

ヨーロッパへのナイルパーチの輸出

アジアへのナイルパーチの輸出

ナイル川発電ダム取水量の増加による湖水位の低下と沿岸域の環境悪化

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ビクトリア湖流域

地域焼畑による大気起源リンの堆積

環境省
Ministry of the Environment

ILEC

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本冊子の引用

本冊子を引用する場合は、下記を明記してください：

ILEC (2007) 『統合的湖沼流域管理：手引書』、財団法人国際湖沼環境委員会、滋賀県草津市。

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表紙の説明

NASA のブルー・マープル (<http://earthobservatory.nasa.gov/Newsroom/BlueMarble/>) から得たものである。

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世界の湖沼環境の悪化を どう食い止めるか

— 生態系の保全と持続可能な利用に向けた「統合的湖沼流域管理（ILBM）」 —





湖沼とその流域

「多様な資源価値を形成する地球上の貴重な存在」

世界の湖沼や湿地、人造湖、ため池（以下、全てをあわせて湖沼と呼ぶ）などは、地球上で最も重要な淡水資源といえることができる。生活用水や工業用水を供給する湖沼は世界のいたるところに存在し、水力発電には人造湖だけでなく自然湖の水位も利用されている。世界の穀物生産の3分の1は灌漑用の湖沼に頼っており、また発展途上国のタンパク質供給の25%は湖沼の淡水魚からだと言われている。湖沼の自然景観や遺跡・史跡などの歴史的景観は人々を魅了する。地球上の全魚種の3分の1が湖沼に生息していると言われ、生物多様性を維持していく意味でも湖沼は非常に重要である。また、湖沼沿岸の植生は水質浄化機能を持ち、洪水調整や周辺の気候緩和も湖沼の重要な機能である。

西暦2000年にミレニアム・サミットで採択された「ミレニアム・エコシステムアセスメント」は、湖沼のような生態系がもつ資源価値を「用水、魚介類、灌漑農業生産物、水力エネルギーなどの資源供給サービス」、「生物生育の場、良好な水質、洪水・渇水調整機能、気象の緩和などの調整的サービス」、「美しい景観や宗教の対象としての神秘性、教育・学術研究の対象などの文化的サービス」、および、この3つを支える「湖水に含まれるエネルギー、湖の生い立ちと共に（地史的に）形成されてきた土壌成分、湖の形状や構造などの基盤的なサービス」から成立するとし、これらの総称を「エコシステムサービス」と呼んでいる。^(注1)

通常、「資源供給サービス」は「調整的サービス」に支えられているものの、過剰に資源開発を行えば、この支えを失い、同時に「文化的サービス」も低下する。「基盤的なサービス」は容易に変化しないが、地史的な環境の異変や地球温暖化の進行などの場合は徐々に、火山の噴火や地震などの場合は一気に変化する。

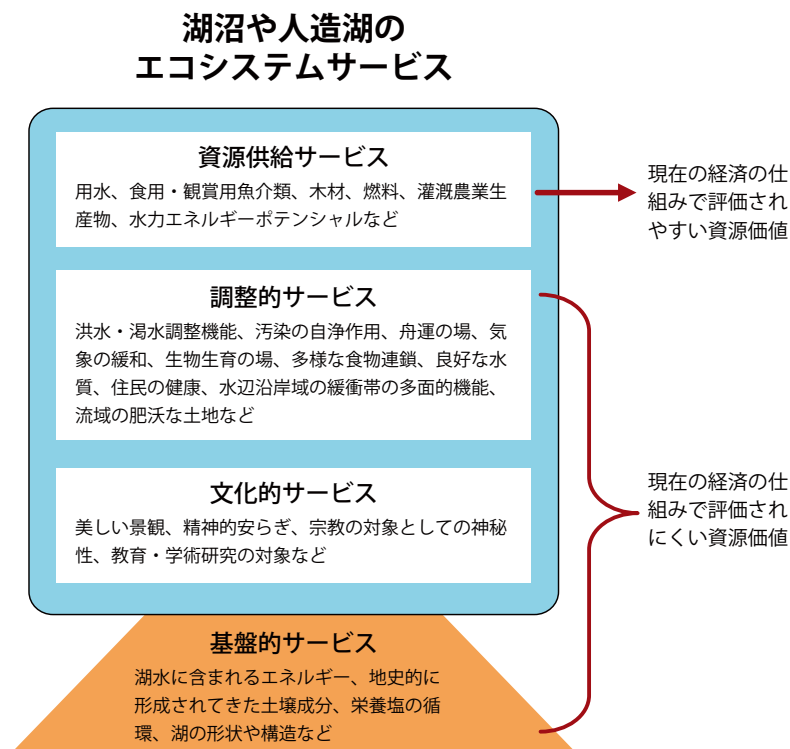


図1 湖沼のエコシステムサービスとその価値の評価

「資源供給サービス」は、一般に私的財としての性格をもつため、その価値に対する料金徴収や市場を通じた売買が可能である。一方、「調整的サービス」や「文化的サービス」は、公共財としての性格をもち、一般にその価値に対して適正な支払いの仕組みが存在しないことが多い。^(注2)

湖沼の場合、前者も後者も同じ限られた場所に集中しているため、過剰な水資源開発や魚の乱獲が水質の悪化や生態系の破壊といった湖沼環境への大きなストレスをもたらし、結果的にエコシステムサービス全体が崩壊していくという一般的な構図をもっている。いったん、そうしたことが起こってしまえば、その回復には多大な金銭的・社会的なコストがかかる。

未だそういった状態に至っていない湖沼の場合には、過剰な資源開発が起らないように未然に予防策を導入することが重要である。しかし、すでに湖沼が大きなストレスを受けて環境が悪化している場合には、対症的な技術の導入で解決することは難しく、流域社会全体が長期にわたって幅広い取り組みを継続していく必要がある。また、湖沼環境の悪化は目に見えないところで徐々に進行するため、科学的な調査や研究が不可欠である。その情報を政策に反映し、必要な組織の体制づくり、適切な技術対策の導入、継続的に必要とされる資金調達の方法を確立することも重要である。このような湖沼流域管理の様々な側面について、これまでの経験を反映してとりまとめ、地球規模で湖沼資源の持続可能な利用と保全・回復を実現していこうというのが「統合的湖沼流域管理」の考え方である。この冊子はその概要を示す目的で作成された。

注1：ミレニアムエコシステムアセスメント（Millennium Ecosystem Assessment）では、資源供給サービスを Resource Provision Services、調整サービスを Regulating Services、文化的サービスを Cultural Services、基盤的サービスを Supporting Services と英語表記している。

注2：一般に、私的財は競合的（誰かが消費してしまえば他の者は消費できない）かつ排他的（料金や配給などによって消費を希望するものに対して制限を設けることができる）であり、公共財は非競合的、非排他的であると定義されている。単純に考えれば、飲料水は私的財で景観は公共財であると言えるが、飲料水はいったん消費され、その排水が処理されれば再び消費可能である。そういった意味では、部分的に非競合的な資源としての性格をもっているといえる。景観も、たとえば景勝地の入園料徴収で入園者数を制限するならば、競合的な資源としての性格をもたせることが可能である。私的財と公共財には様々な中間形態が存在する。後に紹介する GEF-LBIM 報告書では、湖沼の全ての価値（Total Value）を直接的使用価値（用水など）、間接的使用価値（景観など）、オプション価値（将来の選択に任せる価値）、存在価値（資源として利用はできないが自然の存在として守るべき価値）の枠組みを適用して説明している。おおむね、「資源供給サービス」は直接的使用価値、「調整的サービス」と「文化的サービス」は間接的使用価値とオプション価値、「基盤的サービス」は存在価値に相当する。

略語一覧

CEPA	communication, education, and public awareness 広報・教育・普及啓発
GEF	Global Environment Facility 地球環境ファシリティ
GNI	gross national income 国民総所得
IJC	International Joint Commission 国際合同委員会
ILBM	integrated lake basin management 統合的湖沼流域管理

ILEC	International Lake Environment Committee 国際湖沼環境委員会
IWRM	integrated water resources management 統合的水資源管理
LBMI	Lake Basin Management Initiative 湖沼流域管理イニシアティブ
LLDA	Laguna Lake Development Authority ラグナ湖開発公社
LTBP	Lake Tanganyika Basin Project タンガニーカ湖流域プロジェクト
MOU	memorandum of understanding 覚書
NGO	nongovernmental organization 非政府組織
PCBs	polychlorinated biphenyls

SAP	policy塩化ビフェニール類 strategic action program 戦略行動計画
TDA	transboundary diagnostic analysis 国家横断的な診断分析
UNDP	United Nations Development Programme 国際連合開発計画
UNEP	United Nations Environment Programme 国際連合環境計画(ユネップ)
UNESCO	United Nations Educational, Scientific and Cultural Organization 国際連合教育科学文化機関(ユネスコ)
USAID	United States Agency for International Development 米国国際開発援助庁



時と共に変化する湖沼の資源価値

「エコシステムサービスをめぐる自然と人間の関係」

自然湖の年齢は比較的新しいもので数百年だが、古いものは何百万年もの歴史をもっている。一方、人造湖の大多数は 20 世紀になってから建造されたもので、古いものでも数百年だが、小規模なものは人類が文明を築く過程で建造されてきたものも多い。自然湖も人造湖も、その資源価値は時と共に変遷する。湖沼がもつ多様な資源の価値と、それを利用し、保全する流域管理の政策も時と共に変化する（コラム「ある湖の物語」参照）。

コラムの「物語」の湖のエコシステムサービスは以下のように変遷してきた。

1. 人口密度が低く、湖の資源が豊富な時代は、人々は自由にそのサービスの価値を享受することができた。漁や飲み水などの資源は、とくに人々を湖辺に定住させる大きな要因となった。
2. 人口が増加し、漁獲などの資源への需要が増加すれば、減少する資源の獲得をめぐる争いがおこる。争いを回避し、資源を回復させるために社会的ルールを定めるが、需要は常に供給を上回る。魚の産卵・生育の場、多様な食物連鎖、良好な水質などの「調整的サービス」が資源のニーズを支えきれないからである。
3. 「資源供給サービス」を人為的に増大させることを資源開発と呼ぶ。「いけす」養殖はその一つである。人口の増加や産業活動の振興に伴って資源開発は流域全体に広がっていく。過剰な資源開発は湖の「調整的サービス」の質の低下を引き起こす。
4. 流域の資源開発は下流の環境に、下流の資源開発は上流のそれに影響を与える。たとえば肥料や農薬の過剰な投入による水の汚染や耕作地からの土壌の流亡は湖辺の魚の産卵・生育場所に悪影響を与え、流出河川部における発電や洪水・渇水対策のための堰の建設は湖の沿岸一体の水位を変動させるため、水辺の生態系に大きな影響を与える。
5. 大規模な水資源開発は「調整的サービス」や「文化的サービス」の質に影響を及ぼす。堰を築いて取水量を増やそうとすれば、水量が変化し、洪水調整や自浄作用などの機能が低下していく。また、そういった水量や水位の操作は歴史的・宗教的景観の破壊を引き起こすこともある。
6. この湖の場合、都市用水や農業用水といった「資源供給サービス」は、都市の発展と上流の灌漑システムの整備に大きく貢献するが、水草の繁茂やごみの流入によって湖の景観が著しく損なわれ、レクリエーションやレジャーを支える水辺沿岸域の緩衝帯の多面的機能は低下し、さらに人々に水質の悪化や環境の破壊が健康被害をもたらすことにもなる。
7. このような変化は長い時間をかけて静かに進行するため、資源を供給する上で不可欠な「調整的サービス」の機能が回復不可能なほどに低下してしまった。

このような、湖沼がもたらす資源価値の変化を模式的に表せば図 2 のようになる。

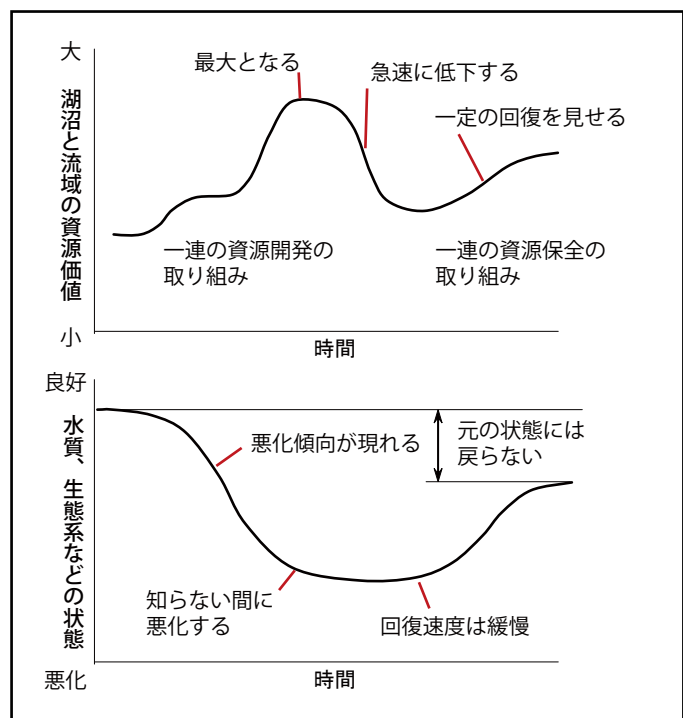


図 2：開発と保全によって変化する資源価値と湖沼環境

コラム

ある湖の物語

人々は数千年前、この湖岸周辺に住居を構えるようになった。人口は少なく、湖の資源は豊富で、他の集落との争いはほとんどない。ある村の魚の水揚げが、別の村の水揚げを減らすようなことはなかった。また、流入河川の水をかんがいに使っても、湖の水位が目に見えて下がってくるようなことはなかった。

湖周辺の人口が増えるにつれ、湖の恵みの一部にかげりが出始めた。まず、漁獲に影響が現れた。雨の少ない年が何年か続き、魚の水揚げが減り始めた。漁師は、湖辺の湿地の水位が下がったため魚の産卵がうまくいかなかったのだと経験的に気づいた。そのうち、まだ産卵に影響が出ていない湿地近くの漁場をめぐって、村と村との間で争いが起き始めた。幸いなことに、本格的な争いになる前に降雨パターンが元に戻り、魚の産卵も見られるようになって、漁獲は回復した。この出来事をきっかけに、漁場の利用について村どうしの取り決めが話し合われた。良好な漁場に入れる漁船の数が村ごとに決められ、魚の産卵期間には湿地に入らないというルールも作られた。これに違反した者は漁業を禁止され、村から出て行った。

湖の流域に人が定住し始め、周辺で耕作が始まった。農地はどんどん開墾され、農民の数も増えてきた。その結果、雨季には、農地から流出する土壌が湖の河口や湿地にたまり、魚の産卵に悪影響が出て魚の数が減少し始めた。しかし、上流部の農民には、開墾や耕作で流出・堆積した土壌が生態系に悪影響を及ぼしているという意識はなく、漁民の苦情にも耳を傾けなかった。農民は、川は雨季にはいつも濁っているもので、漁獲が減ったことと農業とは何の関係もないと信じていた。このことは農民と漁民の根深い対立の原因となったが、漁民は他の産卵場所周辺に移動し、減った収入は沖合漁業やいけす養殖漁業で補ったため、争いは起こらなかった。しかし、お互いに話し合うことのなかった両者の隔たりは大きくなり、生活の場も全く別々になってしまった。時が経ち、湖岸の村々は徐々に人口が増え、市街化していった。漁民の中には漁から離れ、観光案内や貨物運搬に従事するものも現れた。一方、町からあふれ出たゴミが湖や水路に捨てられ、時には湖に流れ出すこともあった。町は環境を改善するために簡易下水路を建設した。集められた下水は沈殿処理の後、排水は湖岸から適当に離れた場所に放流され、汚泥は湿地に埋め立てられた。

さらに何十年が経ち、国は、木綿需要の国際的な高まりをきっかけに、上流域に大規模な綿花畑を開墾する案を発表した。この政策は地域から広く歓迎され、市長や議会も同意した。農民から農地が買い取られ、大規模なかんがい事業が始まった。市民の中には開墾に不安を感じる者も多かったが、この事業が湖にどんな影響を与えるかは全く想像できなかった。農民と手を組んで湖の環境を守りたいと意思表示することはなかった。開墾政策の結果、新しい豊かな農民層が生み出され、古い農民たちはいなくなってしまう。最初のうちは、かんがい農地は何の問題も引き起こさなかった。地域は収入が増加して繁栄し、町は急速に発展していった。政府の農業事務所が開かれ、多くの住民がこのかんがい地域に職場を求めて集まってきた。

数年ほど経ったころに湖辺に問題が起き始めた。敷物のように分厚く重なり合った水草が、湖に流れ込む水路の河口周辺に繁茂し、船着場まで広がってきた。しかし、もう湖と直接の関わりを失っていた多くの人々はこれを深刻な問題だと思わず、ただ迷惑な自然現象と考えた。実際、水草で民芸品を作って売る者も出てきた。人々が湖の本格的な異変に気がついたのは、それから十数年も経ってからだった。湖水の透明度は著しく低下し、茶色く変色した水がかび臭を放つようになった。既に握りしめきれなくなった漁民も臭い魚と水草による航路障害で漁が成り立たなくなり、消えてしまった。年配の住民たちは、湖の美しさや心の安らぎを覚えたころの記憶とのあまりの違いに、自分たちが失った湖の価値の大きさに気がついて呆然とした。人々は、湖の環境悪化は明らかに上流のかんがい農業が直接的な原因だと主張したが、農業事務所は人口増加や工業化が主な原因だと主張した。事態を重視した政府は、湖を以前の状態に戻すために下水道を拡張しようと考え、専門家の委員会を設置すると共に近隣の大学の協力を得て湖の水質と生態系の調査を開始した。しかし、政府も市の役人も住民も、下水道を整備しても栄養塩を除去する高度処理施設を設置しなければ富栄養化防止はできないこと、またそういった施設の建設や維持管理には高額な費用がかかることは知らなかった。湖沼環境改善の道のりは長く、厳しく、大きな犠牲が伴うのだと彼等が知ったのは、ずっと後になってからだった。





世界のほとんどの湖沼で環境が明らかに悪化

「地球規模で増大する湖沼資源開発の圧力」

表1は、一般的に湖沼が抱える「湖内」、「流域」、「地域・地球規模」起源の問題について、世界28湖沼流域を対象に評価し、青は明らかに改善傾向、黄はほぼ横ばい、赤は明らかに悪化傾向、白は言及無し、の判断を表示したものである。これをみると、過剰な資源開発が地球規模で湖沼環境を悪化させていることが分かる。これを「エコシステムサービス」の枠組みで考えれば、「流域起源」の問題と「流域外起源（地球規模を含む）」の問題は「資源供給サービス」の過剰な追求を意味しており、その結果引き起こされるのが「湖内起源」の問題で、その多くは「調整的サービス」の低下である。ちなみに28湖沼は、GEF-LBIMI プロジェクト（Box 1）の一環として、地理的分布（図3）、物理・化学・生物学的特徴、流域の社会・経済状況などのバランスに配慮して選んだ。それぞれの湖沼に関する詳細情報は概要書（Lake Briefs*）に記されている。

* GEF-LBIMI プロジェクト対象湖沼の現状と課題についての報告書 (<http://www.ilec.or.jp/eg/lbmi/index.htm>)

湖沼流域名	湖内起源						流域起源						流域外起源		
	① 魚の乱獲	② 外来魚の移入・侵入	③ 塩分濃度の変化	④ 水草など外来植物の侵入	⑤ 生簀養殖からの栄養塩類	⑥ 沿岸湿地帯など水辺生態系の喪失	⑦ 土砂の流入・堆積	⑧ 降雨地面源負荷の流入	⑨ 農業・化学肥料による汚染	⑩ 大量取水・分水	⑪ 汚水の流入	⑫ 下水道・雨水排水路からの汚染	⑬ 産業による汚染	⑭ 流域内外から風送降下される汚染化学物質	⑮ 流域内外から風送降下される栄養塩類
1. アラル海			→			→				→					
2. バイカル湖							↓				↓	→		→	
3. バリンゴ湖	→						↓			↓					↓
4. ボージ湿地帯							→	→	→		→	↓			
5. 琵琶湖			→			↓		→	→	↑	↑				↓
6. チャド湖						↓	↓			↓					↓
7. シャンブレ湖								↑			↑			→	
8. チリカ湖			↑	↑			↓	↓	↓	↓	↓				
9. ニカラグア湖 (現地呼称：コンボルカ湖)							↓	↓	↓	↓	↓				
10. コンスタンツ湖 (現地呼称：ボーデン湖)		↓				→		→	→		→				
11. 瀋池（ディエンチ）					↑	↓	↓	↓	↓	↓	↓	→		→	
12. 五大湖		↓					↓	↓	↓		↑	→		→	
13. イシク・クル湖		→					↓	↓	↓			↓			↓
14. カリバ湖					↓			↓			→				↓
15. ラグナ湖 (現地呼称：バイ湖)	→	↓	→	→	↓		↓	↓	↓	↓	↓	→			
16. マラウイ/ニアサ湖	↓			↓			↓	↓	↓	↓	↓			↓	↓
17. ナイバシャ湖	↑	→		↑		→	↓	↓		→	↓			↓	
18. ナクル湖							→	→			↓				
19. オーリッド湖	→	↓				↓	↓	↓	↓		↓				
20. ペプシ ⁽¹⁾ / チュード湖 ⁽²⁾	↓		→					→			↓	→			
21. セヴァン湖	↓	↓				↓	↓			↓	↓				
22. タンガニーカ湖	↓						↓				↓	↓			↓
23. チチカカ湖		↓					↓				↓	↓			
24. トバ湖	↓	↓		↓	↓	↓	→	→	↓	↓	↓			↓	
25. トンレ・サップ湖	↓	↓					↑				↓				
26. ツクルイ湖			→				→								
27. ビクトリア湖	→	↓		↑		↓	↓	↓			↓	↓	↓		
28. 興凱 ⁽³⁾ / ハンカ湖 ⁽⁴⁾	↓					↓	↓		↓		↓	↓			
合計発生数	12	11	3	9	4	11	21	16	12	11	23	12	4	4	7

表1：対象28湖沼流域に影響を与えている問題点

改善傾向 横ばい傾向 悪化傾向



Photo: ILEC

① 稚魚まで捕獲してしまう細目網



Photo: USEPA

② 外来種の寄生魚（ヤツメウナギ）の円口



Photo: Thomas Ballatore

③ 塩分が露出したナクル湖岸



Photo: ILEC

④ ホテイアオイによる悪影響



Photo: Lake Laguna Dev. Authority (LLDA)

⑤ ラグナ湖の生簀



Photo: Thomas Ballatore

⑥ 排水路のコンクリート化による魚類生育・産卵域の喪失



Photo: USEPA

⑦・⑧ スペリオル湖に流入する土砂



Photo: USEPA

⑨ 毒性物質による汚染



Photo: Nick Aladin

⑩ 干陸化したかつてのアラル海の一部



Photo: NOAA

⑪ 雨水排水



Photo: USEPA

⑫ 産業排水

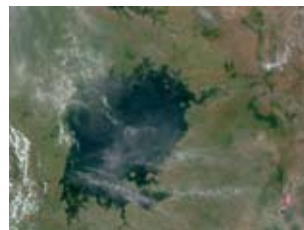


Photo: NASA Visible Earth

⑬ ヴィクトリア湖を覆う焼畑からの煙



Photo: USEPA

⑭ 酸性雨による被害



Photo: NASA Visible Earth

⑮ ヒマラヤにある氷河の融解による湖の水位上昇

Box 1 : GEF- Lake Basin Management Initiative Project (GEF-LBMI プロジェクト、あるいは地球環境ファシリティ・湖沼流域管理イニシアティブプロジェクト)

このプロジェクトは、地球環境ファシリティ（GEF）が資金を提供したわが国初のプロジェクトで、41 ヶ国 28 湖沼を対象とし、多くの国際機関・政府機関・非政府組織・学術研究機関の協力と世界銀行・オランダ水パートナー計画、GEF、国際湖沼環境委員会 (ILEC)、滋賀県（日本）、合衆国国際開発機関 (USAID) の財政支援の下で遂行された。3 回の国際ワークショップには 288 人が参加し、準備された湖沼の概要書（Lake Briefs）と共通課題ペーパー（Thematic Papers）をベースに統合的な湖沼流域管理のあり方について議論した。英語版報告書および湖沼概要書（Lake Briefs）と、日本語暫定訳はそれぞれ以下のウェブサイトからダウンロード可能。

<http://www.ilec.or.jp/eg/lbmi/index.htm>、<http://www.ilec.or.jp/jp/index.html>

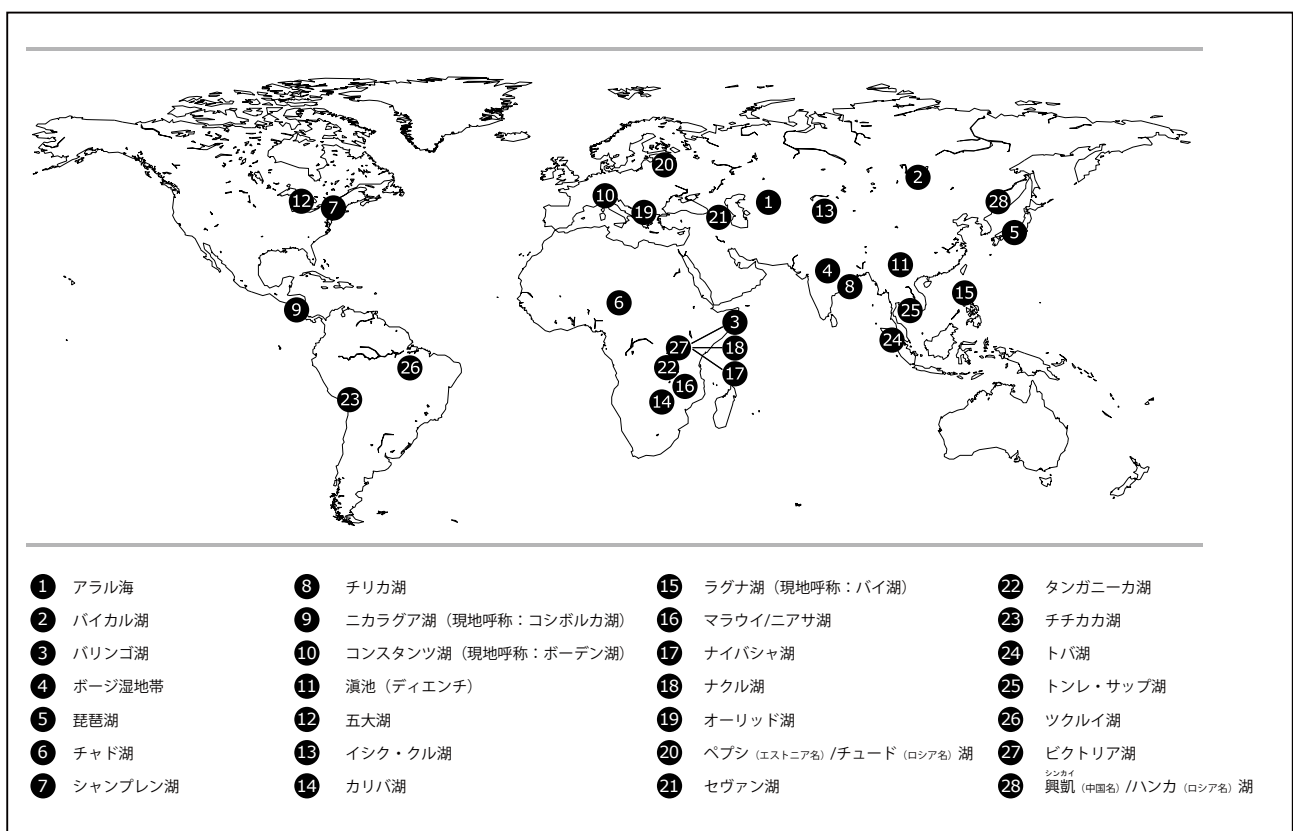


図 3：GEF-LBMI プロジェクトの対象となった 28 湖沼



持続可能な湖沼資源の利用と保全 を左右する静水システムの特徴

「水をめぐる自然と人の関係を見るもう一つの視点」

静水システムの特徴

湖沼流域の資源開発活動が引き起こすストレスは千差万別だが、ストレスが全て水体に集中し、生物の生息環境など「調整的サービス」に大きな影響を及ぼす状況はいずれの場合も共通している。大河川の場合、自然湖、人造湖、取水堰のバックウォーター、沼、湿地など様々なパターンの静水域が流域一体にちりばめられ、入れ子状態になって流域を形成しているのが一般的である（図4）。このような流域の構造は、後に述べる流域の管理のあり方に大きく影響を及ぼすが、その大きな要因となるのが、湖沼の静水システムとしての以下の特徴である。

Box 2

湖沼の静水システムとしての性質を左右する水収支に注目して流域の構造を分類すれば、(a)～(g)に示す7つに分類できる。

(a) 主として表流水の流入	(b) 表流水・地下水の流入と蒸発	(c) 表流水・地下水の流入と非恒常的な河川流出および蒸発	(d) 表流水・地下水の流入と蒸発
コンスタンツ湖 (ドイツ、オーストリア、スイス；湖辺外の流域にリヒテンシュタイン、下流域の国々は示していない)	ナイバシャ湖 (ケニア)	マラウイ/ニアサ湖 (マラウイ、モザンビーク、タンザニア)	イシク・クル湖 (キリギス)
(e) 表流水の流入と海洋への流出	(f) 乾季・雨季に変わる表流水の流入	(g) 堰の制御による表流水の流入	
チリカ湖 (インド)	トンレ・サップ湖 (カンボジア；湖辺外の流域国、中国、ラオス、ミャンマー、タイ、ベトナムは示していない)	ツクルイ湖 (ブラジル)	

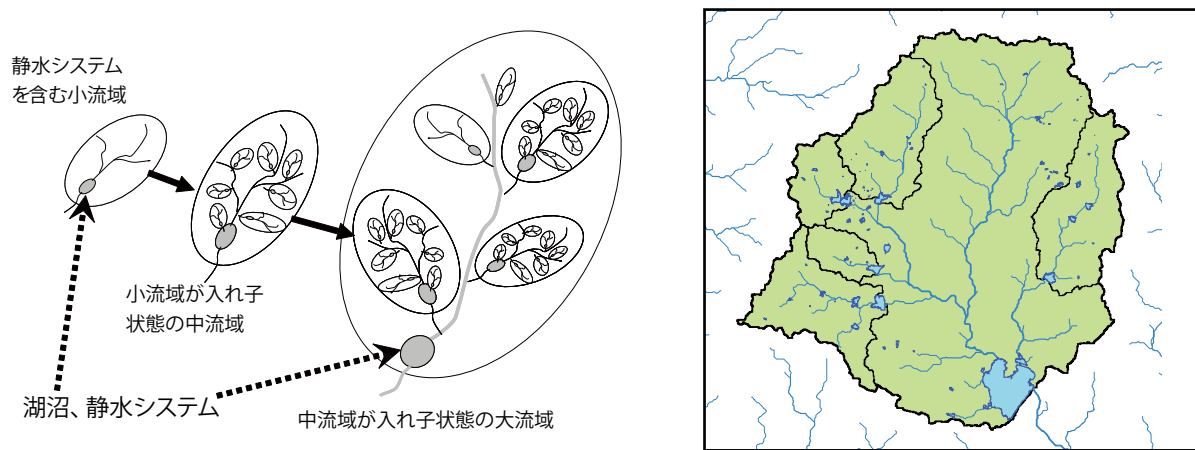


図4：静水域を含む河川流域が入れ子状態を形成する湖沼流域（例：フセインサガル湖 [インド]）

◆ 長い滞留時間—入ってきた物質を長時間ため込む

- 湖沼は流入水量に比べて容積が大きいので、河川と比べて滞留時間が長い。自然湖の中には滞留時間が数年から数十年、中には何百年にもなるものがある。
- 外界から隔離した環境にある湖沼の中には、特異な進化を遂げた生物が固有の種を生み出すことがある。多様な生物種を生み出す湖沼の多くは、長い滞留時間を持ち、安定した環境が維持されている。
- 滞留時間の長い静水システムは、外部から流れ込む水、熱エネルギー、汚染物質などを吸収し、ため込んでしまう。大降雨時の洪水被害の軽減や渇水期の貯水機能は湖沼の資源価値の一つである。
- 陸上や大気中から湖内に入ってくる物質は、長い時間をかけ、生物に取り込まれたり、化学変化をおこし、物理的影響を受けて変質していく。たとえば、河川から流入する粒子状のリンは、酸素があれば湖底に沈殿しても長時間そのままの状態で存在するが、無酸素状態になれば水中に溶け出して植物プランクトンの大増殖の引き金となることがある。

（エコシステムが一旦悪化すれば、その機能を回復することは難しい。取り返しのつかない影響を及ぼす可能性がある場合には、**予防原則に基づいて最悪の状態を避ける判断**を導入しておく必要がある）

◆ 複雑にからみ合う現象—湖内に流入する物質は生物的、物理的、化学的な相互作用を経て、複雑な変化をみせる

- 湖沼には河川とは異なった物理・化学・生物現象の相互作用があり、その環境は複雑である。たとえば、流入する有機物は、水に流され、沈殿する間に化学的に変化し、生物に分解され、水質や生物の生息環境が劇的に悪化することがある。
- 窒素やリンなどの栄養塩が流入すると（富栄養化）、植物プランクトンが爆発的に増え、その死骸が湖底に沈殿することによって、湖内は酸素不足状態になる。ただし、植物プランクトンは、動物プランクトンや魚類の食物連鎖の底辺を成しているため、漁業にとっては適度の富栄養化は望ましい面もある。

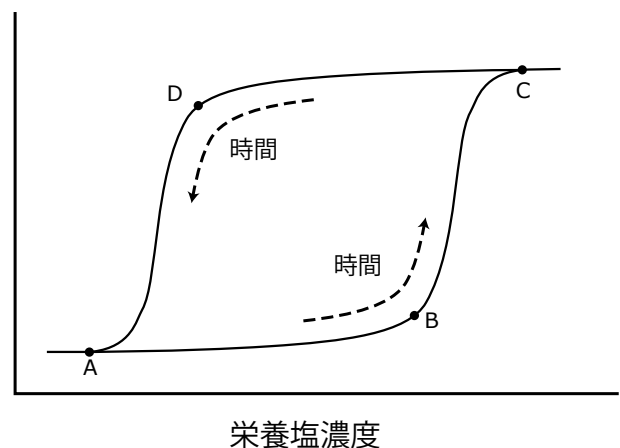


図5：植物プランクトンの異常増殖は突然おこり（A-B-C）、栄養塩削減対策をしてもなかなか元に戻らない（C-D-A）

- 生物現象は、潜伏期間を経て突然起こることがある。たとえばアオコや赤潮は、長期にわたって何の兆候も見せない。しかし、あるレベルを超えた途端に爆発的に発生し、気がついた時には取り返しのつかない状態にまで悪化していることがある。

(エコシステムサービスは、湖内の物理・化学・生物現象と密接に関連しており、その保全や回復に取り組むには科学的なアプローチが不可欠である。)

Box 3

PCB やダイオキシンは非常に脂肪に溶けやすい。したがって生物がそれらを体内に取り込めば脂肪に蓄積し、食物連鎖を通して上位の生物に濃縮されていく。右の表は北アメリカ五大湖における PCB の生物濃縮を示している。

五大湖における生物濃縮

生物	植物プランクトンを基準とした PCB汚染濃度比較
人間	?
セグロカモメの卵	4960
マス(大型魚)	193
ワカサギ(小型魚)	47
動物プランクトン	5
植物プランクトン	1

出典：USEPA およびカナダ政府 (1995 年) より作成。

◆ 様々な事象と現象を統合する性質—人為活動と自然が一体となって一つのシステムを形成している

- 湖沼は、集水域、流出入河川、湖辺エコトーン、湖内現象、湖底環境などが一つの有機的なシステムを作り上げ、そこに関わる人為的要因と自然的要因も相互に複雑にからみ合っていて出来あがっている。
- 水質を考えれば、農地から流れ出る土壌・肥料・農薬、生活環境から出る下水、大気を通して落下する工業から出た化学物質、ボートに付着して運び込まれる有害動植物など、長い時間をかけて湖沼のあらゆる場所に拡散し、生物の生息環境や水利用に影響を与える。
- 生態系を考えれば、最上流の森林域から湖底環境まで移動する有機物、湖内・湖辺と陸域をつなぐ動植物の移動回路、水陸移行帯の魚類の産卵環境など、人為活動と自然の作用が相互に密接に関係している。
(湖沼のエコシステムサービスを持続可能な形で利用・保全していくためには、多くの不確定性を含む自然の仕組みと人の行動を反映する順応的な取り組みが不可欠である。)

「長い滞留時間」は、「予防原則による判断」の重要性を示唆している。湖沼のエコシステムサービスは見えないところで長い時間をかけて静かに低下するため、その予兆を把握することが非常に難しく、気がついたら回復不可能な状態におちいってしまう。「複雑に絡み合う現象」は、技術的にも政策的にも「科学的調査による解明」が不可欠であることを示唆している。水質や生態系の機能に影響を及ぼす集水域の状態や気象や水文現象に関する調査研究に恒常的に取り組むことで、より効果的な技術的・政策的対応が可能になる。さらに、「全てを統合する性質」は「順応的な取り組み」が重要であることを示唆している。湖沼に外部からもたらされる長期的な自然的・人為的ストレスとその影響には多くの不確定要素を伴うので、試行錯誤を繰り返しつつ取り組みを改善していく必要がある。



統合的湖沼流域管理と 流域ガバナンスの課題

「世界の湖沼流域管理の経験から展望を切り開く」

世界の湖沼の資源開発や保全をめぐる取り組みの段階は様々である。ある湖沼は資源開発の初期段階にあり、別の湖沼では環境の悪化による資源価値の低下に悩んでいる。そしてまたある湖沼では保全・回復に向けて取り組みを進めている。資源価値と環境の状態がどの段階にあっても、湖沼が流域の様々な自然現象や人間活動の影響を受けて変化し続けていく点では共通しており、統合的湖沼流域管理の考え方はいずれのケースについても重要である。

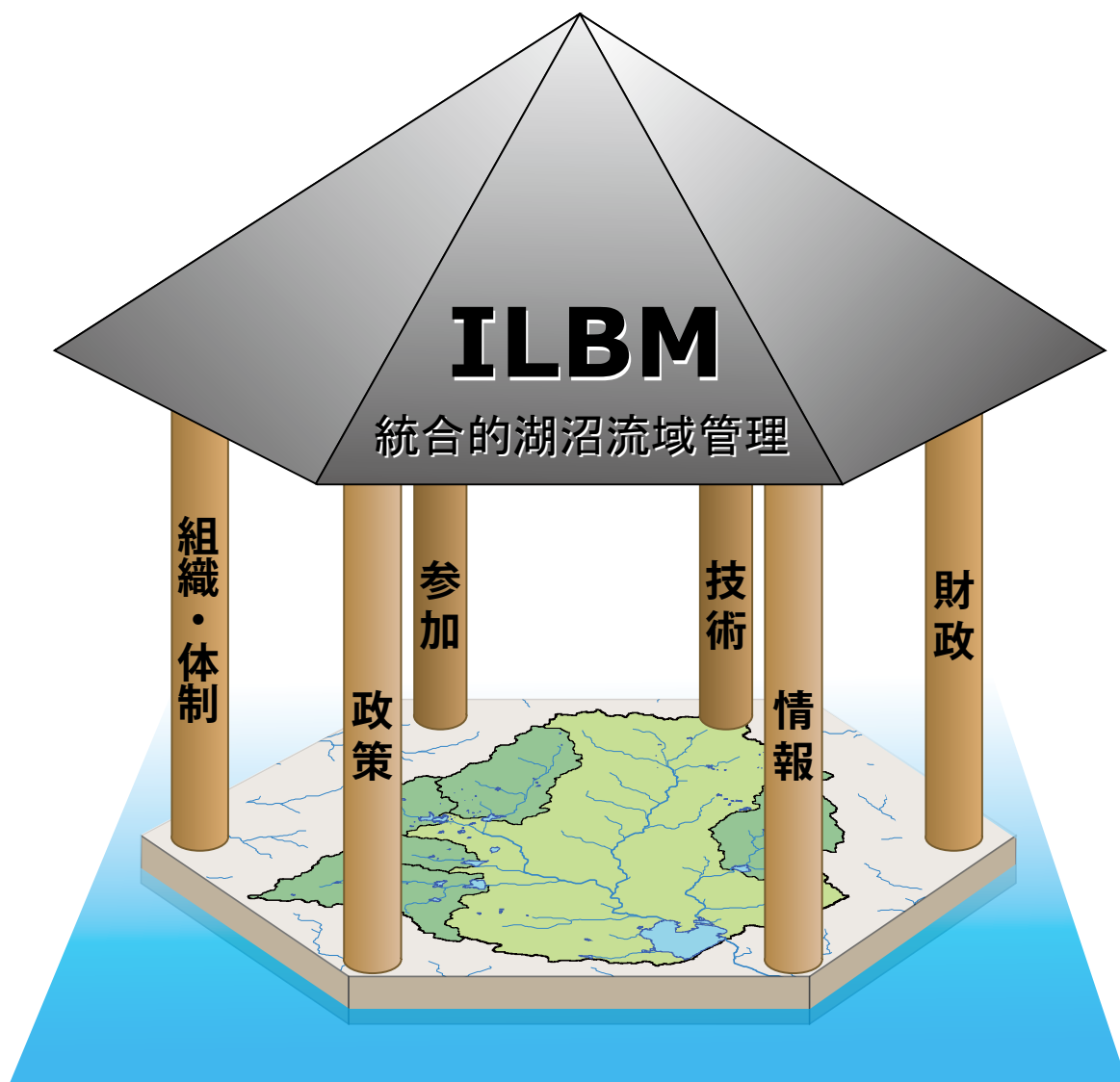


図7：ILBMを支える6つの柱

GEF-LBMI プロジェクトではその結論として、

- 湖沼の管理は流域の管理である
- 湖沼流域管理には国境や行政界を越えた取り組みが必要である
- 多くの湖沼で流域管理がうまく行かない原因の一つとして、実行の伴わない法規制があげられる
- 流域管理には、科学的な知見に基づいた対策技術を導入する必要がある
- 湖沼流域管理には、国の政策に基づいた長期にわたった取り組みが不可欠である
- モニタリングや因果関係を究明する調査研究なしに、湖沼流域管理はできない
- 湖沼流域管理はプロジェクトではなく長期にわたったプログラムである
- 利害関係者（ステークホルダー）が意思決定に参加していない場合には流域管理は成功しない

