diversity

MDPI

Article

Mires in Europe—Regional Diversity, Condition and Protection

Franziska Tanneberger [1,*], Asbjørn Moen [2], Alexandra Barthelmes [3], Edward Lewis [4], Lera Miles [4], Andrey Sirin [5], Cosima Tegetmeyer [3] and Hans Joosten [1]

1 Institute of Botany and Landscape Ecology, Greifswald University, Partner in the Greifswald Mire Centre, 17487 Greifswald, Germany; joosten@uni-greifswald.de
2 Department of Natural History, NTNU University Museum, Norwegian University of Science and Technology, 7491 Trondheim, Norway; asbjorn.moen@ntnu.no
3 DUENE e.V., Partner in the Greifswald Mire Centre, 17487 Greifswald, Germany; alex.barthelmes@greifswaldmoor.de (A.B.); cosima.tegetmeyer@greifswaldmoor.de (C.T.)
4 UN Environment Programme World Conservation Monitoring Centre (UNEP-WCMC), Cambridge CB3 0DL, UK; Edward.Lewis@unep-wcmc.org (E.L.); Lera.Miles@unep-wcmc.org (L.M.)
5 Institute of Forest Science, Russian Academy of Sciences, 143030 Uspenskoye, Russia; sirinproc@gmail.com
* Correspondence: tanne@uni-greifswald.de

Abstract: In spite of the worldwide largest proportional loss of mires, Europe is a continent with important mire diversity. This article analyses the condition and protection status of European mire ecosystems. The overview is based on the system of European mire regions, representing regional variety and ecosystem biodiversity. We combined peatland distribution data with land cover maps of the Copernicus Land Monitoring Service as well as with the World Database on Protected Areas to assess the extent of degraded peatlands and the proportion of peatlands located in protected areas in each European mire region. The total proportion of degraded peatlands in Europe is 25%; within the EU it is 50% (120,000 km^2). The proportion of degradation clearly increases from north to south, as does the proportion of peatlands located within protected areas. In more than half of Europe's mire regions, the target of at least 17% of the area located in protected areas is not met with respect to peatlands. Data quality is discussed and the lessons learned from Europe for peatland conservation are presented.

Keywords: peatland; organic soil; mire type; biogeography; degradation; protected area

Citation: Tanneberger, F.; Moen, A.; Barthelmes, A.; Lewis, E.; Miles, L.; Sirin, A.; Tegetmeyer, C.; Joosten, H. Mires in Europe—Regional Diversity, Condition and Protection. *Diversity* **2021**, *13*, 381. https://doi.org/10.3390/d13080381

Academic Editors: François Munoz, Mariusz Lamentowicz and Corrado Battisti

Received: 20 June 2021
Accepted: 10 August 2021
Published: 16 August 2021

1. Introduction

Globally, the importance of peatlands and the need for their conservation, restoration and sustainable use are increasingly recognized. The Convention on Wetlands (Ramsar Convention) has explicitly addressed peatlands since 1996. The Convention on Biological Diversity (CBD) endorsed the first 'Global Assessment on Peatlands, Biodiversity and Climate Change' [1] in 2007. Within the United Nations Framework Convention on Climate Change (UNFCCC), peatlands remained for many years unnoticed in the land use sector. This disregard started to change in 2006, and in 2010 peatland rewetting was accepted as an accountable activity under the Kyoto Protocol [2]. Peatland rewetting and paludiculture (i.e., agriculture and forestry on wet peatlands) have since been acknowledged and supported by the Food and Agriculture Organization of the United Nations [3,4] and the Intergovernmental Panel on Climate Change [5] as a key climate change mitigation option. Additionally, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) paid attention to peatlands [6], building on a thorough analysis of peatland restoration and ecosystem services [7]. A true milestone was the United Nations Environment Assembly (UNEA) resolution on 'Conservation and Sustainable Management of Peatlands', adopted by all UN member states in 2019. The resolution acknowledged the contribution of peatlands to the implementation of the 2030 Agenda for Sustainable Development [8]. Currently, the United Nations Decade on Ecosystem

Restoration 2021–2030 provides a key framework opportunity for global action on peatland restoration.

Europe looks back at many centuries of peatland utilisation and degradation. Human impact has included using peatlands for gaining food, fodder, fibre and fuel and draining them for intensive agricultural or forestry use and for peat extraction. Peatlands further have been used for urban, industrial, and infrastructural development, and for defence and isolation [9–12]. More recently, large mire areas have been degraded for building water reservoirs or windmills for power production. Human impact has also been indirect: For example, already 3000 years ago, anthropogenic upland deforestation led to changes in river discharge and the consequent widening of estuaries, eventually leading to massive peatland erosion in the perimarine floodplains of the Netherlands [13]. Human activities, however, have also led to the origin and expansion of peatlands in Europe because of interference with landscape hydrology [9,14,15]. In oceanic areas of Europe, mires have formed as a result of land clearing, burning and livestock grazing [16,17]. Such blanket bogs often occur in mosaics with heathlands, established some 3000–4000 years ago [15,16].

The overall area of peatland (defined as an area with a naturally accumulated layer of peat at the surface) in Europe is ~1.000,000 km^2, i.e., ~10% of the total surface area [18]. This includes many—but not all—countries' areas with a shallow peat layer of <30 cm, e.g., in Finland, Norway, European Russia (so-called 'shallow-peat lands'; ~445,000 km^2) and Ukraine. Mires (i.e., peatlands where peat is being formed) cover more than 320,000 km^2 [18], probably >500,000 km^2 (as the estimate in Tanneberger et al. [18] does not cover all peat-forming shallow-peat lands in European Russia). Europe is the continent with, worldwide, the largest proportional loss of mires, because of its long history, high population pressure, and climatic suitability for agriculture as the principal driver of peatland drainage. As peat extraction and human-induced oxidation and erosion have changed many former peatlands into mineral soils, some 10% of the maximum peatland area during the Holocene [19] does not exist anymore as peatland [12]. In 19 European countries, the area of heavily damaged peatlands exceeds 1000 km^2 each [20]. In Finland, nearly 70% of the mire area has been destroyed during the most ambitious programme for mire drainage in Europe, in particular in the 1970s when c. 3000 km^2 were drained annually [21]. In countries such as the Netherlands, not one bog or fen has remained untouched [22]. In spite of these impairments, mires have in many areas of Europe survived, often as the last wildernesses in a predominantly cultural landscape.

The regional diversity of mires in Europe has been first described for Fennoscandia in 1913 [23], followed by Central Europe in 1928 [24] and North-Eastern Europe in 1930 [25]. Soon after World War II, a first description of mire regions for the entire continent was published [26], and this 'regionalisation' has further been improved by many peatland scientists since then. The most recent elaboration of mire regions [27] was informed by the vegetation regions of Europe, which summarize the distribution of vegetation and flora as a function of climate (zones and sections, cf. [28]). In a similar way, the geographical distribution of (primarily) hydromorphic mire types (Supplementary Material Table S1), and (to a lesser extent) mire features, sites and complexes and vegetation and flora were combined to define ten mire regions (simplified map: Figure 1). A detailed description of these regions and the 52 subregions is presented in [27] (their Figure 4.38 and their Table 4.19).

