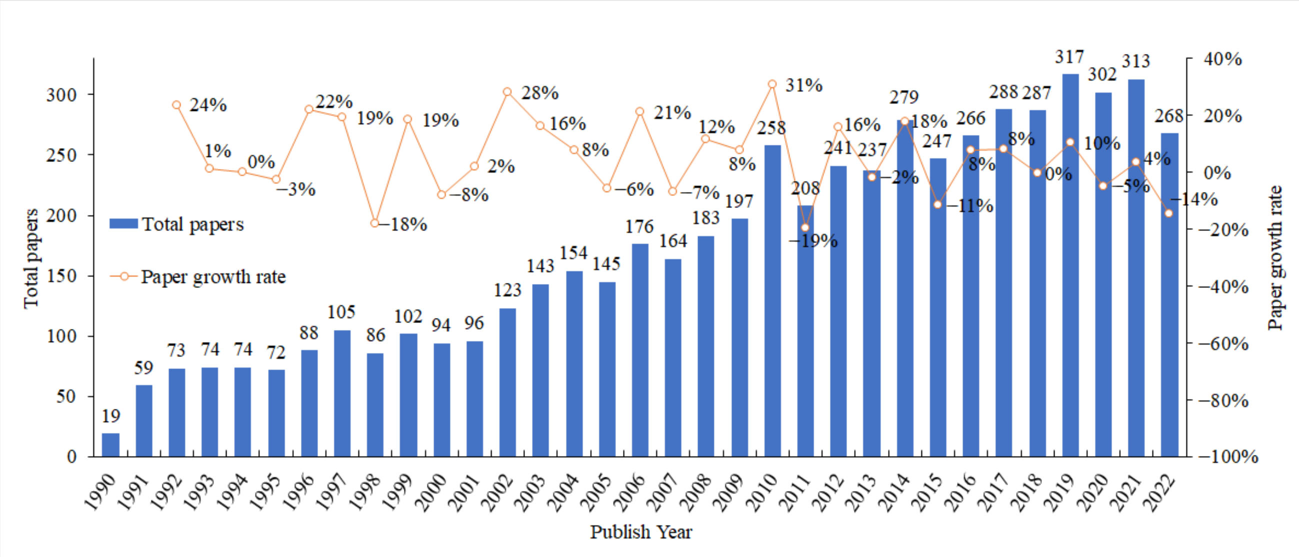

Figure 2. Total papers per year and publication growth rate from 1990 to 2022.

3.2. Publications of Countries and Organizations

We analyzed the top 20 peatland-research-producing countries according to the impact of papers and the level of international cooperation. Using the VOSviewer software [37], the top 20 countries were obtained by setting the total-number-of-papers threshold to 103 and sorting them in descending order based on the number of publications (Table 1).

Table 1. Top 20 countries with the highest number of published papers.

Country	Number of Papers	Citations	Avg. Citations	Avg. Pub. Year	Total Link Strength
USA	773	37,383	48.36	2010.90	542
UK	699	29,915	42.80	2009.93	543
Germany	629	24,198	38.47	2012.00	553
Russia	552	8504	15.41	2013.97	189
Canada	396	15,950	40.28	2011.43	361
Poland	394	5276	13.39	2013.46	152
China	354	9264	26.17	2015.88	271
Netherlands	338	15,689	46.42	2010.25	231
France	294	9518	32.37	2011.92	332
Sweden	264	10,539	39.92	2011.24	302
Finland	263	10,819	41.14	2011.23	182
Spain	224	6866	30.65	2012.85	226
Japan	183	4399	24.04	2010.10	115
Malaysia	178	1639	9.21	2015.98	70
Indonesia	175	3139	17.94	2015.51	131
Czech Republic	169	4627	27.38	2012.31	116
Switzerland	168	8594	51.15	2010.09	205
Australia	132	5770	43.71	2013.02	147
Italy	112	4069	36.33	2012.47	148
Belgium	103	3199	31.06	2011.23	158

Regarding the total number of publications, a total of eight countries in the top twenty have more than 300 publications: the USA, the UK, Germany, Russia, Canada, Poland, China, and the Netherlands. Of these, the top three all have more than 600 articles. The order of the top three countries in total citations and in total publications is the same: the USA, the UK, and then Germany. In terms of total citations, the fourth through seventh countries with the most citations—Canada, the Netherlands, Finland, and Sweden—all had over 10,000. Yet, from the perspective of the average number of citations (Avg. Citations), the top three were Switzerland, the USA, and the Netherlands, indicating that papers published in these countries are more influential. Among them, the USA entered the top three in both the number of papers published and the average number of citations, showing its strong research strength.

The average publication year (Avg. pub. year) represents the mathematical average year of each country's total publications (based on its publications per year); the more recent the average publication year of the country, the more recent is its overall research contribution to the field. The three countries with the most recent average publication year are Malaysia (2015.98), China (2015.88), and Indonesia (2015.51), all of which have average publication years later than 2015, indicating that these countries have produced more articles in recent years. The average year of the top three countries is about 2010, which is on average about five years earlier than the former, indicating that these countries are the ones that have started research in this field earlier and have stronger research power. Among these countries, the UK has the earliest average publication year of 2009.93, indicating that it has the longest history of research.

Using on the "Co-occurrence" function, we obtained a clustering network of different countries in terms of co-occurrence links (Figure 3). In this figure, the current cooperation in this field is divided into three major clusters. These include those represented by the USA, Canada, China, etc. (green); Germany, France, Russia, etc. (red); and the UK, Switzerland, Spain, and Sweden (blue). The size of the circles in the figure represents the country's total number of papers (see Table 1). In addition, the VOSviewer software expresses the significance of different countries in the cooperative network with a total link strength indicator (Table 1): the higher a country's indicator, the greater its significance inside the cooperative network. It can be noted that the top three countries in terms of cooperation are the USA, the UK, and Germany, which is consistent with the top three countries in terms of total publications, with only a minor difference in the ranking. Germany, with the largest link strength indicator value of 553, has the greatest weight inside the cooperation network and is at the very core of the network.

As with the countries, using VOSviewer software with the number-of-papers threshold set to 49, the top 20 research-producing organizations were obtained and ranked in descending order (Table 2) and a collaboration network was obtained, and the clustering and the intensity of collaboration among the organizations were analyzed (Figure 4).

Of the top 20 organizations in terms of total publications, the top three organizations are the Russian Academy of Sciences, the Chinese Academy of Sciences, and the University of Helsinki, Finland. The top three organizations in terms of collaboration intensity still include the Russian Academy of Sciences, in first place, the University of Helsinki (Finland), in second place, and Umea University (Sweden) in third place. Among the most cited institutions, the Russian Academy of Sciences remains in first place, and in second and third place are the University of Bern, Switzerland, and the Chinese Academy of Sciences, respectively. Based on the average number of citations per paper, the top three organizations are the University of Bern (Switzerland), Heidelberg University (Germany), and Umea University (Sweden), indicating a greater impact of the articles issued by these institutions. In these rankings, the Russian Academy of Sciences, the University of Helsinki in Finland, and the Chinese Academy of Sciences were ranked in the top three several times, for total publications, strength of collaboration, and total citations, which can be interpreted as a sign of the superior research strength of these organizations. Among them, the Russian Academy of Sciences is ranked first in all three, reflecting its unparalleled research strength.

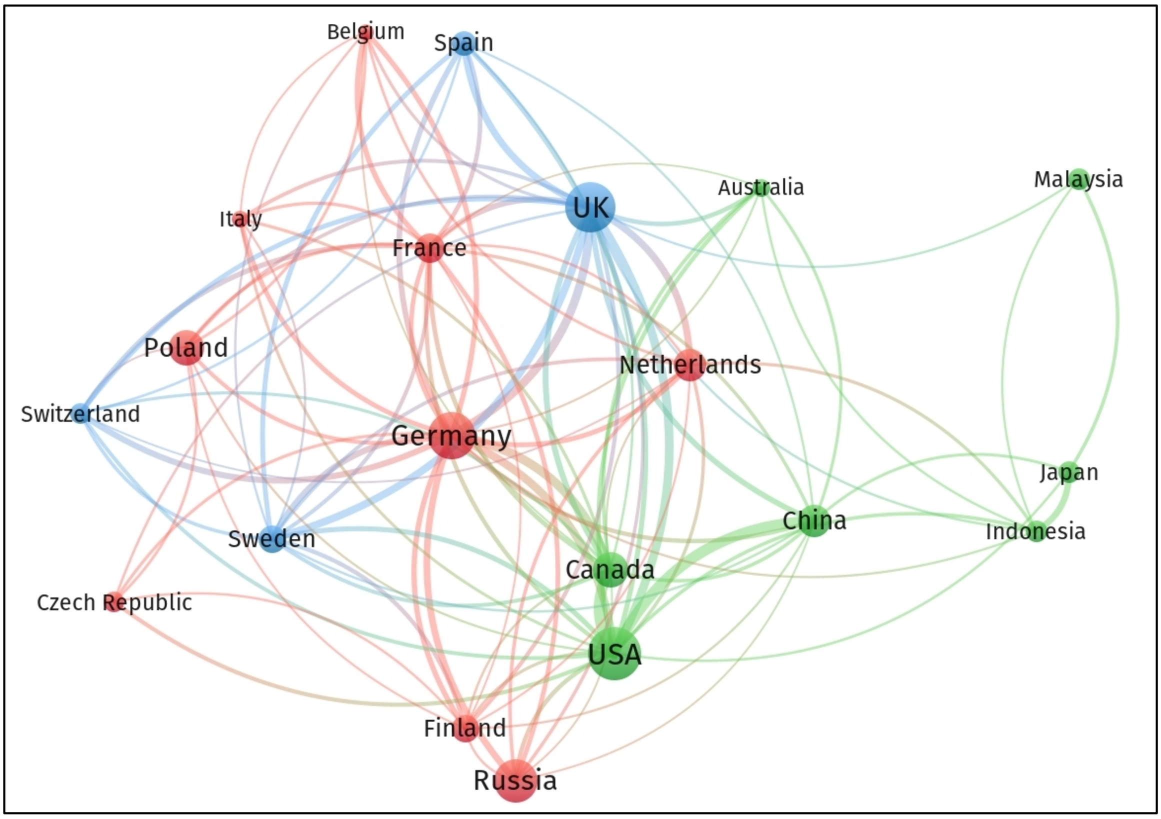

Figure 3. Countries' network visualization in terms of co-occurrence links. Different colors represent different clusters, and countries of the same color collaborate more closely with each other.