などをあげ、各湖沼における取り組みの教訓と課題を①組織・体制、②政策と社会的ルール、③住民や利害関係者の参加と協力、④適切なレベルの技術的対応、⑤情報－科学的知見と歴史的に形成されてきた知恵、⑥財源と財政的仕組み、の6つの課題分野に分類して集約した（図7）。これらは、個々の住民から政府まで公私の区別なく協力しあって課題に取り組む上で不可欠な「流域ガバナンス」の重要な要素ということができ、ILBMはこの「流域ガバナンス」の向上を統合的に推進する政策の枠組みとすることができる。（ILBM、Box 4 参照）

Box 4：統合的湖沼流域管理と湖沼流域ガバナンス

多くの要素が複雑にからみ合っている湖沼資源の利用と保全のあり方を見直し、持続可能な形に変えていくためには、そのきっかけと手がかりが必要である。その方法として、グローバル・ウォーターパートナーシップ（Global Water Partnership, GWP）は、自然活動と人為活動、陸域と水域、大気水・表流水・地下水・生物体中の水、上流と下流、資源の開発利用と保全などを統合的に考え、水の経済的価値を水管理に反映させる統合的水資源管理（Integrated Water Resources Management, IWRM）を提唱している。また、水資源開発、自然資源開発、環境保全を一体的に考えて、河川流域の地域開発に取り組むべきとする統合的河川流域管理（Integrated River Basin Management, IRBM）は、既に 1950 年代から提唱されてきた。

これらの考え方は湖沼の管理にもあてはまるが、湖沼にとって重大な「エコシステムサービスの長期的な変遷を踏まえた取り組み」と「静水システムの特徴を反映した取り組み」という課題が、いずれの計画概念にも十分反映されていない。したがって、このような特徴に十分配慮した概念として「統合的湖沼流域管理（ILBM）」の概念が GEF-LBMI プロジェクトの成果として提唱されることになった。

一方、湖沼流域管理には、従来のように政府が中心的な役割を果たして社会の問題を解決する「統治」でなく、パートナーシップやネットワークなど、公式・非公式の多様な社会的仕組みを生かし、緩やかな幅広い取り組みを推進する仕組み、すなわち「協治（ガバナンス）」の必要性が認識されるようになってきた。ILBM が求めるガバナンスは、湖沼のエコシステムサービスのうち、とくに生物生育の場、良好な水質、洪水・渇水調整機能、気象の緩和などの調整的サービス機能を低下させることなく維持する、あるいは持続的な回復を可能とするものでなければならない。

◆ GEF-LBMI プロジェクトの教訓：

湖沼の流域管理は、資源の開発、利用、保全、調査研究に携わる多くの組織・機関が協力して進めなければならない。通常は、既存組織を強化し、省庁間の連携や中央と地方の連携を強化すると共に調整機能を導入することで対処することが多いが、特定の湖沼の資源開発と保全に取り組む特別の組織を設置するケースもある。これは複数の行政区域を越える流域をもつ湖沼、すなわち越境湖沼（transboundary lakes）の場合には複雑で、とくに国境を超えた横断的な連携には国際機関の関与が求められることが多い。いずれにしても湖沼の流域管理に取り組む組織・体制は時とともに徐々に成熟していくため、新しい組織や再編された組織・体制が短期間に成果を生み出すことは一般に難しい。

◆ ガバナンス向上の取り組みの例：

国際湖沼資源の利用と保全を目的とする協力体制は北米の五大湖、ヨーロッパのコンスタンス湖で長い歴史を経て構築されてきた。国際湖沼の流域管理をめぐる協定の例を Box 5 に示す。

◆ ILBM を推進するための検討課題：

組織・体制のあり方を模索するためには、現在の組織機構は正しく機能しているか、必要な法的権限が与えられているか、関係機関の協力関係を阻害する要因は何か、組織・体制をよりふさわしいものに変えていく政治的な意思と関与が存在するか、組織・体制を運営していくにふさわしい能力の開発と人材育成に必要なものは何か、組織・体制の変遷の過程でどのような軌道修正と新しい取り組みの導入が可能か、などを検討していく必要がある。とくに、水・農業・林業・エネルギーといった部門別の政策を、湖沼流域という視点から見直すことが必要で、場合によっては部門の再編も重要となる。

Box 5：様々な協定の種類

【ビジョン】 チャド湖：GEF の支援により策定されたチャド湖流域の長期（20 年間）戦略的行動計画。1998 年に関連各国によって検討され採用された。2025 年に向けてのチャド湖ビジョンは、流域内に存在する状況から推論された多くの重要課題を浮き彫りにした。

【覚書（MOU）】 シャンブレ湖：1988 年のシャンブレ湖に関する MOU と 1993 年に合衆国のヴァーモント州・ニューヨーク州、カナダのケベック州によって調印された水質協定は、強制力を持たない国際協定の例である。当該 MOU は、科学情報を交換するという形で締結され、集水域保護のための共同計画を推進させた。これによって、三行政区域を個別に代表するシャンブレ湖企画運営委員会が設立され、三つの市民諮問委員会を統括する役割を担うことになった。当該 MOU は五ヵ年更新となっており、同湖流域の総合計画が法的根拠をもつことと計画そのものの制定に必要な場を提供している。この総合計画は現在、検討過程にある。

【協定】 ペプシ湖（ロシアでの呼称はチュード湖）：漁業資源保護利用に関するエストニア共和国政府とロシア連邦政府との協定は 1994 年 5 月 4 日にモスクワで調印された。協定の目標は、同湖の漁業資源を保護し、共同利用する上での協力関係を構築することである。当該協定には、漁業に関する両国の政府間委員会の設立が含まれている。北米五大湖：1972 年に合衆国とカナダが五大湖水質協定に調印した。ニクソン大統領とトルド首相によって調印され、当該協定は条約としての位置づけはされなかったが、両国で水質保護促進に特定の行動を義務づける実質的な協定である。五大湖水質協定は、水質問題に言及するだけではない。水質と同様に重要視しているのは、不安定な相互管轄権問題であろう。この問題を扱うために、当該協定は IJC 五大湖地域事務所（唯一の IJC 地域事務所）を立ち上げ、協定の下において両国政府に対する技術的支援・調整計画および監視事業の実施を推進する特定の権限を与えている。IJC はその職務を果たすために、五大湖水質委員会と科学諮問委員会を設立した。

【条約】 タンガニーカ湖：タンガニーカ湖管理条約は、同湖周辺の沿岸四ヶ国（タンザニア・ブルンジ・コンゴ民主共和国・ザンビア）の権利と義務を定める政府間協定である。同条約には、共同管理・管理原則・戦略的行動計画（SAP）および関連事項を扱う行政的な機構の設立を求めている。同条約は、沿岸四ヶ国それぞれから熟達した法律家や政策策定者を糾合した一連のワークショップを通じて制定された。条約の最終案は、2000 年 7 月に GEF 資金による UNDP のタンガニーカ湖生物多様性プロジェクト（LTBP）の完結時に企画運営委員会が採択された。同条約は 2003 年 6 月 12 日に沿岸四ヶ国によって調印され、現在それぞれの議会での批准についての審議過程にある。少なくとも二ヶ国によって批准された後に実効を持てば、同条約は SAP を実施する法的根拠となり、定期的に検証されることになる。

出典：湖沼概要書（チャド湖・シャンブレ湖・五大湖・ペプシ/チュード湖およびタンガニーカ湖）

<http://www.ilec.or.jp/eg/lbmi/index.htm>

◆ GEF-LBMI プロジェクトの教訓：

湖沼の持続可能な流域管理政策を実現するには、国の基本方針にそれがしっかりと位置づけられていなければならない。その場合、エコシステムサービスの「資源供給サービス」が「調整的サービス」の保全に大きく依存していることが明確に認識されていることが重要である。多くの途上国の場合、これは貧困削減問題と密接に関連しており、国、地方、地域の政策が一貫的に推進されていく必要がある。湖沼の持続可能な流域管理政策を実現するには、社会は一定のルールを守らなければならない。その政策ツールには規制的手法と行政的手法があるが、それぞれに適用上の可能性と限界がある。エコシステムサービスのように対象が広範で、それらが複雑な相互関係をもっている場合、監視や罰則などの規制的手法には限界がある。一方、資源利用の料金徴収、汚染に対する課徴金の賦課、あるいは補助金の導入などの経済的手法は「資源供給サービス」とそれが引き起こす汚染問題には一定の効果を発揮するが、生物多様性の保全にはほとんど適用できない。

◆ ガバナンス向上の取り組みの例：

湖沼流域管理で見られる政策手段を組み合わせ（ポリシー・ミックス）は様々で、湖沼ごとに異なる。代表的な事例を Box 6 に示す。

◆ ILBM を推進するための検討課題：

統合的に湖沼流域政策を推進する上で、政治的コミットメント、利害関係者の参加、行政の継続性、政策の統合化への努力は不可欠である。またエコシステムサービスをめぐる取り組みの優先順位や順応的アプローチが考慮されているか、人的・財政的資源の調達に必要な配慮がなされているか、技術の選択肢と費用・便益について合理的な考え方が示されているかなどは、実際の流域管理計画や流域政策を評価する上で重要な検討課題である。一方、湖沼の持続可能な流域管理政策を実現する上で不可欠な社会的なルールを導入する場合、規制的措施を導入するための適切な根拠法規があるか、規制的措施の影響を受ける関係者や関係機関の参画やそれを執行するために必要な人的・財政的資源の調達は可能か、経済的手法の導入、たとえば湖沼資源の利用に対する料金徴収を制度化する社会環境は整っているか、という点も検討課題である。斬新な経済的手法の導入も徐々に試みられているなかで、このような取り組みの成功例、失敗例の情報を国際的に共有していくことが必要である。

Box 6：湖沼流域管理で見られる政策手段の組合せ

湖沼流域名	法規制			経済的手法			
	基準	禁止 / 割り当て	ゾーニング	資源の利用許可	補助金	排水賦課金	自然資源利用料
アラル海		国家間の水配分 / 割当量固定					
バイカル湖	湖水位基準	生態系ゾーン内の木材伐採禁止	被許可活動を規制するバイカル法によるゾーニング				
バリング湖	漁具基準；3 張以下	漁獲一時禁止		漁業許可；取水許可			水利用料
ボージ湿地帯	水質基準	モーターボート禁止；レクリエーション禁止	渚ゾーニング；住居と植生帯間の緩衝帯		下湖集水域からの移転に対する洗濯人への補助		
琵琶湖	工場・都市・農業排水基準；公害防止自主協定	有リン洗剤禁止；生ゴミ投棄禁止；外来魚移入禁止	国定公園内土地利用制限；レジャーボート航行禁止区域設定；ヨシ群落保護区域		環境保全施設整備に対する特恵的な国庫補助；漁業補償；外来魚駆除への補助		下流水者による直接・間接の水利用負担
チャド湖	水質基準			漁業許可			水利用料（ナイジェリア）
シャンブレン湖	工場排水基準	有リン洗剤禁止；大気汚染物質排出規制（US 大気法）	湿地保護緩衝帯	漁業許可	沿岸保護のための農業補助等		
チリカ湖		環境流量への水配分（提案中）	湖岸帯活動規制ゾーニング（1km）	漁業・エビ養殖許可			

◆ GEF-ILBM プロジェクトの教訓：

湖沼の持続可能な利用と保全を実現するためには住民や利害関係者（ステークホルダー）の参加と協力が不可欠だが、それは多くの場合、容易ではない。しかし、それがもたらす大きなメリットと、それが行われない場合のデメリットは多くの経験から明らかになってきており、参加と協力はあらゆる意味で重要であると認識されつつある。とくに、湖沼のエコシステムサービスについては、地域レベルでは資源の持続可能な利用と保全が生活・生存と密接に関連しているため、地域の意思決定に利害関係者が参加しなければ地域の取り組みの仕組みを機能させていくことができない。また、女性の参加がない政策的意思決定はなかなか地域に根づかないこと、住民参加が成功する背景に、往々にして優秀な NGO や GBO の存在があることが多くの事例に反映されている。



◆ ガバナンス向上の取り組みの例：

世界の多くの湖沼で、生活の糧を歴史的に湖沼に頼ってきた人々がいる。このような人々への配慮なくして持続可能な湖沼流域管理を実現することはできない。Box 7 にチチカカ湖の例を示す。

◆ ILBM を推進するための検討課題：

参加は、組織・体制、政策と社会的ルール、適切なレベルの技術的対応、財源と財政的仕組みの全てに関わる課題である。住民や利害関係者が効果的に参加できる体制が整っているか、関係するすべての利害関係者が参加しているか、利害関係者の参加を通してプログラムにどんな変化が起きているか、そのプログラムの変化を利害関係者はどのくらい認知しているかといったことは、湖沼の流域管理を政策的に進めていく上で重要な検討課題である。成功・失敗の事例を国際的に幅広く共有することが必要である。

Box 7：原住民の持続可能な生計に配慮した湖沼管理の課題－チチカカ湖－

ボリビアとペルーの国境にまたがり、アンデス山脈に位置するチチカカ湖は、巨大湖沼としては世界で最も高所にある。高原に位置し、気温は年間を通して安定しており、夜間は低涼（8～10℃）、昼間は温暖である。同湖は、地域の気象を緩和する効果を有する。植物や動物が独特の進化を遂げていると共に、原住民の居住地ともなっている。都市域や大きな町に見られる混血民族を除き、チチカカ湖流域はほぼ完全に原住民から構成されている。人々は、北部は Quechua 地帯、中部は Aymara 地帯、南部は Quechua 地帯にかたまって住んでいる。加えて、Uro 族の人々が、ペルーの Puno 地域・ボリビアの Desaguadero 川流域およびボリビアの Poopo 湖周辺を含むチチカカ湖の近くの数ヶ所に住んでいる。

スペインの植民地政策によって原住民から取り上げられた広大な土地は、新たな領主に支配される土地資産に変えられた後、国の政策（大農園制度）として引き継がれた。この制度は、1953 年のボリビア農地法および 1969 年のペルー農地法の改正法施行まで継続した。数世紀にわたるこの歴史が、原住民の間に敵意と不信を生みつけたのである。市場の開放につながる近年の政策は農産物の価格低下を招き、これに加えて都市基盤整備とサービスに対する政府の方針は農村との格差という悪影響をもたらしている。にもかかわらず、地元の人々はチチカカ湖流域住民の生計を改善したいという望みを抱いている。格差をうまく是正できれば、住民と湖にとっての展望が見えてくるかもしれない。

しかし、1940 年代のマス類 (*Salmo trutta*) や 1969 年の Poopo 湖への Pejerry (*Bosilichtys bonaerensis*) など、チチカカ湖流域への外来種の移入は在来魚種を絶滅させ、原生動物による魚類への寄生は 1988 年に漁獲された在来魚の 70% に及んでいる。こうした外来魚種の移入が、在来魚種に生計を依存している原住民である Aymara 族や Uro 族の社会的経済的な状況に悪影響を及ぼしてきた。

出典：湖沼概要書（チチカカ湖）

◆ GEF-ILBM プロジェクトの教訓：

湖沼のエコシステムサービスを保全する技術的対応に下水道システムがあり、その導入が湖沼保全の切り札となっている事例は先進国では少なくない。しかし、施設建設にかかる費用負担、維持管理に必要な料金徴収、運転維持管理に必要な技術力、生活環境改善に対する住民の支払い能力などに制約があり、多くの途上国にとってその導入は非常に限定的であるし、今後も引き続き限定的と考えなければならない。また、下水道が対応できるのはポイントソース汚染であり、ノンポイントソース汚染に対する技術的取り組みは限られている。下水道を含め、技術的取り組みで湖沼の水質が劇的に改善した例はあるが、先進国・途上国を問わず、エコシステムサービスを持続可能な形で利用し保全する取り組みの情報は未だ非常に限られている。途上国における湖沼の流域管理をめぐる技術的取り組みの成否は、地域住民の意思決定への参加と施設の維持管理などへの協力に大きく左右されることが多い。



◆ ガバナンス向上の取り組みの例：

先進国では、下水道が湖沼水質を改善する切り札となった例は少なくない。しかし、発展途上国で湖沼水質改善のために下水処理システムを導入するには財政的な負担が大きすぎる。Box 8 に一人当たりの総所得（GNI）と人口密度別に下水処理システム導入の可能性について分析した事例を示す。

◆ ILBM を推進するための検討課題：

どんな技術を導入すべきかの判断は、技術が発揮する効果と共にその技術を支える施設の建設、設備の整備、およびその維持管理に密接に関係する。とくに施設や設備が長期にわたって効果を発揮することが期待されて導入した技術が、制度的、財政的な制約で実際にうまく定着しない事例は数多くある。湖沼の「資源供給サービス」を高める資源開発施設（インフラ）、たとえば湖岸におけるレクリエーション施設の建設は、水辺生態系が持つ水質浄化機能や生物の生息環境といった「調整的サービス」の低下を引き起こす。資源開発で生み出される財を「調整的サービス」の回復に投資できなければ、エコシステムサービスは全体的に低下していく。このような技術的対応をめぐる課題に対する検討は非常に限られており、今後幅広く情報を収集し共有していく必要がある。

Box 8：湖沼流域と下水処理システム

下水処理レベルは国民総所得（GNI）と人口密度によって異なる。人口密度が低く GNI が低い（表中の I-1）湖沼流域では、下水処理はほとんど行われていない。両者が大きくなるに従い（I-2、II-1,II-2）、処理レベルが高まるが、資金の調達は通常は二国間の支援によっている。高 GNI 国（III-1,III-2）では、人口が希薄な地域（III-1）においてすら、二次処理や三次処理が行われており、通常は国や自治体が資金を負担をしている。

GNI/ 人	人口密度	
	1) 100 人 /km ² 未満	2) 100 人 /km ² 以上
I) 低所得経済 \$ 736 以下	I-1) 普及なし 該当湖沼：マラウイ / ニアサ、ジョージ、トンレ・サップ、イシク・クル、チャド、カリバ、タンガニーカ、バリング、チリカ湖 資金：現在計画なし	I-2) 一次処理から二次処理の普及 該当湖沼：ビクトリア、ナイバシャ、ナクル、ボージ湿地帯、トバ湖 資金：大部分は国際的な支援による
II) 中所得経済 \$ 736 ~ \$ 9,075	II-1) 一次処理から二次処理の普及 該当湖沼：アラル海、バイカル、チチカカ、オーリッド、興凱 / ハンカ、ツクルイ、ペプシ / チュード、コシボルカ湖 資金：一部国際的な支援による	II-2) 一次処理から二次処理。普及率上昇。 該当湖沼：滇池、ラグナ湖 資金：大部分は国際的支援 and/or 中央政府による
III) 高所得経済 \$ 9,075 以上	III-1) 二次処理は広く普及。高度処理も一部に普及。 該当湖沼：シャンプレン・五大湖 資金：中央政府と自治体による	III-2) 高度処理が広く普及。 該当湖沼：コンスタンツ・琵琶湖 資金：中央政府と自治体による

◆ GEF-LBMI プロジェクトの教訓：

科学的調査に基づいた知見がなければ湖沼の実体を把握することができないし、実態を把握できなければ有効かつ有意義な政策を決定することができない。たとえば、技術的な取り組みの推進やステークホルダーの利害対立の調整を科学的知見抜きで進めることは難しいし、政治的意思決定の大きな要因は往々にして科学的に裏づけられた主張である。とくに継続的なモニタリングや特定の課題に焦点を合わせた調査・研究は湖沼流域管理には必要不可欠である。



しかし、多くの湖沼において、恒常的に科学的知見を追及・集約する地元の調査・研究機関の存在は限られている。一方、科学的な情報のみに全面的に頼って政策的な意思決定をすることが常に正しいとは限らない。地元の漁民が有する現場の経験に基づいた知識は、科学的調査や研究による情報を補完する重要な情報となる。両者のバランスが重要である。

◆ ガバナンス向上の取り組みの例：

GEF は、国際湖沼の流域管理計画を立案する手法として、各国の関係者が個々に蓄積してきた科学的知見を全員が共有し、協力して計画をつくりあげるかを判定する「国際湖沼の診断分析、TDA」を提唱している。Box 9 にタンガニーカ湖の生物多様性について行われた TDA で使われた枠組みの概要を示す。

◆ ILBM を推進するための検討課題：

湖沼流域管理に関する科学的な調査研究が恒常に行われているか、研究成果情報は常に公開され実際の政策形成に利用できるか、湖沼とその流域をめぐる文献情報や統計データなどへのアクセスは容易か、地域の歴史や伝統など社会科学的な知見は存在するか、データベースは十分に整備されているか、情報管理は効果的に行われているか、モニタリング指標は適切か、などは流域管理を進めていく上で最低限確認しておく必要がある。

Box 9 タンガニーカ湖の国際的な診断分析

生物多様性と持続可能な利用に対する主要な脅威	共通する国際的な影響	共通する行政組織上の問題	一般的な対策事項
・ 持続性の無い漁業 ・ 汚濁の増大 ・ 過剰な土砂堆積 ・ 生物棲息地の破壊	・ 生物多様性の地球規模の喪失 ・ 共有漁業資源の喪失 ・ 水質の悪化	・ 人的物的資源の欠落 ・ 現存規制の施行能力不足 ・ タンガニーカ湖に対する適切な規制の欠落 ・ 組織間協力の欠落	・ 漁業による影響の削減 ・ 汚濁規制 ・ 土砂の流入規制 ・ 生物生息域の保全

◆ GEF-LBMI プロジェクトの教訓：

湖沼資源の持続可能な利用と保全を実現するには「調整的サービス」に含まれる水質や生態系の保全に対する予算措置が必要である。しかし、とくに発展途上国では、資源開発事業には一定規模の予算措置がなされても、保全事業に対する予算規模は極めて限られていることが多い。資源開発に伴って得られる収益の一部を保全事業に充てる仕組みや、汚染に対する課徴金とともに、一般会計からの予算措置が必要だが、実際にはそれも限られている。自然景観や遺跡や史跡などの「文化的サービス」がもたらす観光事業収入も、本来、地域に還元されてしかるべきだが、必ずしもそうっていないケースが多い。GEF 資金や ODA ローンなど、国際的な外部資金による保全事業の場合、自国でプロジェクト終了後の財源調達ができなければ、プロジェクト終了と共に保全事業も終焉を迎える。このような資金は初期投資に有効だが、持続性は限られているため、計画の策定に当たっては、プロジェクト完了後の対応をあらかじめ検討しておく必要がある。

◆ ガバナンス向上の取り組みの例：

湖沼流域管理に汚濁賦課金を導入した中国の滇池（ディエンチ）の例を Box 10 に示す。

◆ ILBM を推進するための検討課題：

バイカル湖、琵琶湖、タンガニーカ湖といった何百万年も前に形成された湖では多くの生物種が固有の進化を遂げ、トンレ・サップ湖のような世界で最も高い生物多様性を維持している湖もある。固有生物種や生物多様性はグローバル公共財（global public goods）で、地球規模で守るべきだとする考え方は主流になりつつある。一方、湖沼の良好な水質や豊かな自然、美しい景観といった「調整的サービス」や「文化的サービス」は、一般的な公共財（public goods）で、それが国民全体にとって価値があると合意できれば国の税収から、地域にとって価値があると合意できれば地域の税収から保全の費用を負担することになる。

しかし、グローバル公共財の保全の費用を誰がどの程度負担するべきかという問題は未だ国際的に合意されておらず、一般的公共財についても、税負担で実現できる保全のレベルは先進国でも限られている。多くの発展途上国では税で保全を実施するほど、エコシステムサービスに対する政策的優先度は高くない。水質や生態系が一様に悪化し続ける理由はここにある。グローバル・ローカルの財源の調達と財政の仕組みや新しい資金メカニズムの可能性について、幅広く情報を収集し、今後の取り組みのあり方について検討する必要がある。

Box 10 中国の滇池（ディエンチ）における利用料

中国の昆明市近くに位置する滇池は、主要な都市地域・工業地域および観光地域の中心である。工業・農業および都市下水からの汚濁が主な問題点であった。同湖の管理機関は、下水と廃水の規制に重点的に投資を行った。2000 年単年度だけで、340,000,000 元（約 41,000,000 ドル）以上が投じられた。進行中の工場排水問題に対処するために、同管理機関は、汚濁処理施設の設置に対する貸付金／助成金制度と汚濁賦課金制度を組み合わせで施行してきた。

15 年前に操業を開始した古い工場は、廃水の水質が排水基準を超えた場合には汚濁賦課金を支払わされた。さらに、1988 年の滇池保護条例により、滇池湖流域内へのいかなる汚濁発生工場も新規立地が禁じられている。

既存の工場が汚濁処理対策に取り組む場合には、政府から必要な投資資金の貸付金を用意された。この貸付金は、環境汚濁賦課金と湖沼流域環境改善のための特別基金を合わせて財源とされた。追加的な措置として、汚濁処理への投資が行われた後に当該工場が排水基準に適合したことが明らかになれば、貸付金は助成金とみなされて返還の必要がなくなった。同湖管理機関は、政府投資・汚濁賦課金および貸付金／助成金計画の組み合わせによって、この重要な湖の主要な汚濁問題の処理に対処してきたのである。

出典：湖沼概要書（滇池）



ILBM を様々な湖沼の流域管理に適用する

「流域ガバナンスの要素を築きあげる」

世界には、山岳湖沼の様にほとんど手つかずのものから、人口や産業の集中によって水質の汚染や生態系機能の低下が著しく進行してしまったものまで様々な湖沼がある。山岳湖沼の様にいまだ人為活動の影響が小さく**ほとんどストレスを受けていない湖沼**の場合でも、観光開発が無計画に行われれば脆弱な湖沼環境は一気に悪化する。一方、環境悪化が既に進行し、**著しくストレスがかかった湖沼**の場合、水質の改善や生態系機能の回復には長い時間と膨大な資金がかかることが予想される。さらに、両者の中間には、保全事業による湖沼環境の改善は遅々として進まないものの、資源利用と保全の長期にわたる**持続可能性を追求する湖沼**が存在する。

ILBM の枠組みは、このような異なったカテゴリーの湖沼について、流域管理のあり方を検討したり、流域ガバナンスの機能を改善・強化したりする上で多くの示唆を与える。例えば、**ほとんどストレスを受けていない湖沼**にとって、ILBM は過剰な資源開発を未然に防ぐための予防的なアセスメントの枠組みとなる。また、**著しくストレスがかかった湖沼**にとっては、ILBM は現状の流域管理の課題を把握し、エコシステムサービスを回復させるための課題を発見するための枠組みということができる。さらに、**持続可能性を追求する湖沼**の場合、ILBM は長期にわたって開発と保全のバランスを追求する指針となる。開発や保全がどんな段階にあっても、ILBM の枠組みを利用して事業の評価を行えば、様々な課題が明らかになるだろう。そして、新たに湖沼流域管理に取り組む場合には、開発や保全の目標設定のレベルに関らず、計画立案の手順を示す手引き書の役割を果たす。

しかし、ILBM が実効性を発揮するためには流域の利害関係者の連携と政治的な支持が不可欠であり、流域社会の共通のビジョンの存在が重要である。

- **共有できるビジョン**：連携するきっかけのひとつとして、共有できる「湖沼ビジョン」を策定することが考えられる。方法はさまざまだが、必ずしも行政的なプロセスは必要としない。さまざまな団体が関わって、相互理解と協力関係を作り上げることが重要である。
- **提携関係（パートナーシップ）**：湖沼流域管理は、関係者や関係機関が多数存在する為、さまざまなレベルの人々の協力が必要になる。部門を横断した連携を実現するには大変な時間がかかる。不確定要因を踏まえ、全体状況を把握しつつ具体的な手がかりを共有して徐々に提携関係を築いていくことが重要である。
- **政治的な支持**：湖沼流域管理が重要な政治的課題になることが重要である。そのためには湖沼流域管理が経済的・社会的・環境的にメリットが大きいことを常に示せるように準備しておくことが重要である。

そういった取り組みを市民が主体的に進めるために考えられた世界湖沼ビジョン (*World Lake Vision, WLV, Box 11*) という枠組みがある。現在、世界の多くの湖沼で WLV の枠組みを利用した個別のビジョン作りが進められている。ILBM と WLV は湖沼の持続可能な流域管理を実現するために不可欠な車の両輪の様なものである。

さらに、このような ILBM の可能性を追求するため、ILEC は湖沼流域管理に取り組む国内外の多くの研究機関、NGO、行政機関をはじめ、GEF、国連環境計画（UNEP）、国連開発計画（UNDP）、ラムサール事務局、世界銀行（WB）等の国際機関と協力し、ILBM シラバスの開発とトレーニング・モジュールの開発（日本国際協力事業団、JICA）、水質保全事業の事後評価への ILBM の適用（例えばインド・ボパール湖、日本国際開

Box 11 世界湖沼ビジョン（World Lake Vision）と政府が策定する計画への ILBM の反映

湖沼と流域の保全について広くビジョンを共有する取り組みは、多くの湖沼で推進されるようになってきた。この背景には世界湖沼ビジョン（World Lake Vision, WLV）と行動計画を策定するプロジェクトの存在がある。ILEC は国連環境計画（UNEP）をはじめとする多くの NGO や湖沼研究機関、専門家などの協力を得て世界湖沼ビジョン：行動へのよびかけ（World Lake Vision：A Call to Action）と世界湖沼ビジョン行動計画報告書（World Lake Vision Action Report）を作成した。世界湖沼ビジョンは以下の 7 つの原則によって構成されている。

- 原則 1 人間と自然の調和した関係は、湖の持続可能性にとって不可欠である。
- 原則 2 湖の流域は、湖の持続的利用のための計画・管理の論理的出発点である。
- 原則 3 湖の環境悪化の原因を除くには、長期的で予防的な対応が必須である。
- 原則 4 湖沼管理政策の作成と決定は、公正な科学と入手可能な最良の情報に基づいて行わなければならない。
- 原則 5 持続可能な利用のため、湖の資源管理において、現世代および将来世代の要求と自然の要求とを考慮しつつ、競合する利用者間の紛争を解決することが必要である。
- 原則 6 重要な湖沼問題の把握と解決のためには、住民およびその他の利害関係者の有効な形での参加を奨励すべきである。
- 原則 7 持続可能な湖の利用のためには、公平性、透明性、すべての関係者への権限付与を基礎とした良好なガバナンス体制が不可欠である。

<http://www.ilec.or.jp/jp/wlv/index.html>

上記の世界湖沼ビジョンは、政府機関が関与し、法的に位置づけられたビジョン計画（Vision Plan）に発展することもある。政府機関の関与は、その他にも個々の省庁が推進するセクター別の行動計画（Action Plan）や管理目標を実現するための管理計画（Management Plan）、複数の省庁が連携して長期にわたる資源開発と保全を追及する総合計画（Comprehensive Plan）などが湖沼流域管理の計画の枠組みの例として存在する。また土地利用のゾーニングなどを目的とする法定計画（Statutory Plan）や環境影響評価（Environmental Impact Assessment）、さらには戦略的環境評価（Strategic Environmental Assessment）も流域管理計画の一環に組み込まれることがある。GEF は流域が複数の国を越境する湖沼流域管理の策定を支援するために、戦略的行動プログラム（Strategic Action Plan）の策定を求めている。ILBM の考え方がこれらの計画に反映されることにより、持続可能な資源の利用と保全に向けた湖沼流域ガバナンスの構築につながることが期待される。

開発銀行、JBIC）、湖沼流域管理を推進する事業の優先度の分析（アフリカ・ビクトリア湖環境管理第 2 期事業、世界銀行）などに取り組んでいる。このような活動を通し、ILBM の考え方が世界の湖沼資源の持続可能な利用と保全に貢献していくことが期待される。

世界湖沼ビジョン (WLV)* と
統合的湖沼流域管理 (ILBM)* は、
湖沼資源の持続可能な利用と
保全に向けて前進する自転車の
両輪に例えることができます。



*** 世界湖沼ビジョン (WLV)**

世界湖沼ビジョン (WLV) は、特定の湖沼に対し、市民・ステークホルダーが主体的な役割を果たしてつくり上げる共有ビジョンを表す。WLV は湖沼が抱える問題とその解決法を見出すための原則、とくに一般市民が政府の役人や専門家の支援を得て取り組むための 7 つの原則から成立している。

*** 統合的湖沼流域管理 (ILBM)**

ILBM は、湖沼と流域の管理を任された組織やステークホルダーが、湖沼がもつ静水システムの特徴を踏まえた上で、その資源の持続可能な利用と保全を実現するために必要な考え方を示している。世界の湖沼環境の改善は、長期にわたる強力な政治的コミットメントの下で、組織体制や仕組み、政策の枠組みや法制度、利害関係者の参加、科学的知見、技術的取り組みの可能性と限界、持続可能な財源の調達に取り組む ILBM を推進することで初めて可能となる。

参考資料：GEF-LBMI 報告書の概要

I 部：「湖沼資源を理解する」は本報告書の総論部分に相当し、主としてプロジェクトの概要を記述している。概要は、第1章「他から学ぶ：湖沼流域管理の経験から」、第2章「湖沼の自然科学的特徴」、第3章「人による湖沼の利用：資源価値、問題、回復対策」から構成される。

1 章 は、以下の項目で構成されている。

- ◇ 動機づけ：なぜ湖沼か、なぜ今か？
- ◇ プロジェクトの目的：過去の成功、失敗例から学び、伝える
- ◇ 対象とする読者
- ◇ プロジェクトの方法論とアプローチ
- ◇ 報告書の構成

2 章 は、湖沼流域管理を遂行上で知っておかなければならない、あるいは流域管理上問題となる湖沼の特徴を概説している。

- ◇ 地球上の湖沼の範囲と分布
- ◇ 湖沼の類型化：流域の類型、湖沼の起源、古さ、気象、塩分濃度、混合と層化
- ◇ 湖沼に共通した特徴：湖沼と他の水システムとの違い（全てを統合する性質、長い滞留時間、複雑な応答動態）

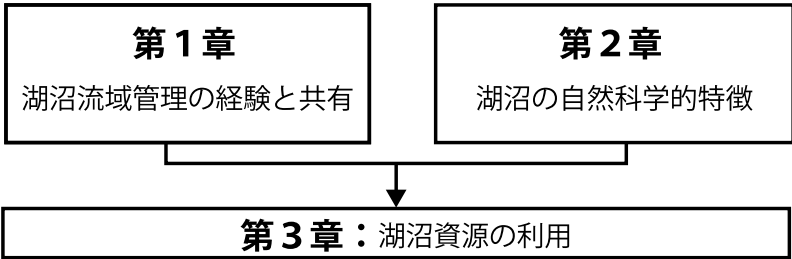
たとえば、「複雑な応答動態」の項では、植物プランクトンの栄養塩濃度の上昇およびその後の水質改善による濃度減少と、植物プランクトン量の増加および減少は変化のパターンが全く異なり、陸域の対策効果が発現するまでに長い時間がかかると説明している。また、PCB（ポリ塩化ビフェニール）は植物プランクトンから食物連鎖を通して鳥類に蓄積されるまでに、何千倍も濃縮される。このような自然科学的な特徴を知った上で湖沼流域保全対策を進めていかなければならないと紹介している。

3 章 は、湖沼とその流域を管理する背景について記述している。

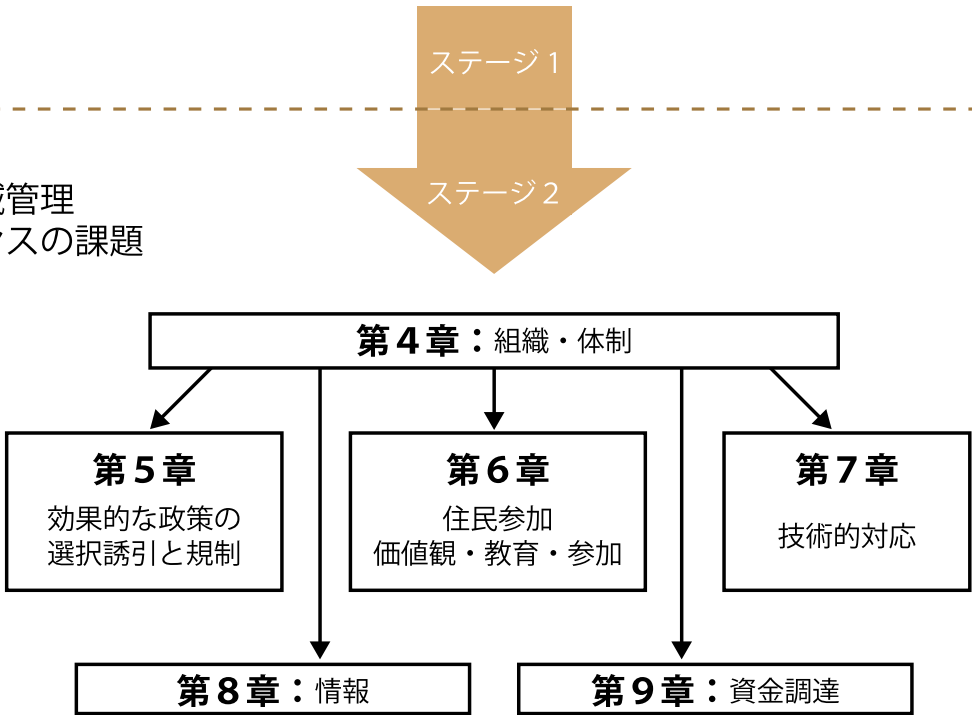
- ◇ 湖沼とその流域の資源価値
- ◇ 総経済価値
- ◇ 世界の湖が直面する典型的な問題
- ◇ 新たに起こりつつある問題
- ◇ 問題への対処：管理介入
- ◇ 湖沼流域管理の要素

この章では、様々な湖沼資源の価値区分の類型を示し、それぞれが湖沼流域管理の要件、すなわち第II部で取り扱う湖沼流域管理の組織・体制・仕組み（第4章）、効果的な政策の選択（第5章）、住民参加（第6章）、技術的対応（第7章）、情報—科学的なアプローチ（第8章）、資金調達（第9章）等とどのように関わっているかを概説した。また、上記を踏まえ、世界の湖が抱える問題とこのプロジェクトで対象とした湖沼との対応を示した。

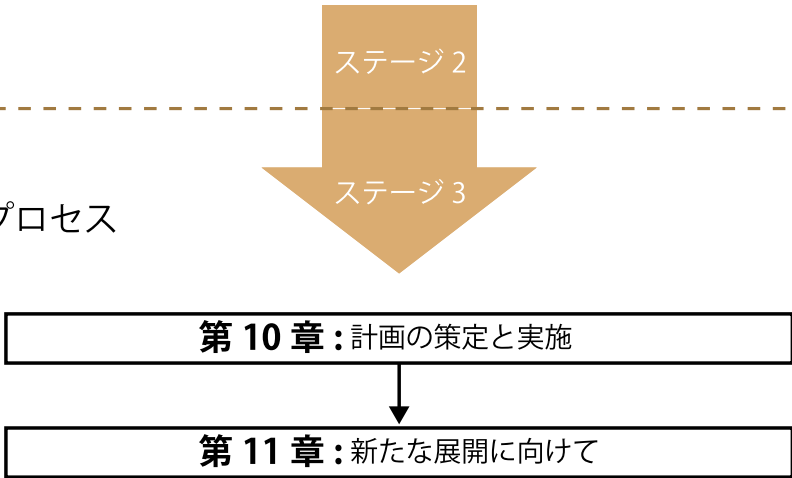
第Ⅰ部：
湖沼資源を理解する



第Ⅱ部：
湖沼流域管理
ガバナンスの課題



第Ⅲ部：
統合化と統合プロセス



II 部：「湖沼のガバナンスという課題にどう取り組むか」は本報告書の各論部分に相当する。

4 章 では、湖沼流域管理において存在する組織・体制、それらが有効に機能するために克服すべき課題を述べている。行政界、領域界を越える湖沼流域（transboundary lake basins）、とくに国際湖沼流域を管理するための組織・体制については、GEF が支援対象としていない湖沼とその流域管理の中で得られた教訓も反映する必要がある。

- ◇ 湖沼流域管理の組織・体制（組織・体制の類型、組織・体制をめぐる課題）
- ◇ 複数の行政界・領域界を含む越境湖沼流域の管理の概説（越境型の協力の形態、協力協定の種類、組織・体制に関する責務）
- ◇ 湖沼流域の制度上の特徴（国・地方レベルの行政、利害関係者の幅広い参加を可能とする組織・体制、既存の組織・体制とその進化）
- ◇ 適切な統治（グッドガバナンス）に向けた組織・体制を強化する要件（法と規則、透明性と責任体制、伝統的な権利）
- ◇ その他、組織・体制に求められる望ましい特色

28 湖沼の主要な教訓

1. 湖沼の集水域と行政区域界は一般に一致しない。したがって、湖沼流域の管理を統合的にすすめるには、それにふさわしい組織・体制の構築が必要である。
2. 湖沼流域管理において重要なのは、異なった組織・制度・仕組みの強力な連携、効果的な参加の推進、様々なセクタープロジェクトの関連性の維持、ドナープログラム間の協同と組織調整、地方行政組織の能力向上などである。
3. 既存の組織・体制の調整機能を強化すれば、あえて新しい組織・体制をつくり上げる必要がなくなることもある。
4. 法や規則、透明性と説明責任、伝統的権利などを適切に反映するガバナンスの枠組みは湖沼流域管理の組織・体制の構築に非常に重要である。
5. 国際湖沼流域を管理するための組織・体制は、集水域が複数の境界域から構成されている場合と、湖自体が複数の境界域に分割されている場合とでは異なる。有効に機能するためには、それぞれの自然・社会・経済的条件を柔軟に反映する必要がある。
6. 国際越境湖沼の場合、メンバー国の政治的意志、義務と責務遂行、およびステークホルダーの強力な参加なくして、総合的な湖沼流域計画は適切に機能しない。

5 章 では、湖沼流域管理を効果的に進めるための政策ツールの選択、とくに経済的インセンティブと規制について記述している。

- ◇ 多少複雑な例
- ◇ 実施される政策手段への反応
- ◇ 市民・住民がかかわりを持つ政策
- ◇ 伝統的規制による方法、コマンド・アンド・コントロール政策
- ◇ 現存する市場を有効に使う、あるいは新たな市場を形成する方法
- ◇ 複数の政策手段の組み合わせ
- ◇ 過去からの経験：政策が成功するために
- ◇ 政策、政策手段、およびガバナンス