The purpose of this article is to inform about the condition and protection status of European mire ecosystems using the system of European mire regions [27], which is the most comprehensive representation of regional variety and ecosystem biodiversity for Europe.

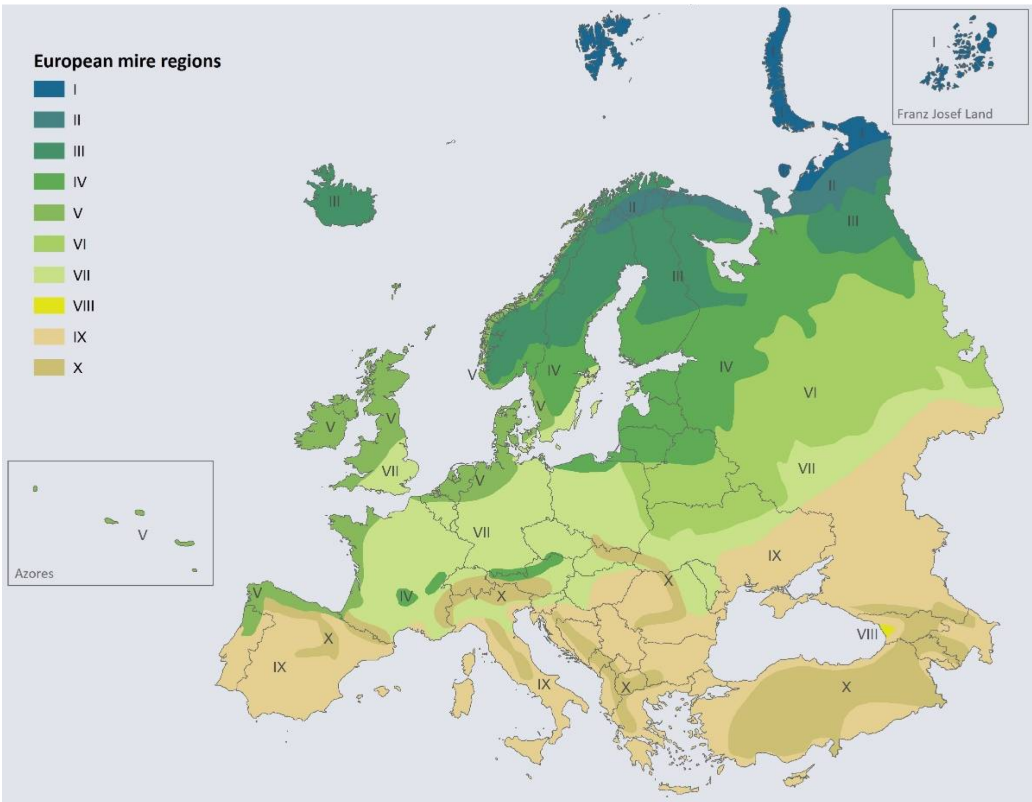

Figure 1. The ten European mire regions (simplified from [27]). (I) Arctic seepage and polygon mire region, (II) palsa mire region, (III) northern fen region, (IV) typical raised bog region, (V) Atlantic bog region, (VI) continental fen and bog region, (VII) nemoral-sub-meridional fen region, (VIII) Colchis mire region, (IX) southern European marsh region, (X) central and southern European mountain compound region.

2. Materials and Methods

2.1. Definitions

We follow the peatland definition of Joosten et al. [29] of "an area with a naturally accumulated layer of peat at the surface". Peat is a "sedentarily accumulated material of which at least 30% (dry mass basis) is dead organic matter". The presence or absence of vegetation is irrelevant to this definition of peatland. No strict criterion for minimum thickness of the peat layer has been adopted, in line with the IPCC definitions of 'organic soil' [5–30] to allow for variety amongst country-specific definitions, which are often historically determined. This peatland concept includes all 'mires', i.e., peatlands where peat is being formed [29].

Europe as a continent is a historical and cultural construct, defined only by convention. The modern definition uses a border between Asia and Europe stretching along the Ural Mountains, Ural River, and the Caspian Sea in the East and the Greater Caucasus range and the Black Sea with its outlets Bosporus and Dardanelles in the South-East. Here, we focus on 46 countries, following [18–29]. For the European part of the Russian Federation, eastern and southern borders as in [31] have been used to comply with existing datasets and maps.

2.2. Peatland Distribution

Peatland distribution data are derived from the 'peatland map of Europe' presented in [18–29], except for Germany, for which a more recent national dataset including all organic soils has been used, from [32].

In case of national or regional datasets consisting fully or partly of point data, we changed these points into a spatial extent (polygon) by applying a country- or region-specific buffer (radius) around these points. This radius was determined by visual inspection using aerial or satellite imagery and optimised to fit the total peatland area per country, given in [18–29]. The following radiuses were thus applied to the point datasets: France (partly) 140 m, Italy 1200 m, Luxembourg 50 m, Macedonia 900 m, Portugal 800 m, Svalbard 10 km, and Ukraine (Carpathian region) 400 m. In case of very old national datasets consisting of polygons, the opposite procedure was applied to account for peatland loss over time (Ukraine: inverse buffer with radius 800 m). The resulting total peatland area in Europe was 1,082,400 km^2 (cf. total peatland area in [18]: 1,039,000 km^2). All spatial analyses were performed in a true-surface projection (Mollweide projection).

2.3. Peatland Condition

To assess peatland degradation, we intersected the estimates of Tanneberger et al., [18] with the land cover maps of the Copernicus Land Monitoring Service (Corine Land Cover—CLC—European seamless vector database RELEASE v18_5), mainly based on PROBA-V satellite observations, organized into Sentinel-2 equivalent tiles of 110 x 110 km with UTM projection [33]. All features in the original vector database were classified and digitised based on satellite images with 100 m positional accuracy (according to CLC specifications) and 25 ha minimum mapping unit (5 ha MMU for change layer) into the standardized CLC nomenclature (44 CLC classes). A list of land cover classes indicating peatland degradation is included in Supplementary Material Table S2. The area of degraded peatland per country/region was derived by intersecting these land cover classes with peatland distribution (using the 'Identity' tool in ArcGIS). This approach underestimates the area of degraded peatland under/after peat extraction and with forest cover. For countries with a high proportion of drained peatlands under forestry use (Estonia, Finland, Iceland, Ireland, Norway, Sweden, UK; [29]) and for Armenia, Azerbaijan, Belarus, Georgia, Russia and Ukraine (which are not covered by the Copernicus Land Monitoring Service), estimates of the proportion of degraded peatland from Tanneberger et al. [18] have been used. For these countries, we used for all mire regions present in the respective country the same proportion of degraded peatland, except for Finland, Norway, Sweden, and for European Russia, where we assumed higher degradation in southern mire regions represented in the country (Supplementary Material Figure S1).