Table 2. Top 20 organizations with the highest number of published papers.

Organization	Number of Papers	Total Link Strength	Citations	Avg. Citations	Avg. Pub. Year
Russian Acad Sci	292	44	5704	19.53	2013.43
Chinese Acad Sci	118	11	4249	36.01	2014.28
Univ Helsinki	100	42	4014	40.14	2011.25
Moscow Mv Lomonosov State Univ	91	38	1443	15.86	2010.70
Swedish Univ Agr Sci	76	27	3430	45.13	2010.64
Polish Acad Sci	76	16	1034	13.61	2012.62
Univ Aberdeen	71	21	2961	41.70	2012.51
Univ Bern	70	16	5035	71.93	2006.16
Univ Utrecht	62	10	2799	45.15	2011.89
Umea Univ	57	42	2931	51.42	2010.93
Heidelberg Univ	57	27	2951	51.77	2008.37
Adam Mickiewicz Univ	55	22	929	16.89	2015.76
CSIC	55	12	1476	26.84	2012.75
Hokkaido Univ	55	3	1420	25.82	2010.35
Univ Rostock	54	3	1346	24.93	2016.63
Finnish Forest Res Inst	53	40	2132	40.23	2007.38
Univ Alberta	53	13	1371	25.87	2014.72
Charles Univ Prague	53	3	712	13.43	2013.89
Univ Vienna	50	12	2189	43.78	2015.62
Univ Santiago De Compostela	49	26	1427	29.12	2013.47

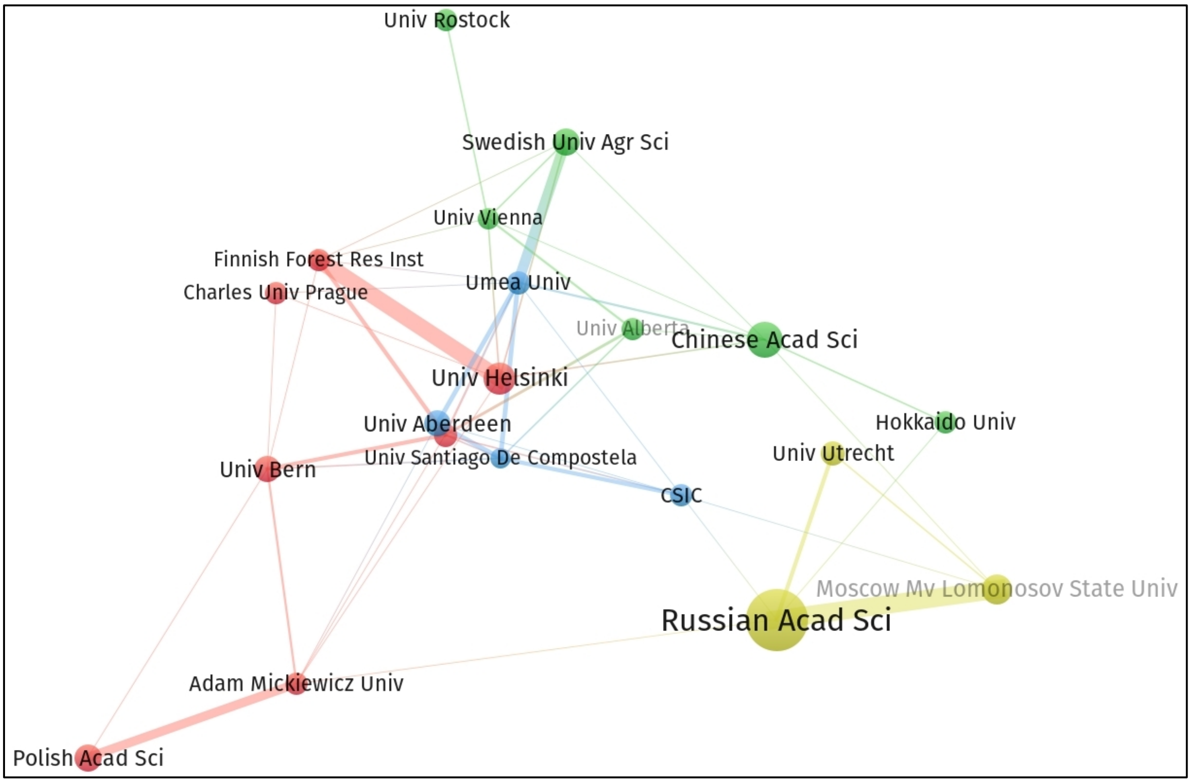

Figure 4. Organizations' network visualization in terms of co-occurrence links. Different colors represent different clusters, and organizations of the same color collaborate more closely with each other.

All of the above high-ranking institutions are more traditional peatland research forces, and an analysis of the average publication year (Avg. pub. year) shows three emerging research institutions: the University of Rostock, Germany (2016.63); Adam Mickiewicz University in Poznan, Poland (2015.76); and the University of Vienna, Austria (2015.62). All of them had average publication years later than 2015, indicating that these institutions have published more papers in recent years. On the other hand, the average publication years of the three organizations with the most published articles are close to 2013, about 2–3 years earlier than the former, indicating that these organizations started peatland research earlier and have a longer history of research. Among the top 20 organizations, the University of Bern, Switzerland, has the earliest average year of publication, 2006.16, indicating that it has the longest peatland research history, and its average number of citations per paper is also the highest, showing that its publications have the highest impact.

In the organizations' network visualization in terms of co-occurrence links (Figure 4), the institutional cooperation in peatland research is mainly divided into four major clusters. These are represented by the Russian Academy of Sciences, Moscow Mv Lomonosov State University, and the University of Utrecht in the Netherlands (yellow); the Chinese Academy of Sciences, the Swedish University of Agricultural Sciences, the University of Vienna in Austria, etc. (green); the University of Helsinki in Finland, the Finnish Forest Research Institute, the University of Bern in Switzerland, etc. (red); and Umea University in Sweden, the University of Aberdeen in the UK, the University of Santiago de Compostela in Spain, and the CSIC (Consejo Superior de Investigaciones Científicas [in Spanish] or Spanish National Research Council [in English]) in Spain (blue). The thickness of the line connecting two organizations represents the number of collaborative papers between them, indicating the intensity of the collaboration, and the size of the circle indicates the organization's total publications.

3.3. Research Areas of Peatland Publications

The WoS database labels each paper with a specific research area as a tool for measuring and analyzing contributions from different research areas. Based on these labels, we obtained the top 10 research areas in peatland research (Figure 5).

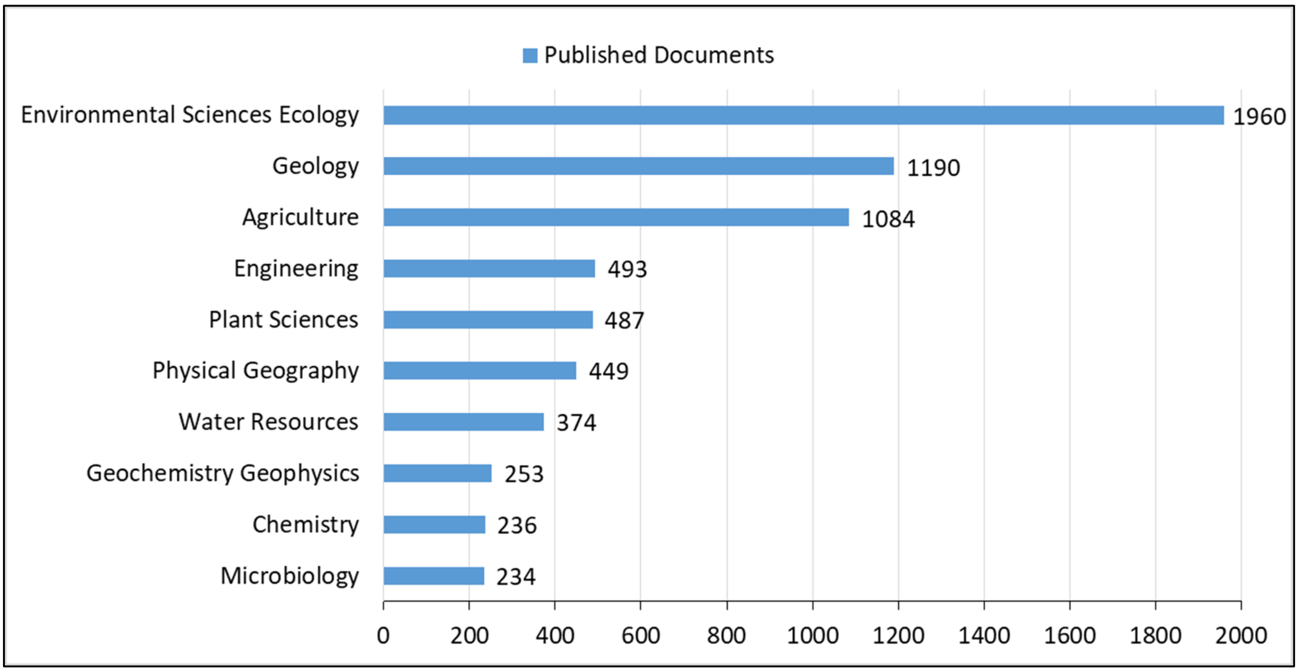

Figure 5. Top 10 research areas of peatland publications.

Based on the research areas labeled using the WoS database, the main research areas addressed in peatland research include environmental sciences ecology, geology, agriculture, engineering, plant sciences, physical geography, water resources, geochemistry geophysics, chemistry, and microbiology. Among these, environmental sciences ecology ranked first, involving 1960 papers, about 34.2% of all papers. The next highest-ranking fields were geology and agriculture, both of which were included in over 1000 papers, indicating that peatland research often involves these two related fields. In fact, these top 10 research areas also reflect the main research content and application scenarios of peatland research. For instance, peat-genesis studies will generally involve geology, while peatland degradation, conservation, etc., will generally involve the fields of agriculture and engineering. Studies on the landscape of peatland environments and the related geographic composition, structure, spatial heterogeneity, and patterns of change in the formation and development of peatlands are related to plant sciences and physical geography. Peatlands' hydrological regulation of underground water levels, runoff, etc., is often related to the field of water resources. The physicochemical action of peatlands and the incomplete decomposition of plant remains, which is one of the necessities for peat formation, involves the fields of geochemistry geophysics, chemistry, and microbiology.