28 湖沼の主要な教訓

1. 人々が長期的な利便を理解しなければ、大きな政策手段の変更を実現することは出来ない。
2. 点源負荷削減は比較的簡単に実現でき、その結果を確認しやすい意味で政策手段の第一段階として採用される。
3. 政策形成を効果的に行うには異なった政策手段を組み合わせて行う必要がある。政策を効果的に遂行するには、湖沼ごとに最もふさわしい手段を採用する必要がある。
4. 適切なモニタリングと法の施行なしに政策手段のみを適用しても効果を検証できない。
5. 湖沼を保全域として隔離して資源の搾取を止めるなどということとはできない。

6 章 は、各湖沼流域での住民参加について課題および取り組みの成功例や方法論を述べている。章は序章、概説と以下の項目から構成されている。

- ◇ 住民参加
- ◇ 利害関係者の関与
- ◇ 効果の向上のために
- ◇ 啓発と教育
- ◇ 地域社会における教育と公共啓発（CEPA）について
- ◇ 女性の参加
- ◇ NGO と CBO の湖沼管理、コミュニケーション、介在支援における役割

28 湖沼の主要な教訓

1. 住民の関心が持続する時間は往々にして行政担当者の関心が持続する時間よりはるかに長い。
2. 地域の文化的伝統や価値観、行動規範などに関する正しい理解なくして湖沼流域管理の計画を地域社会に受け入れられるように策定することは難しいし、実行もされにくい。
3. 通常あまり重視されていない利害関係者に政策形成プロセスに参加してもらうためには、それにふさわしい参加促進のアプローチが必要である。
4. 途上国の場合、地域社会における生活環境を改善することが湖沼流域管理への参加を促進する鍵である。
5. CEPA の効果が発現するには時間がかかる。将来的に大きな成果もたらすことを期待する先行投資としてとらえる必要がある。
6. CEPA プログラムの作成には十分な現状分析とターゲットとするグループが抱えている課題を十分把握する必要がある。
7. 日々の生活を支え、様々な面で不利な状況にある女性の参加を促進することは、湖沼流域管理を実現していく上で非常に重要である。湖沼資源を生活の糧とする途上国の集落の場合、男女が一緒にトレーニングを受けると特に効果が期待できる。
8. NGO や CBO（地域社会に密着した活動を支援する組織）は、政治課題の特定や政治的情勢の展開、組織運営上の機能発揮、ネットワーキング、協力関係、政府機関と地域社会との仲介、財政資源の調達、などに重要な役割を果たす。
9. 湖沼流域の地域プログラムは NGO が推進している様々なグローバルなイニシアティブに連動している必要がある。

7 章 は、湖沼保全の技術的対応がそれぞれの湖沼流域でどのように行われ、またその可能性・制約はどのように考えられているかについて記述している。

- ◇ 集水域対策、ポイントソース対策（下水の迂回放流、通常の下水处理、一次、二次処理、高度処理・三次処理、工業排水処理）
- ◇ 人工湿地の利用
- ◇ 修復事業
- ◇ 湖内対策、生物学的対策（捕食生物の導入、生物学的操作）
- ◇ 湖内対策、化学的対策
- ◇ 湖内対策、物理学的対策
- ◇ 瀑気（ばっき）
- ◇ 他流域からの導水
- ◇ 浚渫（しゅんせつ）
- ◇ 刈り取り

28 湖沼の主要な教訓

1. 技術的な介入だけでは、十分な湖沼とその流域の保全の効果を上げることはできない。根源的な原因を追及する必要がある。
2. 水草の異常繁茂が問題となっている湖沼の場合、その原因を突き止めて対処しなければ一つの種を駆除してもすぐ新たな種がはびこり、問題の解決にはならない。
3. 浚渫の場合、堆積する汚染物質の流出を制御することができれば、長期的効果を発揮する可能性がある。
4. 分水や導水の場合、その恩恵を受ける側にとってはプラスとなる。しかし多くの場合、分水や導水する側にとって様々な不都合が生ずる。
5. 工場排水処理にかかる費用は、未処理水が引き起こす環境問題への対処費用とは比較にならないほど安価である。
6. 下水道整備や下水処理への投資は自然環境の改善というよりは、生活環境の改善を目的として行われる。
7. 下水道整備や下水処理には多額の施設建設投資が必要だが、水質保全や生活環境改善といった大きな社会的便益をもたらす。
8. 湿地が自然の状態のまま残っている場合、保全を最優先に考えるべきである。湿地が埋め立てられたりした場合には、ほとんど必ずと言ってよいほど後に復元への動きが出てくる。
9. 生物学的な手法による湖沼環境改善は思いもよらない影響を引き起こす可能性があるので慎重かつ十分な研究が必要である。

8 章 は、自然、社会の両面から科学的な情報を湖沼流域管理に反映する重要性和湖沼の水質や生態系のモニタリングについて記述している。

- ◇ 湖沼流域管理における情報の必要性
- ◇ 科学的情報を使う（湖沼流域資源の有限性を示す、目に見えない関連性を明らかにする、紛争解決の手がかりとなる、モデリングによる予測を可能とする）
- ◇ 科学に頼らない方法（モニタリングの価値、ベースライン条件、政策の効果の評価、何をモニタリングするか、偶然な発見）
- ◇ 情報の共有（指標を使う、博物館と情報センター、住民参加）
- ◇ 科学的調査とモニタリングの実行、組織化（湖沼流域に密着した研究機関、国際的な資金援助プログラム、断片的な取り組み、GEF の越境診断評価と戦略的アクション計画）
- ◇ 最小限必要な情報量とは

28 湖沼の主要な教訓

1. 情報は高価で、完璧に情報を把握することは不可能である。したがって、完璧な情報がないことを必要な手を打たない理由とすることは間違っている。
2. 地域社会で伝承されてきた知識は往々にして見過ごされやすいが、貴重な内容を含んでいることが多いので、情報源として生かす努力が求められる。
3. 湖沼流域管理の知識ベースが、様々な利害関係者によって築き上げられ、共有され、利用されるためには、全ての利害関係者が現実的な対応策の策定に初期の段階から関与してなければならない。
4. 意思決定者や利害関係者に理解しがたい情報は無視される。
5. 地元の研究機関は、一般に、外部から短期調査の目的などで送り込まれた研究者では果たせない役割を果たす。湖沼の特徴である長い滞留時間と複雑な現象は、長期にわたる地域に密着した調査研究を必要とする。
6. モニタリングは、湖内だけでなく全流域を対象とすべきである。
7. ことをなるべく単純にしておくべきである。たとえば、簡易モデルはときに複雑なモデルで得られると同様に有用な湖沼管理情報を与えることができる。

9 章 は、湖沼流域管理のために必要な財政措置および財源について記述している。

- ◇ 湖沼管理者の悩み
- ◇ 地域で生み出す財源（使用料金、汚染課徴金、独立した財源、内部相互補助金の原則、自然からの贈与あるいは基本的人権に対して支払うべきか、貧困者の中の貧困者という特別なケース）
- ◇ 国の財源
- ◇ 外部資金（特別なケースとしての GEF、外部資金は必要か？外部資金の持続性、資金が途絶えた後は？）
- ◇ 追加的資金を得る実際的な方法

28 湖沼の主要な教訓

1. 国外からの資金調達は魅力的だが（返済しなくて良い贈与のケースもある）、短期で特定の目的のためであることが多い。したがって湖沼流域管理者は地方レベルあるいは国レベルの財政措置・財源を確保する必要がある。
2. 湖沼流域管理は、ほとんどの場合、国あるいは地方レベルの財源に頼ることが多い。したがって国外からの資金は、本格的な事業の執行のためと言うより、それらの取り組みにつながるような萌芽的・触発的な活動に向けるほうが望ましい。
3. 資本を投資して構造物を造る場合の資金は、通常、国レベルあるいは国外から調達する。一方、地域レベルの財源は経常的に必要となる維持管理経費の支払いなどのために重要である。
4. （途上国における）経常的なモニタリングや湖沼科学の調査研究施設の運営などに必要な資金の確保は難しい。これは外部資金が重要な役割を果たし得る分野だが、長期にわたって依存されるべきものではない。
5. 集められたお金が地域に残り、その時々ニーズに応じて使え、かつ地域住民がその用途を決定できなければ、料金徴収を実現することは容易ではない。
6. 国際湖沼のように、湖沼プロジェクトのグローバルな便益を求める場合、プロジェクトごとに対応していくより継続的なプログラムとして対応することが必要である。
7. 持続的にグローバルな便益をもたらすためには、国際的な取り組みと各国の湖沼流域管理機関の緊密な連携が必要である。この場合、外部資金援助機関が新しい資金管理の仕組みをつくり上げていく必要がある。

Ⅲ 部の「総合化」は、第 10 章の「持続的な湖沼流域管理に向けた計画」と第 11 章の「新たな展開に向けて」によって構成されている。

10 章は、湖沼流域を管理するための計画立案について、第 4 章～第 9 章にわたって記述された計画要素がどのように組み立てられ、統合されるべきかについて記述されている。

- ◇ 持続的湖沼流域管理の計画、概説
- ◇ 湖沼流域管理をめぐる計画の形態、ビジョン計画、アクション計画と介入計画、総合計画、法定計画、環境影響評価と戦略的環境評価、戦略的行動計画
- ◇ 湖沼流域計画活動の調整
- ◇ 進捗指標、モニタリングと順応的管理

28 湖沼の主要な教訓

1. 湖沼流域の計画プロセスにおいて、第Ⅱ部で述べた適切な管理に不可欠な 6 つの要素を統合していく必要がある。湖沼流域計画は開発と環境保全の為の地域計画や国土計画と整合性をもたなければならない。
2. 計画の種類によってその詳細さや対象範囲は変わる。合意できる望ましい目標に焦点を合わせることができれば、ビジョン計画の策定を第一歩として、より詳細な管理計画へと発展させていくことができる。
3. 総合計画は異なったセクターの活動を統合化することによって効果をあげていくことができるという利点がある。しかし、それを実施・調整するコストは高く、政治的優先度の変化に柔軟に対応しにくいという難点がある。
4. 法定計画は、既存の法制度や組織・体制の枠組みを生かし、湖沼流域において進行する開発活動を制御することができる。法定計画は、環境影響評価や戦略的環境評価の枠組みとともに、最大限に活用されるべきである。法規定を執行するには、良きガバナンスの枠組みと組織・体制上の執行能力が不可欠である。
5. 現段階では GEF 対象 8 湖沼のうち 3 湖沼については戦略的活動計画（Strategic Action Plan、SAP）が策定された。事例分析によれば、SAP はセクター事業部局と国の機関の連携推進に有効な役割を果たし、共同で流域管理に必要な対応をする基礎を築いた。
6. セクター計画と地域計画の調整は、問題が最も切実なところから着手すべきである。また、時間をかけ、必要に応じかつ臨機応変に進めていくべきである。
7. セクター計画と地域計画は、(1) 別々の調整プロジェクト、(2) 実施成果の事後連結、あるいは (3) 成果の積み重ねによって初期には限定的だったプロジェクトの scope を徐々に拡大すること、などを通して調整することが可能である。

8. 計画は、社会のニーズの変化や外部的要因を考慮して柔軟であるべきである。また、事業成果のモニタリングの結果を反映すべきである。事業によっては当初の予定通りにいかないことがあるが、モニタリングによって新たな課題を見出すことが可能である。

11 章は、以下の項目で構成されている。

- ◇ 既存の湖沼流域管理を再評価する（湖沼管理に向けて再確認すべきこと）
- ◇ 湖沼流域管理への様々な障害（政策上の軋轢、政治的野心、届かない住民の声、政治的・経済的な癒着、縦割り行政の弊害、資金不足）
- ◇ 障害の克服に向けて（創造力を発揮した積極的な活動、関係者間の連帯、ビジョンの共有、政治的な支持の確保、流域外からの支持の確保、セクター間およびセクター内の構造改革、活動の根拠となる科学的な情報の収集）
- ◇ ケーススタディから得た湖沼管理への教訓（流域の観点を持つ、長期的かつ順応的管理手法を用いる、湖沼流域管理の風潮を維持する、セクター間や行政組織間の協働を促進する、ガバナンスと投資の促進、利害関係者の参画、湖沼流域間の協調の促進）
- ◇ グローバルな技術協力、資金協力および情報共有に向けて（グローバルな参加とパートナーシップのために、グローバルな湖沼流域知識ベースの充実のために）

財団法人 国際湖沼環境委員会 (ILEC)

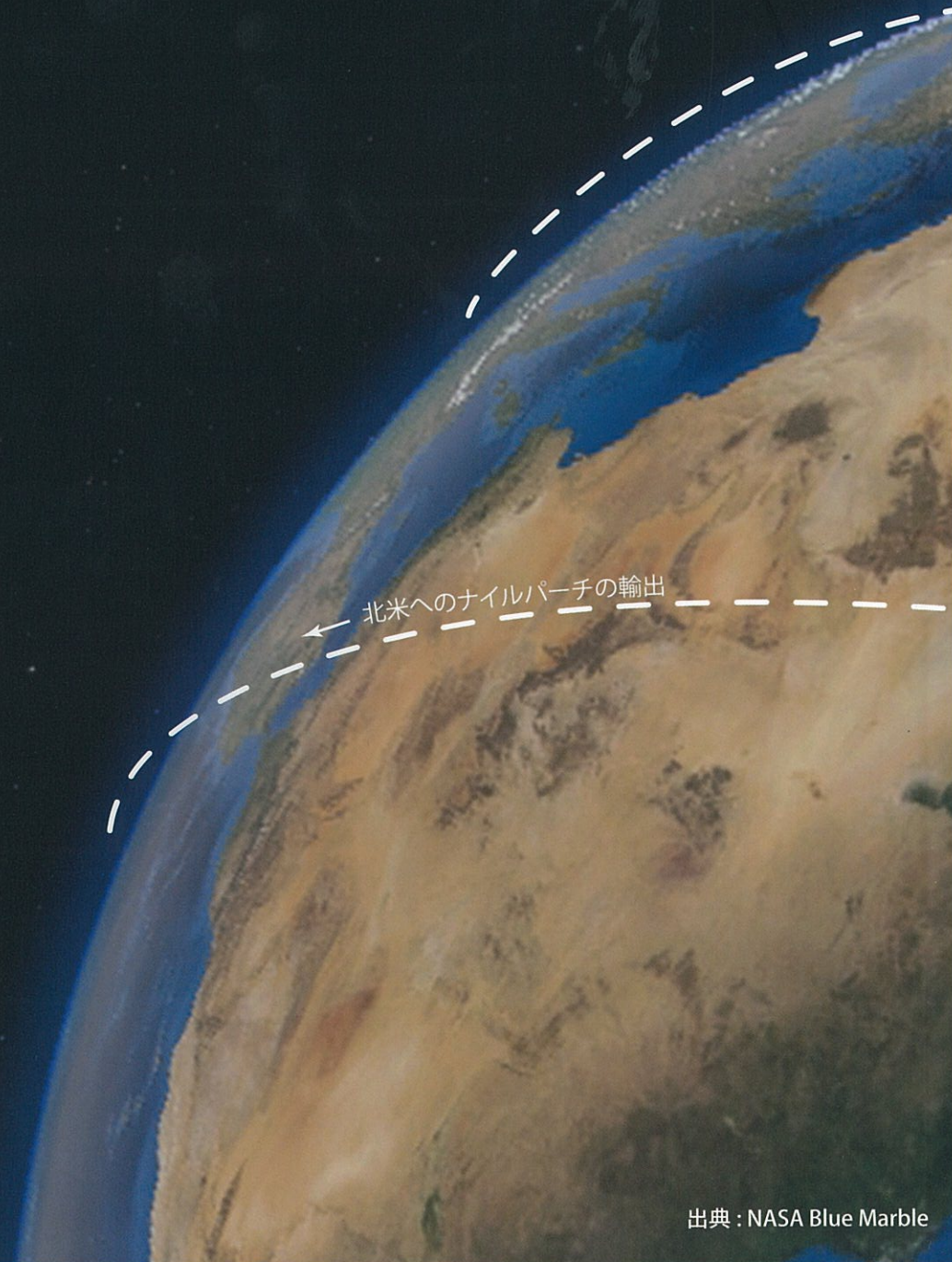
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北米へのナイルパーチの輸出

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出典 : NASA Blue Marble

PEATLAND ATLAS

Facts and figures about wet climate guardians

2023



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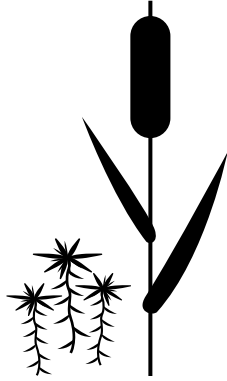
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UN Global Peatlands Initiative, <https://globalpeatlands.org>



PEATLAND ATLAS

Facts and figures about wet climate guardians

2023

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People have been using peat for heat since the Bronze Age. They still do so today in countries like Finland, Belarus and Rwanda. This is not sustainable – but there are new, climate-friendly ideas for how peatlands can help generate heat and power.

42 EUROPE

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NOT JUST A CRIME SCENE

For thousands of years, peatlands have served as the backdrop for horror stories. In gruesome legends and lore, they swallow people and even whole towns, are the home of ghosts, the devil, and many other supernatural spectacles.

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FOREWORD

Peatlands are a mixture of elements: they are both water and land at the same time. They form where the soil is wet all year round. Waterlogging prevents dead plant material from decomposing, creating their characteristic organic soils over thousands of years. And peatlands can be found all over the world, from the Arctic to Europe and the tropics, all the way to Tierra del Fuego at the tip of South America. They are impressive ecosystems, rich in rare animal and plant species. Their peat soils store enormous amounts of carbon, so they play a decisive role in climate protection – as long as they stay wet.

In the past, people in continental Europe showed a great deal of respect – and sometimes fear – for peatlands. They were shrouded in myth: they were dangerous places, home to mysterious creatures which were better avoided or treated with deference. Then, a few centuries ago, people began to make use of these fascinating watery landscapes, draining bogs and fens to make way for houses, woods and fields.

Today, peatlands provide vital services to the communities that live in and around

” Peatlands are impressive ecosystems that occur all over the world.

them: they regulate water levels, maintain water supplies, and moderate floods and droughts. Indigenous communities who have lived in peatlands for generations have deep-rooted cultural ties to the land. They fish, hunt and gather medicinal plants from the peatlands.

But peatlands are still being destroyed all over the world. In Central Europe, well over 90 percent of the peatlands are affected; in the tropics and elsewhere, healthy peatlands are being lost ten times faster than the peat can grow. Agriculture and forestry are the main culprits. In Europe, much of the peatland is used for livestock, particularly for beef and dairy production and for growing fodder. Many governments, and the European Union (EU) through its Common Agricultural Policy (CAP), even subsidize agriculture on drained peatlands. Peatlands are also used to extract peat for fuel and as substrates for horticulture. In the tropics, the destruction of peatlands has proceeded apace, driven by multina-

tionals from the Global North. This has far-reaching consequences for the regions, including the use of fire to clear land for palm oil plantations, and the felling of valuable tropical timber. These peatlands are often peat swamp forests, where giant trees stand on deep layers of peat, so storing large amounts of carbon in the wood and the soil below. Such rainforests provide a refuge for unique plants and animals such as orangutans and lowland gorillas, and at the same time protect people and nature from drought and flooding. All this is now imperilled.

More than 10 percent of the world's 500 million hectares of peatlands have already been drained, and a further 500,000 hectares are destroyed every year. This destruction is both accelerating species extinction and fuelling the climate crisis. Once they dry out, peatlands change from being carbon sinks to sources of greenhouse gases like carbon dioxide (CO₂). Worldwide, drained peatlands are responsible for around 4 percent of all anthropogenic greenhouse gas emissions, peat fires excluded. Intact peatlands must be kept wet and be protected to prevent

” It takes a major peatland transformation to achieve the climate goals.

further emissions. It is also possible to reduce emissions by rewetting drained peatlands. This preserves the peat and retains the carbon it has built up over centuries.

For far too long, many institutions have ignored what is now widely recognized: protecting and restoring peatlands is an important part of tackling the climate crisis. And therefore, we need a fundamental change in the way peatland is managed. Livestock raising and plantations on drained peatland must be reduced. Alternatives to conventional intensive agriculture are needed to use large areas of wet peatland: alternatives that combine agricultural use with climate and biodiversity protection – such as paludiculture. To make the transition, farmers need certainty and support. Protecting the climate is a task for society as a whole because it is about the preservation of an environment worth living in for everyone.

It is clear that we need more effective and joined up governance of peatlands so that they deliver a triple win for the climate, people and the planet urgently. There is growing awareness of the importance of peatlands with countries and stakeholders adopting peatland-related resolutions under different international frameworks. The sustainable management of peatlands can be included in Nationally Determined Contributions and Long-Term Strategies for the Paris Climate Agreement. Peatlands restoration and conservation can help parties meet targets under the Global Biodiversity Framework and Land Degradation Neutrality principles.

The use of drained peatlands damages the environment and should no longer be subsidized. Instead, we need legally binding targets for peatland restoration and attractive financial support for alternative, wetter uses of agricultural and forestry land. We need to act now. This requires effective incentives, public and private initiatives and regulatory and planning mechanisms. Relying on voluntary action is no longer enough.

In all policy areas, peatland conservation must be considered together with the future prospects of local communities, Indigenous peoples, agriculture and forestry in a regional context. Both policymakers and society as a whole must play their part.

The Peatland Atlas 2023 highlights not only the consequences of the destruction of these unique habitats, but also the potential of wet peatlands for mitigating climate change. It outlines strategies to protect and use them to encourage change by all stakeholders. Climate crisis is not in the future: we are already living through it. Summer droughts and record-breaking heat demand swift and effective action. Peatlands, those natural climate reservoirs, can play a vital role. Peat must be wet!

Dr. Imme Scholz
Heinrich-Böll-Stiftung

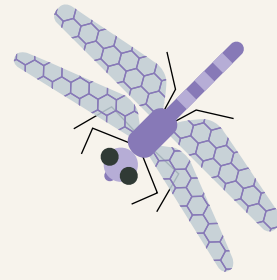
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Dianna Kopansky
Global Peatlands Initiative

12 BRIEF LESSONS

ABOUT PEATLANDS



1 Peatlands exist on all continents. They are the result of **PEAT FORMATION** in soils with soils that are saturated with water.

2 Worldwide, peatlands cover **3 PERCENT OF THE EARTH'S LAND SURFACE** – but they store about twice as much carbon than the biomass of all the world's forests combined.

3 Peatlands are being lost ten times faster than they are growing. Due to human activities, **500,000 HECTARES OF PEATLAND ARE DESTROYED EVERY YEAR**. Intact peatlands urgently need to be protected.

4 Natural peatlands draw considerable amounts of the greenhouse gas carbon dioxide (CO₂) from the atmosphere, which they **STORE AS CARBON IN THE PEAT**. But if they are destroyed, they release large amounts of CO₂ – and damage the climate.

5 A large part of all drained peatlands worldwide is **USED FOR AGRICULTURE**. In the EU: one quarter of all peatlands. They are used primarily for animal husbandry.

6 Peatlands play a crucial role in the **WATER CYCLE**. They filter and store water and help alleviate drought and flooding. The **CLIMATE CRISIS** makes peatlands drier and increases the risk of fires that produce a lot of emissions.

7 Peatlands are home to rare and endangered **PLANTS** and **ANIMAL SPECIES**. Their greatest threat worldwide is artificial drainage and deforestation for agriculture and forestry.

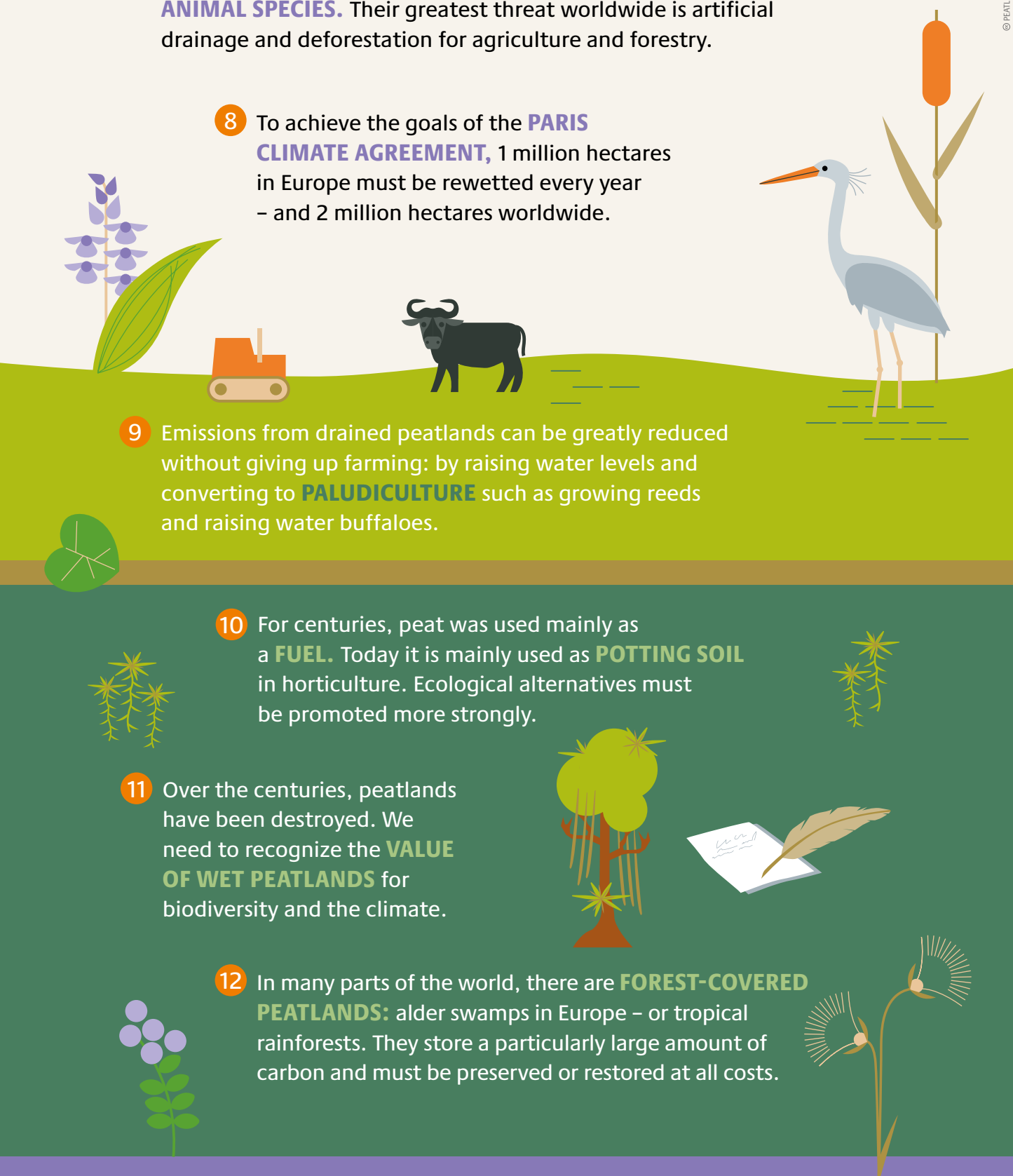
8 To achieve the goals of the **PARIS CLIMATE AGREEMENT**, 1 million hectares in Europe must be rewetted every year – and 2 million hectares worldwide.

9 Emissions from drained peatlands can be greatly reduced without giving up farming: by raising water levels and converting to **PALUDICULTURE** such as growing reeds and raising water buffaloes.

10 For centuries, peat was used mainly as a **FUEL**. Today it is mainly used as **POTTING SOIL** in horticulture. Ecological alternatives must be promoted more strongly.

11 Over the centuries, peatlands have been destroyed. We need to recognize the **VALUE OF WET PEATLANDS** for biodiversity and the climate.

12 In many parts of the world, there are **FOREST-COVERED PEATLANDS**: alder swamps in Europe – or tropical rainforests. They store a particularly large amount of carbon and must be preserved or restored at all costs.



WHAT ARE MIRES AND PEATLANDS?

A VERY SPECIAL ECOSYSTEM

Mires are intact peatlands and home to rare plants, rare animals – and enormous amounts of carbon. But draining them for economic reasons puts them and their resident organisms at massive risk. It poses a massive threat to the climate too.

Mires have long shaped many landscapes around the world. They are fascinating ecosystems, whose development is inseparable from the presence of water. This comes either solely from rainwater or additionally also from groundwater. Unlike as in a lake, this water does not fill a depression in the ground, but it fills pores in the soil. The high water level excludes air from the soil. As a result, dead plant material does not decompose completely, and peat forms, by perhaps a millimetre a year.

One thing that all peatlands – both the natural, undrained mires and also drained peatlands – have in common is that they are long-term and very space-efficient carbon stores. To put that in numbers: peatlands cover just 3 percent of the Earth's land surface, but they harbour around twice the amount of carbon as the biomass in all of the planet's forests. Worldwide, they store 600 billion tonnes of carbon. But peatlands nearly everywhere around the world are threatened by human activities.

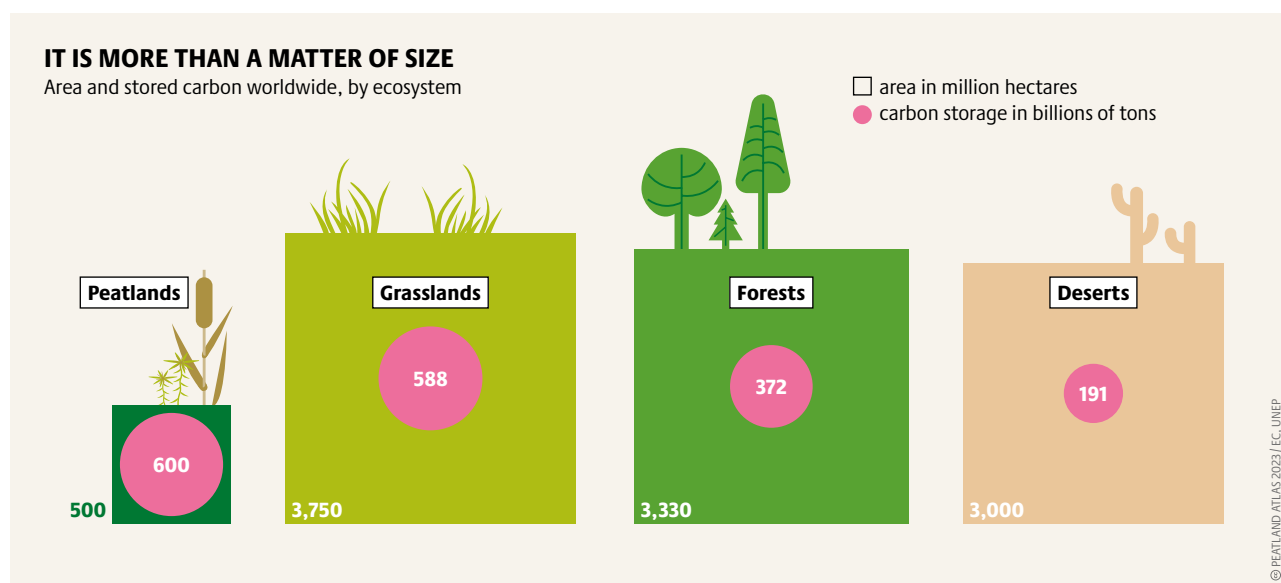
The two main mire types are distinguished based on their water supply. Bogs are fed only by rainwater. They

are poor in nutrients, more acidic and with water tables higher than in their surroundings. Fens, on the other hand, depend on groundwater, spring water or seepage. They are more rich in nutrients and less acidic compared to bogs. The majority of peatlands in Europe are fens.

Mires have also an enormous significance for biodiversity. They provide unique habitats for rare animals and rare plants that are adapted to a wet environment. They are often the last refuges for many rare and threatened species, such as the aquatic warbler, shoebill or orangutan. Many mires are typified by their extent, their openness, and many open water bodies they contain. They offer waders and waterfowl numerous opportunities for rest and overwintering. Not only that: mires improve the quality of water by filtering out pollutants it contains.

Plant genera such as peat mosses occur throughout the world, and numerous species exist that are large, sturdy and colourful, all of which can form peat. Mires in the boreal and temperate regions are often open landscapes with moss and grassy vegetation and relatively few trees. Tropical mires, on the other hand, are often covered with forest. These peat swamp forests are impenetrable areas that are home to species such as lowland gorillas, forest elephants, chimpanzees, bonobos and the Allen's swamp monkey.

Peatlands cover only a small portion of the earth, but they store more carbon than any terrestrial ecosystem



WIDESPREAD LANDSCAPES

Types of peatlands

Peatlands ...

... are areas with a naturally accumulated peat layer at the surface, whether wet or drained

Mire ...

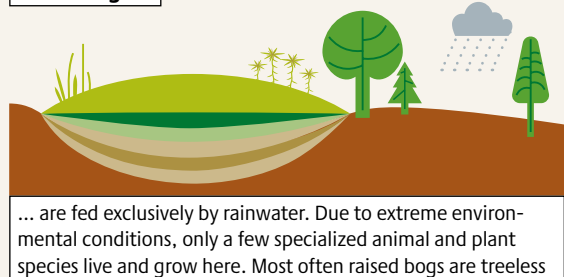
... refers only to intact, undrained peatlands with a vegetation that forms peat

Wetlands ...

... are areas that are inundated or saturated by water to an extent that its vegetation is dominated by plants that are adapted to life in anoxic soil conditions. They do not necessarily contain peat

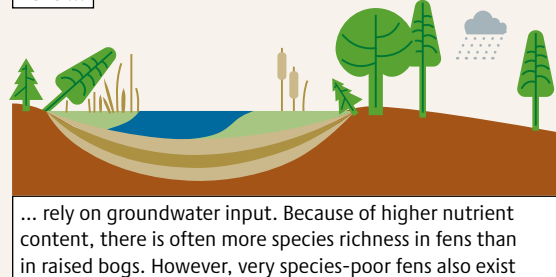
■ bog peat ■ transition peat ■ fen peat ■ organic silt ■ mineral subsoil ■ open water

Raised bogs ...



... are fed exclusively by rainwater. Due to extreme environmental conditions, only a few specialized animal and plant species live and grow here. Most often raised bogs are treeless

Fens ...



... rely on groundwater input. Because of higher nutrient content, there is often more species richness in fens than in raised bogs. However, very species-poor fens also exist

© PEATLAND ATLAS 2023 / BFN

Humankind has used peatlands for thousands of years. Nowadays these lands are used mainly for farming, forestry and peat extraction. As largely applied today, these forms of use require the peatland to be drained. But water is necessary for mires: take it away, and the environment changes dramatically. Oxygen penetrates into the soil, the peat decomposes, and the greenhouse gas carbon dioxide (CO₂) is released – turning the mire into a drained peatland and a climate problem. Drainage also deprives the typical mire species of their habitat.

Europe is the continent that has so far lost the most natural peatlands. Some 10 percent of its erstwhile peat cover has been lost through drainage. Of the remaining peatland area – around 100 million hectares – one-quarter is degraded or damaged. Within the European Union, the figure is one-half.

Drained peatlands are responsible for around 5 percent of all greenhouse gas emissions in the European Union. Drained peatlands no longer act as a carbon sink, but also release greenhouse gases into the atmosphere. This disastrous role becomes even clearer if we look at the emissions from farming, 25 percent of which are caused by drained peatlands. And that is even though peatlands cover just 3 percent of the agricultural area. That is why drained peatlands are one of the major fields of action for climate protection in agriculture and land use.

The central role of water in the functioning of peatlands makes them particularly vulnerable to disturbances. Besides drainage, other threats facing peat-

A number of European peatlands are nature reserves. Since many peatland areas have been destroyed, their number is small

lands include road construction, reservoir creation, oil-sands mining, overgrazing and pollution. Europe is a global peatland degradation hotspot because of widespread land-use changes for agriculture, forestry and peat extraction. Next to Europe, major hotspots are Northeastern China, Southeast Asia and the American Midwest. The degree of drainage directly affects the amounts of greenhouse gas emissions released annually from degraded peatlands.

According to numerous studies, some of the damage to peatlands caused by drainage cannot be repaired; the landscape is permanently changed. That makes it all the more important to stop peatland drainage before it is too late, and to protect mires and peatlands, because if dried-out areas are rewetted, the release of carbon dioxide can be stopped. Such rewetting is one of the central tasks for the present and future.

A comprehensive protection of peatlands can succeed if peatland conservation and land use are brought into harmony. Instead of a total stop to the use of peatlands, what is needed is a range of new, wet ways of managing the land, ranging from wet wilderness to high-intensity paludiculture. That is why technical specialists and environmental groups call on policymakers to provide more support for such socio-ecological transformation through a combination of incentives and regulation. ●

UNDER THREAT ALMOST EVERYWHERE

Peatlands exist in the mountains, in lowlands, along rivers and at the coast. Their vegetation and condition vary from one climate zone to another, but all types of peatland have one thing in common: their continued existence is in danger.

Ever since the 17th century, peatlands have been systematically drained – for peat extraction, settlement, forestry and farming. Beginning in the second half of the 20th century, the industrialization of agriculture accelerated large-scale drainage, especially in temperate zone of the northern hemisphere. As a result, some industrialized countries now have little of their natural peatlands left. Worldwide, over 50 million hectares are currently covered by drained peatlands, and the trend is rising.

In many countries and especially in the Global South there is little data on peatlands. Only enhanced mapping will reveal the true extent of peatland drainage and its consequences for climate crisis. What is certain: worldwide, peatlands are often found in climate zones that mostly have either very high rainfall or very cold temperatures – or both. These are mainly in the tropics at a band around the Equator and in the sub-arctic, boreal and temperate oceanic zones of both the northern and southern hemispheres. The climatic conditions in

these regions cause biomass to be broken down only very slowly, favouring the formation of peat.

Peatlands are relatively less widespread in subtropical regions because moisture is scarcer in these areas. But even here, peat formation is possible under certain circumstances. Some areas receive enough water from large rivers from regions with higher precipitation, such as mountain ranges. As a result peatlands can develop in lowlands and in the deltas of large rivers such as the Brahmaputra in Bangladesh, the Rio Paraná in Argentina, and the Zambezi in Zambia. The total area of peatlands around the globe is estimated at 500 million hectares. But this figure is just an approximation: many large areas are imprecisely mapped, and innumerable smaller peatlands remain undiscovered.

Peatlands occur along coasts worldwide, in salt-marshes and saline reedbeds, and in the tropics often in mangroves – coastal woodlands in areas where seawater and freshwater mix. Peat formation is favoured by marine currents and the humid air masses that are associated with them, such as along Europe's western sea coast and in the Caribbean. On land, flat terrain slows down the natural flow of water on the land surface, resulting in the creation of the huge peatlands in

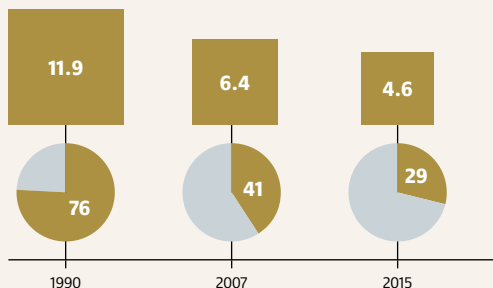
Islands and peninsulas in Southeast Asia are full of tropical peatlands. But industries pose a threat to unique ecosystems

INDUSTRY IS INCREASING, PEATLANDS ARE DISAPPEARING

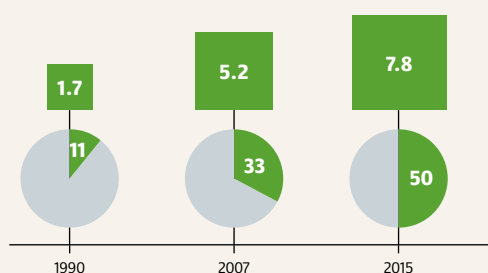
Peatland destruction in Peninsular Malaysia, Sumatra and Borneo

□ in million hectares
○ percentage of all local peatlands

peatlands covered by peat swamp forest

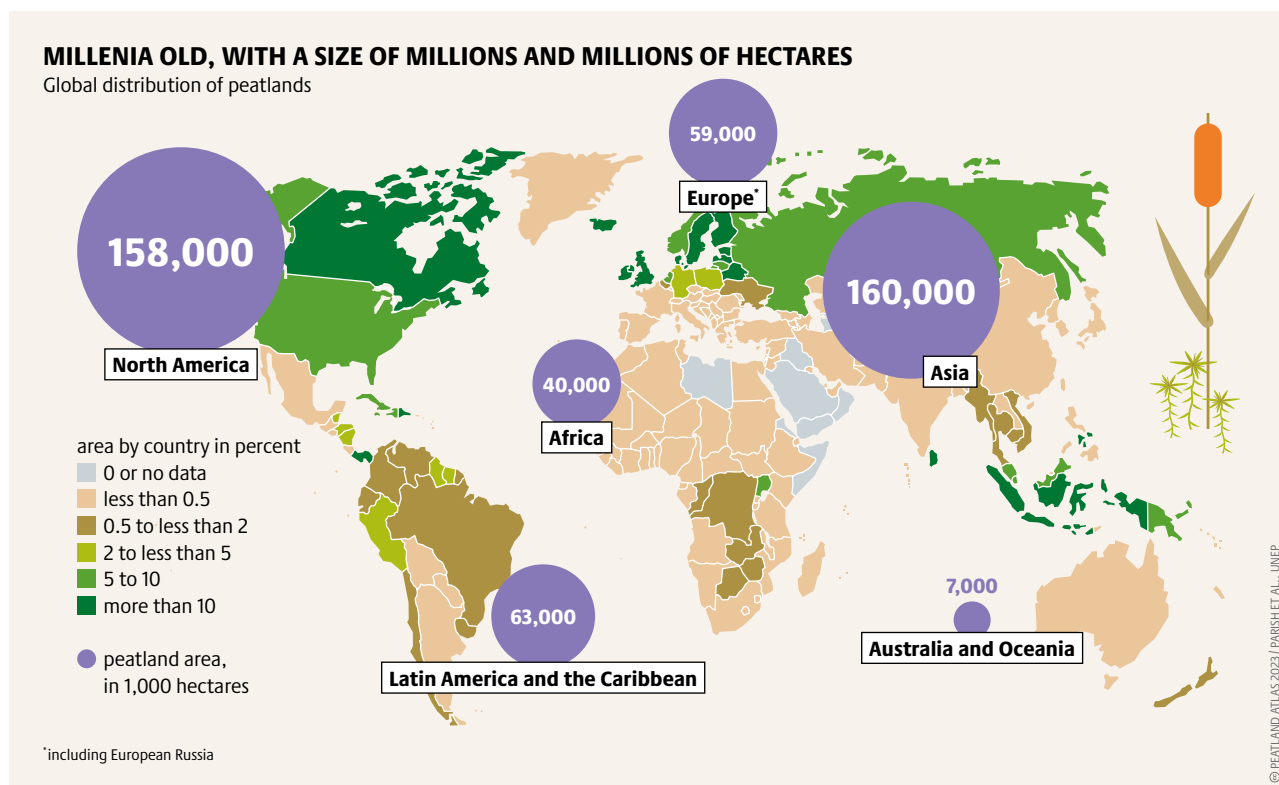


peatlands covered by industrial plantations and small-holder dominated areas



MILLENNIA OLD, WITH A SIZE OF MILLIONS AND MILLIONS OF HECTARES

Global distribution of peatlands



western Siberia, Southeast Asia, the Congo Basin and the western Amazon. Finally, peat can occur anywhere where the local climate and terrain permit permanently high and stable water levels in the soil.