2.4. Protected Areas

Protected area data were extracted from the September 2020 release of the World Database on Protected Areas (WDPA) hosted on Protected Planet [34]. A selection of protected areas was limited to those that overlap peatland distribution, excluding sites with status 'proposed' or 'not reported' and also designated 'UNESCO Man and Biosphere Reserves' (but excluding biosphere reserves did not remove protected areas within them). Various types of protected areas were included, from strict to voluntary. Protected areas represented as points in the WDPA were given a spatial extent by drawing a circle around them that fits their reported area. Protected areas created under different legislative frameworks may overlay each other [35]. Overlaps between protected area polygons were removed using the 'Union' and 'Delete Identical' tools in ArcGIS. This 'flat' layer was projected into Mollweide to calculate areas. The overlay of peatland, mire region, and protected areas was performed in ArcGIS using the 'Identity' tool.

3. Results

3.1. Peatland Cover

Out of the total peatland area, almost one third of European peatlands are located in the typical raised bog region (31%; Table 1), closely followed by the northern fen region (27%). Substantial parts of the total peatland area are also located in the palsa mire region (13%) and in the continental fen and bog region (12%). All other regions include only $\leq$6% of the total peatland area of Europe.

Table 1. Mire regions with characteristic and additional mire massif types (from [27]) and key properties of their peatlands (total area, degraded area, protected area; in km^2 and %). As the degree of degradation differs strongly between European Russia and the rest of the continent, figures are also presented excluding European Russia. The total peatland area in Europe excluding European Russia is 363,100 km^2; that in EU27 countries is 241,000 km^2.

Nb.	Mire Region	Mire Massif Type		Total Peatland Area		Degraded Peatlands		Degraded Peatlands excl. European Russia		Degraded Peatlands EU27 Countries Only		Peatlands in Protected Areas	
		Characteristic	Additional	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
I	Arctic seepage and polygon mire region	Tundra seepage and polygon fen	Palsa mire; Flat fen & marsh	62,700	6	600	1	-	-	-	-	7100	11
II	Palsa mire region	Palsa mire	String-flark fen types and mixed mires	147,100	13	8700	6	1900	16	1400	21	13,700	9
III	Northern fen region	String-flark fen types and mixed mires	Rim raised bog; Blanket bog; Plane bog; Percolation fen; Flat fen & marsh	300,600	27	57,800	26	49,700	36	43,400	40	39,900	13
IV	Typical raised bog region	Typical raised bog; Wooded raised bog	Plane bog; Flat fen & marsh	341,700	31	88,100	26	33,400	49	26,900	50	34,600	10
V	Atlantic bog region	Atlantic raised bog; Blanket bog	Plane bog; Flat fen & marsh	64,200	6	43,500	68	43,500	68	22,800	75	35,900	56
VI	Continental fen and bog region	Wooded raised bog	Plane bog; Percolation fen; Flat fen & marsh	130,900	12	48,900	37	20,100	58	2900	63	19,700	15
VII	Nemoral-submeridional fen region	Flat fen & marsh	Plane bog; Percolation fen	30,600	3	19,300	63	19,300	63	17,500	66	13,700	45
VIII	Colchis mire region	Percolation bog	Flat fen & marsh	600	<1	30	5	30	5	-	-	300	44
IX	Southern European marsh region	Flat fen & marsh	-	16,000	2	8500	53	3800	47	3500	47	6800	43
X	Central and southern European mountain compound region	Flat fen & marsh	Sloping fen; Plane bog; Percolation fen	4000	<1	1300	32	1200	32	1500	44	2200	56
	Total	**-**	**-**	**1,082,400**	**100**	**276,700**	**25**	**172,900**	**48**	**120,000**	**50**	**174,700**	**16**

We estimate that the majority of peatlands in Europe are fens, i.e., peatlands that currently receive water that has been in contact with mineral soil or bedrock, or where the upper layers of peat have been formed under such conditions [29]. In a very rough 'guesstimate' (all peatlands in the regions I–III and 50% of the peatlands in regions VI, VII, IX, and X being considered as fens) and including transitional mires, the approximate total fen area in Europe is ~600,000 km^2. The corresponding approximate bog area (i.e., peatlands merely fed by precipitation) in Europe is ~450,000 km^2.

3.2. Peatland Condition

There is a clear north–south gradient in the degree of degradation, with an increase towards southern Europe (Table 1, Supplementary Material Figure S1). The mire regions with the least degraded peatlands are the Arctic seepage and polygon mire region (1%) and the palsa mire region (6%). The proportion of degraded peatland is particularly high in the Atlantic bog region (68%) and nemoral-sub-meridional fen region (63%), followed by the southern European marsh region (53%) and the continental fen and bog region (37%). If excluding European Russia, the third most degraded region is the continental fen and bog region (58%), followed by the typical raised bog region (49%) and the southern European marsh region (47%). The total proportion of degraded peatlands in Europe is (25%); if excluding European Russia, it is (48%). Within the EU, it is (50%) (120,000 km^2).

It is important to note that these figures only apply to the current area of peatland and exclude the former peatland areas, from which the peat layer has already disappeared entirely due to degradation. In reality, thus, a much higher proportion of the original peatland area has been degraded over time.

European countries with the highest proportion of currently degraded peatland (91%–100%) are Albania, Croatia, Cyprus, Denmark, Germany, Luxembourg, the Netherlands, Portugal, Republic of Macedonia and Slovenia (Supplementary Material Figure S1). More than 80% of current peatlands are degraded in Austria, Greece, Ireland, Italy, Republic of Moldova, Poland, Romania, Serbia, Slovakia, and Turkey. Countries with the lowest proportion of degraded peatlands (less than 20%) are Andorra, Armenia, Azerbaijan, Bosnia-Herzegovina, Faroe Islands, Norway, and Svalbard. Low average values of peatland degradation are typical for European Russia, but the degree of degradation varies strongly [36], depending on the size of the peatland area, differences in natural condition, and history of regional peatland use.

3.3. Peatland Protection

The proportion of peatlands located within protected areas differs substantially between the mire regions and increases from north to south (Table 1, Figure 2). The largest proportion (56%) is found in the Atlantic bog region (V) and in the central and southern European mountain compound area (X), respectively. Between 40% and 45% of the peatlands in the nemoral-sub-meridional fen region (VII), the Colchis mire region (VIII) and the southern European marsh region (IX) are located in protected areas. In all other regions, between 9% (palsa mire region, II) and 15% (continental fen and bog region, VI) of the peatlands are situated in protected areas.