3.4. Hot Keywords and Research Topics

The keywords and abstract of a paper are the core of a well-crafted research paper, accurately reflecting the research objectives and core content of the paper [34–36]. Analyzing the frequency of keywords and the publication year of the papers they occur in can capture the latest and most frequently referred to popular keywords, revealing the research hotspots in different perspectives of the research field. For this purpose, we conducted an extraction and analysis of popular keywords using the keyword co-occurrence analysis function of VOSviewer. The top 103 keywords were obtained by setting a threshold of 19 for the number of co-occurrences of author keywords, and the average publication year

(Avg. pub. year) of these keywords was calculated (Table 3, Figure 6). In Table 3, the keywords are sorted in order of "Avg. pub. year". In Figure 6, the color shifts from yellow through to green and blue to purple as the "Avg. pub. year" becomes relatively older.

Table 3. Top 30 latest keywords.

Keywords	Occurrences	Avg. Pub. Year	Keywords	Occurrences	Avg. Pub. Year
Oil Palm	19	2017.21	Climate Change	173	2013.84
Tropical Peatland	20	2017.20	c	25	2013.84
Permafrost	55	2017.07	Soil Organic Matter	38	2013.68
Greenhouse Gases	43	2015.91	Diversity	34	2013.62
Histosols	55	2015.85	Land Use Change	28	2013.57
Biodiversity	33	2015.33	Modeling	23	2013.57
Indonesia	22	2015.32	Rewetting	25	2013.40
Trace Elements	34	2014.79	Testate Amoebae	30	2013.27
Soil Organic Carbon	23	2014.74	Geochemistry	55	2013.18
Wildfire	43	2014.49	Water Quality	21	2013.14
Organic Carbon	19	2014.21	CO_2	23	2012.96
Organic Soil	21	2014.20	Bacteria	23	2012.95
Bulk Density	19	2014.11	Dissolved Organic Carbon	54	2012.85
Vegetation History	20	2014.10	Subsidence	23	2012.83
Lakes	23	2014.04	Bogs	24	2012.79

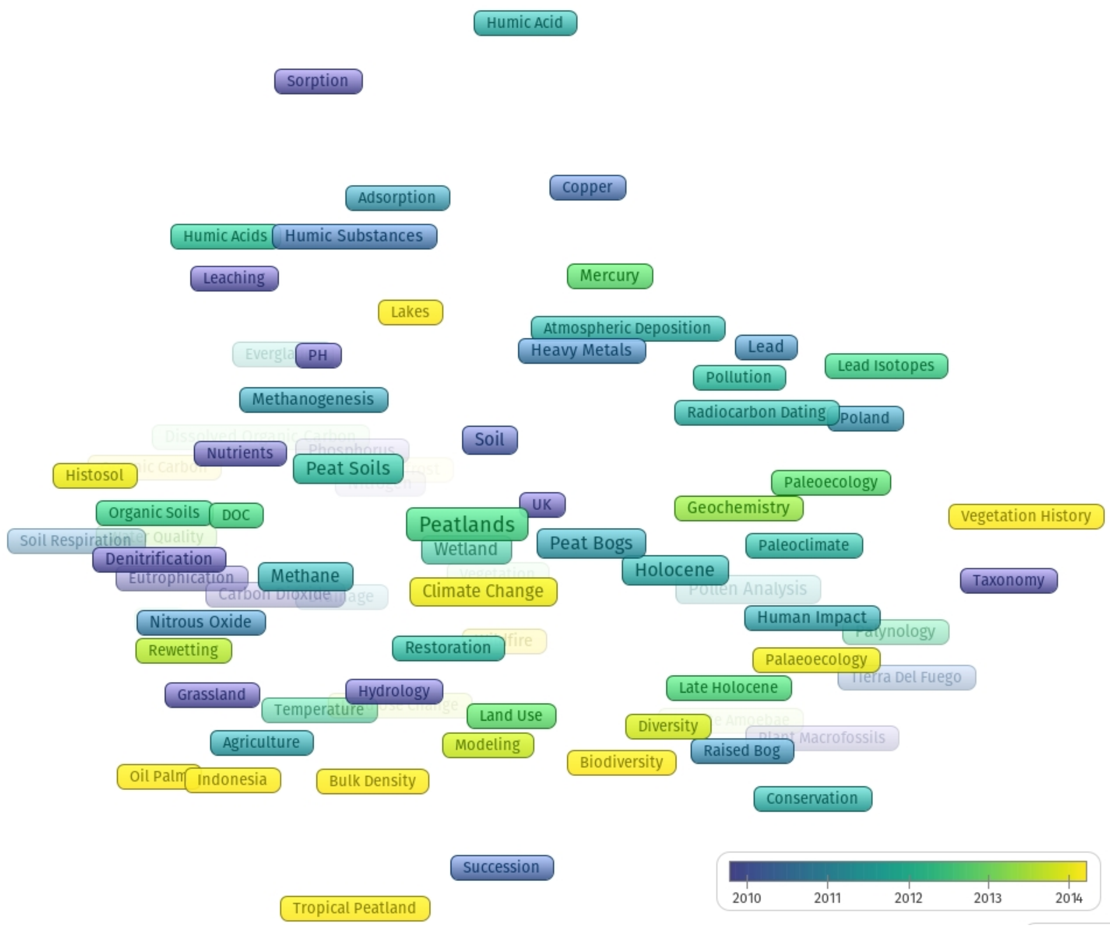

Figure 6. The keyword trends of peatland studies based on the Avg. pub. year.

Combining Table 3 and Figure 6, it can be seen that the main hot keywords in more recent publications include "oil palm", "tropical peatland", "permafrost", "greenhouse gases", "histosols", "biodiversity", "Indonesia", etc., all of which have an average publication year exceeding 2015. These keywords reflect the current hot topics in peatland research and major peatland development areas. By contrast, keywords such as ”land use change”, ”modeling”, ”rewetting”, ”water quality”, and “carbon dioxide” are relatively older, while other keywords cover more traditional research topics such as the physicochemical effects and classification of peatlands.

Based on the co-occurrence of keywords, a thematic clustering of the top 102 keywords was performed (Figure 7 and Table 4). All the keywords were grouped into six clusters (represented as colors in Figure 7), and based on the lexical meanings of the keywords, the major theme of each cluster was defined, identifying the hot topics of peatland research (Table 4). Then, the keywords covered by each topic were analyzed by the average publication year (Avg. pub. year) in order to objectively assess the novelty of the different topics on the time scale.

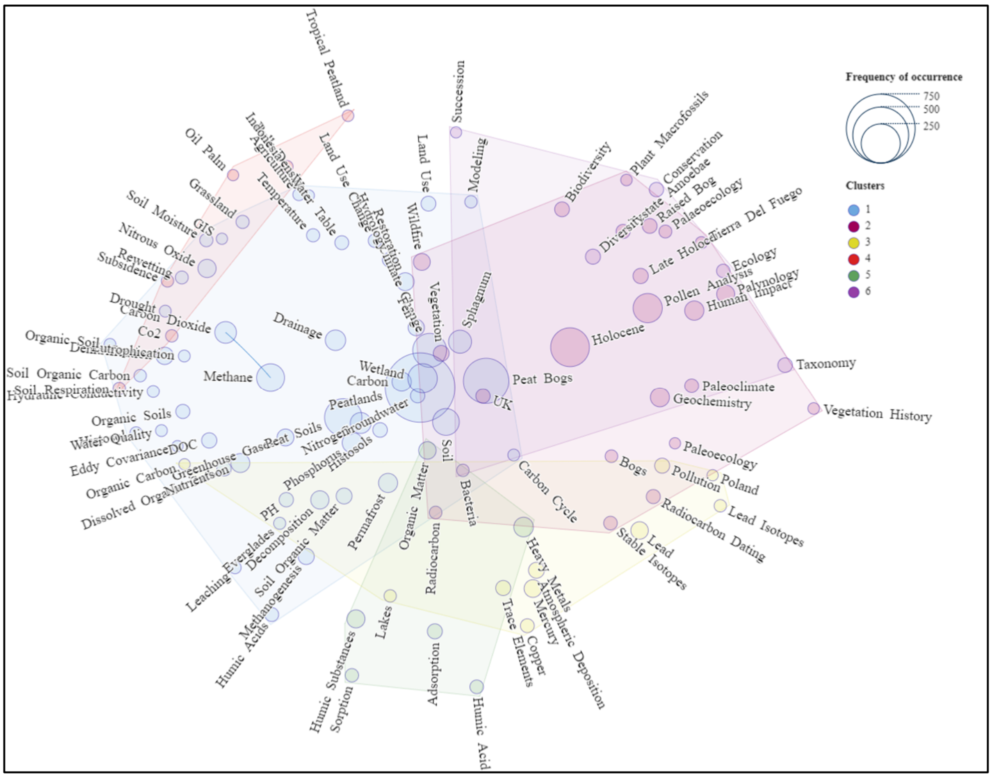

Figure 7. Thematic clustering of keywords including six clusters.

These are the six hot topics of peatland research over the last three decades:

Topic 1. <u>Peatland development and the impacts and degradations under climate change scenarios</u> (blue area in Figure 7, with a total of 52 keywords). The main keywords include “peatlands”, ”peat bogs”, “climate change”, “methane”, “wetland”, “peat soils”, “carbon dioxide”, “nitrogen”, “carbon”, “sphagnum”, “soil”, “phosphorus”, “nitrous oxide”, “drainage”, “fen”, “decomposition”, “permafrost”, “restoration”, “greenhouse gases”, “dissolved organic carbon”, etc.

Topic 2. <u>History of peatland development and factors of formation</u> (pink area in Figure 7, 22 keywords). The main keywords include “Holocene”, “pollen analysis”, “geochemistry”, “human impact”, “vegetation”, “wildfire”, “testate amoebae”, “late Holocene”, “palynology”, “paleoclimate”, “palaeoecology”, etc.