These differences in climate, water source, water quality and the resulting vegetation produce diverse types of peatland. Essentially they all have one feature in common: the presence of a layer of peat in the soil.

In cold subarctic and boreal cool humid oceanic regions, the peat forms mainly from the remains of mosses. Especially in Siberia and over vast areas of Canada and Alaska, fairly treeless peat landscapes are found: seemingly endless expanses dominated by mosses. In the temperate continental and subtropical parts of the world, grass-like plants such as reeds, sedges and rushes take over the role of peat producers and dominate the peatland vegetation. Here, the peat accumulates in the first few feet under the surface, as the underground shoots and roots of these plants grow into the older peat material where they die off. These peatlands reside as grasslands with reed beds of various sizes along rivers, in silted-up lakes and in depressions of different sizes. In tropical lowlands, the peat is often formed by the deep roots of tall trees. Huge, forested peat landscapes cover these tropical peatlands for example in the Congo Basin, Indonesia and Peru.

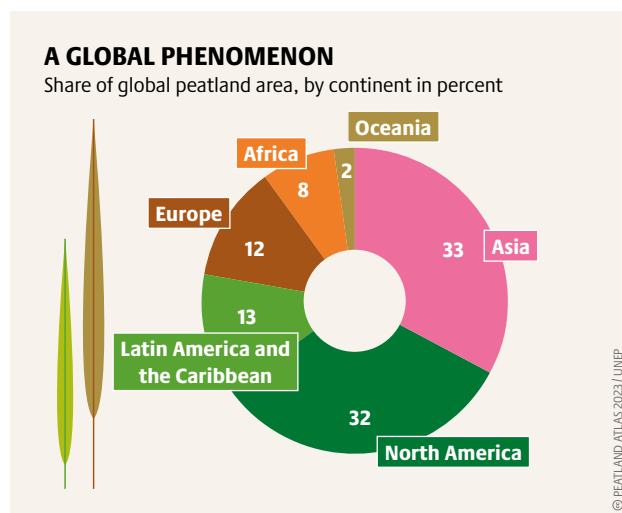
Peatlands exist in 90 percent of all countries. Many of them are located in the sparsely populated areas of Canada, Amazonia and Siberia

Peatlands in an intact or near-natural state are multi-talented: they protect biodiversity, mitigate the climate crisis and are a key factor for flood protection

For the last 20 years these peat swamp forests of the tropics have been increasingly deforested, drained and used for timber production and intensive agricultural production. For many years the hotspot of this trend was in Southeast Asia, especially Indonesia. Infrastructure development and clearing are now increasingly taking place in the extensive peatlands of the Congo and Amazon basins. A further threat to peatlands not only in the subtropics of Africa and South America: the climate crisis. ●

A GLOBAL PHENOMENON

Share of global peatland area, by continent in percent



HELP NEEDED

Huge areas of peatland around the world have already been destroyed. In the tropics, peat swamp forests are being cut down and the land drained. Fires and climate crisis also pose threats. Attempts to protect the peatlands have so far had little success.

Healthy peatlands around the world are being degraded at an alarming rate – through clearing, deforestation, slash-and-burn agriculture and drainage. Drained peatlands are used to establish fast-growing pulpwood or palm oil plantations, or for arable farming, pasture and forestry. Or they are subject to peat extraction or covered with buildings. Of the 500 million hectares of peatland worldwide, over 50 million have already been degraded to such an extent that peat can no longer accumulate, and remaining peat is under threat. Of the peatlands that are still accumulating peat, another 500,000 hectares are destroyed every year by human activities. In many fertile and easily accessible areas where human populations are growing, natural peatlands have been completely lost – as in central and

eastern Europe and Southeast Asia. In the European Union, around half of all the peatlands have been drained. Most of the still-intact peatlands are found in thinly populated areas that are unsuited to agriculture – especially in the northern parts of the globe in Canada, Alaska, Siberia, and in inaccessible rainforest areas near the Equator, such as in the Congo and Amazon basins. Countries in Europe whose peatlands are considered to be well preserved include Sweden, Norway and Bosnia-Herzegovina. There they are 75 to 100 percent still intact.

Especially in the tropics, the destruction of peatlands is currently continuing, with catastrophic consequences. In these regions, the peatlands consist mostly of rainforest where massive trees grow on layers of peat that are metres thick. The trees offer shelter for orangutans, forest elephants and many other species. Rainforests also store enormous quantities of carbon in their vegetation and in the soil. The most effective store is the peat itself. The tropical peatlands of Cuvette Central in the Democratic Republic of the Congo and the neigh-

Rewetting? There is no alternative! But even rewetting can restore old conditions only to a limited extent. So a priority must be the preservation of intact areas

BETTER BUT NOT ENOUGH

Differences between intact peatlands and rewetted peatlands, study from 2021

Rewetted sites have **lower** organic matter content of the top soil layer and **larger** water table amplitudes (**+15 percent**)

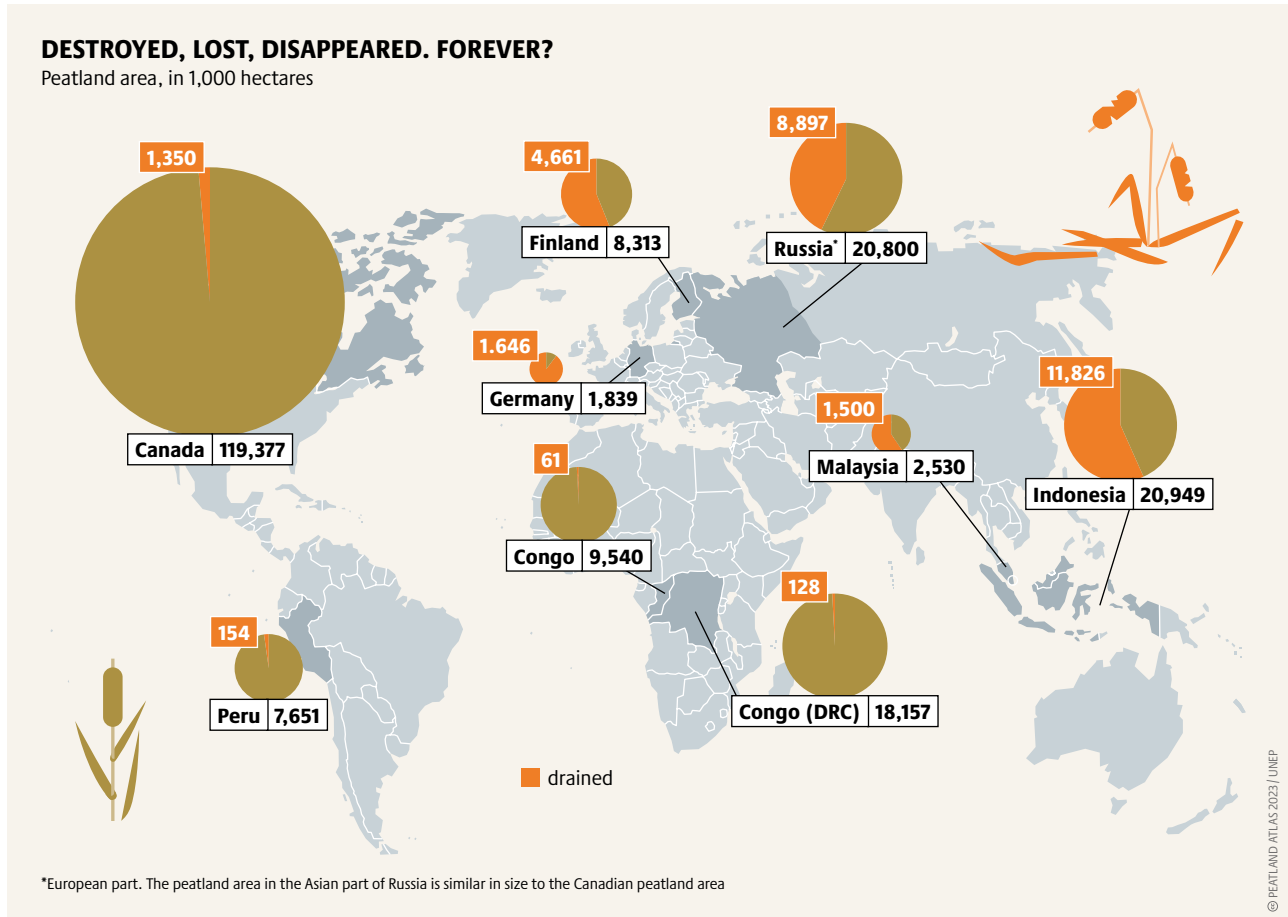
Tall helophytes account for **25.5 percent** in rewetted peatlands. In intact peatlands: **6.2 percent**

Tall plants such as reed canary grass dominate rewetted peatlands. They are highly conductive for gases, which may increase methane (CH₄) emissions, and suppress smaller plants due to light competition to smaller mosses. Flood protection is more efficient with intact peatlands than with rewetted areas

There is less plant richness in rewetted sites. Differences in vegetation: by up to **60 percent** compared to intact peatlands

DESTROYED, LOST, DISAPPEARED. FOREVER?

Peatland area, in 1,000 hectares



bouring Congo cover only 4 percent of the total area of the Congo Basin, but their peat stores around 30 billion tonnes of carbon, the same amount as in the rainforest vegetation of the entire basin.

Over half of the known tropical peatlands are found in Southeast Asia. Many of them are drained and degraded. Over the last 20 years, huge areas of peatlands have been converted to palm oil and acacia plantations, especially in Indonesia and Malaysia. The global production of palm oil has risen from 15 million tonnes in 1994 to over 74 million tonnes in 2019. This massive rise was permitted by the increasing use of palm oil as fuel, processed food and in washing and cleaning products. Acacia plantations, for their part, are used to produce pulp and paper.

Especially in Southeast Asia, uncontrolled, large-scale forest and ground fires have been blazing repeatedly since the 1990s. Under moist natural conditions, peat soils usually do not catch fire, but they burn well when they dry out. Big companies often set fires, either legally or illegally, to clear the land and create space for new plantations. Climate crisis has made many areas even more susceptible to forest fires. Indonesia has recently undertaken greater efforts to raise the water levels in its peatlands again. Its drained peatlands emit more greenhouse gases than any other country in the world. But in the meantime the government has set up

Agriculture destroyed Indonesian peatlands. In recent years, the Indonesian government has committed to restore them in a very comprehensive way

a state agency for peat restoration and has already rewetted an area of over 2 million hectares.

Permafrost soils, which partly consist of frozen peat, are especially threatened by climate crisis. If they thaw, the organic matter they contain breaks down, releasing the carbon in form of the greenhouse gases carbon dioxide (CO₂) and methane (CH₄). In the Arctic, where most permafrost soils are found, the temperature has risen in the last 40 years almost four times faster than the global average.

In the Cuvette Centrale in the Congo Basin in Central Africa, which was scientifically recorded only a few years ago, the government of the Democratic Republic of Congo (DRC) has launched an oil and gas auction that would allow oil companies extensive licenses to exploit the area. With its area of 16.7 million hectares, the Cuvette Centrale is one of the largest contiguous areas of peatland worldwide. It includes more than one-third of the total area of all tropical peatlands, and contains more than a quarter of the carbon they store. If the oil auctions are not stopped, companies may be able to start chopping down trees, establishing palm oil plantations and drilling for oil there. ●

LIFE-GIVING MOISTURE

Peatlands and other types of wetlands foster biodiversity and protect humans and nature from drought and flooding. But they are some of the most threatened ecosystems on the planet. Current efforts to conserve them have so far proven inadequate.

The term wetlands includes a range of different ecosystems: marshes, water meadows, peatlands, floodplains, swamps, rivers, lakes, mangroves – and diverse coastal areas. What they all have in common is lots of water. They are sometimes described as the Earth’s kidneys, because they act as natural filters to absorb pesticides and other chemicals and remove nutrients such as nitrate and phosphorus from the water. Covering a total of at least 1.6 billion hectares, wetlands are found all over the world. They have long been under threat: they are disappearing three times faster than forests. Just since 1970, some 35 percent of all wetlands have been destroyed. This has happened either as a result of deliberate drainage, which has increased markedly since the 1960s, or indirectly through falling groundwater levels. Globally,

some 350 million hectares of wetlands have already disappeared, of which 50 million hectares used to be wet peatlands. These drained peatlands are the source of at least four percent of worldwide greenhouse gas emissions. The biggest losses of wetlands today are the result of unsustainable forms of agriculture and forestry, the pumping of groundwater, and increasing water pollution. The expansion of industry and infrastructure also contributes to the destruction. In all, one percent of the remaining wetlands are lost each year.

60 percent of humanity lives and works in coastal regions protected by wetlands from flooding. One hectare of wetland can absorb up to 5.6 million litres of floodwater. The continuing destruction of wetlands makes it harder to cope natural disasters, whose numbers have risen tenfold since the 1960s. Floodings, droughts and storms are responsible for up to 90 percent of all the climate-related disasters each year, and the Global South is especially hit hard. People who live in poverty and who have contributed the least to climate crisis are suffering the most.

To fight inequality and overexploitation, the United Nations has committed itself to 17 sustainability goals. They can only be achieved with peatland protection

PEATLAND AS A FACTOR

Impact of peatlands and wetlands on selected United Nations Sustainable Development Goals (SDGs)



SDG 2 – Zero hunger: Peatlands improve ecosystem functions and regulate water. They prevent soil subsidence – and ensure food production



SDG 6 – Clean water: Almost all of the freshwater in the world is related to wetlands



SDG 7 – Clean energy: Renewable biomass from peatlands generates heat, sustainable and regional



SDG 11 – Sustainable cities and communities: Peatlands reduce flood risk and cool global climate



SDG 12 – Responsible consumption: Sustainable management of peatlands with paludiculture combines economic independence and ecology



SDG 13 – Climate action: Intact peatlands store huge amounts of carbon



SDG 14 – Life below water: Healthy and productive oceans need functioning coastal wetlands

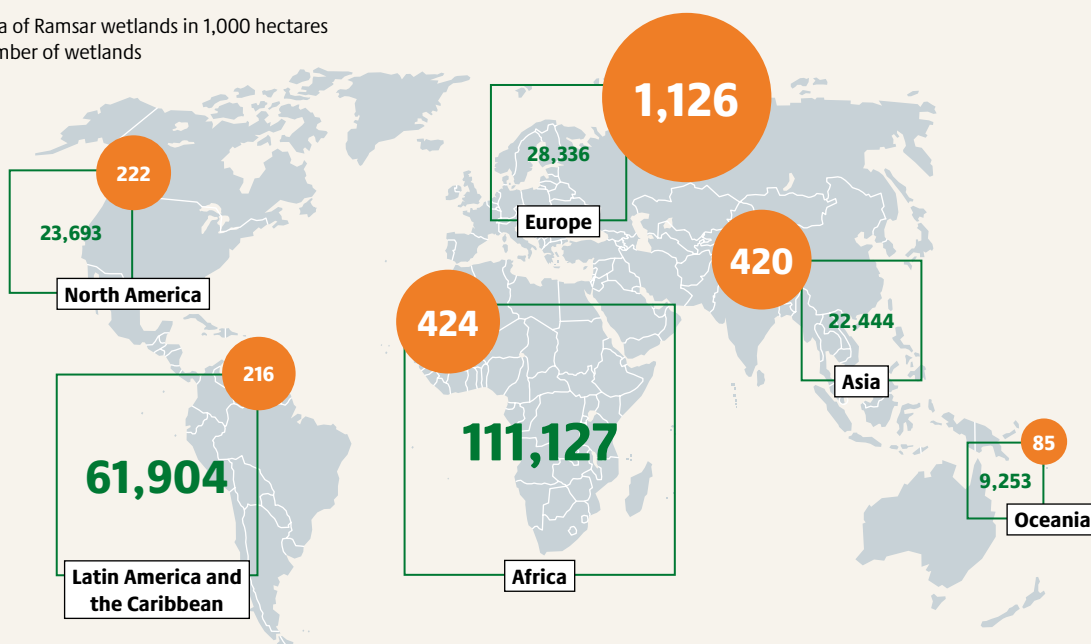


SDG 15 – Life on land: 40 percent of the species live and breed in wetlands

SEAL OF APPROVAL, ALSO FOR PEATLANDS

Wetlands declared to areas of protection by the Ramsar Convention, ratified by 172 countries

- area of Ramsar wetlands in 1,000 hectares
- number of wetlands



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Some 40 percent of the world's species live and reproduce in wetlands. This biodiversity is at risk: in the past five decades, 81 percent of the plant and animal species in inland wetlands have suffered decline, along with 36 percent of the species in coastal and marine areas. The climate also is hugely affected. Although they cover only 1 percent of the Earth's surface (including the oceans), wetlands store around one-fifth of global carbon – as long as they remain intact. If they are drained, the stored carbon oxidizes into carbon dioxide (CO₂) and escapes into the atmosphere.

Although the many ecosystem services provided by wetlands have direct links to the Paris Climate Agreement and the 17 global Sustainable Development Goals of the United Nations, there is only a single international agreement that places their protection centre-stage. The Ramsar Convention goes back to 1971, but it is not legally binding. A total of 172 states have acceded to the Convention. These states provide a list of internationally significant wetlands, similar to UNESCO's list of World Heritage sites. A total of 2,493 sites around the globe, covering a total of 256 million hectares, are currently listed – an area as large as Argentina. For decades the Ramsar Convention neglected peatlands: they were first brought under the protection of the Convention just 20 years ago. However, because of their importance, these peatlands now account for about one-quarter of the designated wetland areas in the Ramsar registry.

Even if a wetland makes it onto the list, it is not automatically granted protected status. The European

657 peatlands covering an area of over 60 million hectares are Ramsar sites. This does not yet grant them protection, but attention

Union, however, has various guidelines which can be used to place such areas under special protection. For example, they can be classified as a nature reserve or a flora-fauna habitat.

The United Nations has designated 2021 to 2030 as the Decade on Ecosystem Restoration. In 2019, the United Nations Environment Assembly (UNEA) passed a resolution that focuses on peatlands for the first time, giving new impetus to efforts to protect this land type. All countries of the world expressed their intention to attach greater importance to the sustainable use and restoration of peatlands. The Kunming-Montreal Global Biodiversity Framework of 2022, part of the Convention on Biological Diversity, focuses on the protection of threatened ecosystems such as wetlands and peatlands, and is the largest commitment ever made by the international community for habitat protection. By 2030, at least 30 percent of particularly degraded land and marine areas are to be restored, so these areas can again perform their ecosystem services. In addition, one-third of all land and marine areas are to be placed under protection by 2030. Like the Ramsar Convention, the Montreal-Kunming framework and the UNEA Resolution are not compulsory. But binding agreements are precisely what experts demand: to be able to restore and protect ecosystems, legally enforceable frameworks are vital. ●

DRAINED PEATLAND RESULTS IN HEATED PLANET

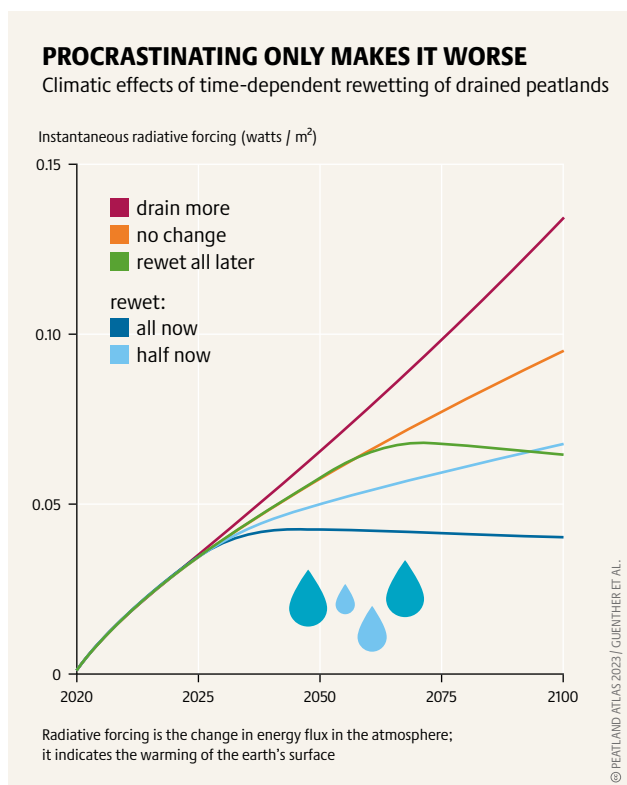
Because they take up greenhouse gases, peatlands cool the climate – but only as long as they are intact. But these peat-covered areas have been – and still are being – drained for agriculture, forestry, peat extraction and human settlement, exacerbating global warming.

Over thousands of years, peatlands have accumulated thick layers of peat – remains of dead plants, under permanent-wet soil conditions. In the oxygen-free environment under water, the plant remains decay only very slowly and are conserved, similar to pickled gherkins. The main component of peat is carbon. Peatlands cover only 3 percent of the Earth's land surface but store in their peat a disproportionate quantity of carbon, around 600 billion tonnes. That is around twice the carbon stored in the biomass of all the Earth's forests on 27 percent of the world's land.

When they were alive, the plants that now make up the peat took the carbon out of the atmosphere as the greenhouse gas carbon dioxide (CO₂) and changed it by photosynthesis into plant material. As long as the peatland remains wet, the carbon stays largely in the peat. A small part of the carbon is, however, emitted as methane (CH₄), a powerful greenhouse gas. Wet peatlands emit around 30 million tonnes of methane per year – about one-third of the global emissions from livestock and manure. However, this emission does not burden the climate, because in the atmosphere methane quickly reacts with oxygen, changes into the weaker greenhouse gas CO₂, and thus loses its strong climate effect. Methane emissions raise the methane concentrations in the atmosphere only when the peatland starts to form. Afterwards the methane concentrations do not keep rising – even with continuous emissions – but soon reach a steady state. The same amount of methane is broken down as is simultaneously emitted. On the other hand, the ongoing sink for CO₂ that natural peatlands represent continuously reduces the CO₂ concentration in the atmosphere. In this way, peatlands have lowered the average global temperature over the last 10,000 years by about 0.6 degrees Celsius.

Globally, around 88 percent of the world's peatlands are still in a largely natural state. But more than 50 million hectares of peatlands have been drained so strongly that no new peat is formed any longer. On the contrary, the penetration of oxygen into the drained peat soil results in its continuous decomposition. That produces CO₂ and nitrous oxide (N₂O). The global warming effect of various greenhouse gases is expressed in terms of CO₂-equivalents. In Central European peatlands, a drop of the average water table of 10 centimetres results in an extra 5 tonnes CO₂-equivalent of emissions per hectare per year. In the tropics, the figure is as high as 9 tonnes.

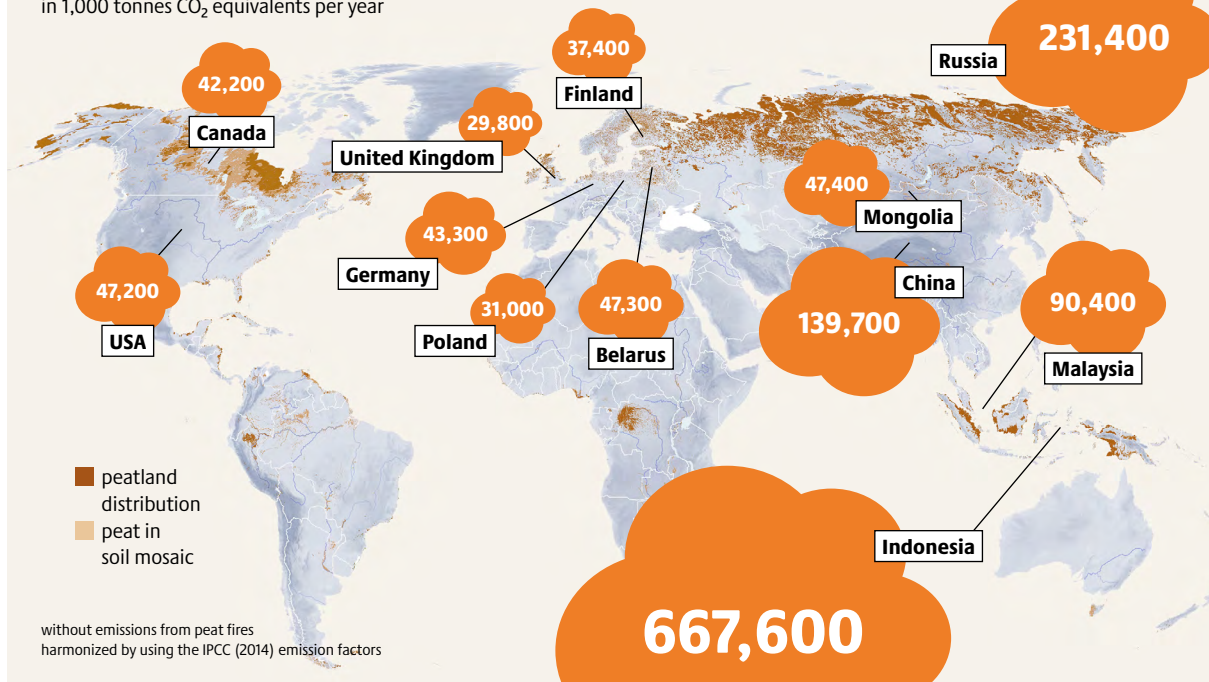
Every year, drained peatlands emit almost 2 billion tonnes CO₂-equivalent, which is twice as much as the whole of global aviation. Almost 90 percent of these emissions consists of CO₂, the rest of methane and nitrous oxide. On top of that are the emissions from peat



A study of 2020 shows: A key factor in climate crisis mitigation is the prompt rewetting of all drained peatlands

FEW STATES CAUSE GREAT DAMAGE

The twelve countries with the world's largest greenhouse gas emissions from drained peatlands, in 1,000 tonnes CO₂ equivalents per year



fires. Peat fire emissions vary considerably over time and are difficult to measure – but on average they may amount to between 500 million and a billion tonnes of CO₂-equivalent a year. Apart from emitting greenhouse gases, peat fires also produce dangerous levels of air pollution, which can spread far beyond its region of origin. According to studies, more than 100,000 people have died as a result of large peat fires in Indonesia in 2015. Over half a million people had acute respiratory problems; the national economic damage is estimated at up to 40 billion euros.

Although drained peatlands make up less than half a percent of the Earth's land area, they are responsible for around 5 percent of all human-induced emissions – peat fire emissions included. Most peatland emissions come from Indonesia, the European Union (EU) and Russia. Within the European Union, half of the emissions come from Germany, Finland and Poland. By far the biggest share of these emissions originates from drained agricultural land.

Without effective policy countermeasures, emissions from drained peatlands could by the end of the century use up over 40 percent of the greenhouse gas budget remaining to keep global warming below 1.5 degrees Celsius. To comply with the goals of the Paris Climate Agreement, net CO₂ emissions must be reduced

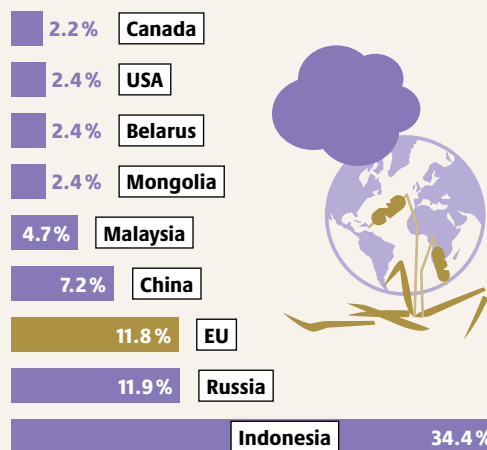
In 2015, peat fires in Indonesia released more greenhouse gases than Japan in the whole year

CO₂-equivalent is a unit of measurement comparing the climatic effect of greenhouse gases such as methane (CH₄), nitrous oxide (N₂O) and carbon dioxide (CO₂)

to zero by 2050. Experts have pointed out that this goal can be achieved only through the immediate and complete rewetting of all drained peatland. That means that globally 50 million hectares of peatland must be rewetted. In the EU, that means 500,000 hectares each year – and worldwide 2 million hectares. ●

THREAT TO ALL CLIMATE GOALS

Share of global emissions from drained peatlands, in percent



FALLACIES OF IMPROVEMENT

Humans have drained peatlands for centuries to provide land for farming and settlement. History may help us recognize the fallacies of supposed improvement, remember the presence of destroyed and often invisible peatlands in our landscapes, and advocate for the protection and restoration of peatlands.

In many parts of Europe, peatlands have largely disappeared as visible elements of the landscape. Centuries of drainage have reduced flood-protection areas and damaged habitats for plants and animals. Drainage has also held important implications for the global climate. Intact peatlands store more carbon than any other ecosystem in the world. When they are drained, the carbon that has accumulated and has been sequestered in the peat over thousands of years is exposed to oxygen, releasing vast amounts of the greenhouse gas carbon dioxide (CO₂) into the atmosphere. Wildfires on drained peatlands accelerate this process. The history of peatland drainage is therefore a crucial chapter in the history of the current biodiversity and climate emergency.

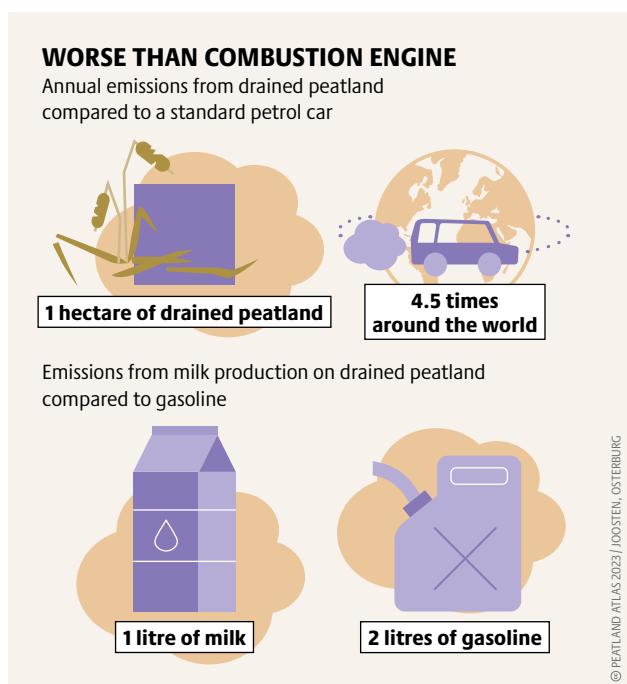
Mentions of peatland drainage go back thousands of years. In continental Europe, wetland reclamation

gained momentum in the 18th century, when monarchs, bureaucrats and educated elites developed drainage schemes to render peatlands useful. They often took inspiration from the Netherlands, where drainage and peat extraction contributed substantially to the country's economic power in the early modern period. Europe's elites believed that peatlands were mistakes of nature which had to be corrected through active human intervention for the sake of cultural and economic progress. Their ambition to improve the nature of peatlands devalued more sustainable uses of these ecosystems, such as fishing, hunting or the gathering of plants.

The reclamation of the Oderbruch – a marshland located along the Oder river in eastern Germany – under Frederick the Great of Prussia is a paradigmatic example of the modern drainage frenzy which caused the destruction of wetland ecosystems as a means of civilization. As driver of settlement and agricultural expansion, the drainage of the Oderbruch has been celebrated as a triumph of human reason over recalcitrant nature and allegedly backward ways of life. It inspired drainage schemes in other parts of Europe.

Drainage schemes always reflected the social and political conditions of their time. The cheap, sometimes unfree, labour of marginalized population groups or convicts was repeatedly mobilized for the laborious reclamation work. Drainage appealed to various political regimes and projects. In the late 19th and early 20th century, it appeared to be a means to prevent the exodus of the rural population and to modernize the countryside. Land drainage became tied to autarky politics and social engineering efforts during the interwar period, when the governments of Poland and the Netherlands, among others, launched ambitious land-reclamation schemes.

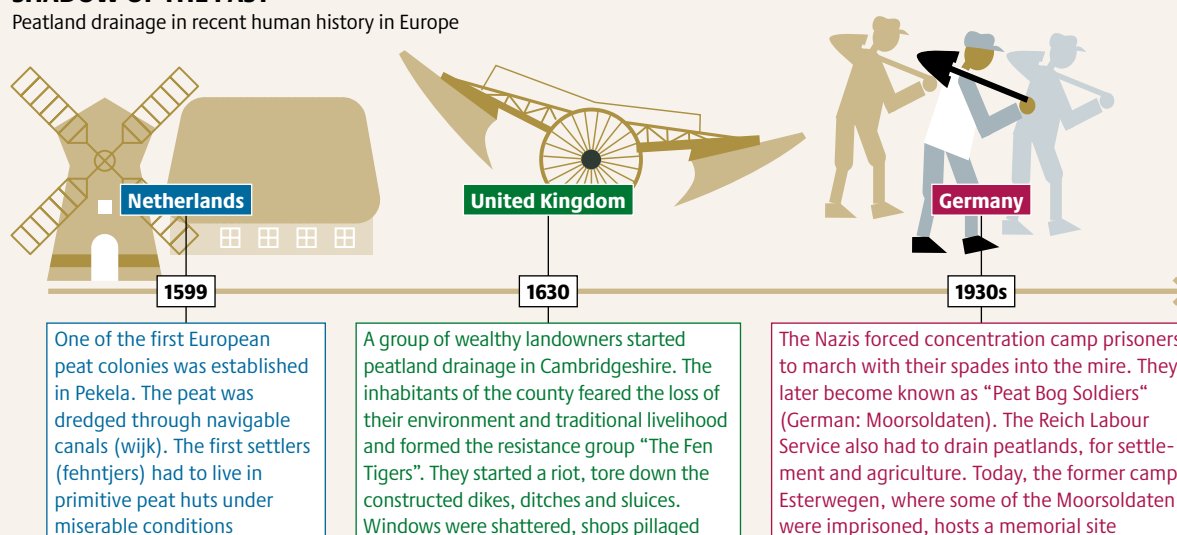
In Germany, the Nazi regime openly linked land reclamation of peatlands with racist ideology. During World War II, Nazi planners sought to drain the land along the Pripyat River in present-day Belarus and northern Ukraine, which they wanted to be settled by German peasants instead of the Jewish and Slavic population. Although these plans were not implemented, the wetlands of eastern Europe became sites of the mass atrocities and genocides committed by the German occupation forces.



A car driving 280 billion kilometers does not emit more CO₂ than drained peatlands in Germany every year

SHADOW OF THE PAST

Peatland drainage in recent human history in Europe



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In the second half of the 20th century, peatland drainage became a function of agricultural productivity, commercial forestry and rural development on both sides of the Iron Curtain, often with the support of national governments. In the UK, landowners could avail of specifically designed drainage grants. In 1950, the West German government agreed to invest considerable resources to develop the Emsland, a poor region in Lower Saxony bordering the Netherlands. The construction of extensive drainage systems was a key element of the scheme, which profoundly changed the environment of the area. State involvement in peatland drainage was most intense in the socialist countries of eastern Europe, particularly in the Soviet Union. After the Soviet government established a Ministry of Land Reclamation and Water Management in 1965, the extensive peatlands of the Baltic republics, Ukraine, Belarus and in northern and western Russia became subject to massive drainage campaigns. The German Democratic Republic (GDR) also carried out ambitious reclamation works, most famously in the Friedländer Große Wiese in its northeastern part.

Drainage reclamation has left deep scars in the landscapes of Europe. Elements of agricultural and forestry infrastructure are markers of the damage done to people and land over centuries of peatland destruction. Livelihoods that used to accommodate intact peatlands have largely disappeared. Animals and plants that once inhabited these wet environments have shrunk in number or completely disappeared.

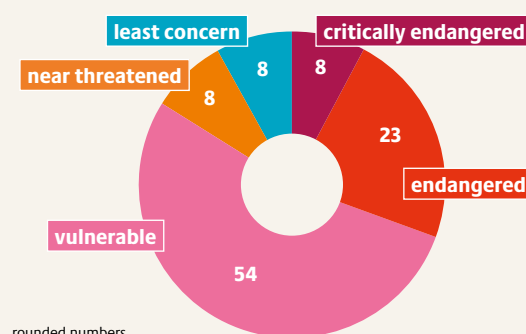
In modern times, peatlands were considered an obstacle to progress. In Western Europe, they have since been converted into farmland to a large extent

By addressing the ecological amnesia surrounding peatlands, history plays an important role as we try to reimagine human-peatland relationships

After centuries of peatland destruction a new paradigm has recently taken shape. While peatlands were long considered useless or dangerous spaces, they are now valued as unique environments. Despite increased support, however, the enormous potential lying in peatlands is far from being exhausted. Often used as farmland or grassland, drained peatlands have generally little in common with their wet, species-rich ancestors. Many are not even recognizable as peatlands. Taking a conscious look into the past makes us aware of the tremendous human and environmental damage linked to the history of drainage and reminds us that supposed improvement has rendered many peatlands invisible. ●

GIVE PEAT A CHANCE

Vulnerability of peatlands in the EU28, in percent



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SAFE HAVENS FOR ECOSYSTEMS IN DANGER

Peatlands all over the world sustain a rich range of habitats and species, including a wide range of threatened and endemic ones. Policymakers are called upon to protect these unique landscapes.

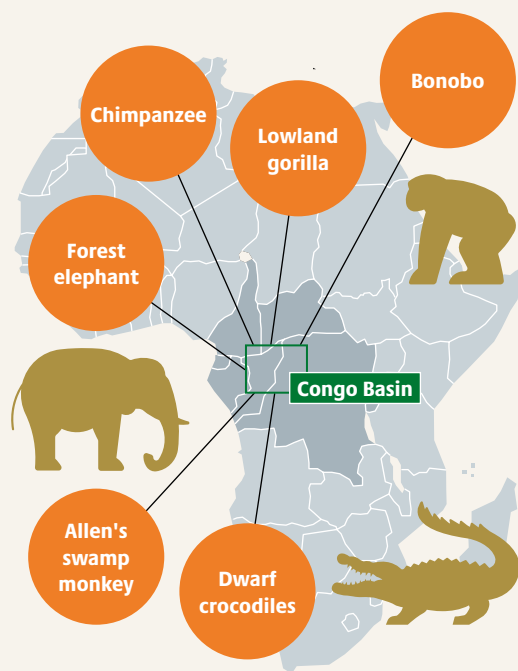
Peatlands are one of a wide range of varied landscapes on our planet, along with forests, grasslands, lakes, marshes, mangroves and other wetlands, all of which contribute to global landscape diversity. Under different conditions, peatlands may be flat, raised or bowl-like. They may have ribbed, polygonal or mounded patterns on the surface, as in the Arctic tundra or the taiga, or be smooth, as along the coast. They may get water from the atmosphere, groundwater, river floods, permafrost or surface flow. They may be covered with trees or reeds – as in the tropics – or mosses, sedges and dwarf trees, as in the taiga.

The surface of a peatland often looks like a piece of art. In the Arctic, where permafrost sculpts the landscape, polygon patterns like ice crystals form on the peatland surface. In the temperate zone, water running from a peat dome creates ridges and hollows. In tropical peatlands, lace-like patterns reflect the former banks of rivers and lakes. All this fascinating diversity of patterns visible from above perform a crucial role in biodiversity: they create a great diversity of habitats within relatively uniform ecological conditions. All habitats in peatlands are densely occupied due to the diversity between and within species of organisms. It has taken thousands of years of evolution to create such highly specialized living communities. Some species have adapted so closely to the extreme conditions of peatlands that they are unable to live in any other habitat. For plants in the temperate zone of Eurasia, there are no more than 15 species that grow exclusively in peatlands: they include the round-leaved sundew or pod grass. In Southeast Asia, some 45 species are recognized as restricted to peat swamp forests, for example, the tropical tree Meranti Bakau, and the woody liana Akar Jitan. In North America, the wood frog is the only species that can successfully reproduce in highly acidic bog waters and can survive deep freezing. The pitcher plant mosquito lays its eggs in the water at the bottom of the pitcher, the larvae is unaffected by the digestive enzymes of the plant – and even providing bacteria to the host plants to help them digest the exoskeletons of other insects that have fallen into the pitcher. Butterfly larvae are tied to plant species at the hormone level: larvae of the ocellate bog fritillary feed on the cranberry only, Cranberry blue lays eggs on blueberry.