There is also a large variety in the proportion of peatlands included in protected areas between countries (Supplementary Material Figure S2). Less than 25% are included in Albania, Azerbaijan, Belarus, Faroe Islands, Finland, Iceland, Republic of Macedonia, Republic of Moldova, Norway, Sweden, Turkey and Ukraine. European Russia is in this class as well, but its mere extent and its tradition of territorial nature conservation makes Russia the leading country with respect to the absolute area of peatlands in protected areas [37]. More than 95% of national peatlands are situated in protected areas in Bulgaria, Cyprus, and Denmark, followed by more than 75% in Croatia, Czech Republic, Italy, Serbia, Slovakia, and the UK.

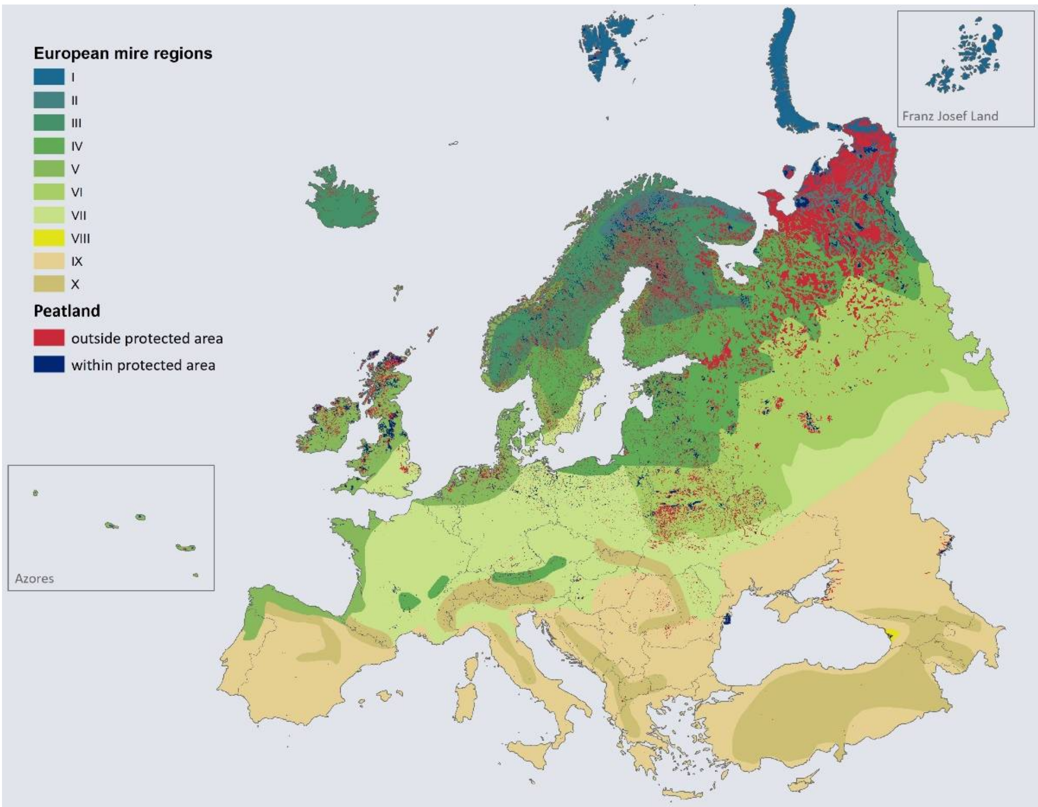

Figure 2. Peatland distribution (after [18]) and protection (after [34]; blue = within protected area, red = outside protected area) in the ten European mire regions (see Figure 1).

3.4. Overview and Key Characteristics of the Ten Mire Regions of Europe

The ten main mire regions (see [27] for details; Figure 1, Table 1) differ substantially in size, mire diversity, peatland condition and protection.

The Arctic seepage and polygon mire region (I; 6% peatland cover) covers the northernmost Europe, mainly in the Russian Federation, including the Russian arctic islands and Svalbard. The region has a dry and cold climate with permafrost and little snow. Tundra seepage and polygon fens are characteristic, and the degree of degradation is low (1%). However, infrastructure projects and vehicle travel are increasingly threatening the highly vulnerable Arctic peatlands, which is especially dangerous under current climate change conditions (Minayeva et al. 2016). Only a very small part of the mires is protected, and this overall picture is not changed by the large absolute area of some protected areas in the North of European Russia, which also include large mire areas [37].

The palsa mire region (II; 13%) covers large areas in the Russian Federation and in northern Finland, Sweden and Norway (including mountainous areas). The region stretches across continental areas of the southern arctic, northern boreal, and low alpine vegetation zones. The characteristic mire type is the palsa mire (high palsa more in the western part, and flat palsa on the eastern plateaus, cf. [29]). The degree of degradation is low (6%). There is no drainage, only roads and other linear structures affecting negligible areas compared to the total peatland cover. However, the average figures do not fully reflect the concentration of impacts in individual regions and, as for the Arctic region, the growing threats against the background of climate change. Additionally, here only a very small part of the mires is protected, and the situation is similar to the region discussed above.

The northern fen region (aapa mire region) (III; 27%) covers large areas in the boreal vegetation zones in northern Europe. String-flark mires are very common in the central and continental parts (Sweden, Finland, Russia); sloping fens are more common in the more oceanic areas (Norway). In this region, short summers and long winters with abundant snow cover facilitate a high groundwater level during the growing period, which allows for the development of sloping fens. Several other mire types such as rim raised bogs, blanket bogs, plane bogs and percolation fens also occur in this region. About one quarter of the peatlands is degraded mainly by forest drainage. On average, 13% of the peatland area is within protected areas, i.e., the largest area (39,900 km^2) within a single mire region given the large total area of peatlands. In European Russia, the Republics of Karelia and Komi have a highly developed system of federal, regional and local protected areas [37].

The typical raised bog region (IV; 31%) is found in Fennoscandia, the Baltics, and northern Russia, i.e., in the slightly oceanic to slightly continental sections of the nemoral-southern boreal zones. Small exclaves of this region occur in mountainous areas north of the Alps. Characteristic mire types are typical and wooded raised bogs. This region is densely populated, and the majority of raised bogs, except those in the Baltic States, Belarus and Russia, has been destroyed. In Sweden and Finland many bogs have been drained along their edges, which has not affected their entire area, but clearly their lagg areas, which are highly important for the bog's hydrology and biodiversity [38]. In general, about one quarter, and without European Russia one half of the peatlands, are degraded. In western and central European Russia many peatlands are affected by drainage for agriculture and forestry, peat extraction, road construction and other infrastructure, but vast untouched peatland massifs reduce the overall percentage of degraded peatlands substantially. Raised bogs themselves have suffered to a lesser extent than fens, especially those in river valleys, which are of greater economic interest and cover smaller areas [34]. Some 10% of the peatlands are within protected areas, which is a low overall proportion but a large absolute area given the high peatland coverage of the region.