Topic 3. <u>Chemical element contaminants in peatlands</u> (yellow area Figure 7, 10 keywords). The keywords are “atmospheric deposition”, “lead”, “pollution”, “mercury”, “trace elements”, “copper”, “lead isotopes”, “lakes”, “organic carbon”, and “Poland”.

Topic 4. Tropical peatlands and their effects (red area in Figure 7, 6 keywords). The keywords are "subsidence", "CO_2", "soil respiration", "oil palm", "Indonesia", and "tropical peatland".

Topic 5. Peat adsorption and its humic acids (green area in Figure 7, 6 keywords). The keywords are "organic matter", "heavy metals", "adsorption", "humic substances", "sorption", and "humic acid".

Topic 6. Influence of peatland conservation on the ecosystem (purple area in Figure 7, 6 keywords). The keywords are "diversity", "bacteria", "succession", "ecology", "conservation", and "taxonomy".

From the average publication year, it can be seen that topic 4 has the most recent research focus, indicating that it is currently a hot research topic, while topics 5 and 6 are relatively more traditional or have longer histories of research.

Table 4. Topic clusters in the published papers on peatlands research from 1990 to 2022.

Cluster	Topic	Keywords Ranked by Occurrences Value	Avg. Pub. Year
1 Blue (52)	Peatland development and the impacts and degradations under climate change scenarios	Peatlands; Peat Bogs; Climate Change; Methane; Wetland; Peat Soils; Carbon Dioxide; Nitrogen; Carbon; Sphagnum; Soil; Phosphorus; Nitrous Oxide; Drainage; Fen; Decomposition; Permafrost; Restoration; Greenhouse Gases; Dissolved Organic Carbon; DOC; Denitrification; Nutrients; Hydrology; Water Table; Soil Organic Matter; Methanogenesis; Rewetting; Everglades; Groundwater; Land Use; Temperature; PH; Eutrophication; Grassland; Drought; Agriculture; Land-Use Change; Soil Organic Carbon; Carbon Cycle; Modeling; Soil Moisture; Histosols; Eddy Covariance; Organic Soils; Organic Soil; Leaching; Hydraulic Conductivity; Humic Acids; GIS; Bulk Density; Water Quality	2011.84
2 Pink (22)	History of peatland development and factors of formation	Holocene; Pollen Analysis; Geochemistry; Human Impact; Vegetation; Wildfire; Testate Amoebae; Late Holocene; Palynology; Paleoclimate; Paleoecology; Plant Macrofossils; Radiocarbon; Stable Isotopes; UK; Radiocarbon Dating; Bogs; Raised Bog; Vegetation History; Biodiversity; Paleoecology; Tierra Del Fuego	2012.19
3 Yellow (10)	Chemical element contaminants in peatlands	Atmospheric Deposition; Lead; Pollution; Mercury; Trace Elements; Copper; Lead Isotopes; Lakes; Organic Carbon; Poland	2012.38
4 Red (6)	Tropical peatlands and their effects	Subsidence; CO_2; Soil Respiration; Oil Palm; Indonesia; Tropical Peatland	2014.38
5 Green (6)	Peat adsorption and its humic acids	Organic Matter; Heavy Metals; Adsorption; Humic Substances; Sorption; Humic Acid	2010.75
6 Purple (6)	Influence of peatland conservation on the ecosystem	Diversity; Bacteria; Succession; Ecology; Conservation; Taxonomy	2010.16

4. Discussion

Based on a systematic bibliometric analysis, this study sorted and analyzed the key trends in peatland-related research publications and identified the hot topics of current research. In light of this, we now systematically review the critical issues in peatland research, dividing them into four aspects: peatland degradation and its adverse impacts, peatland mapping and its methodology, peatland carbon-stocks and carbon-emission assessment, and peatland's ecological value and its evaluation. It should be clarified that peatland research constitutes a complex, large, and systematic body of work. Therefore, this study only reviews and analyzes the relevant hotspots based on the bibliometric results and available information and attempts to analyze these critical issues in greater detail.

4.1. Peatland Degradation and Its Adverse Impacts in the Context of Climate Change

Climate warming has become undeniable [38]. In this context, peatlands have become more sensitive and vulnerable [39]. The global release of CO_2 from peatlands due to warming or degradation has been assessed at about two billion tons per year, which represents 5% of the global carbon-release flux [29]. The adverse effects of peatland degradation and their impacts on other ecological factors associated with peatlands merit serious attention. There are five major impacts of peatland degradation we will consider here.

First, peatland degradation triggers a reduction in the regional water table, which can lead to a decrease in soil evapotranspiration [2,40]. Frequent water-table fluctuations can induce the formation of cracks in the drained peat, which prevents the supply of capillary water to the soil, leading to a vicious cycle of more frequent desiccation and greater depths of desiccation. Eventually, a loose, fine-grained, water-repellent topsoil may form that can support only a limited range of extreme dryland species [41,42], further accelerating deterioration. For instance, millions of hectares of peatlands in Eastern Europe have deteriorated into dry desert environments in just a few decades due to this mechanism [43]. Meanwhile, the reduction in vegetation cover due to the lower water table triggered by peatland degradation has resulted in a specific transformation of landscape patterns and the loss of peatland-specific biodiversity.

Second, nitrogen mineralization due to peat oxidation, which increases nitrogen runoff into downstream rivers, lakes, and coasts, produces landscape alterations and coastal eutrophication [44]. The vast nitrogen reservoirs of peatlands may be released by the intensification of climate-driven hydrological events, e.g., during prolonged droughts or following storms, and subsequently transported to marine ecosystems. Additionally, drainage, liming, and fertilization lead to peat mineralization and sedimentation. Carbon dioxide emissions from peatlands tend to exacerbate the anthropogenic greenhouse effect, while nitrogen leaching from peatlands may lead to the contamination of groundwater resources, including drinking water [45].

Third, drainage causes compaction of the peat body [46], which alters the hydraulic properties of the peat and diminishes the ability of peatlands to store water and regulate runoff [47]. The drainage of peatlands leads to drier soil cover and reduced evapotranspiration. On the other hand, drainage also produces higher annual runoff. Where peat has a low hydraulic conductivity, which is typically the case with mires, drainage will result in a relatively high water table, low water storage capacity, and rapid runoff. Where peat has a high fiber content, low density, and high degree of decay, hydraulic conductivity and storage capacity will be relatively high, and drainage will consequently lead to increased storage and lower flood peaks. After drainage, peat becomes saturated over time due to increased submerged compaction and decomposition, which again can lead to further increases in runoff [47].

Fourth, land subsidence due to peat's susceptibility to compaction can have serious social consequences in densely populated areas, as it can damage infrastructure, such as roads, sewerage systems, and buildings [42,48–51], and lead to flooding. Particularly in coastal areas, peatland subsidence increases the risk of flooding and saltwater intrusion. Much of Malaysia and Indonesia will be at risk of flooding in the near future due to rapid peatland subsidence and sea-level rise [52].

Lastly, when peatland self-regulation is hampered, land-use change or fires will exacerbate flood and drought risks [18,27]. The ecological, hydrological, and biogeochemical functions of peatlands are closely interlinked with climate, and both the direct impacts of humans and indirect impacts of climate change can jeopardize the ecological functioning of peatlands through changes in hydrology [53]. Land-use change in the form of peatland degradation causes carbon release through direct carbon dioxide emissions [54].

4.2. Peatland Extent Statistics and Mapping Methods

Peatland-distribution information can be obtained using traditional soil survey methods; however, large-scale deployment is limited by high costs and time constraints, making mapping the extent of peatlands on a global scale a challenging task [21,55]. Currently, peatland-mapping methods are broadly categorized into two types: top-down methods, such as machine learning [55] and remote sensing inversion [56]; and bottom-up methods, such as national data fusion [14,21]. Mapping peatlands based on these methods is usually achieved by modeling the topographic, geomorphic, climatic, soil, and hydrological data that may signal the existence of peatlands [57–61]. For example, some studies have found a higher accuracy in peatland mapping in the tropics when it is based on multivariate remote sensing data using a machine learning method that employs open access data in an open-source computing environment, which also allows for good repeatability [62]. Moreover, results in Scotland and Canada have also demonstrated the effectiveness of this method [63]. With remote sensing products, a variety of sensors—including optical, radar, or a combination of both—are used for peatland mapping. Optical remote sensing imagery, such as that provided by Landsat 8 OLI and MODIS, are beneficial for peatland mapping, but radar remote sensing imagery has some advantages in predicting peatland area, and it has been demonstrated that the C-band and L-band ranges can better extract peatland distribution information [64,65]. In addition, fusing optical and radar imagery to improve the accuracy of peatland mapping has received much attention in recent years because of the complementary nature of the information captured by optical and radar sensors [66–68]. Regarding the algorithms used for predicting peatland distribution, maximum likelihood estimation (MLE), support vector machines (SVMs), convolutional neural networks (CNNs), random forests (RFs), gradient boosting (GB), extreme gradient boosting (XGBoost), and categorical boosting (CatBoost) have all gradually come into use recently, boosting validation accuracies of up to 83% [16]. Nevertheless, there is a deficiency of peatland-mapping techniques applicable to all regions due to the large regional differences in the climatic backgrounds under which peatlands develop and the underlying environment [69]. Difficulties in obtaining and harmonizing the fundamental data is also a major issue. At the national scale, bottom-up approaches are common. Earth observation (EO), including airborne and satellite-data analysis, is generally utilized as a technique that integrates field-survey and mapping data [16]. Both of the two approaches above have their own specific strengths. The top-down approach maps consistently across the globe, using a clear and consistent definition of peatland, whereas the bottom-up approach has a higher resolution and accuracy and includes regionally appropriate categories that can be aggregated into as accurate and detailed a product as possible [70].