There are many other examples of how peatland specialists can survive in challenging environmental conditions. Peatland plants build a microcosm for specific birds, small and large mammals, insects, soil invertebrates, fungi and bacteria. The specialists and their microcosm cannot survive the loss of their habitats when peatlands are drained and changed to other landscapes. If one species disappears, all other organisms that are dependent on it through symbiosis, food,

NOT ONLY REEDS AND BIRDS

Megafauna populations in Cuvette Centrale peatlands in the Congo Basin, Central Africa

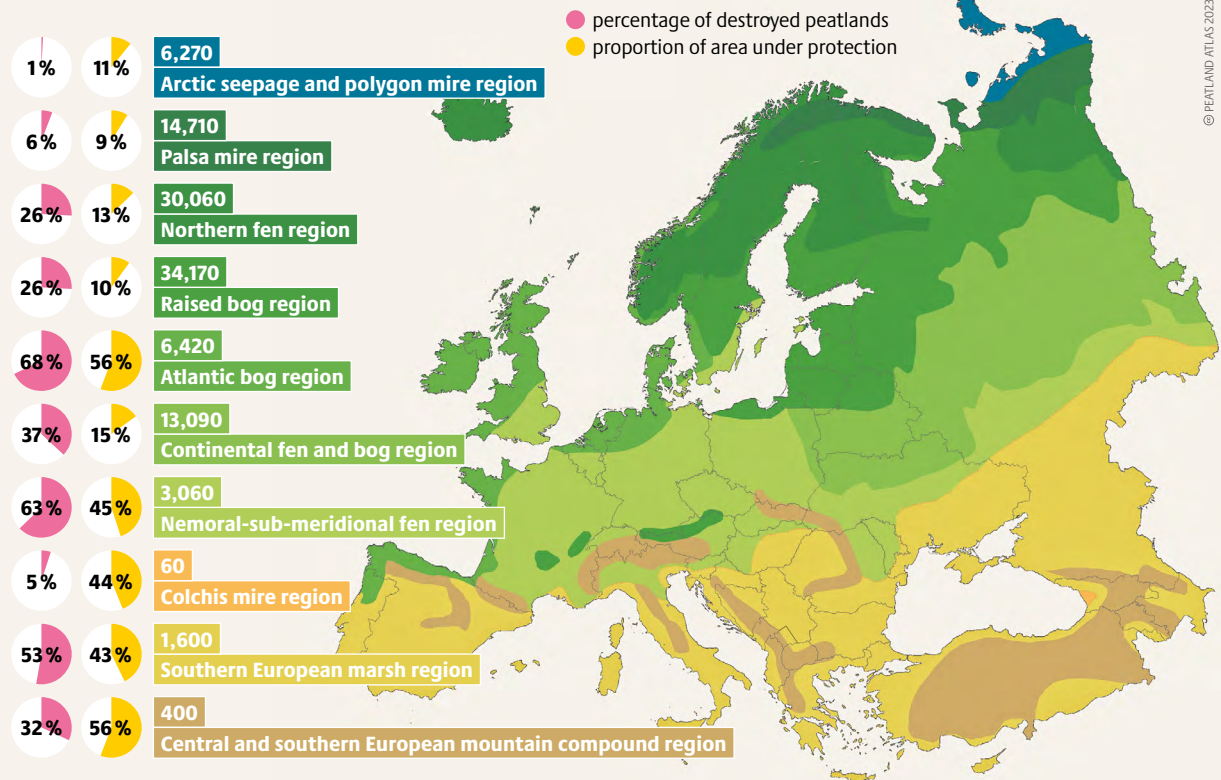


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Peatlands are a patchwork quilt of different types of vegetation and animals. They differ from region to region, continent to continent

VANISHING HABITATS

European peatland regions and total area of peatlands, in 1,000 hectares



shelter or behaviour also disappear. Peatlands also have less-equipped species as visitors – neighbours, nomads or refugees. Species that live in the neighbourhood pay short visits to peatlands during droughts or in the berry season, for nesting or mating, or in search of a wintering ground. Migrating species come to peatlands only to stop over, feed and rest. They usually stop at exactly the same peatland each year, as their ancestors have done for hundreds or even thousands of years. For example: Cranes stop in the German Teufelsmoor on their way to the South, Swedish swifts winter in the Congo Basin. These species lose their landmarks and crucial resting grounds if important peatlands are drained and disappear. Finally, in times of rapid and dramatic loss of other habitats, peatlands are a refuge for species from other landscapes, such as grasslands or forests. Invasive species brought from peatlands in other continents are able to spread in suitable locations. Examples are the insectivorous purple and yellow pitcher plants. These were brought to Europe from North America as ornamentals, and have successfully populated raised bogs in the Alps and the British Isles during the last 20 years, bringing a serious imbalance into these ecosystems.

But why do we need this landscape, geographical, habitat, species and intraspecies diversity in peatlands?

More than half of all pristine peatlands in Europe have been lost – and peatland degradation continues. Biodiversity is at stake

Peatland landscapes have a significant function in maintaining sustainable and resilient socio-ecological systems. The peatlands themselves are built up by the biota that they host. Due to their special features, only the organisms living in peatland can build up peat. Wet peat stores large amounts of carbon and water. That both helps to mitigate climate crisis and provides resilience to landscapes while climate crisis is resulting in much more extreme weather events. Peatland biodiversity not only maintains itself but also sustains very valuable ecosystem services for humanity. The Convention on Biological Diversity and the Kunming-Montreal Global Biodiversity Framework of 2022 call for all countries to protect biodiversity. At least 12 percent of global peatlands are already destroyed. The profits from the use of drained peatlands do not benefit communities that have lost their ecosystem services. We need clean water, settlements near rivers that are protected from flooding, moderated climate conditions, and productive fields and forests. That is why there is need to give strong consideration to biodiversity when restoring and using peatlands. ●

PEATLANDS' RAW MATERIAL

Peat consists of dead organic matter accumulated over thousands of years. Since centuries, peat soils have been exploited to obtain fuel or raw material for growing media. Peat extraction and use is harmful to the environment. Sustainable alternatives will only prevail if politicians act.

Unlike wood or coal, the temperature at which peat burns is reasonably constant and easy to regulate. Peat was already used as a fuel over 4,000 years ago in the Bronze Age. It is still used today as a source of electricity and heat, particularly in Finland, Ireland, Russia, Belarus and Rwanda. Since the middle of the 20th century, it has been used in horticulture as a raw material for growing media. Peat accumulated from peat mosses in particular has many advantages for horticultural use. Its high porosity enables this peat to retain air and water – and release it when required. It also has a stable structure, which is useful especially for long-lasting plant cultures. At the same time, peat contains very few nutrients, pollutants or pathogens.

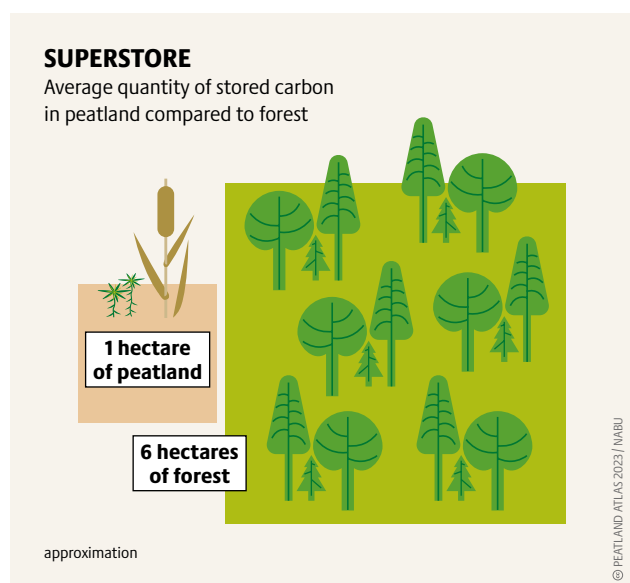
Smaller amounts of peat are also used for other purposes. Peat can absorb liquids quickly, which is why it is used both in livestock bedding and in diapers. Because peat contains hormone-like substances and humic acids and is effective against bacteria, viruses and inflammation, it is considered to be a natural remedy and is used in balneological baths and packs. Dry peat can be

used as insulation material, because it contains a lot of air. In agriculture, peat is applied to improve mineral soils, loosen them up and enrich them with humus. Peat is also used as a raw material in the production of activated charcoal, which is used as a filtering material in industry. Textiles can be made from peat fibre – the name given to the leaf sheaths of sheathed cottongrass, a common plant species of bogs. These fibres are sifted out of the peat when it is being processed for horticultural uses. Peat is also a famous flavouring agent: during the malting process in whisky production, barley is dried slowly over a smouldering peat fire, giving the whisky its famous smoky taste. In Iceland and Germany, people in the past often built houses from peat sods, due to the lack of wood.

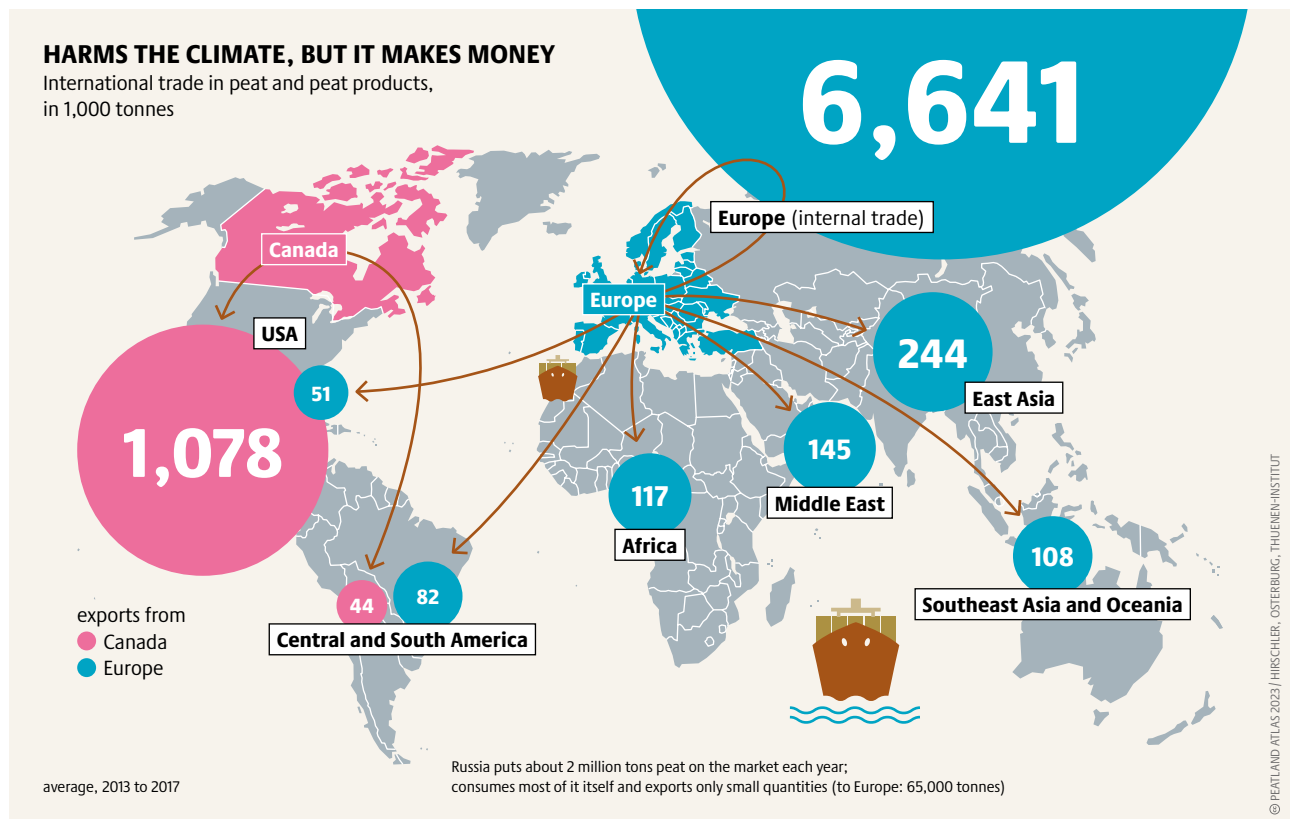
Global peat deposits are estimated at up to 13.8 billion cubic metres. Worldwide, around 24 million tonnes are extracted each year – of this some 83 percent are extracted in Europe alone. Until 2017, more than half of the peat extracted was used as fuel – though this amount decreased considerably in recent years. About 10.3 million tonnes of peat, or 41 million cubic metres, are extracted each year to produce horticultural substrates and potting soil. While peat fuel is generally burned in the country where it is extracted, peat for horticultural use is traded internationally, both as a raw material and mixed into substrates. In Europe, peat extraction for horticulture is concentrated in the Baltic States, Germany, Fennoscandian Peninsula and Ireland. Outside of Europe, peat is also massively extracted in Canada, mostly for export to the USA. Peat extraction for horticulture also exist on a smaller scale in the USA, Russia, Chile and Argentina. The biggest producers and end-users of peat-based substrates are Germany, the Netherlands and the United States.

In the coming decades, the industry expects a strong increase in demand for growing media worldwide, especially in Asia. To meet the societal demands of today, fossil peat should not be used for this purpose, but efforts to produce renewable materials regionally should be significantly increased.

Peatlands store some 600 billion tonnes of carbon, or about one-third of the world's total land-based carbon stores. Peat extraction and use in the European Union (EU) are responsible for greenhouse gas emissions



Garden centres sell good, peat-free potting soil. Using only this would save 400,000 tonnes of CO₂ a year in Germany



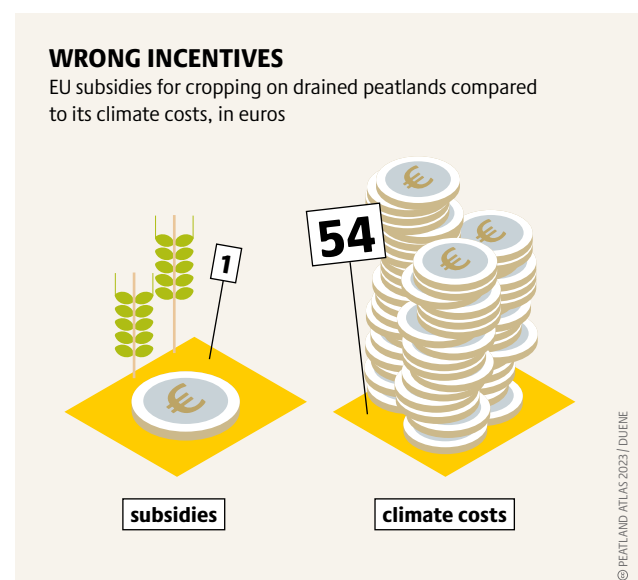
in the order of 21.4 million tonnes of carbon dioxide (CO₂)-equivalent a year. That amounts to about one tenth of the total EU emissions from peatlands. However, the extraction and use of peat, by releasing carbon particularly quickly, result in the highest emissions per hectare of all peatland uses. The Intergovernmental Panel on Climate Change classifies peat as a fossil resource and warns that its use is no longer appropriate in the face of the climate crisis.

That is why several countries are preparing to move away from peat use. One example is Ireland, which aims to end the extraction and use of peat as a fuel by 2030. Finland, currently the European Union's biggest consumer of peat-based energy, aims to cut its consumption by 50 percent by the end of the decade. However, changes in the geopolitical situation since Russia's invasion of Ukraine have thrown such plans into doubt: Finnish companies have cited energy supply uncertainties in announcing plans to resume peat extraction. In several countries, the extraction and use of horticultural peat is being addressed as part of national climate and peatland policies. Germany, for example, plans to phase out the use of peat in hobby gardening by 2026, and to largely replace it in commercial horticulture by 2030. Doing so will require increased

The global trade in peat is booming.
In search for profits, it destroys a fundamentally important carbon store

investments in research and production of peat substitutes. These could come from renewable resources such as wood fibre, bark, compost or coconut fibre, or from biomass produced in paludiculture. Paludiculture is the sustainable production for example of peat moss or bulrush on rewetted peatlands. Demand for such materials is already rising in Europe. ●

Europe's agriculture policies continue to favour climate-harming farming methods. Protecting peatland would be a better economic option



THE COWS THAT EAT PEAT

Our consumption of livestock products has an effect on the climate – through the emission of greenhouse gases and the conversion of natural landscapes into agricultural land. Even more greenhouse gases escape into the atmosphere when peatlands are drained to allow livestock-keeping or to grow fodder crops.

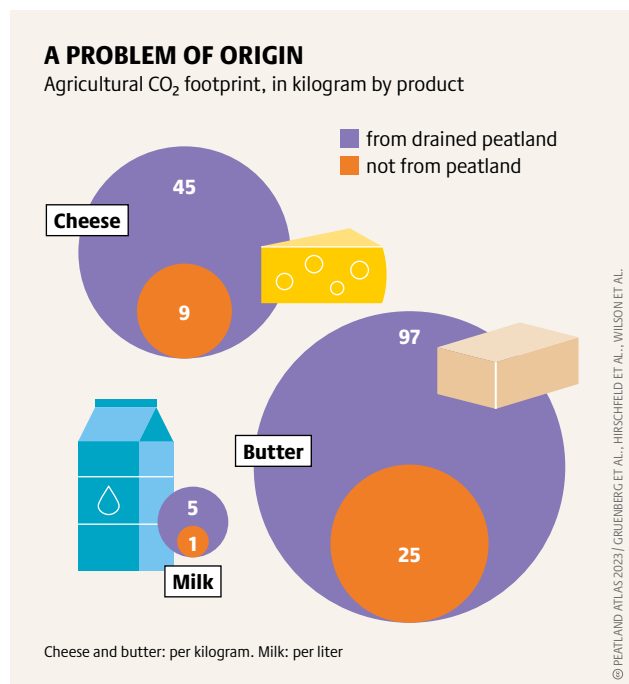
Half of all drained peatlands worldwide outside the tropics are now used for farming. In countries such as Germany and the Netherlands, the figure rises to almost three-quarters of all peatlands. Most are used for keeping livestock, especially as grassland for cattle. European peatlands and other wetlands have historically been used for animal husbandry involving the hand-mowing of fodder, the drying of hay or bedding in nearby higher and drier areas, and grazing on the drier margins of the peatlands. In other parts of the world, these forms of extensive wetland utilization are still common. In Kazakhstan and China, herders harvest fodder and bedding material and allow their animals to graze easily reachable reed beds. In the Flooding Pampa in Argentina or the Pantanal in Brazil, large-scale grazing takes place in wetlands that undergo alternating periods of drought and flooding. But

overgrazing and degradation is often a severe problem, for example in Mongolia, where around 80 percent of the country's cattle are concentrated on peatlands.

While peatlands drained for farming are dominated by meadows and pastureland, they are also used as arable land to grow fodder crops such as silage maize. That requires draining, fertilizing and cultivating the land, which results in very high greenhouse gas emissions. Although peatlands occupy only around 3 percent of the agricultural area of the European Union, their drainage is responsible for 25 percent of the emissions from agriculture and agricultural land use.

Not only is arable farming harmful to the climate; but so is intensive grassland farming on drained peat soils. These areas are used to grow feed, for example for dairy cattle that require high-quality, energy-rich feed. The emissions of carbon dioxide (CO₂) and nitrous oxide (N₂O) caused by drainage can reach 20 to 50 tonnes per hectare per year on intensive grassland. On top of that the high-performance grasses, high fertilization rates and cutting frequencies of four or more mowings a year result in a monotonous, species-poor grassland. Peatlands are used for intensive dairy farming in north-western Germany, Finland, and especially the Netherlands. The city of Gouda, which gave its name to a world-famous type of Dutch cheese, is located in the centre of a peatland that was drained back in the 11th century.

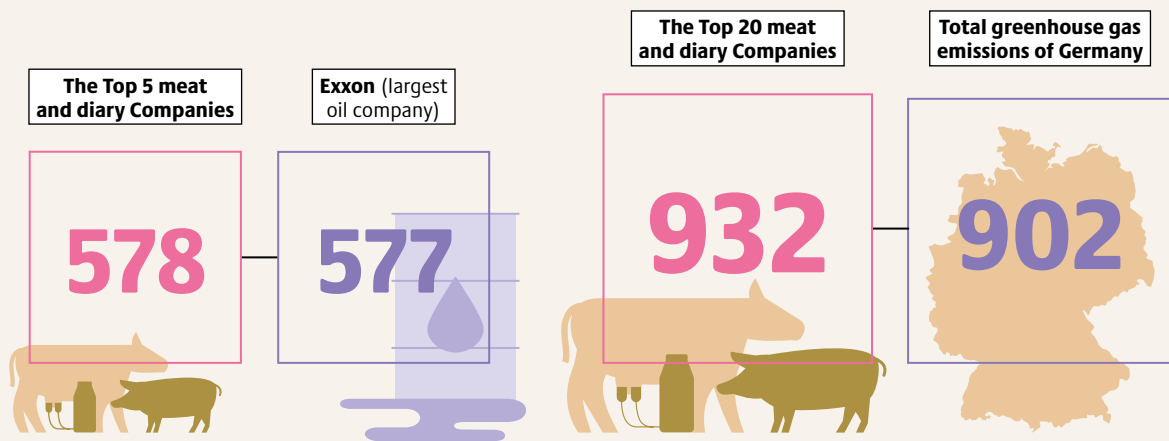
Beef cattle farming can be slightly less harmful to the climate. Fodder quality requirements are lower than in dairy farming, and synergies with biodiversity objectives are possible. The extensive grazing with beef cattle, especially on non-peat soils, can maintain grassland habitats that harbour threatened plants and animals. Cattle eat what humans cannot digest, and so do not compete with us for nutrients. On peat soils, extensive grazing allows for reduced drainage. This can cut annual emissions to less than 20 tonnes of CO₂ per hectare. To preserve the peat and meet climate targets, however, high water levels are needed that cannot be achieved with such grazing. The ground would be too soft for common cattle breeds and the animals would sink into the mud. In addition, the cattle's digestive system is less able to deal with feed from wet pastures, and hoof diseases and parasites such as liver flukes and lungworms are more of a problem. The actual carbon



CO₂ price: arable land and grassland on drained peatlands can hardly be profitable. But carbon costs are currently externalized

DAMAGE DONE BY AGRICULTURE

Emissions of the world's largest dairy and meat producers, in billions of tons of carbon dioxide (CO₂), excluding emissions from drained peatlands



These numbers from 2017 do not include the enormous climate damage caused by drained peatlands. Taken these into account, the companies in the meat and dairy industries are among the largest emitters of greenhouse gases

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footprint of beef products varies, and depends heavily on the type of husbandry and the organic content of the soil. If cattle are kept on drained peat soils, the carbon balance includes not only their methane (CH₄) emissions but also the emissions due to peat degradation. In case of suckler cow husbandry, additional emissions of approximately 80 kilograms of CO₂-equivalent per kilogram of slaughter weight are calculated just for the rearing phase of the calves.

The consumption of meat and milk accounts for a large part of the greenhouse gas emissions attributable to the food system. The effects on the climate are much larger if the animals are kept on drained peat soils. Experts and environmental organisations therefore call for other more sustainable utilisation options for large peatlands. As soon as drained peatlands are rewetted – which is indispensable in order to meet climate targets – only the higher-lying parts are suitable for traditional, extensive grazing. Water buffaloes are an exception since they can also be kept in swampy areas. Around 95 percent of the world's population of water buffaloes are kept in Asia, and especially in India, Pakistan and China. They are used for work in rice fields and for transport. Their meat and milk are an important food source for buffalo keeper in these countries. For Germany it was shown that herd management and marketing are much more demanding than with conventional cattle.

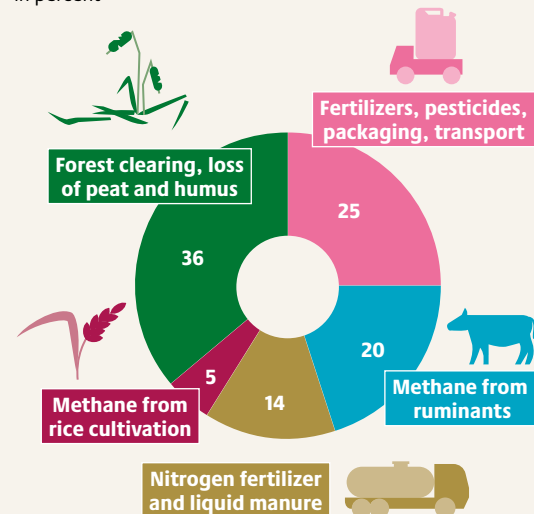
Many farms face major economic challenges in renouncing the use of peatlands. For these farms, palu-

Corporations whose business is based on peatland destruction often refuse transparency when it comes to peat-related emissions

diculture could offer an opportunity. This is a sustainable use of wet or rewetted peatlands. Plant species are cultivated that thrive on permanently waterlogged soils and that produce raw materials that can help decarbonize the economy. Using peatlands in this way enables a double transformation: the necessary withdrawal of livestock from rewetted peatlands meets the need for healthier, climate-friendly diets. ●

INPUT AND OUTPUT

Share of greenhouse gas emissions from global agriculture, in percent



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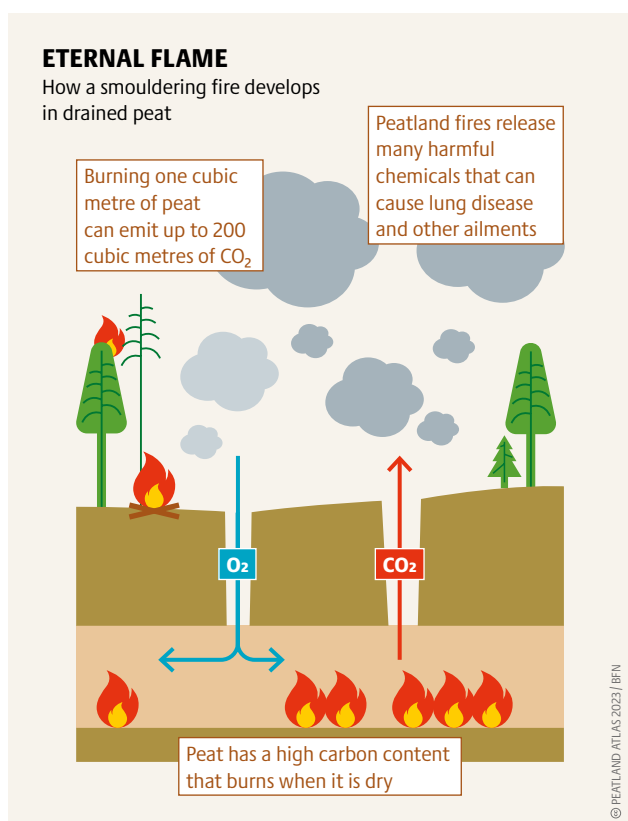
Global drainage of peatlands causes twice as much CO₂ emissions as global air traffic

PEAT, WIND & FIRE

Three percent of the world's peatlands have been destroyed for forestry purposes, releasing large quantities of greenhouse gases into the atmosphere. Drained peat soils are the scene of devastating fires that are used to clear land.

Around the world, some 15 million hectares of peatlands have been drained to make way for plantations or forestry. Often enough the term forestry also means the monocultural cultivation of trees such as pines in plantations. When we refer to peatlands and forests, three drainage-based land use changes can be distinguished: the drainage of already forested mires, the drainage of open, rather treeless peatlands for afforestation, which mostly occurs in the nordic countries, and the drainage of naturally forested peat swamp forests in the tropics for the establishment of plantations after clearcutting the original forest. All can be conducted by large enterprises but also by smallholders, facilitated by the industrialization of forestry and agriculture.

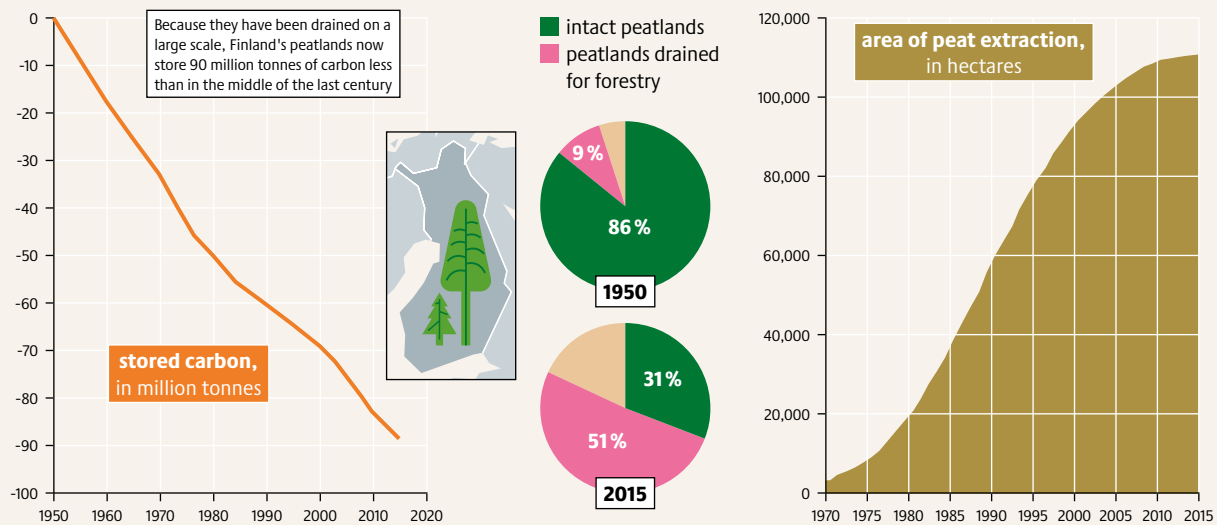
Drainage for intensive, even industrialized land use always leads to a decline in biodiversity. In dense tree plantations, hardly anything can grow on the ground or in the undergrowth. In Europe, the largest areas of peatlands that have been drained for forestry are found in Finland and Russia, where they cover an area of 6.6 million hectares. One-third of Finland's forests are on peat soils, making peat-forest management very important for the country's economy. Since the middle of the last century, Finland has drained more than half of its peatlands – though the government is now making effort to restore them by reversing the drainage. In the tropics, drainage of peat swamp forests accelerated during the past decades due to an increasing global demand for tropical crops, timber and pulp wood such as from palm oil or acacia. Especially Southeast Asia has been a hotspot of peatland drainage, but also other tropical peatland forests are currently under threat as the need for arable land and forestry increases. The dilemma of forestry on drained peatlands is that newly planted trees sequester carbon, but at the same time the drained soils release vast amounts of greenhouse gases into the atmosphere. The decomposing peat emits carbon dioxide (CO₂), while the drainage ditches and canals release methane. Emissions of nitrous oxide may also rise, especially if fertilizer is applied. Drained organic soils are also susceptible to forest and peat fires. Large, long-lasting peat fires occur in the high-latitude parts of Canada and Eurasia, as well as in tropical areas and pose an additional great threat to the climate. Furthermore, these fires produce large amounts of toxic smoke that can be deadly for people and animals. To prevent fires from raging each year and causing loss of biodiversity, significant health issues, massive emissions, widespread destruction and loss of life, it is necessary to maintain and restore moisture levels in peat soils. Rewetted peatland forests provide good conditions for sustainable forestry. Society can benefit in many ways from the climate effect of wet peatland forest, if on the one hand the carbon remains bound in the peat, and on the other hand additional carbon is sequestered in long-lasting timber products. Like other wetlands, peatland forests also act as local cooling: shade and respiration by the natural vegetation



Peatland fires, for example in Asia, are often caused by fires used to clear land for industry and forestry

CAN'T SEE THE PEAT FOR THE TREES

Carbon storage in wet peatland in Finland, and area used for peat extraction



create a microclimate with cooler temperatures and fresh air.

In temperate climates, black alder can grow in areas with high water tables. Its average rotation length – the time from planting to harvest of a stand – is between 60 and 80 years. The wood of the black alder is suitable for special construction purposes and is cheaper than oak or birch. Still, the profitability of such forests is low because of the trees' growth forms as well as their harvest is difficult on soft, wet peat soils, in regions where these soils do not freeze.

A similar problem occurs in tropical peatland forests. There, some large individual trees are so valuable that it is economically profitable to harvest only them, leaving the surrounding trees standing. However, dense stands of other trees and soft ground make it difficult to use machinery. Often, trees are felled illegally, with individual logs being floated down narrow, hand-dug canals. These uncontrolled channels can lead to the lowering of the water table and the gradual degradation of the peat swamp forest, causing emissions and subsidence. To limit both uncontrolled and intended drainage, policies, social and financial incentives, as well as monitoring and law enforcement are needed to manage the land sustainably. Paludiculture, the cultivation of plants adapted to wet peatland environments, and sustainable peat swamp fisheries can combine the preservation of ecosystem services with production of food, feed, fuel, fibre and other goods.

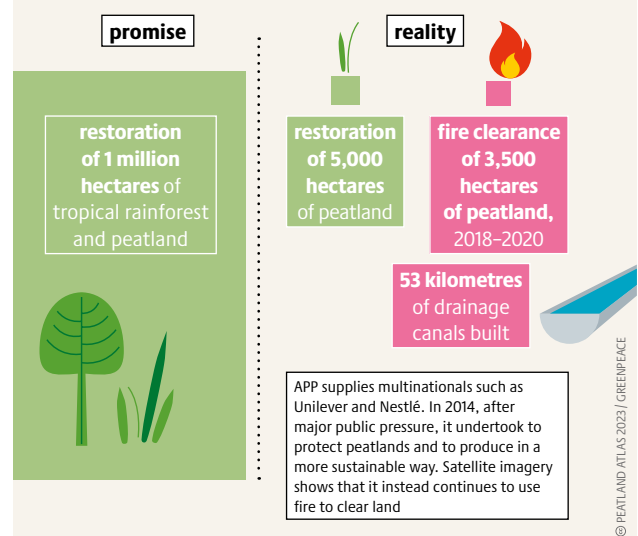
Companies advertise their green credentials – but without legal measures, they cannot be prevented from continuing to overexploit nature

One-quarter of Finland is covered in peat, mainly in forested areas. Some regions of Finland have lost up to 90 percent of their peatland

Already in 2002, the International Mire Conservation Group and the International Peatland Society, proposed a framework for the Wise Use of peatlands. In 2014, the Food and Agriculture Organization of the UN (FAO) has published the report Towards climate-responsible peatlands management. It also highlights the need for capacity development and information dissemination, community engagement, and good governance. ●

MUCH SMOKE

Activities of the paper firm Asia Pulp & Paper (APP) in Indonesia



FILL IT UP TO THE TOP

Drainage pipes and ditches are still being used to drain peatlands. Rewetting is urgently needed to protect both the climate and biodiversity. But how does this work – and what do we have to consider?

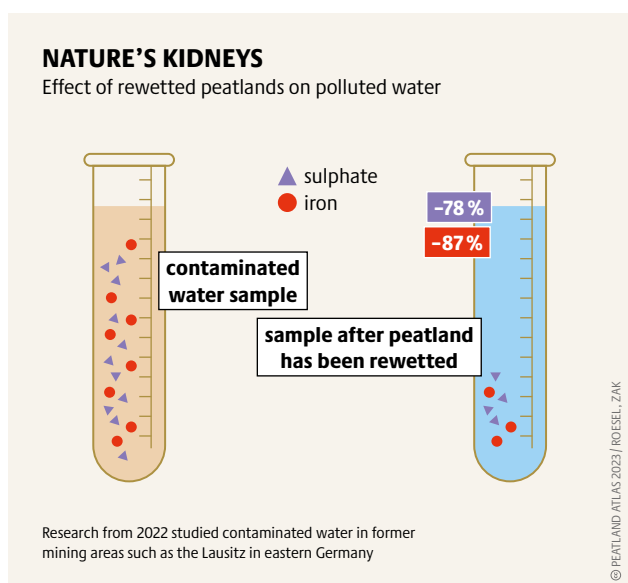
To protect the climate, a peatland should have a water table that is close to the surface of the soil. The majority of intact or rewetted peatlands do not look like a lake, but rather are swampy areas with scattered pools of water. They may have open vegetation or be thickly forested. Because every peatland is different, the rewetting process must be planned for each one individually. Waterflow must be identified, the height differences of the land surveyed, and drillings made in the soil. The soil samples reveal the thickness of the organic layer and the characteristics of the peat – whether it is very permeable or highly decomposed and impervious to water. This information forms the basis for a plan on how to retain water in this particular peatland, and what optimal water level should be aimed at. The rewetting of larger, hydrologically connected areas is usually practical and less demanding. After the conversion works are completed, comprehensive monitoring will be needed to check how the water levels and the habitat for peatland-typical species develop.

For all peatland types, the first step is to bring water back into the peat. In general that means turning

off the pumps, pulling the drainage pipes out of the ground, and blocking up the ditches. Special excavators are used to do this. They ride on extra-wide caterpillar tracks so they do not sink into the soft ground.

The subsequent process of rewetting depends on the type of peatland. If it is rain fed, as in raised bogs, dams are often built to prevent the water from running off to the sides. To build these, suitable peat is heaped and compacted by driving over it with excavator tracks to reduce the flow of water underneath the dam. In some peatlands, it may make more sense to insert a solvent-free pond liner vertically into the ground, creating a kind of enormous bathtub that will fill up with rainwater. The previously dried-out peat will then soak up the water and swell. Adjustable overflows make it possible to set the water level at the optimal height for peat forming. In fens, which are fed mainly by various groundwater and surface water flows, it is necessary to take wider areas into consideration during rewetting. A stream that flows through the depression can be used to provide water to the rewetting of the peat body. By filling in ditches and removing drainage pipes, sufficient water will pond up in the fen. In the ideal situation, this water will be low in nutrients. That allows peatland-typical species that are used to a nutrient-poor environment, such as small sedges and orchids to reestablish. Nutrient-rich and polluted water, which often comes from the surrounding agricultural land, should, if possible, be dammed up in the marginal areas. In this way, the nutrients can be deposited or broken down by chemical processes. Too many nutrients result in more rapid decomposition of the peat and would pollute the peatland.

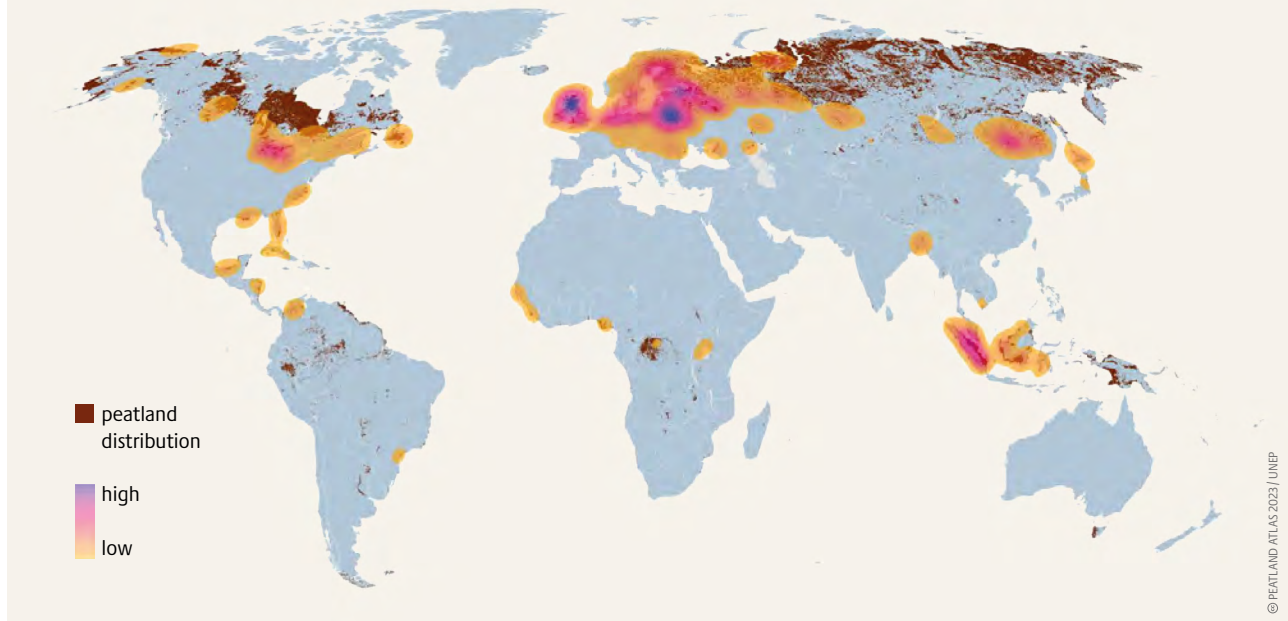
In order to maintain the peat body and also to stimulate peat formation, a certain water level is essential. In addition, erosion caused by too fast water flow should be avoided by giving the water enough space permitting an even distribution. The type of adapted land management will depend on how the peatland will be used in the future. After establishing a suitable water level, land management needs to ensure the establishment of vegetation to protect the peat soils. Especially, in the tropical peatlands that are often fed by heavy rainfalls the reestablishment of peat swamp



Water cleaning through chemical reactions: if rewetted with contaminated water, peatlands extract the pollutants

BAD INFLUENCE

Hotspots of human impact on peatlands



forest vegetation is crucial to slow down run off and avoid erosion.

If everything works out, the peatland will again become a functioning store of water and carbon. That is good not just to climate protection, but also helps mitigate the already present effects of climate crisis. The peatland will act as a sponge to absorb heavy rain and as a natural air conditioner that cools the air.

But despite these urgently needed benefits, not all peatlands can be rewetted immediately. Most of the drained peat soils all over the world are still used for farming or forestry. Transforming them for use under waterlogged conditions will require careful preparation and planning. The complete rewetting of a peatland can only be successful if enough surplus water is available. Such a surplus is not any longer available in all peatlands. Especially in these times the proceeding climate crisis can locally lead to falling groundwater levels and more frequent periods of drought. That said, wet peatlands can counteract precisely these water shortages by retaining precipitation over a large area during wetter times of the year, so contributing to a more even water balance.

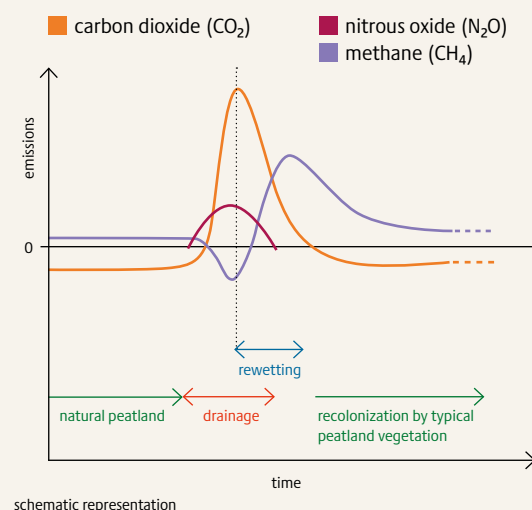
Dealing with these complex interactions requires political will – complemented by the right expertise. Planning departments and construction firms still have too few staff with experience in rewetting techniques and who are familiar with water balances, peat charac-

Anthropogenic changes in peatlands like drainage cause major challenges. Effective governance of peatlands can deliver solutions

teristics and the specific flora and fauna of peatlands. Training such local peatland specialists will be a decisive factor in ensuring the success of peatland transformation. Understanding for rewetting is required among the population, which can be achieved by raising awareness for peatland climate protection and by creating alternative sources of income. ●

RECOVERY TAKES TIME

Greenhouse gas emissions from drained and rewetted peatlands



Greenhouse gases prevent solar energy from being retransmitted into space – thereby heating the Earth up

DEFENDING DIVERSITY

Europe is rich in peat landscapes, which differ widely according to the region and climate. But one thing that the European Union's programmes to protect peatlands have in common is that they are not very effective.