The Atlantic bog region (V; 6%) is located along the oceanic coast of western Europe, from Azores/Portugal to Ireland, the northern parts of the British Isles and western Norway. The region is characterised by Atlantic raised bogs and blanket bogs. For centuries, these peatlands have been heavily impacted by peat extraction for fuel, agricultural drainage and grazing of domestic animals. In recent decades, building of wind power plants became an additional threat to the mires. Today, the large majority of these (former) mires (68%) is damaged. More than half of the peatland area is located in protected areas, i.e., the protected areas also include a substantial part of degraded peatlands.

The continental fen and bog region (VI; 12%) stretches from the Polesie (eastern Poland, southern Belarus, northern Ukraine) to large parts of Central European Russia. The region is characterized by mosaics of fens and bogs; most common are wooded raised bogs in the north and percolation fens in the south. The long land use history of this region as well as the more southern location has led to a high degree of peatland degradation (52%). The degree of protection is low (15%).

The nemoral-sub-meridional fen region (VII; 3%) comprises large parts of England, France, Germany, and other Central European countries, and extends as a narrow belt towards the Ural Mountains. Flat fen is the most characteristic mire type, while plane bogs and percolation fens also occur. The majority of peatlands is degraded (63%); almost half of the total peatland area is located in protected areas.

The Colchis mire region (VIII; <1%) is the smallest mire region and is located at the Black Sea coast in Georgia, i.e., in the sub-meridional vegetation zone and highly oceanic vegetation section. The region is characterized by percolation bogs, which are unique to this region. Almost half of the peatlands are within protected areas.

The southern European marsh region (IX; 2%) comprises wetlands of southern Europe from the Iberian Peninsula to Azerbaijan, around the Mediterranean and Black Sea. The region stretches from west to east over the warmest and driest (incl. continental) parts of Europe. Most wetlands are located in river deltas and floodplains, coastal lagoons, and at freshwater lakes. The peatlands often have only a thin peat layer and most of them are heavily influenced by drainage (52%) or have already disappeared.

The central and southern European mountain compound region (X; <1%) is different from other regions, as it relates to the vertical distribution of mire types. It occurs in the mountain areas of central and southern Europe. Flat fens and percolation fens are most common, but also sloping fens and bogs occur, and about one third is degraded. More than half of the peatland area is located in protected areas.

4. Discussion

4.1. Data Quality

The peatland map of Europe [18] combines available systematic national data with proxy data and expert judgement, using a definition of 'peatland' consistent with IPCC guidance. National soil data are, however, very diverse and disparate (e.g., different techniques, sampling methods, densities, and scales of field survey, different criteria for classifying peat and peaty/peatland soils), and the critical compilation presented in [18] should be used as an approximation to identify gaps and priority areas for further field surveys and data collection. As the most comprehensive map currently available, it is most appropriate for the analysis presented in this paper. The 'upsizing' of point data, necessary because of a lack of area specific data, is a critical issue and must be done carefully, preferably combined with a check of point data coherence with spatial information. Generally, more effort for data improvement is needed to cover peatlands in regional and global maps, and in particular in reporting greenhouse gas emissions from organic soils [39].

The analysis of the degree of peatland degradation is further limited by the currently available datasets used as proxy for degradation. In this study, we use land-use data from the Copernicus Land Monitoring Service. Whereas agricultural land cover classes have a high indicative value for peatland drainage and degradation, forestry land cover classes cannot be directly used as an indicator. Additionally, important land use classes such as abandoned peat extraction sites are not included. Therefore, this approach underestimates the area of degraded peatland with forest cover and under/after peat extraction, and correction factors based on expert assessment had to be used. In future, other European land use datasets as well as other proxies such as soil moisture derived from remote sensing should be tested to improve the analysis. In any assessment of peatland degradation, it is important to note that figures derived from the current peatland area exclude the former peatland area, from which the peat layer has already disappeared entirely due to degradation. In reality, thus, a much higher proportion of the original peatland area has been degraded over time.

The best available spatial data on protected areas have been used, as UNEP-WCMC works with national and regional partners to ensure that data are as up to date as possible. Data for Europe are updated once a year via the European Environment Agency (EEA). Very recently designated sites may not have been incorporated into this analysis. Furthermore, in addition to protected areas, the Convention on Biological Diversity (CBD) has now defined "Other Effective Area-Based Conservation Measures" (OECMS), which alongside protected areas lead to the effective conservation of nature. OECMs are now being collated by UNEP-WCMC in an own database but have not been mapped yet for much of Europe, and are thus not included in this analysis. The data contained in WDPA entail various types of protected areas. As protected area systems differ in terms of definition, regulation of activities allowed, and enforcement, the actual degree of protection and its enforcement differs between countries.

4.2. Designation of Protected Areas vs. Peatland Protection

In each mire region, at least 10% of the peatland area is located in the protected area network, but in five European mire regions (I–IV and VI), with a total area of 115,000 km^2 of peatland, the proportion does not exceed 15%. Given the CBD's Aichi Target 11 ("By 2020, at least 17% of terrestrial and inland water, and 10% of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well-connected systems of protected areas and other effective area-based conservation measures [. . .]"), this proportion is insufficient. It should be also noted that this target refers to both quantitative and qualitative criteria, i.e., that not only the proportion of peatlands in protected areas matters, but also their condition. This, and the gaps in protection, have been recently described for peatlands in the Nemunas catchment region [40]. As peatlands are areas of particular importance for biodiversity and ecosystem services [1,7,8], our analysis underlines the need to enlarge the protected area network with regard to peatlands. For Europe, this would respond to the EU Biodiversity Strategy for 2030, calling for legal protection of at least 30% of the EU's land area and strict protection of at least a third of the EU's protected areas [41]. It would also respond to the proposed target for the post-2020 Global Biodiversity Framework of 30% of areas of land and sea being covered by protected areas and OECMs [42], a global target equally ambitious.

At the same time, a critical assessment of the degree of protection of a peatland situated in a protected area seems necessary. Often, protected areas including peatlands have been designated for other purposes than mire protection. For example, in Norway, large national parks in the mountains have large mire areas. These mires are then also protected, but not as mires (i.e., including their catchment). In mire regions V and VII, and possibly others as well, the protected area network contains substantial areas of degraded peatlands. This may point at a low degree of effective protection. The IUCN management categories may serve as a (very rough) proxy to analyse this further. The designation of a protected area may even hamper restoration. For example, in Germany, several large, drained peatlands under high-intensity grassland use are designated as habitats for migrating birds using short sward grasslands as resting areas. Peatland restoration—which is generally beneficial for mire-typical birds and other biodiversity—would probably result in a loss of habitat quality for the concerned species.