4.3. Research on Carbon-Stock Assessment and Carbon Emissions in Peatlands

High carbon stocks are a major characteristic of peatlands. Peatland ecosystems have the highest carbon stock per hectare of any natural ecosystem in the world [5,71], and store about twice as much carbon as global forest biomass [72]. Peatlands cover only about 3% the global land area but store one-third of the world's soil carbon [73,74], holding the largest carbon stocks in the terrestrial biosphere [8], with total carbon stocks estimated at 450,000–650,000 Mt of carbon [5]. Boreal peatlands, accounting for the majority, are estimated to hold 400,000–550,000 Mt [17,21,75], tropical peatlands are estimated to hold 100,000 Mt [9,12], and southern peatlands are estimated to hold 15,000 Mt of carbon [21]. The great magnitude of peatland carbon stocks has been well acknowledged [76,77]. Although three methods for estimating carbon stocks in peatlands are reviewed by Yu [78]—the time–history method, the peat-volume method, and the carbon-density method—a uniform and reliable estimate of peatland carbon stocks in all countries of the world has not yet been accomplished.

Emissions from peatlands are an unavoidable issue. It is well recognized that when peatlands are disturbed, drained, and/or degraded, they disproportionately increase greenhouse gas (GHG) emissions. The emission routes are mainly atmospheric, with microbial degradation leading to a rapid loss in peat, mainly as carbon dioxide and nitrous oxide, when oxygen enters the upper peat layer. During peat fires, dry peatland smoldering releases large quantities of other gases, causing widespread haze with deleterious effects on human health [79,80]. In addition to the atmospheric routes, degraded peatlands lose carbon to water as dissolved and particulate carbon, which later partially oxidizes and contributes carbon dioxide and methane to the atmosphere, leaving a small portion to reach the oceans [81]. Overall degraded peatland emissions, excluding peat fires, exceed 1940 Mt CO_2e per year, approximately 3% of the total global anthropogenic GHG emissions [5,13,82]. The resulting prediction is that if emissions from drained peatlands continue at this rate until 2100, they will consume 41% of the GHG emissions budget for maintaining global warming below +1.5 °C and 12% of the GHG emissions budget for maintaining global warming below +2 °C [72]. In many countries, peatland emissions account for a significant proportion of their total national emissions, thereby emphasizing the importance and urgency of integrating peatlands and their emissions into nationally determined contributions (NDCs). It is predicted that the carbon balance of peatlands will change from a carbon sink to a carbon source this century [83–85]. Yet, peatland ecosystems remain omitted from the major Earth system models used for future climate change forecasts. Given their essential contribution to the global carbon cycle, it has been demonstrated that peatland science is a key area of research and that there is still a long way to go before we adequately comprehend the peatland–carbon–climate nexus [3].

4.4. Peatland Ecosystem Values and Their Evaluation

Peatlands provide critical ecosystem values and functions. For instance, in the boreal and polar regions, peatlands provide communities with berries, mushrooms, reindeer grazing areas, and fishing or hunting grounds [86,87]. In addition, peatlands are key "archives" of environmental evolution, and the analysis of peat cores can reveal changes in past vegetation, hydrological and climatic conditions, and the impact of human activities [88,89]. Peatlands also play an important hydrological role. Domed peatlands are essentially hydrologically self-regulating, maintaining high water levels during the dry season and preventing flooding during the rainy season [18,27,90]. Peatlands may also retain and release water into the surrounding landscape and aquifers, helping to maintain base flows in nearby rivers and streams [91–93], and are critical for regulating regional water quality and quantity [14]. Furthermore, peatlands play a role as distinctive habitats, with pristine peatlands inhabited by a wide range of highly specialized plants and fish that are adapted to acidic and low-nutrient environments [94,95], and the conservation of rare and endangered species is vital for supporting other ecosystem services, such as food security and ecotourism. Moreover, peatlands not only have important ecological functions but also provide significant socio-economic resources and offer economic benefits to local residents [96,97]. Considering the values and functions discussed above, it is clear that the conservation, restoration, and sustainable management of peatlands to ensure that they can effectively provide the services on which human life depends are necessary [98] and will become an essential nature-based solution (NbS). Not only will this help to confront climate change, support biodiversity and livelihoods, and secure a range of ecosystem services, but it will also contribute to sustainable development goals (SDGs) [99].

Despite their ecological value, peatlands have long been inhospitable areas, regarded as wastelands, and only considered valuable when utilized for agriculture, forestry, or peat extraction [32]. This view, which singles out the direct supply value of peatlands, has led to a focus on the exploitation of peatlands in many areas and has caused serious damage to their local ecosystems, triggering environmental degradation, biodiversity loss, nutrient loss, and water-quality and -quantity declines [33]. Although other ecosystems, such as forests, grasslands, and farmlands, have been recognized for their service values [100,101], relatively few studies have focused on the ecological service values of peatlands. Since the 1990s, research estimating the ecological service value of peatlands has gradually increased, but due to the limitations of outdated technical methods and the difficulty of obtaining data, often only simple estimates were made of the service value of a single element. For example, of the biodiversity value of peatlands in northwestern Switzerland was estimated in 2003 [102]. As science's understanding of peatland-ecosystem functions grows, research assessing the value of peatland services is increasing and estimation methods are gradually evolving [32,33,103,104]. Due to their fragile ecological environment in many areas, peatland ecosystems have been characterized by reduced stability, increased vulnerability, and weakened service values under the influence of climate change and human activities [72,105]. Unfortunately, international research on peatland-ecosystem services in general is still in its infancy, and among studies, there are obvious differences in methodologies, price parameters, standards, and socio-economic levels, which leads to calculations that do not necessarily reflect the true ecosystem service value of peatlands at the local scale [86]. As a result, when assessing the actual ecosystem service values of peatlands, not only should the generalized international research methods be considered, but also the actual environmental situation in the region where the peatland is located needs to be considered, and a suitable service-value assessment system should be constructed for the local ecological environment [106].

5. Conclusions

Based on the integrated methodologies of bibliometrics and the literature review, this study systematically offers an analysis of the current state of peatland research. It identifies the research situation and the influence of major countries and institutions, delineates the major research areas, pinpoints the core keywords, and spotlights the hot research topics. It provides a comprehensive review of the critical issues and research progress across four key dimensions: (1) peatland degradation and its adverse impacts, (2) peatland mapping and its methodology, (3) peatland carbon-stock assessment and carbon emissions, and (4) peatland's ecological value and its assessment. Peatland research has seen growth in last 10 years, with the USA, UK, and Germany leading. The UK has the longest history of peatland research, while Germany is the most influential center of international cooperation. The Russian Academy of Sciences, the Chinese Academy of Sciences, and the University of Helsinki are top in publications, while the University of Bern, Heidelberg University, and Umea University lead in citations. Environmental sciences ecology, geology, and agriculture are the main areas of peatland research, and common keywords are "oil palm", "tropical peatland", "permafrost", etc. Six hot topics identified were the following: "Peatland development and the impacts and degradations under climate change scenarios", "History of peatland development and factors of formation", "Chemical element contaminants in peatlands", "Tropical peatlands", "Peat adsorption and its humic acids", and "Influence of peatland conservation on the ecosystem".

This study also discusses key issues in peatland research. The concerns include peatland's sensitivity and fragility and degradation impacts. There is also a lack of universal peatland-mapping techniques, and a lack of global estimation of carbon stocks in peatlands, and there is an urgent need to carry out relevant assessments. Also, it is urgent that countries include peatlands and their emissions in their NDCs. Research on peatland ecological services is limited, so building a valuation system is urgent.

To help solve these issues, it is necessary to enhance research integration to bridge knowledge gaps and conduct comprehensive research on peatlands as complex systems. Strengthening research related to peatland conservation, restoration, hydrological regulation, and carbon dynamics is necessary for human well-being. Better research will help policy or decision makers develop better management plans for environmental protections, ecosystem functioning, and climate warming mitigation.

The limitations of this study include the subjectivity in the selection of the thematic search terms in the bibliometric analysis and the natural limitations in the selection of bibliometric indicators in the research methodology. Additionally, the problem of data inadequacy and neglect triggered by the scope of the data and by language issues in the data is inherently present. For the literature review, four key aspects were selected, but in reality, peatland research is a complex, large, and systematic research oeuvre that still requires further expansion and more detailed analysis.