Peatlands cover a total of 35 million hectares in the European Union (EU). The EU country with the highest proportion of peatlands is Finland, where peat covers around 25 percent of the land surface. Some 20 percent of Ireland and Estonia are covered by peat, followed by Sweden with 15 percent. Uncertainties in data show that the figures are not directly comparable between countries. For example, peatlands are not designated as such in some countries.

Peatlands in the European Union have a long land use history. Around half of the peatlands are classified as degraded due to peat extraction and drainage for agriculture or forestry. Southern Europe has the highest proportion of degraded peatlands, although this region also has more peatlands in protected areas, for example in EU Natura 2000 sites. LIFE, the EU's programme for nature, is also financing peatland projects across EU, but their spatial extent remains limited. Most intact areas where peat is still accumulating are located in the northern parts of the continent. In the European Union, around 120,000 hectares, or just under one percent of the total drained area, has so far been rewetted.

The European Union has a concerted agricultural policy for the last 60 years – the Common Agricultural Policy (CAP). With an annual budget of 55 billion euros, it has a major influence on the direction of agriculture. The use of drained peatlands is fully eligible for support, whereas rewetting has in the past usually led to a loss of support due to the change of use involved. Only 12 of the EU's 27 Member States have included peatland conservation in their national plans for implementing the CAP. And on only two percent of peatlands water abstraction via drainage is banned. Between 2014 and 2020, only 2,500 hectares were actively restored under the CAP.

With the start of a new funding period in 2023, it is now possible for Member States to subsidize rewetted areas via the CAP's direct payments mechanism. That makes raising the soil water levels more attractive to farmers, but at the same time payments for drained agricultural sites continue. Also, scientists say that the protection of peatlands in national implementation plans is far from sufficient, with only a minority of Member States making use of this option.

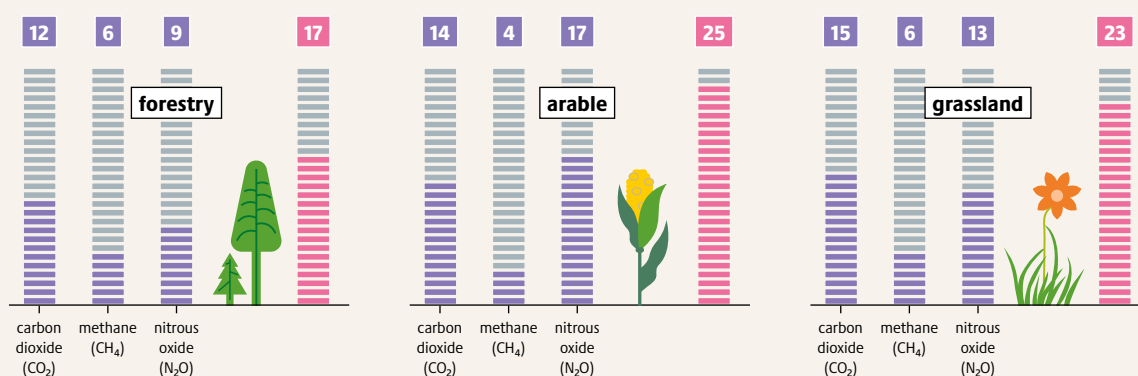
Beyond the flat-rate area payments, there are at least some promising efforts to improve the situation of peatlands in the EU through targeted support measures such as organic farming schemes and agri-environmental and climate schemes. But it is still too early to judge their success. This will depend largely on the

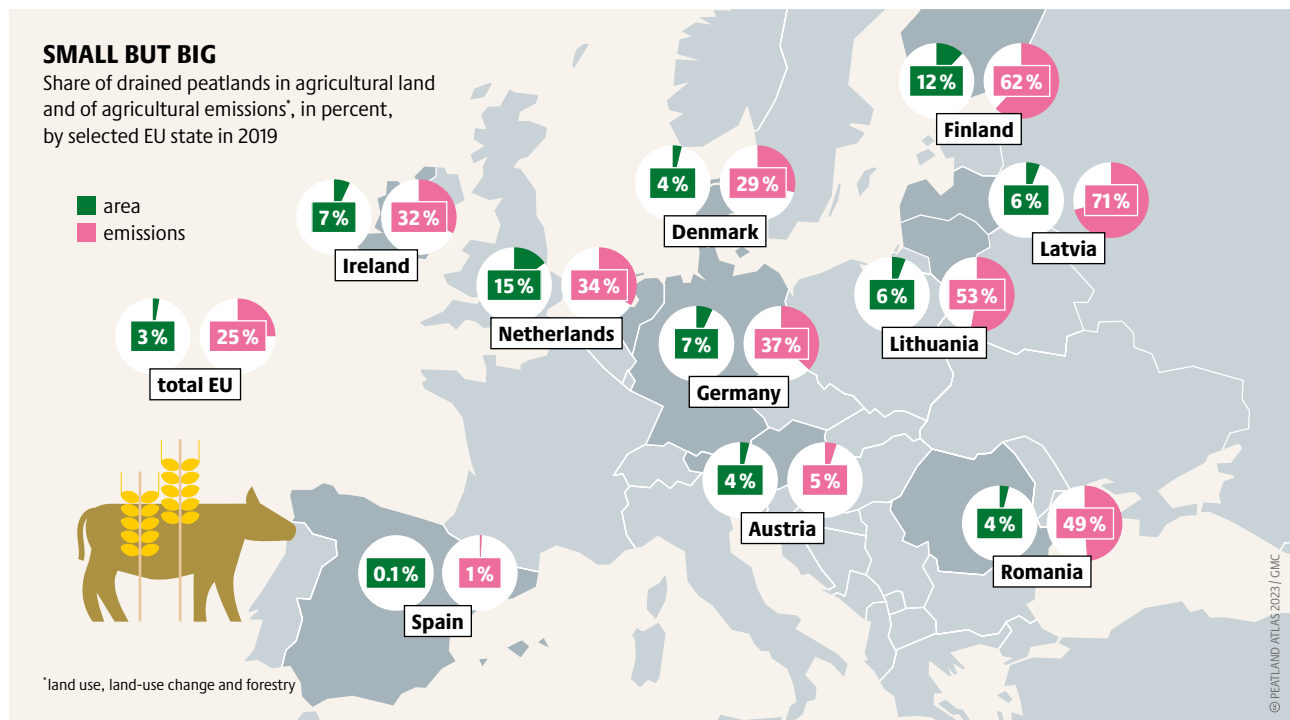
Many states fail to take part in the EU-wide documentation of peatland emissions. Member States often lack data and knowledge

FALLING THROUGH THE CRACKS

Number of EU states that document emissions from drained peatlands under forestry, arable land and grassland

■ number of EU states conducting documentation
■ number of EU states with emissions from drained peatlands





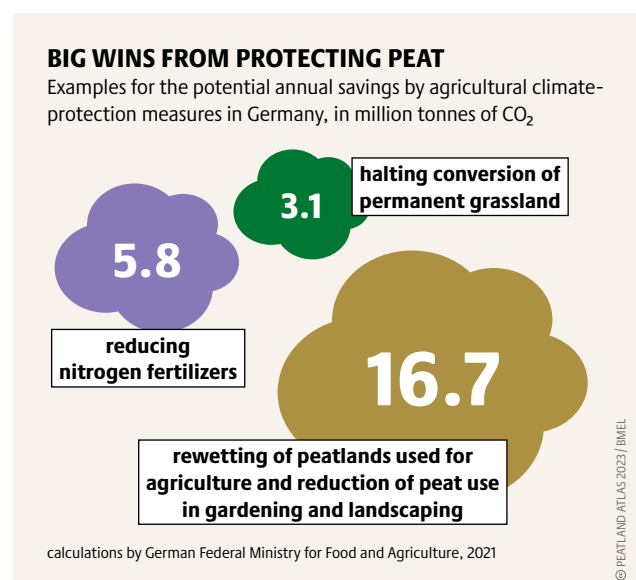
budget available and farmers' acceptance of the tailored measures.

The European Green Deal is more promising to bring about a change in the right direction as it covers biodiversity, land use and soil policies in a coherent manner. As part of the deal, the European Commission proposed the Nature Restoration Law in June 2022. This aims to set concrete, legally binding goals for restoring ecosystems for the Member States. The proposal includes a special role for peatlands. It requires that the Member States step by step restore 70 percent of their degraded and agriculturally used peatlands by 2050, half of it through rewetting. Yet this law has seen strong resistance by parts of the EU legislator. The Council of the EU has adopted its position in June 2023, yet introduced more flexibility for Member States. It has also reduced the area of peatlands, which has to be restored to 50 percent. The European Parliament on the other hand has completely deleted the peatland restoration targets as part of agricultural lands in its position. Trilogue negotiations between Parliament, Council and EU Commission are ongoing, yet it can be expected that the final law will be less ambitious than the original proposal by the EU Commission. Scientists and environmental NGOs state that even with the Commission's proposal an insufficient area of peatlands would be rewetted to reach overarching goals for example for climate action or biodiversity conservation.

The climate crisis means we must change the way we farm. Protecting peatlands will play a crucial role

It can be very effective: in many countries, rewetting peatlands could save large amounts of agricultural emissions

European legislation requires individual Member States to balance emissions and carbon storage in their land use. Despite the current rules, emissions from drained peatlands have not yet decreased significantly. Peatlands in the European Union currently emit 220 million tonnes of CO₂-equivalent per year. Overall, drained peatlands are responsible for 7 percent of the EU's greenhouse gas emissions – they are by far the largest source of emissions from agricultural land use and forestry. ●



THE CONSEQUENCES OF CONSUMPTION

The consumption and production of commodities such as timber are major drivers of deforestation and forest degradation. They also cause peatland degradation on a grand scale.

Europe is a major hotspot for peatland degradation because of peat extraction and the use of peatlands for agriculture and forestry. Other major hotspots are Northeastern China, Southeast Asia and the American Midwest. An estimated 88 percent of the world's peatlands remain largely unused and undrained. But these ecosystems are increasingly threatened. This is particularly true in the tropics, where only in the last decades peatlands have been extensively drained and their land use converted to

provide food, fibre, timber, fodder and fuel. The three main commodities on global peatland are palm oil, cattle and rice. Especially in Southeast Asia, many of the most peatlands are form under forests.

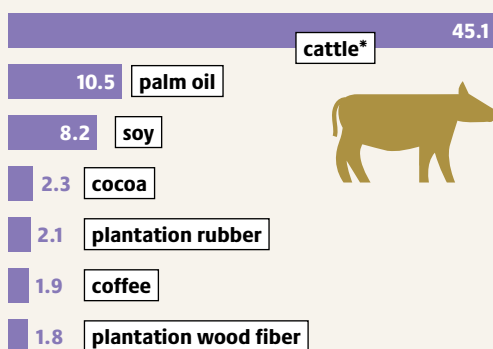
Palm oil is well known for its link to deforestation. This crop is the most efficient producer of vegetable oil, accounting for about 30 percent of world production. After India, the European Union (EU) is the second largest importer, importing 6.3 billion euros worth of palm oil and palm oil products in 2021, mostly for biofuels. Indonesia and Malaysia are the largest producers of palm oil from drained peatlands. Together they supply almost 75 percent of the EU's imports.

Meat and dairy products also put pressure on peatlands. Eighty percent of Mongolia's cattle graze on degraded and natural peatlands, for example, though these cover only 2 percent of the country. On the other side of the world, the Pantanal in Brazil – a major wetland including peatlands – is under pressure from cattle production and widespread forest fires used to clear land for expanded pasture. The Pantanal's wetland area has shrunk by almost one-third since the 1980s, but a recent law allows extensive cattle ranching and tourism in protected areas in the region. In 2022, Brazil was the EU's largest source of agri-food imports, accounting for 12 percent of its total imports. In 2022, around 52,342 tons of meat (excluding poultry) were imported from Brazil to the German market. The import value in that year was about 111 million euros.

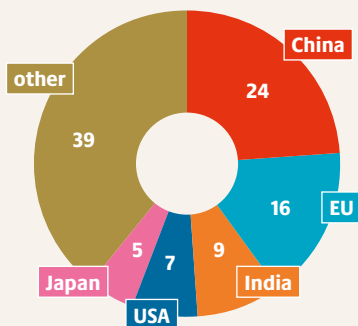
The EU imports around 1.2 million tonnes of milled rice per year, mainly from Southeast Asia. Peatlands and rice production have a troubled history. The most notorious example of rice production on peatlands was the Mega Rice Project, launched in 1996, which aimed to drain and convert 1 million hectares of peatland on the Indonesian island of Kalimantan. The project failed to produce rice on a commercial basis and was abandoned after three years. It failed because the peat, which was more than half a metre thick, provides fewer nutrients than mineral soil, and because it was difficult to control the water levels – which are crucial for rice production. However, Indonesians

CHAINSAWS AND SUPPLY CHAINS

Total forest replacement 2001–2015, by commodity in million hectares



Deforestation associated with international trade, in percent



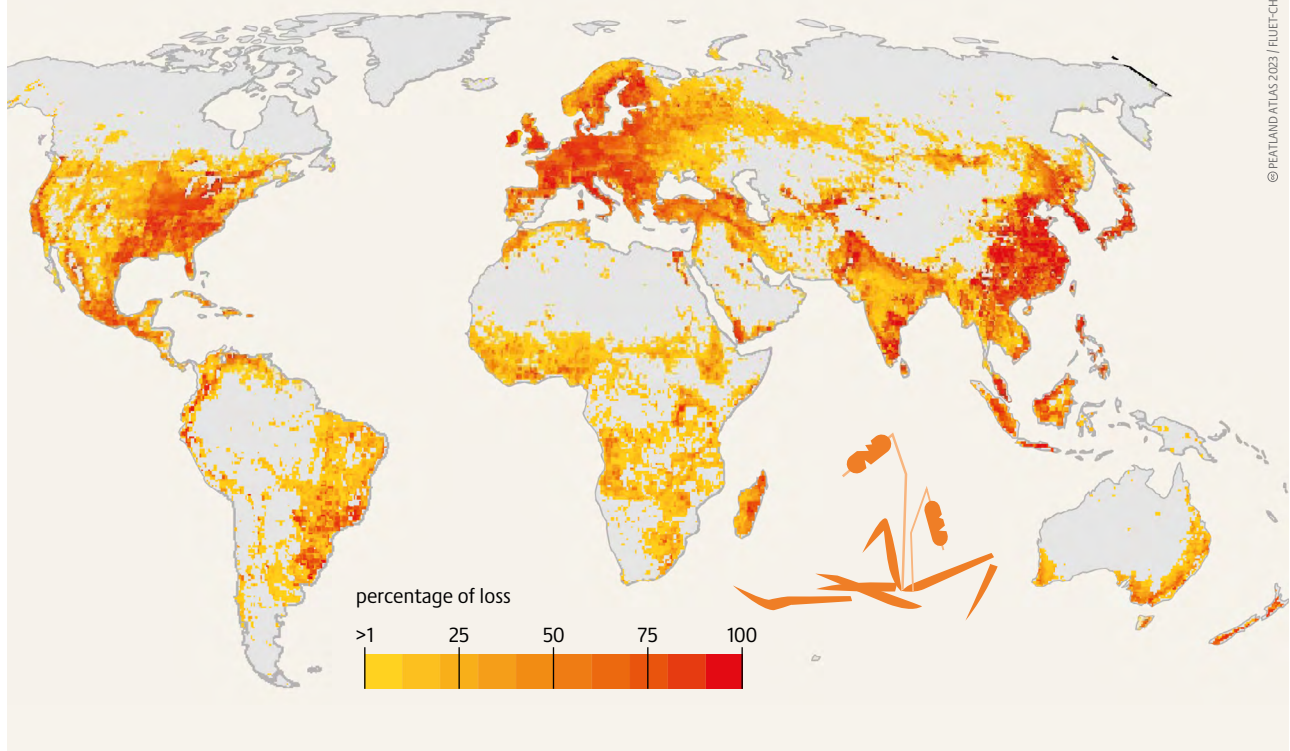
*pasture as land use

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Since 2000, Indonesia lost almost 20 percent of tree cover. The EU is the second largest importer of tropical deforestation

20 PERCENT OF THE WORLD'S WETLANDS HAVE BEEN DESTROYED

Loss of wetlands since 1700



are still suffering the consequences of the large-scale drainage undertaken for the project, as it is difficult to restore such peatlands to their functioning state. Fires in the former Mega Rice Project area released 173,000 tonnes of carbon each year and created a haze that blanketed the region and forced many activities to come to a halt. Despite this, the Indonesian government has shown interest in restarting rice production in the project area. It is negotiating a free-trade agreement with the EU to increase trade and investment while promoting sustainable development – which should include peatland management issues.

To reduce damage to forests worldwide, the European Union recently adopted a law on deforestation, which came into force in June 2023. It requires companies to trace the commodities they are selling back to the plot of land where they were produced. This is a step forward for forest protection and management, and many forest organisations have welcomed the law and its aim to promote trade of deforestation-free products in EU markets. But the law's scope is limited to forests, so it could have the effect of encouraging commodity production to shift away from forest land to peatlands and other ecosystems, putting these areas under additional threat. This is despite the legislators' recognition that efforts to protect forests should not lead to the conversion or degradation of other natural ecosystems. Reviews of the law in 2024 for other wooded land, and in 2025 specifically for wetlands and peatland, will pro-

Using 3,320 records, scientists found out that wetlands larger than India were destroyed globally in the last three centuries

vide an opportunity to expand its scope to include peatlands and peatland-friendly supply chains.

Many countries lack accurate inventories of their peatlands. This makes it difficult to monitor the volume of imports into the EU that have been produced on drained peatlands. Data collection and monitoring of agricultural production on drained peatlands are urgently needed to support peat-rich countries to invest in alternative production practices, such as paludiculture, which have proven benefits for climate and biodiversity. A good example is the EU-funded "People for Peat" project, which supports better peatland management in Southeast Asia. Global agricultural, forestry, mining, food and beverage industries need to invest in product certification and in making their supply chains peat-friendly by ensuring that they avoid the additional loss of peat and do not cause further degradation. The certification scheme of The Roundtable on Sustainable Palm Oil (RSPO) is an example: it does not allow the establishment of new plantations on peatlands. Non-government organisations urge that such measures be included as well as better data collection and monitoring in future revisions of the EU's deforestation law, and for the law's scope to be extended to include peatlands by 2025. ●

MORE FROM THE MARSH

Reeds are used to make thatch for roofs, and grass fibres are used to make furniture: paludiculture combines peatland conservation with agriculture. Strong political support is needed to give this sustainable way of using rewetted peatlands a chance of success.

Many peatlands were originally drained to create husbandry or for peat extraction. Rewetting does not mean that they should be left unused. The use of wet and rewetted peatland for agriculture or forestry is called paludiculture. This concept was developed more than 20 years ago. The name comes from *palus*, the Latin word for swamp. While drainage aims to subject an organic soil to a particular type of land use, paludiculture allows it to be used in accordance with the natural conditions. It stops peat decomposition and reduces greenhouse gas emissions. The idea is to maintain high water levels that keep the peat completely waterlogged all year round, so preserving the peat.

Typical paludiculture plants are those that can cope well with these high moisture levels and whose above-ground biomass has an economic use: they in-

clude reeds, peat mosses, rushes, papyrus, alder, sedges and other grasses. Paludiculture does not focus on food production, but on renewable raw materials that can be used in construction, as insulation or in manufacturing. Biomass from paludiculture can also be used to produce paper, cardboard, other packaging materials, and bio-based chemicals used to make pharmaceuticals, along with resins and bioplastics. It is also possible to raise livestock on wet, swampy land. Water buffaloes, for example, have wide hooves that make them suitable for use in landscape maintenance. Peat moss, bulrushes and reed produce a variety of raw materials for substrates for peat-free horticulture. Energy can also be produced with paludiculture biomass. Local power stations can burn hay harvested from wet meadows to produce heat for many homes.

Papyrus is a highly productive aquatic perennial with stout stems that can reach 4 to 5 metres in height. It typically dominates valley peatlands in Africa, but also forms floating mats along lakeshores or in permanent wetlands. It has a long history of being used to make paper, boats, mats, baskets and thatch. It is also burned as fuel in cooking stoves. Sanitary pads can be made from the fibres, and are marketed in Uganda under the name MakaPads. Papyrus is harvested mostly from natural stands. It is important to harvest such stands sustainably to promote regrowth and to generate a reliable income, but recommendations on how to do this are often not available, or are not followed.

In Indonesia, there are approaches that combine rewetting, the revegetation of peat-swamp forest, and the revitalization of rural livelihoods around peatlands. Several tree species are being cultivated in rewetted, degraded peatlands and used by smallholders. One of these is Jelutong, which produces a latex used in dentistry, insulation materials and chewing gum.

As a result of their adaptation to the special habitats, many wetland plants have developed specific characteristics that can be put to very good use. Peat moss, for example, acts as a sponge, making it an ideal substitute for peat as growing media for plants. One kilogram of peat moss can hold up to 30 litres of water. Bulrushes have air-conducting tissues in their leaves which they use to transport air to submerged parts of the plant. These tissues give the plants great stability,

SUPPLIES FROM SOGGY SOIL

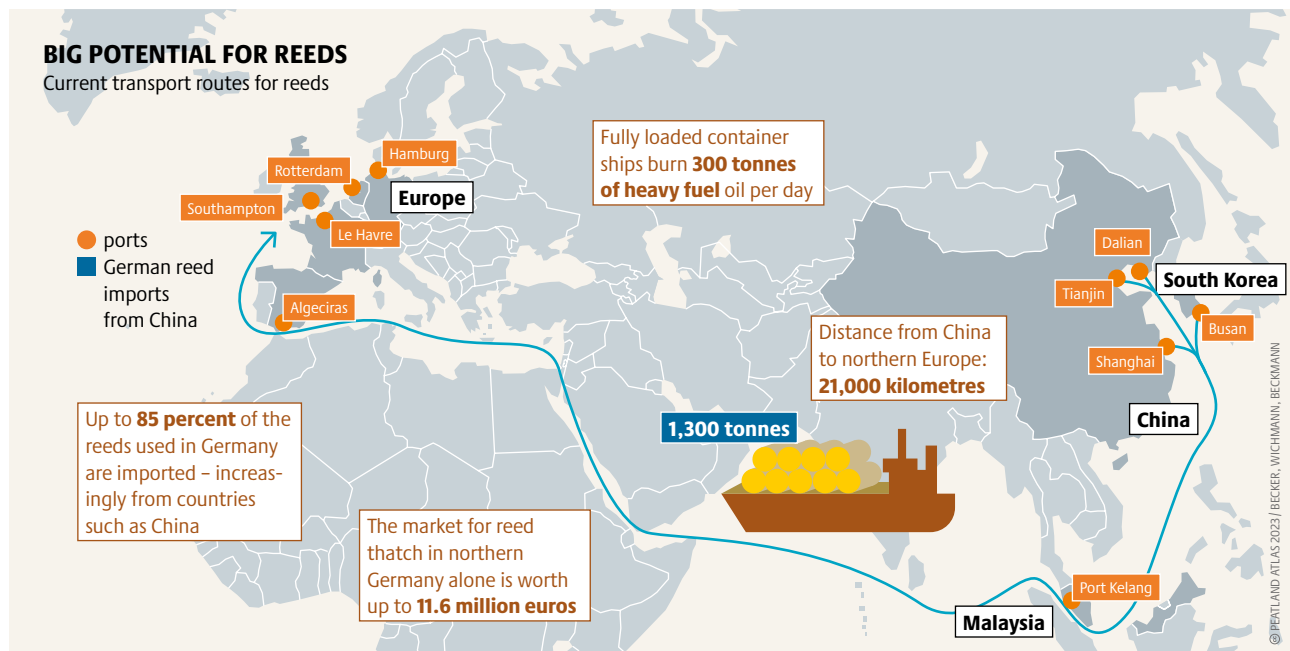
30 examples of paludiculture



	construction	fuel	biogas	livestock bedding	fodder (pasture)	fodder (silage)	medicine	food	peat substitute
bogbean									
cranberry									
reed canary grass									
bulrush									
reed									
black alder									
sedge									
sundew									
peat moss									
gypswort									
willow									

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Examples of the variety of paludiculture species with special economic interest. The bogbean for example can be used to treat liver problems



making bulrush a promising raw material for building and insulation materials.

For farmers and foresters, switching from a system based on draining the peat to paludiculture poses an enormous challenge. They have to establish new plantations, raise water levels and purchase new equipment. They often need to carry out construction work, so they have to plan and obtain the necessary permits. To cultivate wet peat soils at all, they need adapted vehicles that exert a low pressure on the ground. And because the crop can no longer be processed like palm oil or used to feed dairy cattle, they need to develop new processing methods and distribution channels. Without political support, farmers will not be able to cope with this mammoth task.

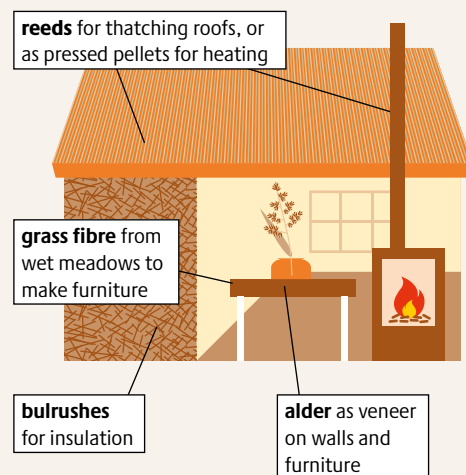
Blown-in wall- and attic-insulation made from bulrush, or furniture boards made from grass fibres: many prototypes from paludiculture products already exist. In Europe, for example, they already are an ecological alternative to raw materials that would otherwise have to be imported from far away. But there are still few paludiculture products on the market: there is simply not enough rewetted peatland yet to grow the raw materials that is needed to produce them in larger scale. This means that there is not enough raw material for processing companies to invest in the new production methods needed to switch to paludiculture. Experts are therefore calling for public investment along the entire value chain. Public construction projects could set an example by using climate-friendly

Rather than shipping reeds halfway round the world, they can be grown more cheaply and sustainably in Europe using paludiculture

building materials from regional paludiculture. Paludiculture products have multiple positive impacts on the climate: rewetting the land reduces greenhouse gas emissions from peat oxidation and helps to store carbon in the soil. Paludiculture products replace materials produced from non-renewable resources using fossil fuels. Product labelling, subsidies or area payments could provide stronger incentives for farmers and companies to switch to this sustainable form of production. ●

HOME REMEDIES

Use of paludiculture products in house construction



Paludiculture products have so far been used mainly in tiny houses. But they can be used in regular houses too

SCORCHED EARTH

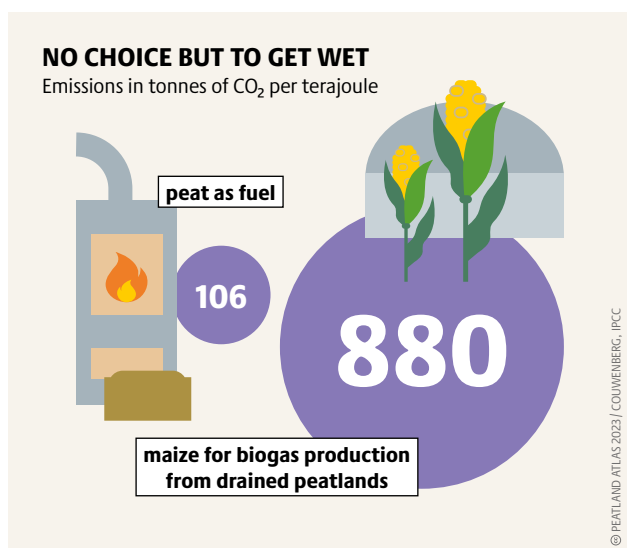
People have been using peat for heat since the Bronze Age. They still do so today in countries like Finland, Belarus and Rwanda. This is not sustainable – but there are new, climate-friendly ideas for how peatlands can help generate heat and power.

Extracting and burning peat not only destroys layers of organic matter that have accumulated over thousands of years. Extracting the peat requires draining the peatland, releasing huge amounts of carbon that had been drawn from the atmosphere and stored in the ground in the form of peat. Although it has long been known that burning peat affects the climate, the material is still extracted for energy, mostly from raised bogs. In 1999, over 21 million tonnes were extracted in Europe alone, mainly in the northern and eastern parts of the continent. Different reporting standards across Europe mean that there are few reliable figures for more recent years. Peat is still an important energy source in Belarus and Finland. In 2020, peat accounted for 3.4 percent of Finland's total energy consumption. The Finnish state is a major shareholder in Fortum, an energy company that is helping to build a peat-fired power plant in Rwanda, among other projects. This climate-damaging but potentially very profitable project is being carried out under the guise of development aid.

The Rwandan government has commissioned two peat-fired power plants, one at Gishoma, near Lake

Kivu, with a capacity of 15 MW, and the other at Gisagara, on the Akanyaru River, with a capacity of 80 MW. The Gishoma plant was due to start operating in 2017 and the Gisagara plant in 2020. According to projections, by 2024 peat will account for 17 percent of the country's energy mix. However, both plants have yet to come on stream due to furnace malfunctions and seasonal flooding. Nevertheless, peat extraction is already underway near both plants, with some of the peat being used as fuel by nearby cement factories.

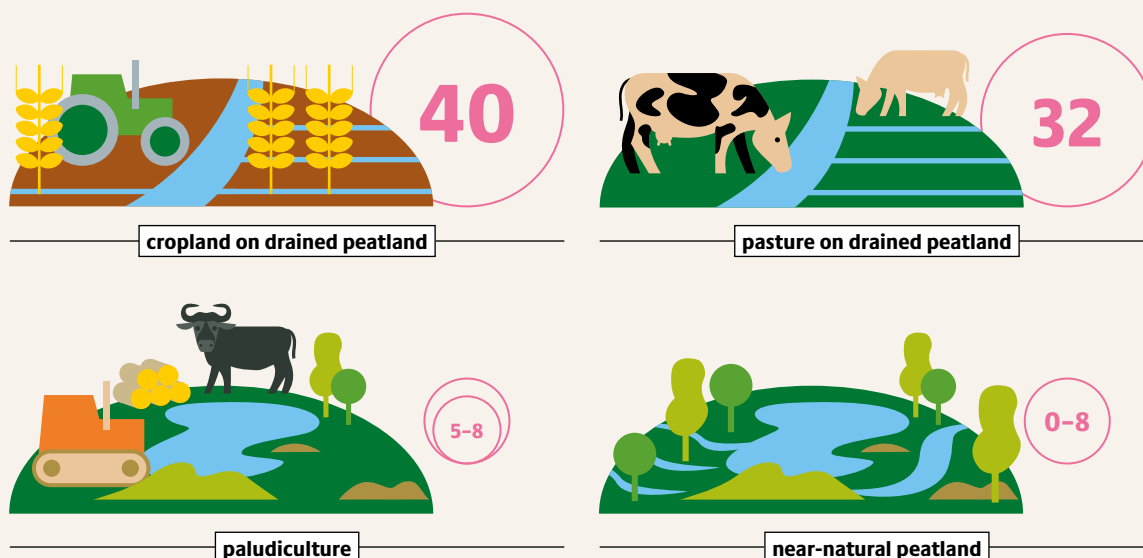
To stop the destruction of peat and the huge greenhouse gas emissions caused by drainage, the waterbody in peatlands must be restored to its original level. This rewetting process goes hand in hand with other forms of land use. One way of reconciling agriculture and peat conservation is paludiculture. This type of peatland use depends on high water levels. Biomass from paludiculture offers the opportunity to switch regional energy supplies to renewable resources. It is not dependent on wind and sunshine and can therefore be an important part of the energy transition. Unlike wood, the biomass can be harvested every year. Burning it releases only as much carbon into the atmosphere as was sequestered in the previous year – not over decades as with wood. Despite harvesting the above-ground biomass, peat can still accumulate because plants such as sedges produce peat from their roots, which are not harvested. They remain in the wet soil and turn into peat over the years. Biomass from paludiculture can be used in thermal power stations or biogas plants. Suitable species from wet meadows include sedges, reed canary grass, as well as reeds and rushes. Their biomass can be burned using combustion systems adapted to the high ash content and critical components of the biomass. This avoids unwanted emissions of carbon monoxide and nitrogen oxides and prevents premature wear and tear on power plants. Biodiversity also benefits when mowing is scheduled outside the breeding season of reeds or meadow breeding birds. Biomass must be harvested when dry, as only dry material has a high calorific value. Once dry, it can be rolled into bales for storage or pressed into pellets. Pilot projects show how this can work. Since 2014, a power plant in Malchin, a town in northeastern Germany, has been producing 3,500



When burned, biomass from drained peatlands emits more CO₂ than fossil fuels. There is no way around it: peatlands must be rewetted

INTENSIVE USE HARMS THE CLIMATE MORE

Annual emissions of greenhouse gases, in tonnes of CO₂ equivalents per hectare



© PEATLAND ATLAS 2023 / GMC, THUJENEN-INSTITUT

megawatt hours of heat from local wet meadows. This is enough to supply around 500 homes, as well as several schools and offices, via a heating network.

Wind turbines and solar farms can also be built on peatlands. But up to now the necessary rewetting of peatlands has often not been taken into account in the planning of such wind and solar farms, even though it is essential for meeting our climate targets. The systems that have been built are not adapted to wet conditions, which hinders peatland restoration and thus the reduction of greenhouse gases from peatlands. A further difficulty is that rewetted peatlands need to develop a continuous vegetation cover to protect the peatland. Solar farms must therefore allow enough light to pass through to ensure plant growth under the solar panels. There is still a lack of suitable demonstration sites where it can be clearly shown that such renewable energy systems can be successfully installed on wet and unstable soils.

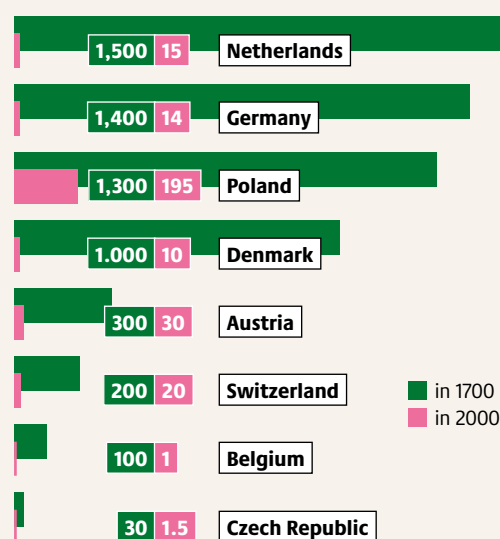
One step in this direction is Germany's Renewable Energy Sources Act of 2023, which prohibits subsidies for solar farms on drained peatlands, but provides additional financial support for solar farms on permanently rewetted peatlands that were previously used for agriculture. As peatlands also play an important role in preserving biodiversity, experts are urging that the feasibility and environmental impact of such systems is tested first. Depending on their suitability and

Harvesting biomass for heating and grazing water buffaloes: paludiculture makes a sustainable and profitable use of peatlands possible

the rewetting process, solar farms on peatlands should be restricted to drained, degraded or cultivated areas outside actual or potential protected areas. And the effects of wet peatlands and solar farms to each other need to be monitored in order to counteract any negative consequences. ●

VERY LITTLE LEFT

Area of raised bogs in Europe, in 1,000 hectares



© PEATLAND ATLAS 2023 / BFN

Centuries ago, peat was an important source of fuel in Germany. It came mainly from bogs, which have been particularly damaged by peat extraction

SMALL CONTINENT, ANCIENT LANDSCAPES

Few peatlands in Europe are located within protected areas, and even there, they are not always protected adequately. National agricultural policies provide little or no support for the development of sustainable peatland-management practices.

Peatlands can be found in all countries in Europe except Malta. They are concentrated in north-western and eastern Europe and in the Nordic countries. In southern Europe, peatlands are less common. Areas with a natural surface peat layer more than 30 cm thick cover almost 59 million hectares in Europe, this equals 12 percent of the world's peatlands. If shallower peatlands are included, the total area is 100 million hectares, or about 10 percent of the total surface area. Europe's main mire regions vary substantially in size, mire diversity, peatland condition and protection. Throughout Europe, only 16 percent of the peatland area is located within protected areas, and often this does not equal adequate protection.

The largest peatlands in Europe are a 178,000-hectare mire named Ocean in the Republic of Komi, and the 96,000-hectare Polisto-Lovatsky mire in Pskov Oblast in western Russia. The smallest peatlands are located in the highlands and steppes and cover only a few square metres. Across Europe, the average depth of peat is 3 to 4

metres, with maximum depths typically 10 to 12 metres. The deepest peatland in Europe can be found in northern Greece at up to 190 metres: The Philippi peatland. This area provides a unique opportunity to study the transition from peat to coal at a depth of around 120 m.

The EU's European Red List of Habitats, which covers the EU, the rest of western Europe and the Balkans, includes 13 treeless peatland habitats, three of which are considered as vulnerable and one as critically endangered. Including non-EU countries in eastern Europe would result in a different list of rare peatland habitats. Bogs and spruce-dominated peatlands are not endangered in the Carpathians and Urals or in the Russian part of the East European Plain.

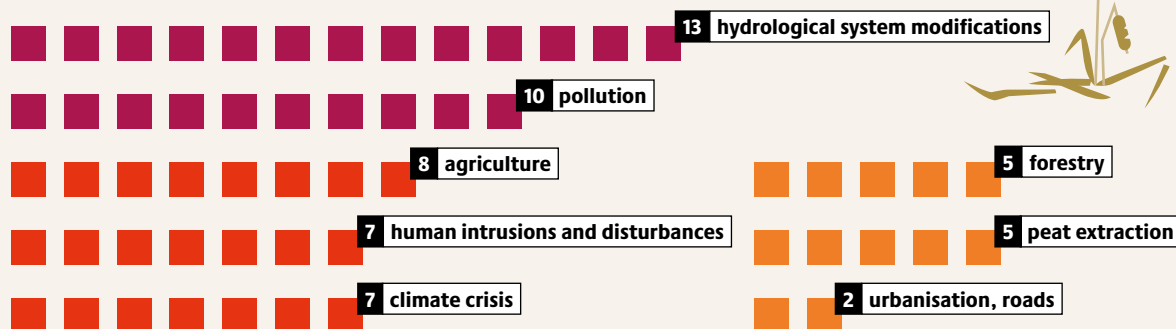
Mire landscapes often include rather few species, but highly specialised ones. The proportion of endangered species in peatlands is often higher than in other ecosystems. The IUCN's Red List of Threatened Species includes nine European vascular plants and five types of birds. Important umbrella or flagship species in European fens are the aquatic warbler, the fen orchid and for bogs the golden plover and the wood sandpiper.

Europe has a long history of peatland use and degradation. Human impacts have included using peatlands for food, fodder, fibre and fuel, and draining them for

13 mire habitats – all defined as open and treeless wetlands with vegetation on accumulating peat – are assessed in EU28's Red Lists

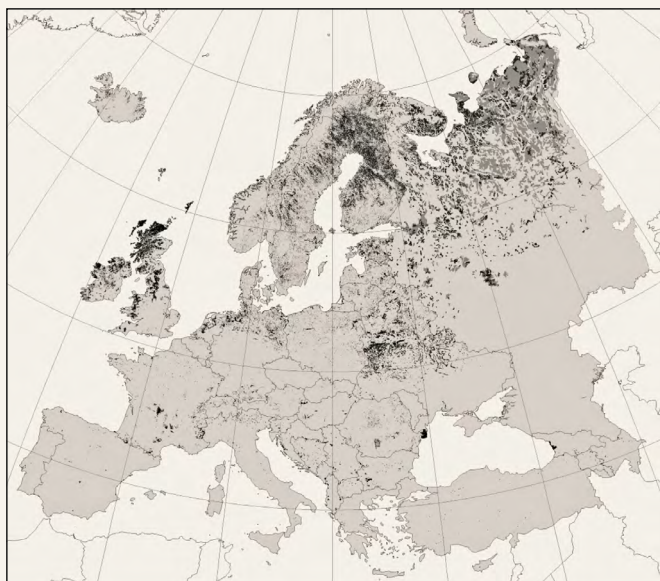
FACING DANGER

Number of Red List mire habitats in the European Union, by threat



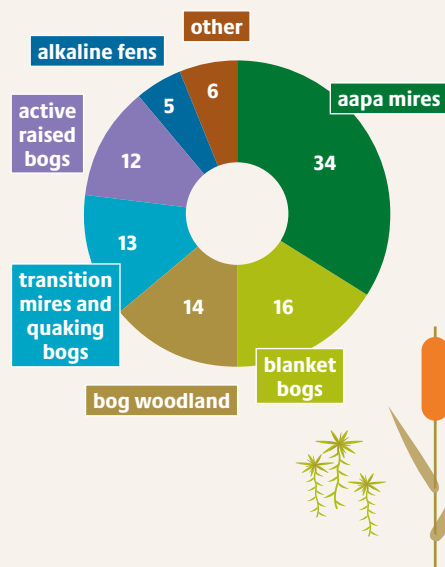
ACROSS EUROPE BUT MAINLY IN THE NORTH

Distribution of peatlands in Europe



small and sparsely distributed peatlands are slightly enlarged for better visibility

Relative area coverage in EU28 per mire habitat type in percent



© PEATLAND ATLAS 2023 / EC, TANNERBERGER ET AL.

intensive agriculture, forestry and peat extraction. Peatlands have also been used for urban, industrial and infrastructural development. More recently, large areas of peatland have been cleared to make way for water reservoirs or windmills to generate electricity. Human impact has also been indirect. For example, as early as 3,000 years ago, the anthropogenic deforestation of upland areas led to changes in the flow of rivers and the consequent widening of estuaries, resulting in massive peatland erosion in the perimarine floodplains of the Netherlands. However, human activities have also led to the creation and expansion of peatlands in Europe through interference with landscape hydrology. In oceanic parts of the continent, blanket bogs have formed as a result of land clearing, burning and livestock grazing. Such blanket bogs often occur in mosaics with heathlands that were established some 3,000 to 4,000 years ago.

Europe is the continent with the largest proportional loss of actively accumulating peatlands, due to its long history, high population pressure and climatic suitability for agriculture as the main driver of peatland drainage. As peat extraction and human-induced oxidation and erosion have transformed many former peatlands into mineral soils, about 10 percent of the maximum peatland area during the Holocene (the period since the last ice age, 10,700 years ago) no longer exists as peatland. Nineteen European countries each have more than 100,000 hectares of severely degraded peatlands. In Finland, nearly 60 percent of the peatland area was destroyed during Europe's most ambitious peatland drainage programme, espe-

Factors like temperature influence the distribution of distinct mire types. Peatlands cover about 60 million hectares of Europe's land area

cially in the 1970s, when about 300,000 hectares were drained each year. In countries such as the Netherlands, not a single peatland has been left untouched, and only a very small remnant of peatland remains undrained. Nevertheless, Europe still has a significant diversity of mires, which are often the last wilderness areas in a predominantly cultivated landscape.