The following considerations may guide the inclusion of more peatland areas being protected and the better management of peatlands already included in the protected area network:

- The most important criteria for identifying mires of international conservation importance are similar to those on a local/national scale. The local criterion 'representativeness' identifies 'rareness' on an international scale. The local criterion 'rareness' normally identifies mire components that on an international scale are either rare, or at the margin of/outside their main distribution area. Such marginal/azonal occurrences are 'distinctive' and have a high conservational value [43,44].
- Application of objective selection criteria, and the use of optimally efficient selection strategies indicate that a very large number of protected areas (and a very large area) are necessary to secure biological diversity. In the framework of the climate and biodiversity crisis, the protection of all still-pristine peatlands and the rewetting/restoration of all drained and otherwise degraded peatlands is necessary.
- Management should be guided by nature conservation (natural biodiversity purposes) especially in strictly protected areas, and by provision of other ecosystem services (regulating and provisioning services) in less strictly protected areas (e.g., biosphere reserves) and in the unprotected peatland areas (e.g., enhanced by appropriate agricultural funding schemes).
- For all protected peatlands, it is fundamental to also protect their catchment (see below).
- Different mire types may be functionally connected, for example petrifying springs and spring fens, both protected habitat types under EU law. This implies that restoration of damaged petrifying springs and spring fens should aim at restoring the complexes as a whole with both habitats included, and should not focus solely on the separate habitat types [45].

4.3. Lessons Learnt from Europe

In Europe, hardly any mires have survived in areas with a climatic and edaphic suitability for arable agriculture. This accounts for both rainwater and groundwater fed mires, although the latter have suffered even more because of their more nutrient rich character after drainage.

In various European countries with long-term peatland drainage, the losses have been so severe that the majority of the former peatland area is no longer peatland because all peat has been removed or oxidized. Examples are the Netherlands and Denmark, which in former times had >50% and 30% of their land area consisting of peatland and now only 3% and 2%, respectively. The start of peatland degradation has mostly not resulted from sneaking expansion but from concerted and extensive targeted development. Enormous areas of peatlands have been drained in the framework of large-scale 'melioration' plans, unemployment relief works, and works of prisoners of war. These rapid developments were initially encouraged by the good results of the drainage activities in terms of land (and water) productivity. Setbacks such as soil degradation, subsidence, and huge greenhouse gas and nutrient emissions only became apparent decades later. Much of the damage is virtually irreversible, but at least subsidence and emissions can be stopped or strongly reduced by effective rewetting [46].

The problems associated with peatland drainage in Europe have in no way been solved. The EU is, after Indonesia, the second largest greenhouse gas emitter from drained peatland in the world [47,48]. In countries with abundant peatland, the idea of an unlimited resource has hampered timely and adequate conservation and the development of wise use strategies. Formerly bog rich countries such as Ireland, the United Kingdom, Denmark, the Netherlands and Germany have failed to save even one complete bog massif from drainage, a situation comparable to present-day Borneo.

Having learnt through trial and error, the following constructive lessons have emerged:

- Peatland conservation implies primarily the conservation of its hydrology. Even small drops of the water level can affect peat accumulation and conservation and initiate ongoing peatland degradation.
- To conserve a peatland, its entire 'hydrological unit' has to be conserved, i.e., the entire peat body and—certainly in cases of groundwater fed systems—also the mineral catchment area and hydrological buffer zone.
- If peatlands must be used, they should be used wet [3–49]. This recent insight has not yet resulted in large scale implementation of suitable production techniques, because the techniques and rules and modalities still have to be developed, accepted and adapted [50].

Peatlands have a vital role in addressing the twin climate and biodiversity crises. Consequently, an increasing number of EU policies have started to improve the management of drained peatlands as an essential ecosystem-based solution to avoid greenhouse gas emissions, reinstall carbon sequestration, reduce nitrogen mineralization, enhance nitrogen removal, and restore peatland-specific biodiversity [48]. Such policies should build on research and practical knowledge of European mire regions and target better protection and management in each of the mire regions.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/d13080381/s1, Table S1: Main occurrences of ombrotrophic (grey) and minerotrophic (white) hydromorphic mire massif types in the various mire regions of Europe (from [27]). C=characteristic type, x = additional. Table S2: List of CORINE land cover classes regarded as indicating peatland degradation. There are more classes containing degraded peatlands, but not exclusively and in unknown proportion to the peatland areas contained that are not degraded. Figure S1: Proportion (%) of degraded peatlands per country (from [18]). For Finland, Norway, Sweden, and European Russia, we assumed higher degradation in southern mire regions (see below the map). Figure S2: Proportion (%) of peatlands within protected areas per country.

Author Contributions: Conceptualization, methodology, F.T., A.M., H.J.; resources, F.T., C.T., A.B., E.L., L.M., A.S.; formal analysis, F.T.; C.T.; writing—original draft preparation, F.T.; writing—review and editing, all; visualization, C.T. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding. We acknowledge the support for the Article Processing Charge from the DFG (German Research Foundation, 393148499) and the Open Access Publication Fund of the University of Greifswald.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Restrictions apply to the availability of these data. Data was obtained from various sources (see [18]) and can be shared only in accordance with consent provided by data holders. The peatland of Europe [18] is available as 300dpi geotiff at: http://mires-and-peat.net/pages/volumes/map19/map1922.php (accessed on 25 July 2021). Further information about the Global Peatland Database: https://www.greifswaldmoor.de/global-peatland-database-en.html (accessed on 25 July 2021).