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References

1. Clymo, R.S.; Turunen, J.; Tolonen, K. Carbon Accumulation in Peatland. *Oikos* **1998**, *81*, 368. [CrossRef]
2. Rixen, T. Carbon Leaching from Tropical Peat Soils and Consequences for Carbon Balances. *Front. Earth Sci.* **2016**, *4*, 74. [CrossRef]
3. Loisel, J.; Gallego-Sala, A.V.; Amesbury, M.J.; Magnan, G.; Anshari, G.; Beilman, D.W.; Benavides, J.C.; Blewett, J.; Camill, P.; Charman, D.J.; et al. Expert Assessment of Future Vulnerability of the Global Peatland Carbon Sink. *Nat. Clim. Change* **2021**, *11*, 362. [CrossRef]
4. Yuan, F.; Ricciuto, D.M.; Xu, X.; Roman, D.T.; Lilleskov, E.; Wood, J.D.; Cadillo-Quiroz, H.; Lafuente, A.; Rengifo, J.; Kolka, R.; et al. Evaluation and Improvement of the E3SM Land Model for Simulating Energy and Carbon Fluxes in an Amazonian Peatland. *Agric. For. Meteorol.* **2023**, *332*, 109364. [CrossRef]
5. UNEP Global Peatlands Assessment. *The State of the World's Peatlands: Evidence for Action toward the Conservation, Restoration, and Sustainable Management of Peatlands*; Main Report; United Nations Environment Programme: Nairobi, Kenya, 2022.
6. Chen, C.; Loft, L.; Matzdorf, B. Lost in Action: Climate Friendly Use of European Peatlands Needs Coherence and Incentive-Based Policies. *Environ. Sci. Policy* **2023**, *145*, 104–115. [CrossRef]
7. Dise, N.B. Peatland Response to Global Change. *Science* **2009**, *326*, 810–811. [CrossRef]
8. Temmink, R.J.M.; Lamers, L.P.M.; Angelini, C.; Bouma, T.J.; Fritz, C.; Van De Koppel, J.; Lexmond, R.; Rietkerk, M.; Silliman, B.R.; Joosten, H.; et al. Recovering Wetland Biogeomorphic Feedbacks to Restore the World's Biotic Carbon Hotspots. *Science* **2022**, *376*, eabn1479. [CrossRef]
9. Dargie, G.C.; Lewis, S.L.; Lawson, I.T.; Mitchard, E.T.A.; Page, S.E.; Bocko, Y.E.; Ifo, S.A. Age, Extent and Carbon Storage of the Central Congo Basin Peatland Complex. *Nature* **2017**, *542*, 86–90. [CrossRef] [PubMed]
10. Antala, M.; Juszczak, R.; van der Tol, C.; Rastogi, A. Impact of Climate Change-Induced Alterations in Peatland Vegetation Phenology and Composition on Carbon Balance. *Sci. Total Environ.* **2022**, *827*, 154294. [CrossRef]
11. Wang, J.; Song, C.; Zhang, J.; Wang, L.; Zhu, X.; Shi, F. Temperature Sensitivity of Soil Carbon Mineralization and Nitrous Oxide Emission in Different Ecosystems along a Mountain Wetland-Forest Ecotone in the Continuous Permafrost of Northeast China. *CATENA* **2014**, *121*, 110–118. [CrossRef]
12. Page, S.E.; Rieley, J.O.; Banks, C.J. Global and Regional Importance of the Tropical Peatland Carbon Pool. *Glob. Change Biol.* **2011**, *17*, 798–818. [CrossRef]
13. Leifeld, J.; Menichetti, L. The Underappreciated Potential of Peatlands in Global Climate Change Mitigation Strategies. *Nat. Commun.* **2018**, *9*, 1071. [CrossRef] [PubMed]
14. Xu, J.; Morris, P.J.; Liu, J.; Holden, J. Hotspots of Peatland-Derived Potable Water Use Identified by Global Analysis. *Nat. Sustain.* **2018**, *1*, 246–253. [CrossRef]
15. Loisel, J.; van Bellen, S.; Pelletier, L.; Talbot, J.; Hugelius, G.; Karran, D.; Yu, Z.; Nichols, J.; Holmquist, J. Insights and Issues with Estimating Northern Peatland Carbon Stocks and Fluxes since the Last Glacial Maximum. *Earth-Sci. Rev.* **2017**, *165*, 59–80. [CrossRef]
16. Minasny, B.; Berglund, O.; Connolly, J.; Hedley, C.; de Vries, F.; Gimona, A.; Kempen, B.; Kidd, D.; Lilja, H.; Malone, B.; et al. Digital Mapping of Peatlands—A Critical Review. *Earth-Sci. Rev.* **2019**, *196*, 102870. [CrossRef]
17. Hugelius, G.; Loisel, J.; Chadburn, S.; Jackson, R.B.; Jones, M.; MacDonald, G.; Marushchak, M.; Olefeldt, D.; Packalen, M.; Siewert, M.B.; et al. Large Stocks of Peatland Carbon and Nitrogen Are Vulnerable to Permafrost Thaw. *Proc. Natl. Acad. Sci. USA* **2020**, *117*, 20438–20446. [CrossRef] [PubMed]
18. Lupascu, M.; Varkkey, H.; Tortajada, C. Is Flooding Considered a Threat in the Degraded Tropical Peatlands? Sci. *Total Environ.* **2020**, *723*, 137988. [CrossRef] [PubMed]
19. Nijp, J.J.; Metselaar, K.; Limpens, J.; Teutschbein, C.; Peichl, M.; Nilsson, M.B.; Berendse, F.; van der Zee, S.E.A.T.M. Including Hydrological Self-Regulating Processes in Peatland Models: Effects on Peatmoss Drought Projections. *Sci. Total Environ.* **2017**, *580*, 1389–1400. [CrossRef] [PubMed]

20. Belyea, L.R.; Malmer, N. Carbon Sequestration in Peatland: Patterns and Mechanisms of Response to Climate Change. *Glob. Change Biol.* **2004**, *10*, 1043–1052. [CrossRef]
21. Yu, Z.; Loisel, J.; Brosseau, D.P.; Beilman, D.W.; Hunt, S.J. Global Peatland Dynamics since the Last Glacial Maximum: GLOBAL PEATLANDS SINCE THE LGM. *Geophys. Res. Lett.* **2010**, *37*, L13402. [CrossRef]
22. Erwin, K.L. Wetlands and Global Climate Change: The Role of Wetland Restoration in a Changing World. *Wetl. Ecol. Manag.* **2009**, *17*, 71–84. [CrossRef]
23. Ratnayake, A.S. Characteristics of Lowland Tropical Peatlands: Formation, Classification, and Decomposition. *JTFE* **2020**, *10*, 1–16. [CrossRef]
24. Rowland, J.A.; Bracey, C.; Moore, J.L.; Cook, C.N.; Bragge, P.; Walsh, J.C. Effectiveness of Conservation Interventions Globally for Degraded Peatlands in Cool-Climate Regions. *Biol. Conserv.* **2021**, *263*, 109327. [CrossRef]
25. Waddington, J.M.; Lucchese, M.C.; Duval, T.P. Sphagnum Moss Moisture Retention Following the Re-vegetation of Degraded Peatlands. *Ecohydrology* **2011**, *4*, 359–366. [CrossRef]
26. Carvalho, F.; Brown, K.A.; Waller, M.P.; Boom, A. Leaf Traits Interact with Management and Water Table to Modulate Ecosystem Properties in Fen Peatlands. *Plant Soil* **2019**, *441*, 331–347. [CrossRef]
27. Evers, S.; Yule, C.M.; Padfield, R.; O'Reilly, P.; Varkkey, H. Keep Wetlands Wet: The Myth of Sustainable Development of Tropical Peatlands—Implications for Policies and Management. *Glob. Change Biol.* **2017**, *23*, 534–549. [CrossRef] [PubMed]
28. Parish, F.; Sirin, A.A.; Charman, D.; Joosten, H.; Minaeva, T.Y.; Silvius, M. *Assessment on Peatlands, Biodiversity and Climate Change*; Wetlands International: Ede, The Netherlands, 2008.
29. Wilson, D.; Blain, D.; Couwenberg, J.; Evans, C.D.; Murdiyarso, D.; Page, S.; Renou-Wilson, F.; Rieley, J.; Sirin, A.; Strack, M.; et al. Greenhouse Gas Emission Factors Associated with Rewetting of Organic Soils. *Mires Peat* **2016**, *17*, 06. [CrossRef]
30. Morecroft, M.D.; Duffield, S.; Harley, M.; Pearce-Higgins, J.W.; Stevens, N.; Watts, O.; Whitaker, J. Measuring the Success of Climate Change Adaptation and Mitigation in Terrestrial Ecosystems. *Science* **2019**, *366*, eaaw9256. [CrossRef] [PubMed]
31. Fewster, R.E.; Morris, P.J. Permafrost Peat Carbon Approaching a Climatic Tipping Point. *Nat. Clim. Change* **2022**, *12*, 320–321. [CrossRef]
32. Wichmann, S.; Brander, L.; Schafer, A.; Schaafsma, M.; Van Beukering, P.J.H.; Tinch, D.; Bonn, A. Valuing Peatland Ecosystem Services. In *Peatland Restoration and Ecosystem Services: Science, Policy and Practice*; Cambridge University Press: Cambridge, UK, 2016; ISBN 978-1-107-02518-9.
33. Kimmel, K.; Mander, Ü. Ecosystem Services of Peatlands: Implications for Restoration. *Prog. Phys. Geogr. Earth Environ.* **2010**, *34*, 491–514. [CrossRef]
34. Liu, W.; Zheng, J.; Wang, Z.; Li, R.; Wu, T. A Bibliometric Review of Ecological Research on the Qinghai–Tibet Plateau, 1990–2019. *Ecol. Inform.* **2021**, *64*, 101337. [CrossRef]
35. Liu, W.; Wang, Z.; Li, R.; Wu, T. A Bibliometric Analysis of Mountain Ecosystem Services, 2000–2019. *Environ. Sci. Pollut. Res.* **2022**, *29*, 16633–16652. [CrossRef] [PubMed]
36. Liu, W.; Li, R.; Shi, X.; Wu, T.; Wu, X.D. Hotspots and Trends in Frozen Soils Research in 2010–2019. *Permafr. Periglac. Process.* **2023**, *34*, 169–179. [CrossRef]
37. van Eck, N.J.; Waltman, L. Software Survey: VOSviewer, a Computer Program for Bibliometric Mapping. *Scientometrics* **2010**, *84*, 523–538. [CrossRef] [PubMed]
38. Helbig, M. Warming Response of Peatland CO2 Sink Is Sensitive to Seasonality in Warming Trends. *Nat. Clim. Change* **2022**, *12*, 743–749. [CrossRef]
39. Diáková, K.; Čapek, P.; Kohoutová, I.; Mpamah, P.A.; Bárta, J.; Biasi, C.; Martikainen, P.J.; Šantrůčková, H. Heterogeneity of Carbon Loss and Its Temperature Sensitivity in East-European Subarctic Tundra Soils. *FEMS Microbiol. Ecol.* **2016**, *92*, fiw140. [CrossRef] [PubMed]
40. Tamkevičiūtė, M.; Edvardsson, J.; Pukienė, R.; Taminskas, J.; Stoffel, M.; Corona, C.; Kibirkštis, G. Scots Pine (*Pinus Sylvestris* L.) Based Reconstruction of 130 years of Water Table Fluctuations in a Peatland and Its Relevance for Moisture Variability Assessments. *J. Hydrol.* **2018**, *558*, 509–519. [CrossRef]
41. Joosten, H.; Sirin, A.; Couwenberg, J.; Laine, J.; Smith, P. The Role of Peatlands in Climate Regulation. In *Peatland Restoration and Ecosystem Services*; Bonn, A., Allott, T., Evans, M., Joosten, H., Stoneman, R., Eds.; Cambridge University Press: Cambridge, UK, 2016; pp. 63–76. ISBN 978-1-107-02518-9.
42. Faul, F.; Gabriel, M.; Roßkopf, N.; Zeitz, J.; van Huyssteen, C.W.; Pretorius, M.L.; Grundling, P.-L. Physical and Hydrological Properties of Peatland Substrates from Different Hydrogenetic Wetland Types on the Maputaland Coastal Plain, South Africa. *South Afr. J. Plant Soil* **2016**, *33*, 265–278. [CrossRef]
43. Swindles, G.T. Widespread Drying of European Peatlands in Recent Centuries. *Nat. Geosci.* **2019**, *12*, 922–928. [CrossRef]
44. Wang, H.; Richardson, C.J.; Ho, M.; Flanagan, N. Drained Coastal Peatlands: A Potential Nitrogen Source to Marine Ecosystems under Prolonged Drought and Heavy Storm Events—A Microcosm Experiment. *Sci. Total Environ.* **2016**, *566–567*, 621–626. [CrossRef]
45. Höper, H. Carbon and Nitrogen Mineralisation Rates of Fens in Germany Used for Agriculture. A Review. In *Wetlands in Central Europe: Soil Organisms, Soil Ecological Processes and Trace Gas Emissions*; Broll, G., Merbach, W., Pfeiffer, E.-M., Eds.; Springer: Berlin/Heidelberg, Germany, 2002; pp. 149–164. ISBN 978-3-662-05054-5.