The high degree degradation makes Europe the world's second largest emitter of greenhouse gases from drained peatlands, after Indonesia. The climate crisis is also causing peat loss from undrained peatlands as a result of prolonged droughts and heatwaves, fires, vegetation change and permafrost degradation. Large and rapid losses of ancient permafrost carbon have only recently begun and will increase in the future, according to studies.

Problems associated with unsustainable peatland management, including drainage for agriculture and forestry, have not been fully addressed in land use and climate policies in Europe. Furthermore, EU and national agricultural policies, with their established subsidy systems, do not or only little support the development of sustainable peatland management practices. As a result, the problems associated with peatland drainage in Europe are far from being solved. The continent lags far behind Indonesia – a country that has already rewetted more than 20 times the area that Europe has rewetted in its entire history. ●

ICE AGE LEGACY

One-third of the world's peatlands are in North America. Those landscapes close to urban areas have suffered severe degradation, and urgent repair work is needed to restore them. In the north of the continent, peatlands are increasingly threatened by the oil and mining industries.

North America's peatlands take on a wide variety of forms: from the fens and sedge marshes of the Everglades, to the cypress swamps of the eastern United States, to the bogs and fens of the boreal forests of Canada and Alaska, which make up the majority of North America's peatlands. The whole continent has a total of 158 million hectares of peatlands, which are currently estimated to store 185 billion tonnes of carbon.

Although more than 98 percent of North America's peatland remains intact, drainage in more populated regions has resulted in significant degradation. Nearly 2 million hectares have been drained for agriculture, which accounts for most of the area converted, while additional areas have been lost to development.

The remaining peatlands are increasingly threat-

ened by the northward spread of the oil and mining industries. These have already disturbed at least 500,000 hectares of peatland and may expand further in the coming decades. There are numerous mining claims on peatlands in Canada. Resource exploration and access to mine sites require additional infrastructure such as roads, which further affect the landscape in ways that are still poorly understood. Large areas of boreal forest have been flooded to create reservoirs for hydroelectric power plants. Such disturbances have contributed to the decline in the number of woodland caribou in Alberta.

Climate crisis poses an additional threat to North America's peatlands. In the south, warm, dry summers can dry out the peat and exacerbate the risk and severity of wildfires. In the north, much of the peat is underlain by permafrost. As this thaws in a warming climate, it changes the hydrology and releases large quantities of carbon in the following years. However, climate crisis may also cause the peatland to expand northwards. It is uncertain whether the peat will continue to absorb carbon as the climate continues to change.

Wetlands are part of the traditional territories of many Indigenous communities. They rely on the land to survive

INDIGENOUS PERSPECTIVES ON PEATLANDS

Artwork "Our Connection to the Land" by Omuishkego artist Gerry McComb, 2023

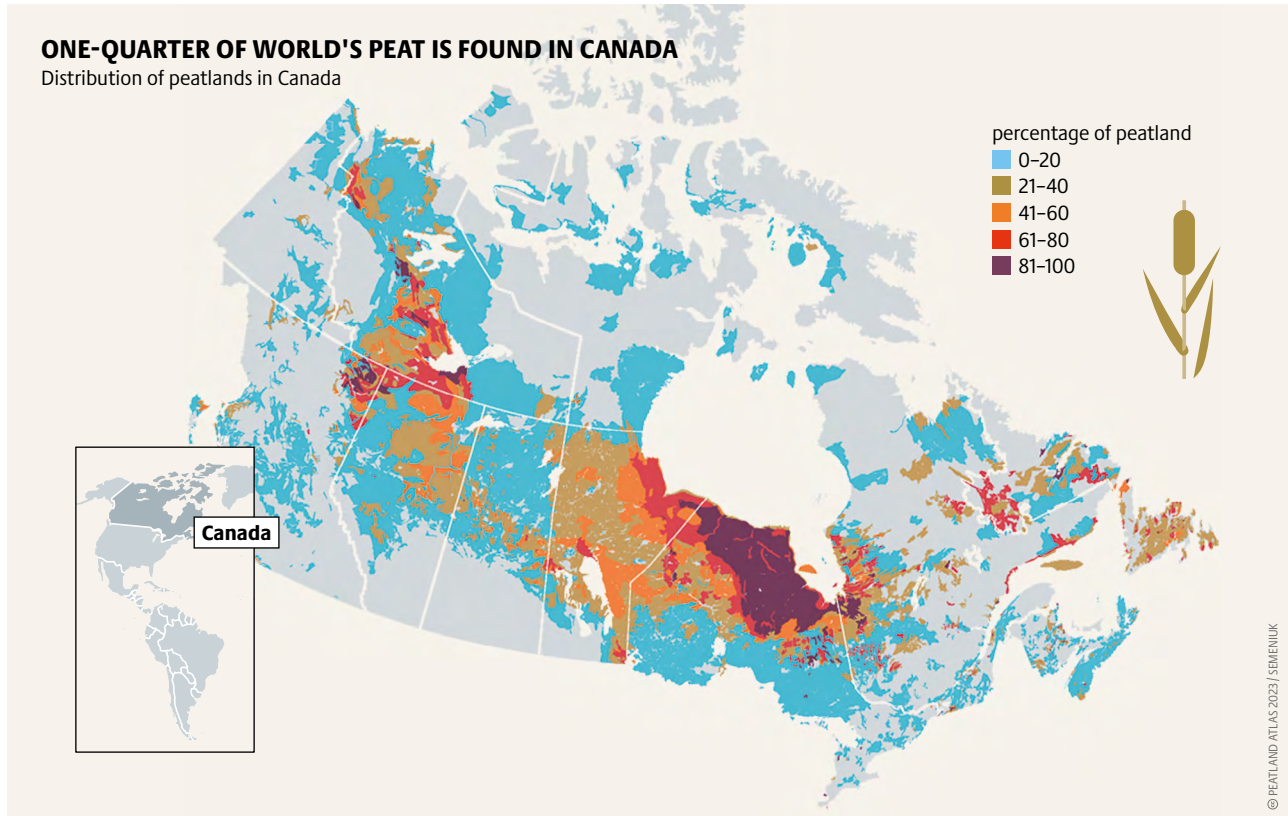
"Our ancestors walked and traveled these lands for thousands of years, the peatlands have been forming beneath our feet and storing carbon for thousands of years cooling the planet for the Omuishkego and the whole world. They are too precious to be disrupted or drained. We need them to be whole for our survival and renewal as a people."



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ONE-QUARTER OF WORLD'S PEAT IS FOUND IN CANADA

Distribution of peatlands in Canada



Major peatland areas in North America include the Everglades and the Hudson Bay Lowlands. The Everglades, in southern Florida, is a subtropical peatland that developed about 5,000 years ago. It has been designated as a wetland area of global importance by the Ramsar Convention. Originally 1.1 million hectares, almost half has been converted to agricultural and urban use. A huge system of drainage canals was begun in the late 1800s, and by the early 1980s most of the remaining Everglades had been surrounded by dykes. Massive drainage and water management efforts were undertaken to prevent flooding of agricultural land and coastal settlements. The supply of water to the Everglades was reduced, causing some peatlands to dry out and decompose or burn. This in turn led to enormous carbon losses: The Everglades have lost 75 percent of peat stocks, releasing 1.3 billion tonnes of carbon dioxide (CO₂) into the atmosphere. This poor water management has made the Everglades one of the largest wetland contributors to emissions in North America. In 2000, the US Congress authorized the Comprehensive Everglades Restoration Plan to restore, preserve and protect the wetland ecosystem. A key measure is to reestablish the natural hydroperiod, which will reduce greenhouse gas emissions while providing for the region's other water-related needs, including water supply and flood protection. At a cost of 23.2 billion US dollars and due to be completed by 2050, it will be the largest hydrological restoration project ever undertaken in the United States.

Six of ten most severe wildfires in Canadian history occurred within the past decade – and destroyed many peatlands

The Hudson and James Bay Lowlands in Canada are one of the largest continuous peatland complexes in the world. It stores an estimated 30 billion tonnes of carbon, or more than 15 percent of the carbon contained in all North America's peatlands. The area covers 33.5 million hectares along the Hudson and James Bay coastlines. This region is home to Indigenous communities who have been stewards of the land since time immemorial. The peat has developed over the last 7,000 years, slowly accumulating up to 3 metres of organic matter. The depth and age of the peat are strongly influenced by the legacy of the last ice age, where land was exposed along the coast as it rebounded from the weight of the ice sheet. This process still is occurring today, with the land rising at a rate of 1.2 metres every 100 years. The slow accumulation of peat over millennia means that the carbon stored in the soil is particularly vulnerable to development, as the organic matter cannot be replenished in the timescale needed to mitigate climate crisis. Although the region remains relatively pristine, threats include mineral exploration and development. Protecting these peatlands will be critical for mitigating climate change. Conservation should be led by Indigenous people to protect the social and ecological values of the landscape for the people who live there. ●

YOU CANNOT PROTECT WHAT YOU DO NOT KNOW

From lowland swamps dominated by tall palms to the treeless cushion bogs of the high Andes, Latin America and the Caribbean are home to a huge range of peatlands. But relatively little is known about them – making conservation difficult.

Latin America and the Caribbean have a wide range of peatland types: palm and freshwater swamps, mangroves, a variety of forests, shrublands and grasslands, and moss and cushion peatlands in high Andean mountains. They vary in their appearance, dominant vegetation, and main source of water. They are home to unique plants, shelter rare, endemic and endangered animal species, and provide resting and breeding sites for migratory birds. Lowland Amazonian peatlands host particularly high levels of regional species diversity.

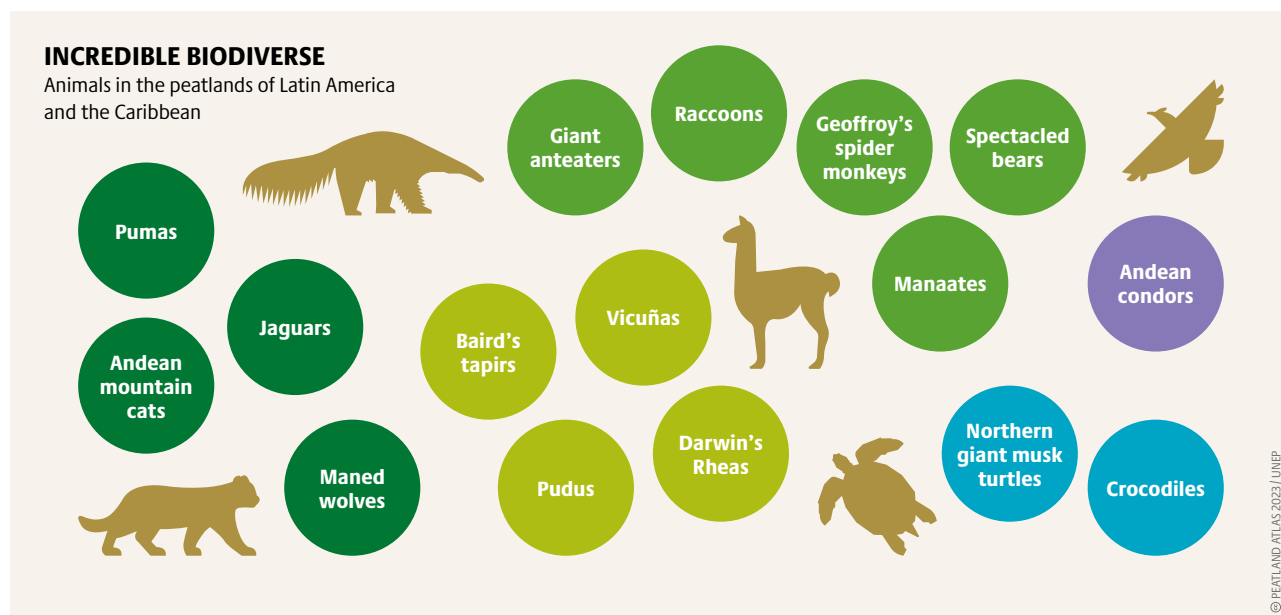
The region's peatlands also supply products for local consumption and trade: fruits, flowers, leaf fronds and fibres, building materials and honey. Aguaje palms in the Amazon swamps produce fruit for eating or for processing into drinks, ice cream or oil. They are an important source of income for many families in rural areas

of Peru and in the city of Iquitos on the Amazon. Herders in the Andes and Patagonia use peatlands known as bofedales as pasture for the native alpacas and llamas, as well as for sheep, cattle and horses. The peatlands are also an important source of water for several large cities and for agriculture.

More than 3 percent of the region's peatlands are degraded. Throughout the region, and especially in Central America and the Caribbean, peatlands are drained for cultivation or pasture. Peat is also extracted for commercial use, particularly for horticulture. While in some countries such as Peru, the peat is dug on a small scale by informal businesses, in Chile and Argentina, peat and peat moss are extracted on a larger scale from pristine peatlands. This industry is regulated by mining policies and is a growing threat. In Chile, the exportation of dry Sphagnum fibre has increased four-fold between 2001 and 2019, to 4,615 tons worth 21 million US Dollars.

The greenhouse gas emissions from drained peatlands in Latin America and the Caribbean are estimated at 91 million tonnes of carbon dioxide equivalent

Peatlands in Latin America and the Caribbean are a biodiverse Ecosystem; home to mammals, reptiles, amphibians



ACCOUNTED FOR ALMOST 50 PERCENT OF THE GLOBAL TOTAL OF TROPICAL PEATLANDS

Distribution of peatlands in Latin America and the Caribbean, in 1,000 hectares



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per year. Yet few countries have policies that specifically address peat or peatlands and their conservation and restoration. Argentina, for example, has designated specific areas for peatland conservation. Peru banned the commercial peat extraction in 2021, allowing only traditional and domestic use. Ecuador has a water fund that conserves and rewets high-altitude peatlands. But other countries allow, or even encourage, the draining of wetlands for agriculture, especially for sugarcane, bananas, palm oil and rice, or for urban growth, as in Brazil, Cuba, Mexico, Panama and Peru. Drainage is not the only threat. Other drivers of change include the extraction of oil, gas and peat for fuel, overgrazing, mining, fires and climate crisis. New concessions for oil and gas, hydropower, logging and palm oil may outstrip current threats.

Research on peatlands in the region is still in its early stages, so knowledge and data are scarce. Many governments are unaware of the presence or importance of peatlands within their borders. There are several reasons for this lack of awareness: the history of colonialism, the lack of common terms and classifications, and the diversity of peatlands complicates their recognition. In addition, in many countries only few scientific institutions conduct research on the subject. Most peat research is carried out by foreign institutions, so linguistic or cultural barriers can hinder the spread of information and hamper conservation, restoration and sustainable management efforts. A lack of governance

Most countries in Latin America and the Caribbean lack peatland inventories. The area of peatlands could be significantly larger than previously assumed

and regulation are common challenges, as are corruption and poverty. However, Indigenous and local communities have traditional knowledge of how to manage water, grasslands and livestock, and how to use resources and manage peatlands in a sustainable way.

The situation of the peatlands in the Peruvian Amazon is an example of what can happen when the existence and value of peatland ecosystems are recognized. Policies had put peatlands on a path of extractive use, neglecting their value in storing carbon and providing ecosystem services. This began to change in the last years, when the extent and importance of tropical peatlands in Latin America were recognized, leading to growing national and international interest, and to initiatives in research, sustainable management and conservation. Traditional knowledge about the classification and use of these ecosystems is now being studied, and the strong spiritual connection of Indigenous peoples to peatlands is being recognized. The Peruvian government now acknowledges the importance of peatlands as a carbon sink. While the situation in Peru has improved, much more needs to be done in terms of research and policymaking there and in other countries in the Amazon basin to ensure that the peat there is protected. ●

PROGRESS FOR PEATLANDS

Southeast Asia is home to wide areas of tropical peatlands, but many have been damaged by drainage and huge peat and forest fires. But Indonesia and other countries have been making significant progress in peatland conservation, with a big impact on mitigating the climate crisis and conserving biodiversity.

Peatlands cover about 24 million hectares in Southeast Asia, about 40 percent of the world's tropical peatlands. The largest area of peatlands is in Indonesia, with about 20 million hectares, followed by Malaysia, with 2.6 million hectares. Most have developed on lowland floodplains in areas of high rainfall. Peat accumulates mainly in swamp forests, forming deposits up to 20 metres thick. It forms much faster than in temperate regions because of the year-round growing conditions, but it can also degrade much more quickly when drained or cleared.

The region's peatlands are of global importance for biodiversity conservation. The peat swamp forests are highly diverse, with more than 1,000 species of higher plants recorded, including 45 that are unique to this habitat. Some sites have more than 250 tree species. The fauna is also very diverse, with 123 mammal species, 268 different birds, 75 reptiles, and 219 fish species recorded. About 45 percent of the mammals and 33 percent of the bird species are on the International Union for Conservation of Nature's Red List of Threatened Species. The peatlands also provide habitat for many rare

and endangered fish species, with more than 30 new species described in recent years, many of which are restricted to single sites.

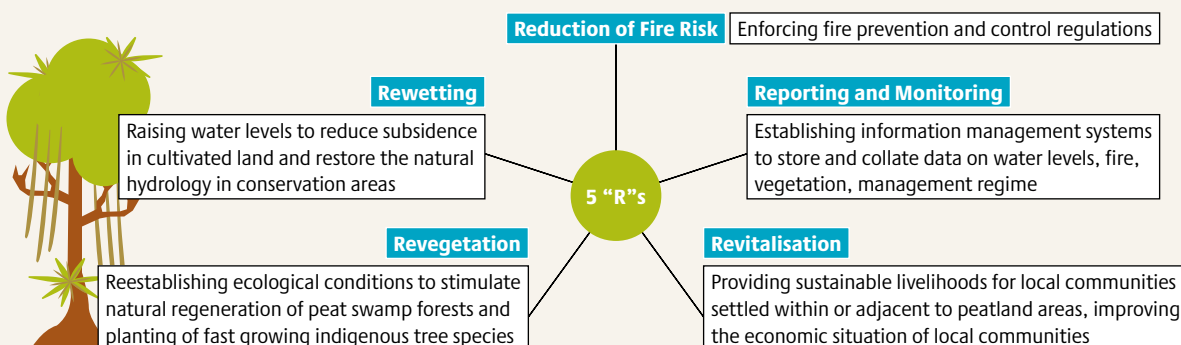
In addition, the peatlands in Southeast Asia provide a range of ecosystem services, including water and food supply, flood control and carbon storage. They store an estimated 68.5 billion tonnes of carbon, making them one of the largest terrestrial carbon stores. And they are also an important source of timber and of many non-timber forest products like fish, rattan, honey and latex. Peatland ecosystems provide significant benefits to Indigenous peoples and local communities who live in and around them.

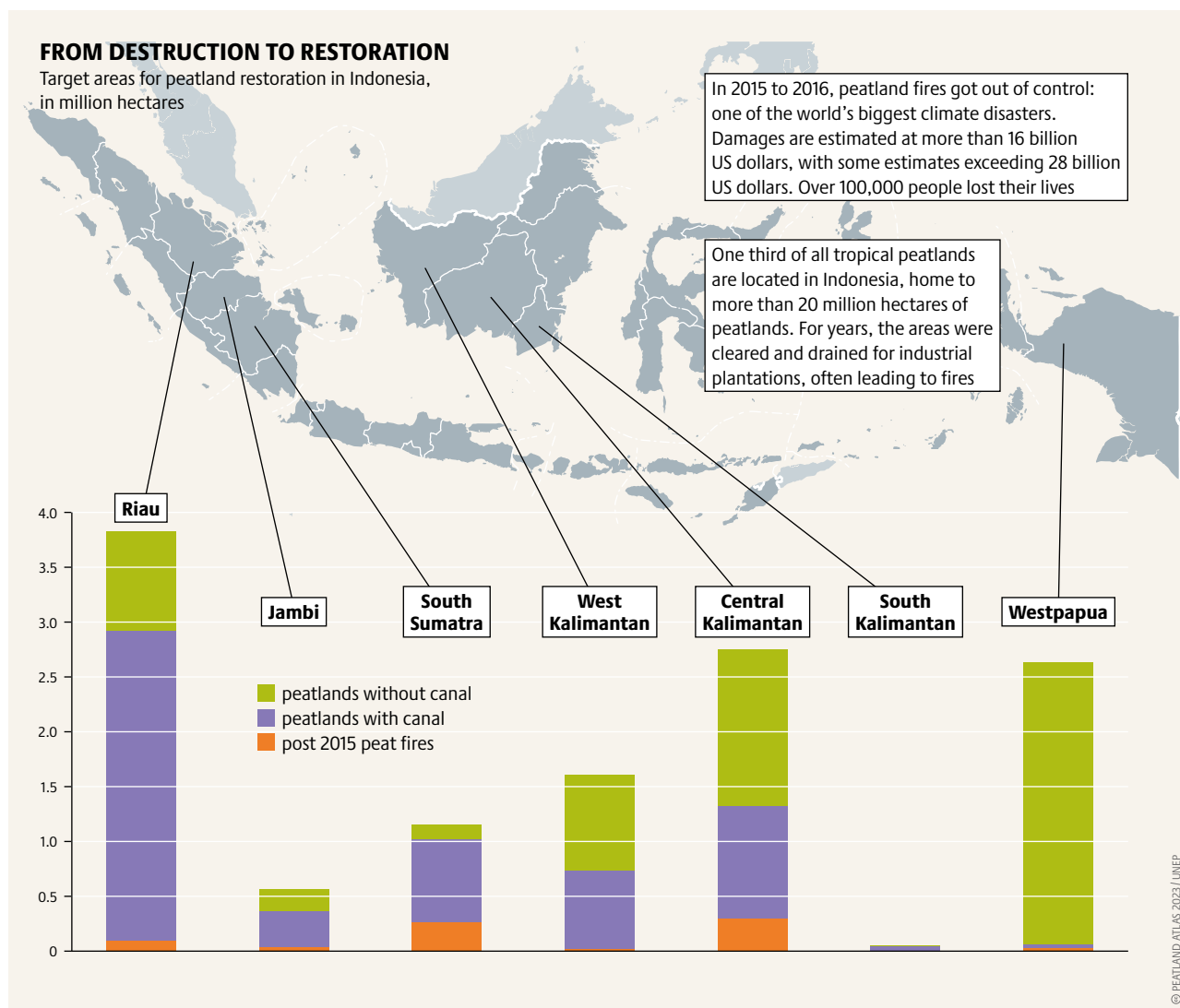
During the past 30 years, the region's peatlands have been degrading very rapidly. In Sumatra, Kalimantan and Peninsular Malaysia (which account for almost two-thirds of the region's peatlands), the area of peatland covered by swamp forests fell from 76 percent in 1990 to just 29 percent in 2015. A mere 6 percent is classified as pristine. Drainage of peatlands in Southeast Asia is responsible for 15 percent of the global CO₂ emissions from land use, land use change and forestry. Fires in degraded peatlands in the region are estimated to additionally emit a similar amount on average and significantly more CO₂ in drought years, making drained peatlands one of the largest sources of greenhouse gas emission in the region and globally. The protection and restoration of peatlands has therefore

Measures like the 5R Peatland Management Approach can help achieving ecological restoration goals, while obtaining local communities endorsement

A LONG WAY TO LONG-TERM SUSTAINABILITY

The community-led five "R"s of the 5R Peatland Management Approach in Southeast Asia





become an important component of national strategies for climate mitigation, as well as for biodiversity conservation and efforts to combat land degradation. The main causes of degradation have been the large-scale development of palm oil and forest plantations, combined with logging, drainage and fires.

Peatland degradation and fires have had massive social, environmental and economic impacts. The approximately 6 million hectares of peatlands that have burned in the last 25 years (particularly during El Niño-related droughts) have produced massive clouds of smoke, or haze, affecting more than 50 million people. The 2015 haze caused an estimated 100,000 premature deaths in the region, and economic losses of between 16 and 28 billion US dollars in Indonesia alone.

The Association of Southeast Asian Nations (ASEAN) adopted their Peatland Management Strategy for the years 2006 to 2020. This has been extended to 2030. It provides a broad framework for the long-term protection and sustainable use of peatlands and for the development of national action plans and landscape management plans.

Established in 2016, the Indonesian Peatland Restoration Agency was mandated to rehabilitate millions of hectares of peatland

Indonesia, with the region's largest area of both peatlands and peat fires, has undertaken major reforms. It has halted the conversion of peatlands for agriculture and plantations, and adopted a wide range of new regulations and policies. It has pioneered an approach to manage the hydrology of peatlands. All peatlands in the country must be mapped and divided into conservation and utilisation zones based on their hydrology, peat depth and importance for conservation.

More than 50 percent of the peatlands in the country have been zoned for conservation, although only 15.6 percent of these peatlands are in formally protected areas. Groundwater management structures have been installed and improved on nearly 4 million hectares. As a result, peatland fires have significantly declined, degradation and subsidence of production areas have decreased and good progress has been made with restoration. ●

GUARDIANS OF BIODIVERSITY AND CLIMATE STABILITY

Some of the world's most important and most recently recognized peatlands can be found on the African continent. They are home to unique and rare flora and fauna – and threatened by the oil companies' greed for money.

Peatlands cover nearly 40 million hectares across Africa. The largest area, in the Congo Basin, stores around 30 billion tonnes of carbon, while the Nile Basin – where nearly more than half of all the peatlands are now drained – has another 10 billion tonnes. Africa's peatlands are renowned for their unique biodiversity. The South African palmiet wetlands are dominated by the endemic palmiet, a semi-aquatic shrub

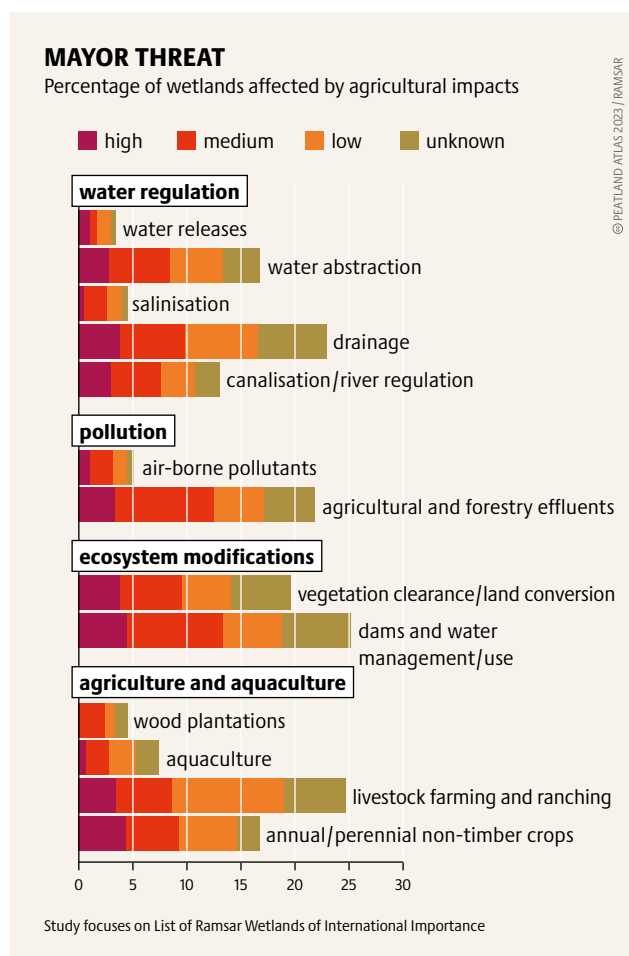
which provides a home for many rare and valuable species. The Bale mountains in Ethiopia, dominated by cushion plants unique to the Afroalpine zone, are home to more than half the global population of the Ethiopian wolf, the rarest canid in the world.

In the centre of the continent – in the heart of the Congo Basin Forest, the second largest tropical forest after the Amazon – lies the Cuvette Centrale peatland complex. It is shared by the Democratic Republic of Congo (DRC) and the Congo. Covering 16.7 million hectares, it is one of the largest contiguous peatland complexes in the world. The Cuvette Centrale is a major carbon store, a very unique and invaluable ecosystem, a biodiversity hotspot and a lifeline for local communities. It accounts for more than a third of the world's tropical peatlands and contains more than a quarter of the carbon stored in such areas. This makes it very essential for mitigating climate crisis.

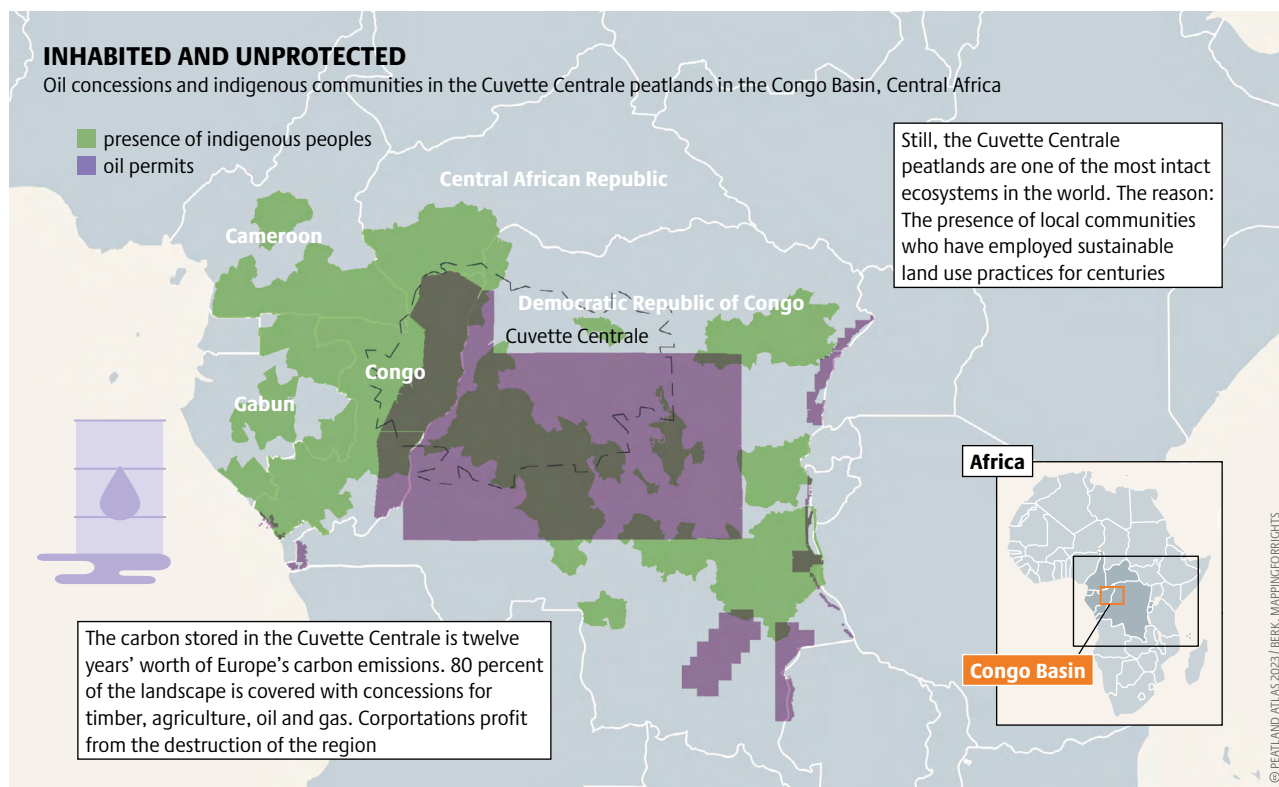
Most of the peatlands in the Cuvette Centrale occur near rivers, in large basins between rivers, or under rare, palm-dominated swamp forests that cover old river channels. The area boasts an astonishing array of biodiversity: a rich tapestry of species, many of which are unique, such as forest elephants, western lowland gorillas and Allen's swamp monkeys. The diverse habitats of the peatlands, ranging from open marshes and swamps to open water channels and forested islands, contribute to the stability and resilience of the biodiversity throughout the region. At 6.5 million hectares, the Tumba-Ngiri-Maindombe wetlands, the world's largest Ramsar wetland site of international importance, overlap with the Cuvette Centrale.

The vast wetland ecosystem of the Cuvette Centrale plays a vital role in water regulation, maintaining local water sources, regulating floods and droughts, and supporting agricultural activities. Communities in and around the peatlands depend on these water resources. Indigenous communities have lived in the region for generations and have deep-rooted cultural ties to the land. They fish, hunt and gather medicinal plants in the peatlands.

Despite its immense value, the Cuvette Centrale



Agriculture is likely to have several negative effects on many global wetlands. Water extraction and diversion are one of them



faces several threats. Expanding agricultural activities, oil and logging concessions, and infrastructure development pose significant risks to this fragile ecosystem. In November 2021, the government of the Democratic Republic of Congo signed a 10-year agreement to protect the Congo Basin forest, including its peatlands. But just a few months later, it announced its intention to auction off concessions for 27 oil and 3 gas exploration blocks. Several of the blocks overlap with the Cuvette Centrale peatlands. The results of the auction are expected in March 2024. In the meantime, a civil society-led campaign is trying to persuade oil companies not to bid for the concessions and is pressuring the government not to proceed with the auction.

Despite the importance of the Cuvette Centrale, binding national regulations for peatland protection are not in place. A key factor protecting the peatlands is current inaccessibility. If the oil auction is successful, oil companies will enter the deep forest and open up roads to allow exploration and access. This will also allow other forms of exploitation, such as logging, which will accelerate degradation.

International cooperation, such as the Central African Forest Initiative, research projects and partnerships with local communities are essential to the conservation of the Cuvette Centrale peatlands. Conservation

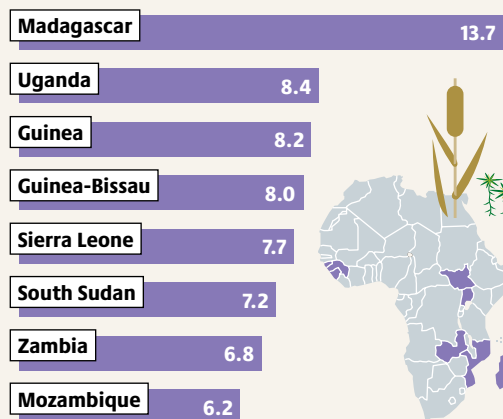
Africa contains some of the world's biggest peatlands. The emissions resulting from degradation are around 130 million CO₂ equivalents per year

NGOs fear a total clearcut logging since the Democratic Republic of the Congo recently announced plans to lift its moratorium on new logging

efforts should focus on establishing protected areas, implementing sustainable management practices and monitoring conservation efforts. Sustainable land-use practices must be prioritized in partnership with indigenous communities, and awareness of the importance of peatland conservation for biodiversity and climate stability must immediately be raised. ●

REMINDER FOR CLIMATE ACTION

African countries with the highest greenhouse gas emissions from peatlands, per year in million tonnes of CO₂ equivalents



NOT JUST A CRIME SCENE

For thousands of years, peatlands have served as the backdrop for horror stories. In gruesome legends and lore, they swallow people and even whole towns, are the home of ghosts, the devil, and many other supernatural spectacles.

If our ancestors had come up with the idea of equipping the world with information boards and warning signs, the pathways to peatlands would long ago have been decorated with signs saying things like “Warning: Entrance to Hell” or “Caution: Beware of the ghosts”. Many a solitary wanderer who ventured into a peatland was never seen again. What could possibly be to blame, if not the evil beings that lurked in these inhospitable places? The legends of such dangerous outings through the peatlands at night were crystalized into a well-known poem by the German author Annette von Droste-Hülshoff, whose “Boy on the Moor” is haunted by all the eerie noises and figures that local legends can offer: unholy spinners, a cursed woman, and ghostly gravediggers. All are damned souls from whom only the innocent can, with luck, escape.

There even exist legends of peatlands that have engulfed entire villages and towns. Some of these con-

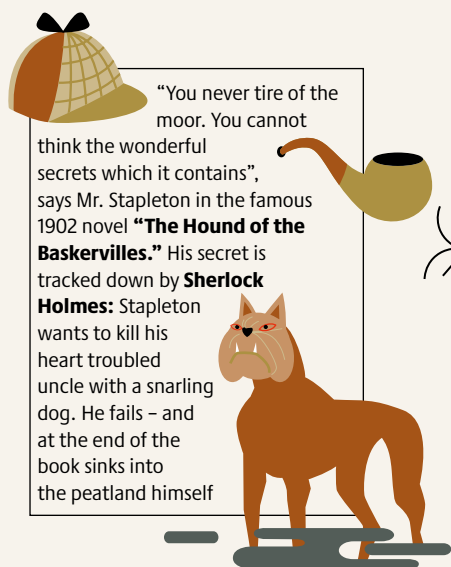
tain a historical kernel of truth, as with a village in the Red Moor of the Rhön, a range of hills in central Germany, that was in fact destroyed in the Thirty Years War. In another legend, a village was overtaken by divine punishment. It sank into the waters because of the sinful lives of its inhabitants. According to sayings, spooky voices can be heard at night, and on particularly holy days, the town rises so high that in the hours before midnight, its church spires can be seen emerging above the surface.

In Ireland, people still talk about the *púca*, or *pooka*: a mythical being that wanders through the bogs and can take on different forms – a black horse, a rabbit, or a human. The *púca* is always up to something. The Irish historian P.W. Joyce describes its deceitful nature “as a contradictory mix of merriment and malignity”. The Okavango Delta in Botswana is guarded by a mythical, dragon-like snake called Mukisi. This Mukisi is a type of demon that protects the whole river system from overuse. If one were to kill the Mukisi, everything else would die along with it. Such guards have a monumental task: they try to protect remote, scarcely touched

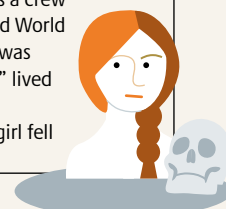
Myths about peatlands have always grown in people's minds like bulrushes in peat

SWAMPY CHAMBER OF HORRORS

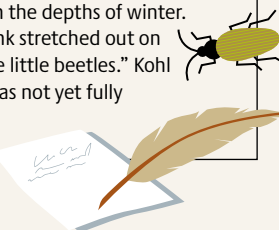
Peatland in literature, travelogues and as cemetery



Bog bodies have posed mysteries for centuries. In Germany, the last body mummified in a peatland was found in 2005. The first assumption was that it was a crew member of an Allied aircraft from the Second World War. Investigations showed that the corpse was much older: The “girl from the Uchter Moor” lived 2,650 years ago. There are no indications of violence; it remains a mystery whether the girl fell into the peatland or was buried there



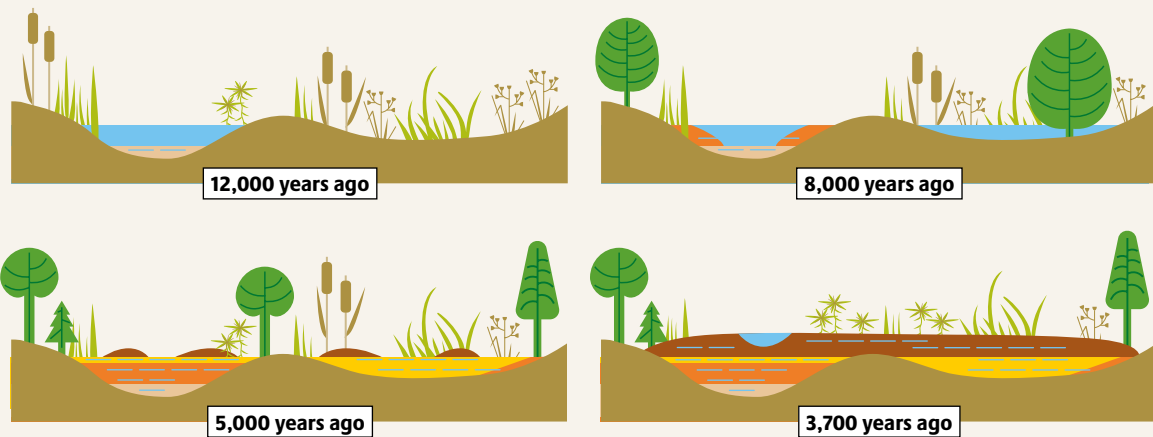
The **German travel writer Johann Georg Kohl** wrote about the famous peatland area in Wallhöfen in northern Germany: “Although we were in the middle of the most beautiful season, everything on this moor plateau was dead and barren, as if in the depths of winter. We could imagine it to be a huge, rotten tree trunk stretched out on the ground, on whose dead bark we crunched like little beetles.” Kohl wrote this 160 years ago – and to this day, word has not yet fully spread about the fascinating plants, animals and ecosystem service the peatland offers to people



GROWTH OF ONE MILLIMETER PER YEAR

Development of a raised bog

- | | | |
|--|---|---|
| ■ water | ■ digested sludge | ■ quarry peat |
| ■ water impermeable soil layers | ■ fen peat/carex peat | ■ bog peat |



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environments that are threatened on all sides, for example by forest fires, droughts, habitat destruction, industrial development, excessive hunting and charcoal production, as well as by the wounds left to following generations by colonialism, war and the displacement of Indigenous peoples.

Will-o'-the-wisps have a firm place in the mythology of peatlands. Eyewitnesses describe them as bright flames, sometimes as jumping blue flames, or perhaps as similar to candlelight. This variability may have contributed to the different roles they play in the world of legends: sometimes as the souls of the deceased who must wander the Earth for all eternity because of their evil deeds, or as the souls of the victims of murder, who cannot find their rest. Or as goblinlike creatures who either guide travellers on their way through the peatland, or lead them to their ruin, or simply play tricks on them. Today we explain the phenomenon of will-o'-the-wisps as gases produced by the rotting of organic material that spontaneously ignite when they escape from the ground.

Peatlands were long regarded as areas that do not belong to this world. They are a kind of intermediate realm, neither water nor land. They symbolize the manifold functions of water, which stands for life, renewal and cleansing, but also for death and destruction. Peat water was allocated powers of healing and fertility, and today people still enjoy the effects of moor bathing – immersing themselves in a mix of peat and water from the peatland. But on the other hand, peatlands were places for punishment, where sacrilegious deeds or ways of life were to be atoned for. This happened not just in legends, but also in fact. The evidence for this takes the form of the so-called bog bodies. For

In Europe, peatlands are relicts of the last Ice Age. They formed in locations with excess water from melting glaciers

hundreds of years, peat cutters have repeatedly found corpses whose well-preserved status made people of the time uneasy. We now know that the lack of oxygen and the highly acidic environment slows down the process of decomposition. But it is still not completely clear how such bog bodies came about. Some show signs of “overkill” – multiple possible causes of death – such as Lindow Man from England, who had axe blows to the skull, knife wounds in the chest and signs of strangulation. One theory is that criminals were executed in the peatland; another is that human sacrifices were made there. There are also bodies that were buried after a natural death. It is thought that the peatland was used for emergency burials, as the last resting place for people who were excluded from society.