Acknowledgments: We are grateful to the reviewers for their work.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Parish, F.; Sirin, A.; Charman, D.; Joosten, H.; Minayeva, T.; Silvius, M.; Stringer, L. (Eds.) *Assessment on Peatlands, Biodiversity and Climate Change*; Global Environment Centre and Wetlands International: Kuala Lumpur, Malaysia; Wageningen, The Netherlands, 2008; p. 206.
2. Joosten, H. Sensitising global conventions for climate change mitigation by peatlands. In *Carbon Credits from Peatland Rewetting. Climate—Biodiversity—Land Use*; Tanneberger, F., Wichtmann, W., Eds.; Schweizerbart: Stuttgart, Germany, 2011; pp. 90–94.
3. Joosten, H.; Tapio-Biström, M.-L.; Tol, S. (Eds.) *Peatlands—Guidance for Climate Change Mitigation through Conservation, Rehabilitation and Sustainable Use*, 2nd ed.; Food and Agriculture Organization of the United Nations and Wetlands International: Rome, Italy; Ede, Netherlands, 2012; p. 114. Available online: http://www.fao.org/3/a-an762e.pdf (accessed on 16 June 2021).
4. Biancalani, R.; Avagyan, A. (Eds.) *Towards Climate-Responsible Peatlands Management*; Food and Agriculture Organization of the United Nations (FAO): Rome, Italy, 2014; p. 117. Available online: http://www.fao.org/3/a-i4029e.pdf (accessed on 16 June 2021).
5. IPCC. *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands*; Hiraishi, T., Krug, T., Tanabe, K., Srivastava, N., Baasansuren, J., Fukuda, M., Troxler, T.G., Eds.; IPCC: Geneva, Switzerland, 2014; p. 354.
6. Sirin, A.; Minayeva, T.; Joosten, H.; Tanneberger, F. 3.3.2.8 Peatlands. In *The IPBES Regional Assessment Report on Biodiversity and Ecosystem Services for Europe and Central Asia*; Rounsevell, M., Fischer, M., Torre-Marin Rando, A., Mader, A., Eds.; Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services: Bonn, Germany, 2018; pp. 217–220.
7. Bonn, A.; Allott, T.; Evans, M.; Joosten, H.; Stoneman, R. (Eds.) *Peatland Restoration and Ecosystem Services: Science, Policy and Practice*; Cambridge University Press/British Ecological Society: Cambridge, UK, 2016; p. 493.
8. UNEP. Resolution Adopted by the United Nations Environment Assembly on 15 March 2019. 4/16. Conservation and Sustainable Management of Peatlands. 2019. Available online: https://wedocs.unep.org/bitstream/handle/20.500.11822/28480/English.pdf?sequence=3&isAllowed=y (accessed on 16 June 2021).
9. Maltby, E.; Caseldine, C.J. Prehistoric soil and vegetation development on Bodmin Moor, southwestern England. *Nature* **1982**, *297*, 397–400. [CrossRef]
10. Joosten, H.; Clarke, D. *Wise Use of Mires and Peatlands: Background and Principles Including a Framework for Decision-Making*; International Mire Conservation Group and International Peat Society: Saarijärvi, Finland, 2002; p. 304.
11. Joosten, H. Human impacts: Farming, fire, forestry and fuel. In *The Wetlands Handbook*; Maltby, E., Barker, T., Eds.; Wiley-Blackwell: Chichester, UK, 2009; pp. 689–718.
12. Joosten, H.; Tanneberger, F. Peatland use in Europe. In *Mires and Peatlands of Europe. Status, Distribution and Conservation*; Joosten, H., Tanneberger, F., Moen, A., Eds.; Schweizerbart: Stuttgart, Germany, 2017; pp. 151–172.
13. Pons, L.J. Holocene peat formation in the lower parts of the Netherlands. In *Fens and Bogs in The Netherlands: Vegetation, History, Nutrient Dynamics and Conservation*; Verhoeven, J.T.A., Ed.; Kluwer: Dordrecht, The Netherlands, 2002; pp. 7–79.
14. Törnqvist, T.E.; Joosten, J.H.J. On the origin and development of a Subatlantic "man-made" mire in Galicia (northwest Spain). *Proc. Int. Peat Congr.* **1988**, *I*, 214–224.
15. Moore, P.D. The origin of blanket mire, revisited. In *Climate Change and Human Impact on the Landscape*; Chambers, F.M., Ed.; Chapman & Hall: London, UK, 1993; pp. 217–224.
16. Kaland, P.E. The origin and management of Norwegian coastal heaths as reflected by pollen analysis. In *Anthropogenic Indicators in Pollen Diagrams*; Behre, K.-E., Ed.; Balkema: Rotterdam, The Netherlands, 1986; pp. 19–36.
17. Lindsay, R.; Clough, J. United Kingdom. In *Mires and Peatlands of Europe. Status, Distribution and Conservation*; Joosten, H., Tanneberger, F., Moen, A., Eds.; Schweizerbart: Stuttgart, Germany, 2017; pp. 705–719.