46. Sinclair, A.L.; Graham, L.L.B.; Putra, E.I.; Saharjo, B.H.; Applegate, G.; Grover, S.P.; Cochrane, M.A. Effects of Distance from Canal and Degradation History on Peat Bulk Density in a Degraded Tropical Peatland. *Sci. Total Environ.* **2020**, *699*, 134199. [CrossRef] [PubMed]
47. Beheim, E. The Effect of Peat Land Drainage and Afforestation on Runoff Dynamics. In *The Environmental Role of Wetlands in Headwaters*; Krecek, J., Haigh, M., Eds.; Springer: Dordrecht, The Netherlands, 2006; pp. 59–75.
48. van Asselen, S.; Stouthamer, E.; van Asch, T.W.J. Effects of Peat Compaction on Delta Evolution: A Review on Processes, Responses, Measuring and Modeling. *Earth-Sci. Rev.* **2009**, *92*, 35–51. [CrossRef]
49. Erkens, G.; Van Der Meulen, M.J.; Middelkoop, H. Double Trouble: Subsidence and CO_2 Respiration Due to 1000 Years of Dutch Coastal Peatlands Cultivation. *Hydrogeol. J.* **2016**, *24*, 551–568. [CrossRef]
50. van den Born, G.J.; Kragt, F.; Henkens, D.; Rijken, B.; van Bemmel, B.; van der Sluis, S.; Polman, N.; Bos, E.J.; Kuhlman, T.; Kwakernaak, C.; et al. *Dalende Bodems, Stijgende Kosten: Mogelijke Maatregelen Tegen Veenbodemdaling in Het Landelijk En Stedelijk Gebied: Beleidsstudie*; Planbureau voor de Leefomgeving: Den Haag, The Netherlands, 2016.
51. Couwenberg, J.; Baumann, M.; Lamkowski, P.; Joosten, H. From Genes to Landscapes: Pattern Formation and Self-regulation in Raised Bogs with an Example from Tierra Del Fuego. *Ecosphere* **2022**, *13*, e4031. [CrossRef]
52. Vernimmen, R.; Hooijer, A.; Yuherdha, A.T.; Visser, M.; Pronk, M.; Eilander, D.; Akmalia, R.; Fitranatanegara, N.; Mulyadi, D.; Andreas, H.; et al. Creating a Lowland and Peatland Landscape Digital Terrain Model (DTM) from Interpolated Partial Coverage LiDAR Data for Central Kalimantan and East Sumatra, Indonesia. *Remote Sens.* **2019**, *11*, 1152. [CrossRef]
53. Wu, J. Response of Peatland Development and Carbon Cycling to Climate Change: A Dynamic System Modeling Approach. *Environ. Earth Sci.* **2012**, *65*, 141–151. [CrossRef]
54. Wit, F.; Rixen, T.; Baum, A.; Pranowo, W.S.; Hutahaean, A.A. The Invisible Carbon Footprint as a Hidden Impact of Peatland Degradation Inducing Marine Carbonate Dissolution in Sumatra, Indonesia. *Sci. Rep.* **2018**, *8*, 17403. [CrossRef] [PubMed]
55. Melton, J.R.; Chan, E.; Millard, K.; Fortier, M.; Winton, R.S.; Martín-López, J.M.; Cadillo-Quiroz, H.; Kidd, D.; Verchot, L.V. A Map of Global Peatland Extent Created Using Machine Learning (Peat-ML). *Geosci. Model Dev.* **2022**, *15*, 4709–4738. [CrossRef]
56. Gumbricht, T.; Roman-Cuesta, R.M.; Verchot, L.; Herold, M.; Wittmann, F.; Householder, E.; Herold, N.; Murdiyarso, D. An Expert System Model for Mapping Tropical Wetlands and Peatlands Reveals South America as the Largest Contributor. *Glob. Change Biol.* **2017**, *23*, 3581–3599. [CrossRef]
57. Bhatti, J.S.; Apps, M.J.; Tarnocai, C. Estimates of Soil Organic Carbon Stocks in Central Canada Using Three Different Approaches. *Can. J. For. Res.* **2002**, *32*, 805–812. [CrossRef]
58. Connolly, J.; Holden, N.M.; Ward, S.M. Mapping Peatlands in Ireland Using a Rule-Based Methodology and Digital Data. *Soil Sci. Soc. Am. J.* **2007**, *71*, 492–499. [CrossRef]
59. Connolly, J.; Roulet, N.T.; Seaquist, J.W.; Holden, N.M.; Lafleur, P.M.; Humphreys, E.R.; Heumann, B.W.; Ward, S.M. Using MODIS Derived fPAR with Ground Based Flux Tower Measurements to Derive the Light Use Efficiency for Two Canadian Peatlands. *Biogeosciences* **2009**, *6*, 225–234. [CrossRef]
60. Thompson, D.K.; Simpson, B.N.; Beaudoin, A. Using Forest Structure to Predict the Distribution of Treed Boreal Peatlands in Canada. *For. Ecol. Manag.* **2016**, *372*, 19–27. [CrossRef]
61. DeLancey, E.R.; Kariyeva, J.; Bried, J.T.; Hird, J.N. Large-Scale Probabilistic Identification of Boreal Peatlands Using Google Earth Engine, Open-Access Satellite Data, and Machine Learning. *PLoS ONE* **2019**, *14*, e0218165. [CrossRef] [PubMed]
62. Rudiyanto; Minasny, B.; Setiawan, B.I.; Saptomo, S.K.; McBratney, A.B. Open Digital Mapping as a Cost-Effective Method for Mapping Peat Thickness and Assessing the Carbon Stock of Tropical Peatlands. *Geoderma* **2018**, *313*, 25–40. [CrossRef]
63. Hird, J.N.; DeLancey, E.R.; McDermid, G.J.; Kariyeva, J. Google Earth Engine, Open-Access Satellite Data, and Machine Learning in Support of Large-Area Probabilistic Wetland Mapping. *Remote Sens.* **2017**, *9*, 1315. [CrossRef]
64. Kasischke, E.S.; Melack, J.M.; Craig Dobson, M. The Use of Imaging Radars for Ecological Applications—A Review. *Remote Sens. Environ.* **1997**, *59*, 141–156. [CrossRef]
65. Zhou, Z.; Li, Z.; Waldron, S.; Tanaka, A. InSAR Time Series Analysis of L-Band Data for Understanding Tropical Peatland Degradation and Restoration. *Remote Sens.* **2019**, *11*, 2592. [CrossRef]
66. Crowson, M.; Warren-Thomas, E.; Hill, J.K.; Hariyadi, B.; Agus, F.; Saad, A.; Hamer, K.C.; Hodgson, J.A.; Kartika, W.D.; Lucey, J.; et al. A Comparison of Satellite Remote Sensing Data Fusion Methods to Map Peat Swamp Forest Loss in Sumatra, Indonesia. *Remote Sens. Ecol. Conserv.* **2019**, *5*, 247–258. [CrossRef]
67. Poggio, L.; Lassauce, A.; Gimona, A. Modelling the Extent of Northern Peat Soil and Its Uncertainty with Sentinel: Scotland as Example of Highly Cloudy Region. *Geoderma* **2019**, *346*, 63–74. [CrossRef]
68. Lopes, M.; Frison, P.; Crowson, M.; Warren-Thomas, E.; Hariyadi, B.; Kartika, W.D.; Agus, F.; Hamer, K.C.; Stringer, L.; Hill, J.K.; et al. Improving the Accuracy of Land Cover Classification in Cloud Persistent Areas Using Optical and Radar Satellite Image Time Series. *Methods Ecol. Evol.* **2020**, *11*, 532–541. [CrossRef]
69. Silvestri, S.; Christensen, C.W.; Lysdahl, A.O.K.; Anschütz, H.; Pfaffhuber, A.A.; Viezzoli, A. Peatland Volume Mapping Over Resistive Substrates With Airborne Electromagnetic Technology. *Geophys. Res. Lett.* **2019**, *46*, 6459–6468. [CrossRef]
70. Chen, S.; Arrouays, D.; Leatitia Mulder, V.; Poggio, L.; Minasny, B.; Roudier, P.; Libohova, Z.; Lagacherie, P.; Shi, Z.; Hannam, J.; et al. Digital Mapping of GlobalSoilMap Soil Properties at a Broad Scale: A Review. *Geoderma* **2022**, *409*, 115567. [CrossRef]
71. Adams, J.M.; Faure, H. A New Estimate of Changing Carbon Storage on Land since the Last Glacial Maximum, Based on Global Land Ecosystem Reconstruction. *Glob. Planet. Change* **1998**, *16–17*, 3–24. [CrossRef]

72. Humpenöder, F.; Karstens, K.; Lotze-Campen, H.; Leifeld, J.; Menichetti, L.; Barthelmes, A.; Popp, A. Peatland Protection and Restoration Are Key for Climate Change Mitigation. *Environ. Res. Lett.* **2020**, *15*, 104093. [CrossRef]
73. Holden, J. Peatland Hydrology and Carbon Release: Why Small-Scale Process Matters. *Phil. Trans. R. Soc. A.* **2005**, *363*, 2891–2913. [CrossRef]
74. Scharlemann, J.P.; Tanner, E.V.; Hiederer, R.; Kapos, V. Global Soil Carbon: Understanding and Managing the Largest Terrestrial Carbon Pool. *Carbon Manag.* **2014**, *5*, 81–91. [CrossRef]
75. Gorham, E. Northern Peatlands: Role in the Carbon Cycle and Probable Responses to Climatic Warming. *Ecol. Appl.* **1991**, *1*, 182–195. [CrossRef]
76. Murdiyarso, D.; Hergoualc'h, K.; Verchot, L.V. Opportunities for Reducing Greenhouse Gas Emissions in Tropical Peatlands. *Proc. Natl. Acad. Sci. USA* **2010**, *107*, 19655–19660. [CrossRef]
77. Crezee, B.; Dargie, G.C.; Ewango, C.E.N.; Mitchard, E.T.A.; Emba, B.O.; Kanyama, T.J.; Bola, P.; Ndjango, J.-B.N.; Girkin, N.T.; Bocko, Y.E.; et al. Mapping Peat Thickness and Carbon Stocks of the Central Congo Basin Using Field Data. *Nat. Geosci.* **2022**, *15*, 639–644. [CrossRef]
78. Yu, Z.C. Northern Peatland Carbon Stocks and Dynamics: A Review. *Biogeosciences* **2012**, *9*, 4071–4085. [CrossRef]
79. Goldstein, J.E.; Graham, L.; Ansori, S.; Vetrita, Y.; Thomas, A.; Applegate, G.; Vayda, A.P.; Saharjo, B.H.; Cochrane, M.A. Beyond Slash-and-Burn: The Roles of Human Activities, Altered Hydrology and Fuels in Peat Fires in Central Kalimantan, Indonesia. *Singap. J. Trop. Geogr.* **2020**, *41*, 190–208. [CrossRef]
80. Marlier, M.E.; Liu, T.; Yu, K.; Buonocore, J.J.; Koplitz, S.N.; DeFries, R.S.; Mickley, L.J.; Jacob, D.J.; Schwartz, J.; Wardhana, B.S.; et al. Fires, Smoke Exposure, and Public Health: An Integrative Framework to Maximize Health Benefits From Peatland Restoration. *GeoHealth* **2019**, *3*, 178–189. [CrossRef] [PubMed]
81. Pawson, R.R.; Evans, M.G.; Allott, T.E.H.A. Fluvial Carbon Flux from Headwater Peatland Streams: Significance of Particulate Carbon Flux. *Earth Surf. Process. Landf.* **2012**, *37*, 1203–1212. [CrossRef]
82. Evans, C.D.; Peacock, M.; Baird, A.J.; Artz, R.R.E.; Burden, A.; Callaghan, N.; Chapman, P.J.; Cooper, H.M.; Coyle, M.; Craig, E.; et al. Overriding Water Table Control on Managed Peatland Greenhouse Gas Emissions. *Nature* **2021**, *593*, 548–552. [CrossRef] [PubMed]
83. Miettinen, J.; Hooijer, A.; Vernimmen, R.; Liew, S.C.; Page, S.E. From Carbon Sink to Carbon Source: Extensive Peat Oxidation in Insular Southeast Asia since 1990. Environ. *Res. Lett.* **2017**, *12*, 024014. [CrossRef]
84. Wang, S.; Zhuang, Q.; Lähteenoja, O.; Draper, F.C.; Cadillo-Quiroz, H. Potential Shift from a Carbon Sink to a Source in Amazonian Peatlands under a Changing Climate. *Proc. Natl. Acad. Sci. USA* **2018**, *115*, 12407–12412. [CrossRef]
85. Escobar, D.; Belyazid, S.; Manzoni, S. Back to the Future: Restoring Northern Drained Forested Peatlands for Climate Change Mitigation. *Front. Environ. Sci.* **2022**, *10*, 834371. [CrossRef]
86. Bonn, A.; Reed, M.S.; Evans, C.D.; Joosten, H.; Bain, C.; Farmer, J.; Emmer, I.; Couwenberg, J.; Moxey, A.; Artz, R.; et al. Investing in Nature: Developing Ecosystem Service Markets for Peatland Restoration. *Ecosyst. Serv.* **2014**, *9*, 54–65. [CrossRef]
87. Harrison, P.A.; Vandewalle, M.; Sykes, M.T.; Berry, P.M.; Bugter, R.; de Bello, F.; Feld, C.K.; Grandin, U.; Harrington, R.; Haslett, J.R.; et al. Identifying and Prioritising Services in European Terrestrial and Freshwater Ecosystems. *Biodivers. Conserv.* **2010**, *19*, 2791–2821. [CrossRef]
88. Rozema, J.; Boelen, P.; Doorenbosch, M.; Bohncke, S.; Blokker, P.; Boekel, C.; Broekman, R.A.; Konert, M. A Vegetation, Climate and Environment Reconstruction Based on Palynological Analyses of High Arctic Tundra Peat Cores (5000–6000 Years BP) from Svalbard. *Plant Ecol.* **2006**, *182*, 155–173. [CrossRef]
89. Wang, M.; Moore, T.R.; Talbot, J.; Riley, J.L. The Stoichiometry of Carbon and Nutrients in Peat Formation. *Glob. Biogeochem. Cycles* **2015**, *29*, 113–121. [CrossRef]
90. Dommain, R.; Couwenberg, J.; Joosten, H. Hydrological Self-Regulation of Domed Peatlands in South-East Asia and Consequences for Conservation and Restoration. *Mires Peat* **2010**, *6*, 5.
91. Hooijer, A. Hydrology of Tropical Wetland Forests: Recent Research Results from Sarawak Peatswamps. In *Forests, Water and People in the Humid Tropics*; Bonell, M., Bruijnzeel, L.A., Eds.; Cambridge University Press: Cambridge, UK, 2005; pp. 447–461. ISBN 978-0-521-82953-3.
92. Wösten, H.; Hooijer, A.; Siderius, C.; Rais, D.S.; Idris, A.; Rieley, J. Tropical Peatland Water Management Modelling of the Air Hitam Laut Catchment in Indonesia. *Int. J. River Basin Manag.* **2006**, *4*, 233–244. [CrossRef]
93. Ishii, Y.; Koizumi, K.; Fukami, H.; Yamamoto, K.; Takahashi, H.; Limin, S.H.; Kusin, K.; Usup, A.; Susilo, G.E. Groundwater in Peatland. In *Tropical Peatland Ecosystems*; Osaki, M., Tsuji, N., Eds.; Springer: Tokyo, Japan, 2016; pp. 265–279. ISBN 978-4-431-55681-7.
94. Posa, M.R.C.; Wijedasa, L.S.; Corlett, R.T. Biodiversity and Conservation of Tropical Peat Swamp Forests. *BioScience* **2011**, *61*, 49–57. [CrossRef]
95. Giam, X.; Koh, L.P.; Tan, H.H.; Miettinen, J.; Tan, H.T.; Ng, P.K. Global Extinctions of Freshwater Fishes Follow Peatland Conversion in Sundaland. *Front. Ecol. Environ.* **2012**, *10*, 465–470. [CrossRef] [PubMed]
96. Harrison, M.E.; Ottay, J.B.; D'Arcy, L.J.; Cheyne, S.M.; Anggodo; Belcher, C.; Cole, L.; Dohong, A.; Ermiasi, Y.; Feldpausch, T.; et al. Tropical Forest and Peatland Conservation in Indonesia: Challenges and Directions. *People Nat.* **2020**, *2*, 4–28. [CrossRef]
97. Budiman, I.; Bastoni; Sari, E.N.; Hadi, E.E.; Asmaliyah; Siahaan, H.; Januar, R.; Hapsari, R.D. Progress of Paludiculture Projects in Supporting Peatland Ecosystem Restoration in Indonesia. *Glob. Ecol. Conserv.* **2020**, *23*, e01084. [CrossRef]

98. Goldstein, A.; Turner, W.R.; Spawn, S.A.; Anderson-Teixeira, K.J.; Cook-Patton, S.; Fargione, J.; Gibbs, H.K.; Griscom, B.; Hewson, J.H.; Howard, J.F.; et al. Protecting Irrecoverable Carbon in Earth's Ecosystems. *Nat. Clim. Change* **2020**, *10*, 287–295. [CrossRef]
99. Ayompe, L.M.; Schaafsma, M.; Egoh, B.N. Towards Sustainable Palm Oil Production: The Positive and Negative Impacts on Ecosystem Services and Human Wellbeing. *J. Clean. Prod.* **2021**, *278*, 123914. [CrossRef]
100. Daily, G.C.; Polasky, S.; Goldstein, J.; Kareiva, P.M.; Mooney, H.A.; Pejchar, L.; Ricketts, T.H.; Salzman, J.; Shallenberger, R. Ecosystem Services in Decision Making: Time to Deliver. *Front. Ecol. Environ.* **2009**, *7*, 21–28. [CrossRef]
101. Glina, B.; Sykuła, M.; Mendyk, Ł. Land Use Changes and Landscape Pattern Dynamics of a Peatland Area under Diversified Human Impact: The Grójec Valley (Central Poland). *Bull. Geography. Phys. Geogr. Ser.* **2019**, *16*, 21–30. [CrossRef]
102. Chapman, S.; Buttler, A.; Francez, A.-J.; Laggoun-Défarge, F.; Vasander, H.; Schloter, M.; Combe, J.; Grosvernier, P.; Harms, H.; Epron, D.; et al. Exploitation of Northern Peatlands and Biodiversity Maintenance: A Conflict between Economy and Ecology. *Front. Ecol. Environ.* **2003**, *1*, 525–532. [CrossRef]
103. Law, E.A.; Bryan, B.A.; Meijaard, E.; Mallawaarachchi, T.; Struebig, M.; Wilson, K.A. Ecosystem Services from a Degraded Peatland of Central Kalimantan: Implications for Policy, Planning, and Management. *Ecol. Appl.* **2015**, *25*, 70–87. [CrossRef] [PubMed]
104. Saarikoski, H.; Mustajoki, J. Valuation through Deliberation—Citizens' Panels on Peatland Ecosystem Services in Finland. *Ecol. Econ.* **2021**, *183*, 106955. [CrossRef]
105. Miettinen, J.; Liew, S.C. Status of Peatland Degradation and Development in Sumatra and Kalimantan. *AMBIO* **2010**, *39*, 394–401. [CrossRef]
106. Reed, M.S.; Bonn, A.; Evans, C.; Glenk, K.; Hansjürgens, B. Assessing and Valuing Peatland Ecosystem Services for Sustainable Management. *Ecosyst. Serv.* **2014**, *9*, 1–4. [CrossRef]