18. Tanneberger, F.; Tegetmeyer, C.; Busse, S.; Barthelmes, A.; Shumka, S.; Moles Marine, A.; Jenderedjian, K.; Steiner, G.M.; Essl, F.; Etzold, J.; et al. The peatland map of Europe. *Mires Peat* **2017**, *19*, 1–17. Available online: http://mires-and-peat.net/pages/volumes/map19/map1922.php (accessed on 16 June 2021).
19. Joosten, H. *The Global Peatland CO2 Picture. Peatland Status and Drainage Related Emissions in all Countries of the World*; Wetlands International: Wageningen, The Netherlands, 2009; p. 11.
20. Barthelmes, A. The global potential and perspectives for paludiculture. In *Paludiculture—Productive Use of Wet Peatlands. Climate Protection—Biodiversity—Regional Economic Benefits*; Wichtmann, W., Schröder, C., Joosten, H., Eds.; Schweizerbart Science Publishers: Stuttgart, Germany, 2016; pp. 200–203.
21. Lindholm, T.; Heikkilä, R. Finland. In *Mires and Peatlands of Europe. Status, Distribution and Conservation*; Joosten, H., Tanneberger, F., Moen, A., Eds.; Schweizerbart: Stuttgart, Germany, 2017; pp. 376–394.
22. Joosten, H.; Grootjans, A.; Schouten, M.; Jansen, A. The Netherlands. In *Mires and Peatlands of Europe. Status, Distribution and Conservation*; Joosten, H., Tanneberger, F., Moen, A., Eds.; Schweizerbart: Stuttgart, Germany, 2017; pp. 523–525.
23. Cajander, A.K. Studien über die Moore Finnlands. [Studies of the mires of Finland]. *Acta For. Fenn.* **1913**, *2*, 1–208. (In German) [CrossRef]
24. von Bülow, K. Die deutschen Moorprovinzen. [The German mire provinces]. *Jahrb. Der Preußischen Geol. Landesanst.* **1928**, *49*, 207–219. (In German)
25. Katz, N.Y. Zur Kenntnis der Moore Nordosteuropas. [On the peatlands of Northeastern Europe]. *Beih. Bot. Zbl.* **1930**, *2*, 287–394. (In German)
26. Kats, N.Y.; Кац, Н.Я. Типы болотСССР и Западной Европы и их географическое распространение. [Mire types of the USSR and Western Europe and their geographical distribution]. *Geogr. Mosk.* **1948**, 320. (In Russian)
27. Moen, A.; Joosten, H.; Tanneberger, F. Mire diversity in Europe: Mire regionality. In *Mires and Peatlands of Europe. Status, Distribution and Conservation*; Joosten, H., Tanneberger, F., Moen, A., Eds.; Schweizerbart: Stuttgart, Germany, 2017; pp. 97–150.
28. Eurola, S.; Vorren, K.D. Mire zones and sections in North Fennoscandia. *Aquil. Ser. Bot.* **1980**, *17*, 39–56.
29. Joosten, H.; Tanneberger, F.; Moen, A. *Mires and Peatlands of Europe. Status, Distribution and Conservation*; Schweizerbart: Stuttgart, Germany, 2017; pp. 2–10.
30. IPCC. *2006 IPCC Guidelines for National Greenhouse Gas Inventories*; Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T., Tanabe, K., Eds.; Agriculture, Forestry and Other Land Use; National Greenhouse Gas Inventories Programme, IGES: Japan, Tokyo, 2006; Volume 4, Available online: http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html (accessed on 16 June 2021).
31. Bohn, U.; Gollub, G.; Hettwer, C.; Weber, H.; Neuhäuslová, Z.; Raus, T.; Schlüter, H. *Karte der Natürlichen Vegetation Europas. [Map of the Natural Vegetation of Europe]. Maßstab 1:2,500,000. [Scale 1:2,500,000] Teil 1: Erläuterungstext. [Part 1: Explanatory text] 655 p. Teil 2: Legende. [Part 2: Legend] 153 p. Teil 3: Karten: 9 Blätter + Legendenblatt + Übersichtskarte 1:10,000,000. [Part 3: Maps: 9 Sheets + Legend Sheet + General Map 1:10,000,000] Teil 4: Interaktive CD-ROM, Erläuterungstext, Legende, Karten. [Part 4: Interactive CD-ROM, Explanatory Text, Legend, Maps], 2000–2004*; Landwirtschaftsverlag: Münster, Germany, 2004; Available online: https://is.muni.cz/el/1431/podzim2012/Bi9420/um/Bohn_etal2004_Map-Nat-Veg-Europe.pdf (accessed on 25 July 2021). (In German)
32. Tegetmeyer, C.; Barthelmes, K.-D.; Busse, S.; Barthelmes, A. *Aggregierte Karte organischer Böden Deutschlands*; Greifswald Mire Centre: Greifswald, Germany, 2020; p. 10. ISSN 2627-910X. (In German)
33. Buchhorn, M.; Smets, B.; Bertels, L.; Lesiv, M.; Tsendbazar, N.-E.; Masiliunas, D.; Linlin, L.; Herold, M.; Fritz, S. Copernicus Global Land Service: Land Cover 100 m: Collection 3: Epoch 2019: Globe. *Zenodo* **2020**. [CrossRef]
34. UNEP-WCMC; IUCN. Protected Planet. 2020. Available online: https://www.protectedplanet.net/en (accessed on 18 May 2021).
35. Deguignet, M.; Arnell, A.; Juffe-Bignoli, D.; Shi, Y.; Bingham, H.; MacSharry, B.; Kingston, N. Measuring the extent of overlaps in protected area designations. *PLoS ONE* **2017**, *12*, e0188681. [CrossRef] [PubMed]
36. Minayeva, T.; Sirin, A.; Bragg, O. (Eds.) *A Quick Scan of Peatlands in Central and Eastern Europe*; Wetlands International: Wageningen, The Netherlands, 2009; p. 132.
37. Sirin, A.; Minayeva, T.; Yurkovskaya, T.; Kuznetsov, O.; Smagin, V.; Fedotov, Y.U. Russian Federation (European Part). In *Mires and peatlands of Europe. Status, Distribution and Conservation*; Joosten, H., Tanneberger, F., Moen, A., Eds.; Schweizerbart: Stuttgart, Germany, 2017; pp. 589–616.
38. Minayeva, T.Y.; Bragg, O.M.; Sirin, A.A. Towards ecosystem-based restoration of peatland biodiversity. *Mires Peat* **2017**, *19*, 1–36. [CrossRef]
39. Barthelmes, A. (Ed.) *Reporting Greenhouse Gas Emissions from Organic Soils in the European Union: Challenges and Opportunities. Policy Brief*; Greifswald Mire Centre: Greifswald, Germany, 2018; p. 16. ISSN 2627-910X.
40. Manton, M.; Makrickas, E.; Banaszuk, P.; Kołos, A.; Kamocki, A.; Grygoruk, M.; Stachowicz, M.; Jarašius, L.; Zableckis, N.; Sendžikaite, J.; et al. Assessment and Spatial Planning for Peatland Conservation and Restoration: Europe's Trans-Border Neman River Basin as a Case Study. *Land* **2021**, *10*, 174. [CrossRef]
41. European Commission. EU Biodiversity Strategy for 2030, Bringing Nature Back into our Lives. 2021. Available online: https://eur-lex.europa.eu/resource.html?uri=cellar:a3c806a6-9ab3-11ea-9d2d-01aa75ed71a1.0001.02/DOC_1&format=PDF (accessed on 25 July 2021).
42. United Nations Environment Programme. First Draft of the Post-2020 Global Biodiversity Framework. 2021. Available online: https://www.cbd.int/doc/c/914a/eca3/24ad42235033f031badf61b1/wg2020-03-03-en.pdf (accessed on 30 July 2021).

43. Joosten, H. A world of mires: Criteria for identifying mires of global conservation significance. In *Peatlands Use—Present, past and Future*; Lüttig, G.W., Ed.; Schweizerbart: Stuttgart, Germany, 1996; pp. 18–25.
44. Joosten, H. Identifying Peatlands of International Biodiversity Importance. 2001. Available online: http://www.imcg.net/pages/publications/papers/identifying-peatlands-of-international-biodiversity-importance.php (accessed on 16 June 2021).
45. Grootjans, A.P.; Wołejko, L.; de Mars, H.; Smolders, A.J.P.; van Dijk, G. On the hydrological relationship between Petrifying-springs, Alkaline-fens, and Calcareous-spring-mires in the lowlands of North-West and Central Europe; consequences for restoration. *Mires Peat* **2021**, *27*, 1–18.
46. Joosten, H. *Ramsar Global Guidelines for Peatland Rewetting and Restoration*; Ramsar Convention Secretariat: Gland, Switzerland, 2021.
47. Greifswald Mire Centre (GMC); Wetlands International; National University of Ireland (NUI) Galway. Peatlands in the EU Common Agricultural Policy (CAP) After 2020. Position Paper. 2020. Available online: https://www.greifswaldmoor.de/files/dokumente/Infopapiere_Briefings/202003_CAP%20Policy%20Brief%20Peatlands%20in%20the%20new%20EU%20Version%204.8.pdf (accessed on 16 June 2021).
48. Tanneberger, F.; Appulo, L.; Ewert, S.; Lakner, S.; Brolcháin, N.Ó.; Peters, J.; Wichtmann, W. The Power of Nature-based Solutions: How peatlands can help us to achieve key EU sustainability objectives. *Adv. Sustain. Syst.* **2020**, *5*, 2000146. [CrossRef]
49. Wichtmann, W.; Schröder, C.; Joosten, H. (Eds.) *Paludiculture—Productive Use of Wet Peatlands*; Schweizerbart Science Publishers: Stuttgart, Germany, 2016; p. 272.
50. Ziegler, R.; Wichtmann, W.; Abel, S.; Kemp, R.; Simard, M.; Joosten, H. Wet peatland utilisation for climate protection—An international survey of paludiculture innovation. *J. Clean. Prod.*. submitted.