“Death for the first, misery for the second, bread for the third” goes a German saying that summarizes the experiences of three generations to transform the Teufelsmoor, large peatlands near Bremen in northern Germany to wrest cultivable fields from it, or to cut peat – once an important fuel like lignite. One might add a fourth phrase to the saying: “Pictures for the fourth.” At the end of the 19th century, numerous artists settled in northern Germany. They founded a famous artists’ colony in the village of Worpswede, on the edge of the Teufelsmoor. Through their paintings of the barren landscape and the life of poor farmers in the area, they developed their own visual language, a modern, realistic and nonetheless legendary image of the peatlands. ●

A FEASIBLE OPPORTUNITY – WITHOUT ALTERNATIVE

Rewetting drained peatlands will be a major challenge for societies all over the globe. Achieving success will take innovativeness, political initiative and a paradigm shift in the global economy.

For much of Western history, draining peatlands was regarded as a cultural and technical achievement. In many regions, removing water from the land was a first, vital step in the economic development of an area. But the ecological crises of our times now force us to start over again, as peatlands fulfil many important functions for both humanity and the environment. The cultural and technical achievements of the present and future will be to develop and establish new ways to coinhabit these wet landscapes.

Paludiculture, wetland restoration and solar farms are among the many promising ways of replacing previous land uses for fens and bogs. Such transformation is necessary to mitigate the climate crisis, it will help to preserve biodiversity and to enhance flood protection. In technical terms, rewetting is fairly easy: ditches must be blocked, pumps converted, and drainage stopped. But managing the social, cultural and especially the economic shifts are much more complex. To transform non-sustainable social habits of using peatlands, simul-

taneous changes are needed at various levels. For example, the legal framework has to be adjusted to remove the financial incentives for draining wetlands.

Stricter regulations of supply chains are needed, along with stronger controls, especially for large companies. Local authorities and organisations responsible for managing soil and water face the major task of adapting the infrastructure and ownership situations to the necessary water levels. Agricultural and forestry enterprises require new forms of management to completely upend their current approaches. Experts point out that if they are to succeed in making this huge adjustment, farming and forestry enterprises and smallholders will need public financial support, which must ensure planning security and promote new markets for the products from wet peatlands.

Every peatland has different prerequisites, in hydrological terms as well as in political terms. There can therefore be no general template for rewetting: each peatland will require a specific solution for the rewetting, and for the land use and coinhabiting afterwards. Decisions on shaping the transformation process should be made at the regional level – preferably in a joint effort by local and regional authorities, farm enterprises, soil and water associations, nature conservation bodies, Indigenous peoples and local residents, environmental groups, the companies involved, and spatial planners. These actors can all bring knowledge for the future management of the peatlands based on experience in their field. Policymakers have the responsibility of establishing participatory mechanisms to combine this knowledge and interlink different levels from local to higher levels of government and the international community.

At the European Union level, the Common Agricultural Policy (CAP) is an important mechanism for managing how peatlands are used. This stipulates that areas used for paludiculture are eligible for financial support. But these efforts conflict with other parts of the CAP that continue to support types of farming that rely on drainage. In the European Union alone, half a million hectares of peatland have to be rewetted every

THEORY WITHOUT PRACTICE

Area of peatland that a country like Germany have to rewet annually, in hectares

50,000

necessary



2,000

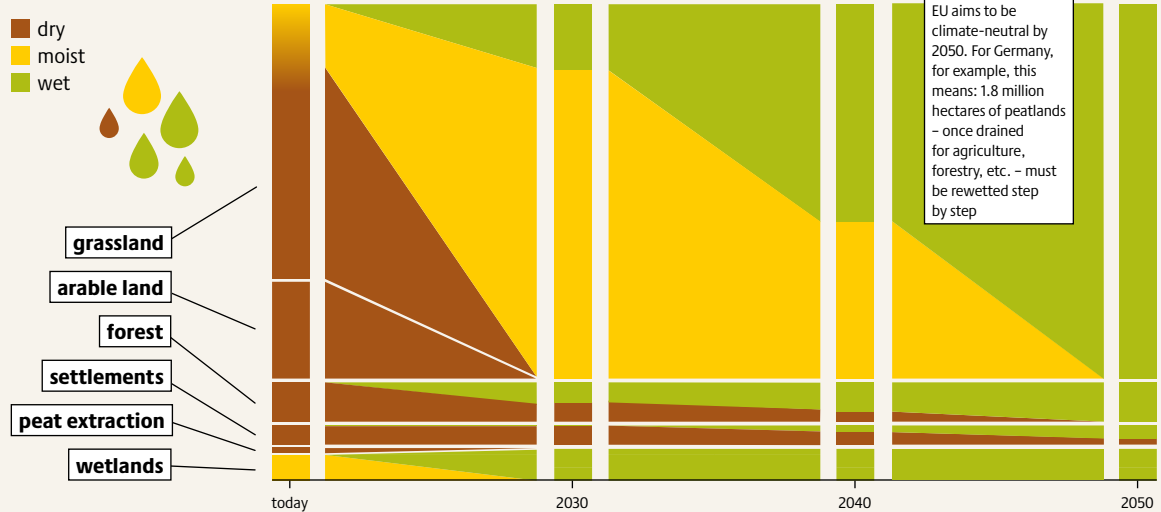
actually

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To meet the goals of the Paris Climate Agreement, peatlands must be restored – immediately

REWETTING FOR FUTURE

Possible transformation path for peatlands to achieve carbon neutrality by 2050, using Germany as an example, by current type of use



year to meet the Paris Agreement. With above-average emissions, the EU is still one of the main contributors to the climate crisis and holds historical responsibility for the current global inequalities.

Carbon credits might be a possible incentive for rewetting land to conserve peat voluntarily. Incentives and freedom of action are also needed for companies and cooperatives that work on paludiculture. To successfully transform the peatlands, it is necessary to take serious people's worries about the loss of a familiar environment with which they identify, as in some parts of the world peatlands have been drained for decades. Regional cooperation can link different issues – from agriculture to product development and marketing, to tourism and nature conservation. All this will require a strong willingness for political, social and ecological innovation.

This peatland transformation – as every other socio-ecological transformation – can only be successful if the omnipresent drivers of the destructive neo-colonialist economy are overcome. It is a chance to strengthen social and political processes that declare cooperation instead of competition to be the principle of action. These processes target the preservation of natural resources and are not based on exploitation of nature and people.

Ideas of responsible land use, equal distribution of resources and consumption within ecosystem boundaries are not limited to peatland utilization. Current

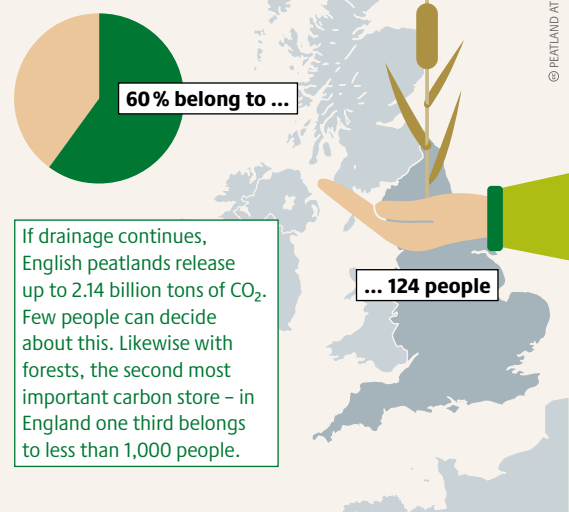
England's peatlands are the country's largest carbon store in the country. Property rights hinder necessary measures for protection and rewetting

Studies show without doubt: If rewetting of peatlands is delayed, it will be impossible to achieve the 1.5-degree target

negotiations of land use claims follow a competitive mindset. We are in urgent need of abandoning one-dimensional utilitarian way of thinking in favour of more complex thinking that understands and respects peatlands as more than mere usable landscapes, instead promotes the protection of these essential habitats for the benefit of all living beings. Only with both, ecological resilience and a just social foundation, the global society can confront the climate crisis. ●

PEATLANDS AND PROPERTY

Who owns peatlands, using the example England



AUTHORS AND SOURCES FOR DATA AND GRAPHICS

All online links were last checked in August 2023. See page 2 for the websites where you can download a clickable PDF of this atlas. Lengthy links have been shortened using the bit.ly web address conversion service.

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MICHAEL SUCCOW STIFTUNG, PARTNER IN THE GREIFSWALD MIRE CENTRE

After being awarded the 1997 Right Livelihood Award, Michael Succow founded one of the first nature conservation foundations in eastern Germany in 1999. Since then, the Succow Stiftung has been actively involved in the preservation of valuable landscapes and sustainable land use guided by the precept: “Preserve, sustain, value”. At home and abroad, it renders important contributions to the protection of peatlands and climate, to biodiversity conservation through the development of protected areas, and to ecological education. It is a founding partner in the Greifswald Mire Centre (GMC). As an interface between science, politics and practice, the GMC works locally and worldwide with over 70 peatland experts from various disciplines.

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The Global Peatlands Initiative (GPI) is an international partnership launched at UNFCCC COP 22 in Marrakech, Morocco, in late 2016. Led by the United Nations Environment Programme (UNEP), its goal is to protect and conserve peatlands as the world's largest terrestrial organic carbon stock and to prevent this carbon stock from being lost and emitted into the atmosphere. Drawing attention to peatland issues and helping countries and partners to understand and make evidence-based decisions about their management enables the Initiative to contribute to several Sustainable Development Goals. The GPI makes an impact by highlighting cases, gathering lessons and sharing best practice examples from different types of peatland ecosystems found all around the world.

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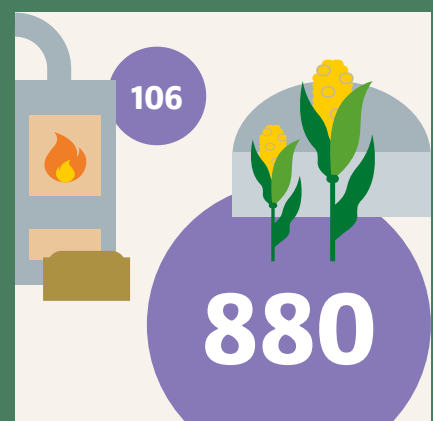
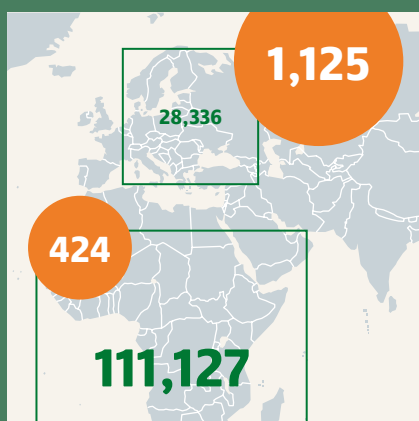
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Wet peatlands are habitat for specialized animal and plant species.
They store more carbon than any other terrestrial ecosystem.

from: **A VERY SPECIAL ECOSYSTEM**, page 12

Drained peatlands emit greenhouse gases.
This exacerbates the climate crisis.

from: **DRAINED PEATLAND RESULTS IN HEATED PLANET**, page 20

Tropical peatlands host significant biodiversity.
They are under threat from politics and corporations.

from: **GUARDIANS OF BIODIVERSITY AND CLIMATE STABILITY**, page 50

Climate targets require area-wide rewetting of peatlands.
Paludiculture enables their sustainable use.

from: **MORE FROM THE MARSH**, page 38



Food and Agriculture
Organization of the
United Nations



SUSTAINABLE
DEVELOPMENT
GOALS

Peatland mapping and monitoring

Recommendations and technical overview



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Foreword

The world's leading peatland experts have come to a collective conclusion - comprehensive peatland mapping and monitoring are urgently needed. Peatlands have a great potential to influence global greenhouse gas emissions, and in this decade we need to take urgent and innovative actions to limit global warming to a maximum of 2 °C. In most cases worldwide, peatlands have been drained and degraded due to the lack of knowledge about their location, extent, benefits and potential for climate change mitigation and risk reduction. Current estimates suggest 11-15 percent of peatlands on Earth have been drained, and another 5-10 percent are degraded due to other changes such as removal or alteration of vegetation. These degrading peatlands consequently emit huge amounts of greenhouse gases that persist for years if not decades.

The scientific basis for mapping and monitoring peatlands has developed rapidly in recent years. Countries must take advantage of and consider adopting practical and innovative approaches and tools for peatland mapping and monitoring into national monitoring and reporting frameworks. Mapping and monitoring can be used to inform climate and biodiversity policies and commitments, as well as to continuously adapt peatland restoration efforts.

Peatland mapping and monitoring are both highly complex endeavours, but are key to understanding the real extent and location of these huge carbon stores and guide the course of action for ecosystem conservation and restoration during this decade and beyond. It is part of FAO's mandate to support developing countries with advancing the sustainable management of peatland landscapes, and develop national capacity for peatland mapping and monitoring, as well as to foster knowledge sharing and data generation. FAO's peatland network consists of dozens of experts and organizations with the shared mandate to jointly find solutions to conserve the carbon in the soil while fostering sustainable livelihoods and development. We recognize the important advances already made in the subject in temperate and boreal regions and stress the need for continuing monitoring of peatland status in tropical as well as in temperate and boreal regions.

"Peatlands mapping and monitoring: Recommendations and technical overview" is the result of 35 contributors from 14 countries and different organizations working together to provide examples, tools, methodologies and solutions to peatland mapping and monitoring challenges, especially in developing countries. These recommendations are an important step forward in guiding the world on the best ways to integrate peatlands into land monitoring systems to further facilitate the conservation and restoration of these unique ecosystems. I encourage you to take full advantage of the information included in this publication.



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Executive summary

Mapping peatlands is the basis for successful monitoring systems. Worldwide, innovative mapping approaches have facilitated the inclusion of peatland areas into sustainable land use management plans and conservation strategies. Monitoring changes in peatland ecosystems, be they natural, degraded, or in the process of restoration, is instrumental in maintaining peatland's water, species richness and carbon. Robust mapping processes offer a solid baseline for monitoring and help establish management objectives for specific peatland areas.

This report presents the peatland mapping methodologies commonly used – based on ground and remotely sensed input data. It also offers an overview of advantages and limitations of different monitoring approaches as a practical guide to facilitate decision-making and cater for country-specific requirements, in order to ensure that emissions and emission reductions are measurable, reportable and verifiable. It also provides information on other benefits from peatland conservation, restoration, rehabilitation and sustainable management. Country case studies present examples of current needs and recent achievements, in both mapping and monitoring. Suggestions for an architecture of peatland monitoring and how it could be organized within a country's institutions are also provided.

Global conventions and national policy frameworks recognize the importance of peatlands for protecting habitats and biodiversity, as large and vulnerable carbon stocks, and (when degraded) as globally important sources of greenhouse gas emissions. Countries should consider mapping, monitoring and reporting peatlands for national and international processes including general land use planning, nationally determined contributions to the Paris Climate Agreement, national adaptation plans, nationally appropriate mitigation actions, as well as fire risk reduction and other disaster risk reduction strategies. The national policy frameworks contribute to the achievement of international commitments, as well as helping to ensure better conditions for communities.

Countries, practitioners, researchers and technical agencies can use this report to identify mapping and monitoring needs, and define suitable approaches and tools to ultimately reflect peatlands into national land use monitoring systems, such as national forest monitoring systems. Soil carbon and emissions from soils have long been underestimated, and existing systems may also need to be adapted to fully integrate peatland considerations.

Keywords: greenhouse gas; peatlands; organic soils; monitoring; reporting; climate change; wetland; IPCC; remote sensing; Earth observation; data; water; plant; peat; UNFCCC; emission reduction

Peatland mapping and monitoring at a glance

Peatland mapping and monitoring require collection and measurement of different data types depending on the status of the peatland area. In pristine peatlands (Figure 1) information on natural characteristics is needed to monitor future changes, including potential climate change impacts that may lead to increased emissions and disaster risks.

If drainage is undertaken (Figure 2), peatlands generally become sources of greenhouse gas emissions, and additional parameters must be monitored to support corrective action and avoid continued degradation, and to contribute information to report for various conventions. Peatland restoration monitoring (Figure 3) can inform the design, strategy, selection of site and management approaches, and improve restoration efforts through technical adjustments.



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Figure 1

Data needed for peatland monitoring – Case 1: Pristine peatlands – no ongoing drainage

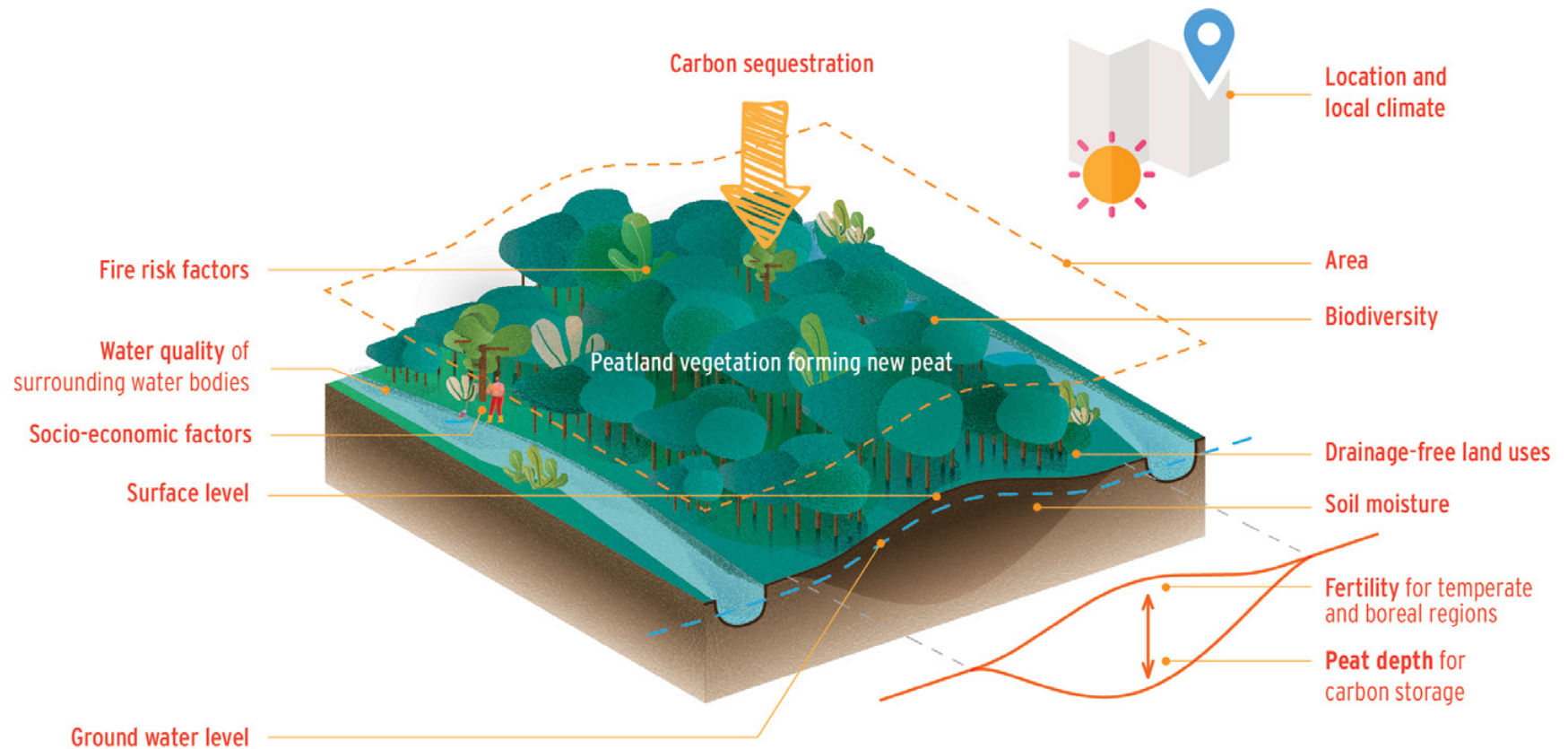


Figure 2

Data needed for peatland monitoring – Case 2: Drained peatland with canals

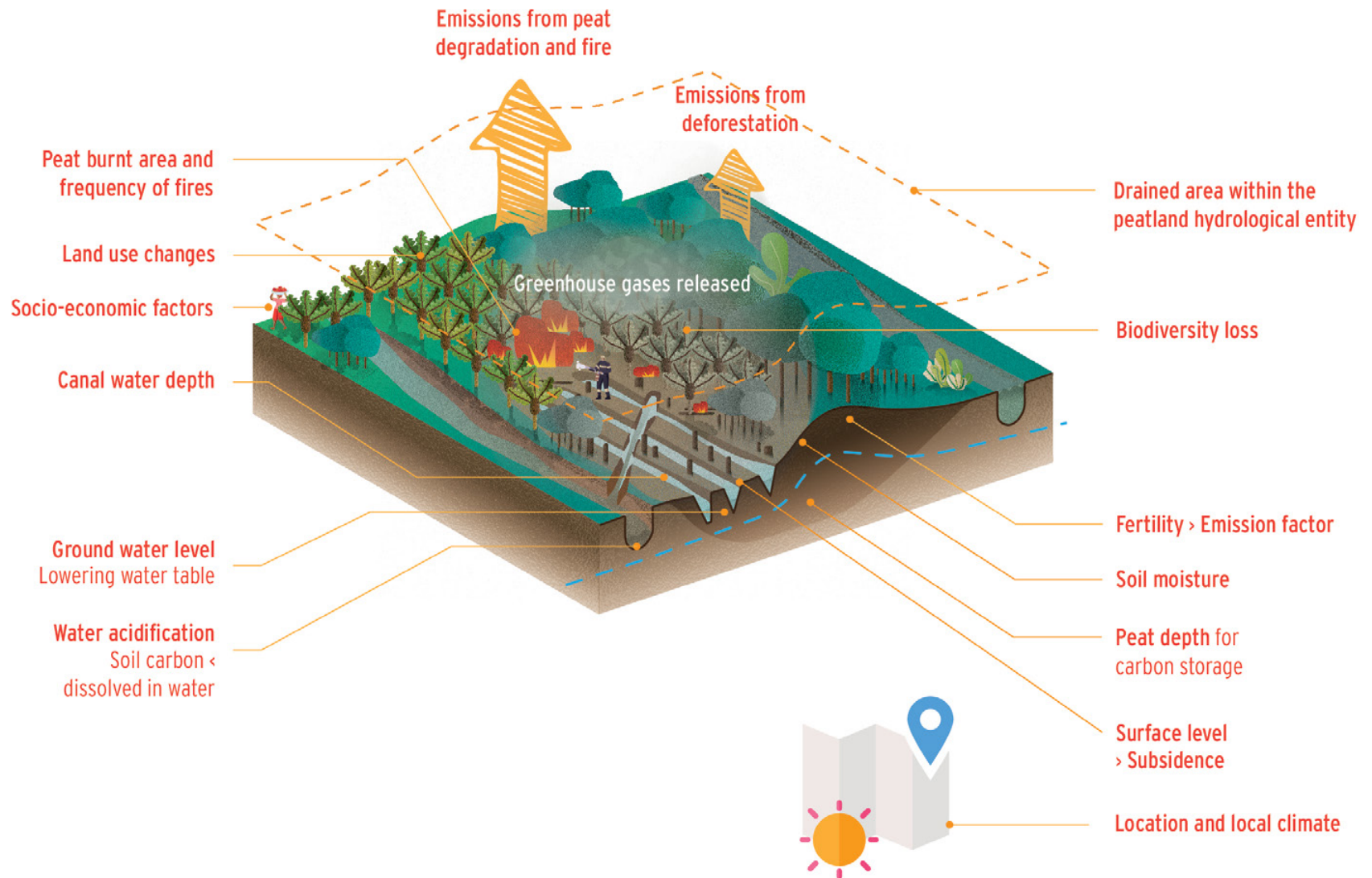
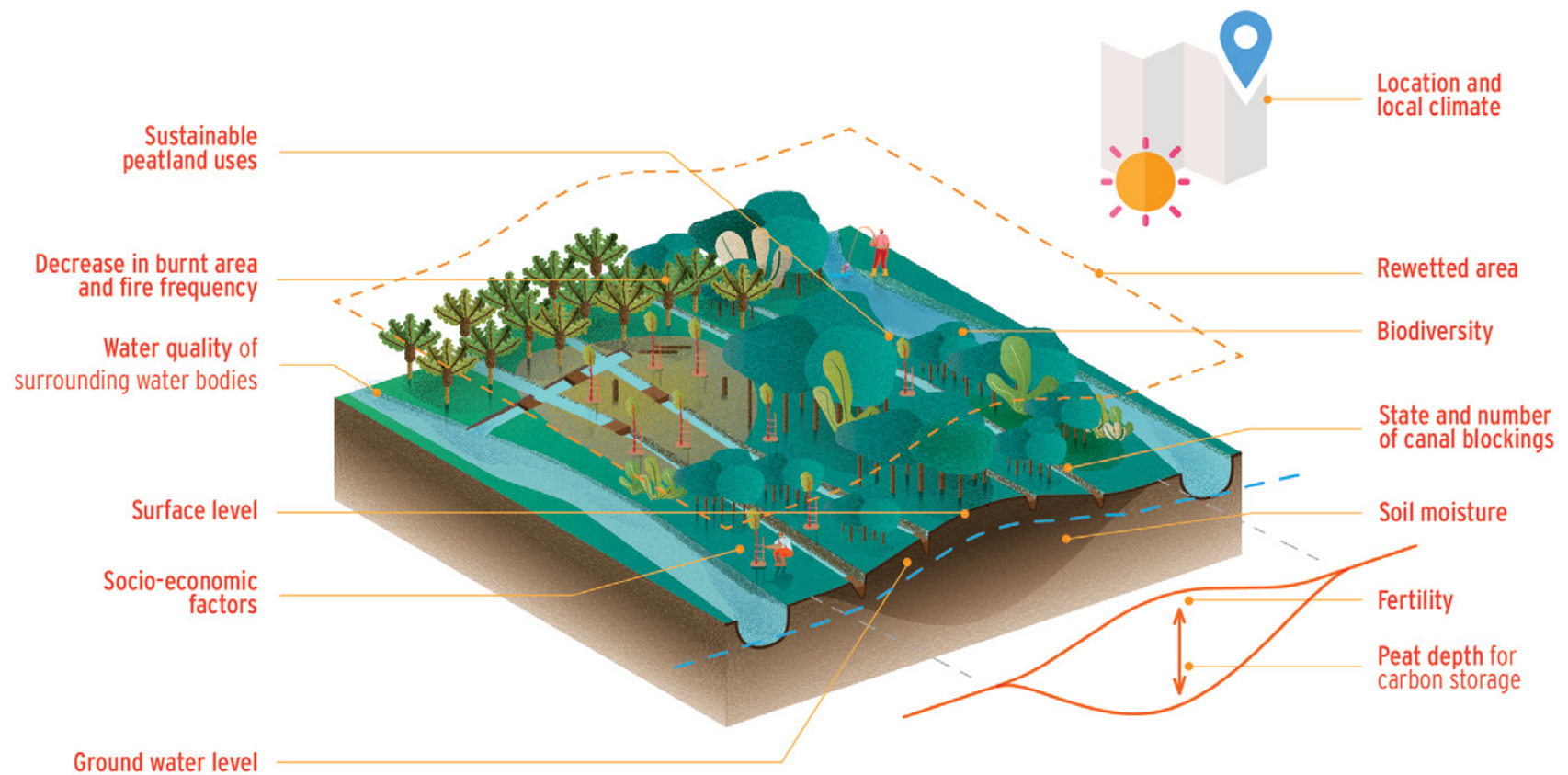


Figure 3

Data needed for peatland monitoring – Case 3: Restoration monitoring



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Abbreviations and acronyms

AFOLU	agriculture, forestry and other land use	LDN	Land degradation neutrality is a target defined under the UNCCD
AGB	aboveground biomass	LIDAR	Laser Imaging Detection and Ranging
ASEAN	Association of Southeast Asian Nations	MEAs	multilateral environmental agreements
BRG	Badan Restorasi Gambut (Peatland Restoration Agency of Indonesia)	MINAM	Ministerio del Ambiente (Peruvian Ministry of Environment)
C	Carbon	MoEF	Indonesian Ministry of Environment and Forestry
CBD	Convention on Biological Diversity	MRV	measurement, reporting and verification
CIFOR	Centre for International Forestry Research	NAMA	Nationally Appropriate Mitigation Action
DOC	dissolved organic carbon	NAP	National Adaptation Plan
DRR	disaster risk reduction	NDC	Nationally Determined Contribution to the Paris Climate Agreement under the UNFCCC
EbA	ecosystem-based adaptation	PRIMS	Indonesian Peatland Restoration Information and Monitoring System
ENSO	El Niño-Southern Oscillation	RFMRC	Regional Fire Management Resource Centre (Indonesia)
FLR	forest and landscape restoration	RSP0	Roundtable on Sustainable Palm Oil
GFMC	Global Fire Monitoring Centre	SDGs	Sustainable Development Goals
GHG	greenhouse gas	SEPAL	System for Earth Observation Data Access, Processing and Analysis for Land Monitoring
GPI	Global Peatlands Initiative	SFDRR	Sendai Framework for Disaster Risk Reduction 2015-2030
GWFN	Global Wildlife Fire Network	UNFCCC	United Nations Framework Convention on Climate Change
GWL	ground water level	UNCCD	United Nations Convention to Combat Desertification
InSAR	interferometric synthetic aperture radar	VHR	very high resolution
IPCC	Intergovernmental Panel on Climate Change		
IUCN	International Union for Conservation of Nature		
LAPAN	Lembaga Penerbangan Dan Antariksa Nasional (National Institute of Aeronautics and Space of Indonesia)		

Chemical formulae and units

CH₄	Methane	Gt	gigatonne
CO₂	Carbon dioxide	N₂O	Nitrous oxide
CO₂eq	Carbon dioxide equivalent	Pg	petagram



Chapter 1

Introduction: why map and monitor peatlands?

by Susan Page



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Peatlands, also called “organic soils”, “bogs”, “fens”, “swamps” and “mires”, are the world’s most carbon-dense terrestrial ecosystems. Peatlands are formed from partially decomposed plant remains that have accumulated over thousands of years under conditions of waterlogging. Peat soils hold an estimated 650 billion tonnes (Gt = Pg) of carbon on only 3 percent of the Earth’s land surface – a carbon store that is equal in magnitude to the amount of carbon in the Earth’s vegetation, and more than half of the carbon in the atmosphere (Yu *et al.*, 2010; Page *et al.*, 2011; Dargie *et al.*, 2017). Peatlands thus play a critical role in the global carbon cycle and in climate regulation. However, peatlands also deliver a range of other benefits for humanity, including water regulation, flood control, food, and cultural and livelihood opportunities. They support a diversity of habitats and unique and rare plant and animal species. The layers of accumulated peat contain an archive of information on changes in climate, vegetation and human activity since the last Ice Age.

Peatlands are, however, highly vulnerable. Undisturbed peatlands are characterized by water levels that are close to the surface throughout the year. Near-constant waterlogging and the consequent lack of oxygen slows down decomposition by micro-organisms and, as a result, the organic material (peat) accumulates slowly over time. In northern peatlands, the accumulation of 1 m of peat may take over a thousand years, but as some peatlands have been accumulating over several millennia, they have reached depths of 5 m or more (Yu *et al.*, 2010). In the tropics, higher plant productivity has resulted in even deeper deposits – exceeding 15 m in some locations (Page *et al.*, 2011).

When the water table in a peatland is drawn down, for example to permit agriculture or forestry, oxygen enters the upper peat column. This facilitates microbial degradation (oxidation) of the peat and a rapid loss of stored carbon to the atmosphere, mainly in the form of the greenhouse gas (GHG) carbon dioxide (CO₂). Undamaged peatlands are usually net accumulators of carbon – i.e. more carbon is taken up via photosynthesis and carbon capture by the vegetation and peat than is lost from decomposition and subsequent release into the atmosphere. The capacity of intact peatlands to sequester carbon from the atmosphere and to store it over a long term is key to their role in climate change mitigation.

In drained peatlands, however, this role is reversed, with decomposition rates many orders of magnitude greater than in the absence of oxygen. Ongoing anthropogenic disturbance can therefore convert peatlands from slow carbon sinks and long-term stores to fast carbon sources, as carbon stored over millennia is released back into the atmosphere within a matter of decades. Understanding the location and scale of these disturbances is vital in supporting efforts to rehabilitate and restore peatland functions, including their role in climate change mitigation.



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The most widespread drainage-based uses of peatlands today are for agriculture and forestry and, to a lesser degree, for peat extraction. Although enormous extents of peatlands in North America and the Russian Federation are still intact, around 20-25 percent of the world's peatlands have been moderately or significantly degraded through disturbances to their hydrology and vegetation, especially in Europe, Central and Southeast Asia, East Africa, southernmost America and the Amazon. Globally, the most widespread uses of peatland today are for forestry and agriculture, amounting to an estimated total area in excess of 1 million km² (Joosten and Clarke, 2002) and possibly exceeding this area if peatland used as pasture for extensive livestock grazing is also included (FAO, 2014). (See also: Leifeld, J., *et al.* 2019.) Some of the most rapid and extensive land use changes have taken place recently in Southeast Asia as a result of land conversion to large-scale plantations or smaller-scale agriculture. Around the world, peatland drainage and associated peat fires are estimated to be responsible for

approximately 5 percent of anthropogenic CO₂ emissions (IPCC, 2014b). Next to the globally significant emissions, important local and regional impacts of peatland drainage include increased risk of peat fires and haze, which cause severe impacts on human health – for example, the peatland fires in Southeast Asia and the boreal zone during 2019 – and of flooding (due to land subsidence caused by peat compaction and oxidation).

At global and national levels, peatlands receive growing recognition and are integral to a number of national and international conventions and policies aimed at protecting habitats, biodiversity and carbon stocks, and reducing GHG emissions.

The most relevant conventions are:

- **The United Nations Framework Convention on Climate Change** (UNFCCC) includes peatlands (organic soils) in its Kyoto Protocol, the Paris Climate Agreement, and national GHG reporting and accounting. The Intergovernmental Panel on Climate Change (IPCC) gives technical recommendations to the UNFCCC, and has produced guidance on reporting on GHG emissions from drained, rewetted and burning organic soils. Reporting has to follow the principle of transparency with respect to measurement, reporting and verification (MRV).
- **The Convention on Biological Diversity** (CBD) requires in its Aichi Targets the conservation and restoration of peatlands, highlighting their role in mitigating and adapting to climate change, as well as supporting rare and threatened wildlife.
- **The Ramsar Convention on Wetlands** has passed several resolutions and recommendations on peatland conservation, wise use and climate change.
- **The United Nations Convention to Combat Desertification** (UNCCD) acknowledges peatlands as an important component of land use planning and integral to the climate change agenda, because of their carbon storage and the opportunity their restoration offers for reducing GHG emissions (UNCCD, 2015) and achieving part of the land degradation neutrality (LDN) target.

A growing number of international agencies and initiatives also underline and support improving management, including the conservation and restoration of peatlands:

- **The United Nations Environment Programme**, leading the global environment agenda, and the Food and Agriculture Organization of the United Nations (FAO) have recently been asked to lead the implementation of the 2021-2030 UN Decade on Ecosystem Restoration as

a measure to fight the climate crisis and enhance food security, water supply and biodiversity. The Decade covers all ecosystems, but focuses on terrestrial, freshwater (including peatlands) and mangrove systems (UN, 2019a).

- **FAO** is a technical agency of the United Nations supporting countries to improve the sustainability of cropland, livestock, forestry, fisheries and aquaculture management, including support to reduce GHG emissions and avoid losses of other ecosystem services caused by unsustainable peatlands management. FAO provides tools and guidance for peatland monitoring and development of sustainable livelihood sources from peatland landscapes.
- **The International Union for Conservation of Nature** (IUCN) passed a resolution, “Securing the future for global peatlands”, at the 2016 World Conservation Congress, calling for action to protect, restore and sustainably manage peatlands (IUCN, 2016).
- **The Bonn Challenge** is a global effort to bring 150 million ha of degraded and deforested land into restoration. By 2020 and 350 million ha by 2030. The initiative, launched by an international coalition in 2011, also encourages the restoration of peatlands.
- Within Europe, **the EU Habitats Directive** includes peatland ecosystems as priorities for conservation and restoration, while the European Climate Change Programme requires most peatlands and organic soils in Member States to be accounted for by 2020.

UNFCCC has particularly important implications for peatlands because countries have to account for GHG emissions associated with peatland use, such as from forestry, agriculture and extraction, in their national inventory submissions under the Kyoto Protocol.

Building on these international agreements and policy initiatives, various countries have taken steps to conserve and protect their peatlands, and restore degraded sites. Successful results depend on robust and user-friendly assessment and monitoring methodologies to identify and better understand the changes and impact of activities in both pristine and particularly valuable peatlands, as well as in degraded sites. Effective peatland mapping and monitoring would enable users to:

- locate peat deposits to more accurately assess peatland area and carbon stock, including remote and inaccessible sites;
- obtain information on the peatland condition (i.e. intact or degraded, and the extent, type and likely causes of degradation), in order to identify areas at risk of degradation or in need of restoration;

- formulate appropriate action plans, including law enforcement, rehabilitation or restoration; and
- monitor the success of management interventions and allow corrective action if targets are not being met.

Mapping of peatland occurrence is a prerequisite for monitoring peatland change. Maps of peat location, extent and condition are required to monitor potential conflicting land use activities (such as agriculture or forestry, infrastructure development or extraction). The location of drainage canals or ditches, logging tracks and roads is required in order to identify current and incipient threats. Moreover, historical examples of fire occurrence are also useful indicators for anticipating additional threats and emissions.

Peatland monitoring methods will differ, depending for example on the extent of the peatland, the nature of any human disturbances, planned restoration interventions, required resolution, objectives, accessibility, available resources, and target environmental parameters. The ideal approach would ensure that emissions and emission reductions are measurable, reportable and verifiable, while also providing information on the delivery of other peatland ecosystem services in order to fulfil the reporting requirements to other conventions and the overlying United Nations Sustainable Development Goals (SDGs, see Chapter 5). Ideally, peatland monitoring will form part of national land monitoring and reporting system(s) and build on them.

Sound methodologies are needed in the collection and collation of key indices that allow the assessment, through widely recognized proxies, of peatland hydrological function and carbon loss. This will require robust, accessible supporting assessments and monitoring methodologies, for the identification of both pristine and particularly valuable peatlands and of degraded sites, which should be targeted for management interventions. The value of peatlands can be defined as water provision and storage, flood control, carbon storage, biodiversity and other ecosystem services.

Especially at the early stages of mapping, remote-sensing approaches need to be combined with on-site measurements of, for example, GHG emissions, peat subsidence, ground water level (GWL), soil moisture, vegetation cover and diversity, in order to calibrate and validate the remote-sensing results. On-site measurements – or “ground-truthing” – of remote-sensing approaches offer opportunities as well as technical challenges. The main challenge is to obtain on-site high-quality measurements across satisfactory temporal and spatial scales (encompassing different site conditions, diurnal, seasonal and annual variability), which may require substantial financial and technical resources.

The case studies show that some countries have already applied various peatland mapping and monitoring approaches, although these are rarely sufficiently comprehensive. Others have developed some elements but need technical support and capacity-building to set up

and integrate peatlands into national systems. Effective peatland mapping and monitoring will probably combine contemporary remote-sensing techniques with the necessary ground-truthing and field measurements. For example, established remote-sensing techniques can be used to assess land cover, land use and vegetation condition at landscape scale, whereas newer developments may allow the monitoring of GWL and soil moisture (a proxy measure for water level and GHG emissions) as well as peatland subsidence (a proxy for water level and carbon loss).



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Chapter 2

Peatland mapping

by Ronald Vernimmen, Aljosja Hooijer, Hans Joosten,
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Peatland mapping

by Ronald Vernimmen, Aljosja Hooijer,
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and Hesti Tata

Mapping of peatlands has been addressed with many different methodologies, and detailed guidelines are available for a variety of locations (e.g. Barthelmes, Ballhorn and Couwenberg, 2015; Bourgeau-Chavez *et al.*, 2018; Gumbricht *et al.*, 2017). Peatlands are formed in different climatic zones, and thus hold several vegetation types and occur in different ecosystem settings. In tropical climates, for example, they might occur in mangroves and peat swamp forests, while in subtropical and warm temperate climates most have reed or sedge vegetation, and in boreal, cool temperate, subarctic and arctic regions most are dominated by mosses (Gumbricht, 2012; Prager, Barthelmes and Joosten, 2006). Consequently, approaches to mapping need to vary depending on ecologic and landscape features, and the availability of information to define the occurrence of peatlands and peat soils. A combination of various ecologic and landscape variables – as well as expert analyses – is used to identify probable peatlands, and produce detailed peatland maps.

Prior to defining monitoring needs, baseline maps are required to identify the peat location and the historic and current land cover and land use characteristics. It is recommended to incorporate an internationally recognized definition of peatland for mapping (see e.g. Box 1, Box 2, and the Chapter 8. Recommendations). Knowing the location of drainage canals or ditches, logging tracks, roads, and preferably local livelihood sources (e.g. hunting, fishing, gathering non-timber products, irrigation with water extracted from peatlands, peat extraction) helps to identify current and future threats and processes affecting and/or protecting peatlands. Historical fire occurrence is also a useful indicator for further threats given that once-burnt areas burn more easily again. Maps of legal status and concession extents, together with potential spatial and other land use plans, are recommended to be integrated into the maps to identify and avoid potential issues and future threats.

This chapter presents the main components for peatland mapping and delineation, which correspond to the essential monitoring parameters discussed in the following chapters. Also, the data sources listed here – focused on remote-sensing techniques – are intended to build

upon the field and secondary data already available in different countries, and the data sources usually considered in peatland mapping exercises. Bearing in mind the key features for peatland delineation and mapping, countries are encouraged to design their mapping methodologies and adapt them to their specific needs, goals, information availability and landscape features. Mapping activities are necessary to integrate peatlands into productive and conservation planning.

BACKGROUND

Key features of peatland delineation

Comprehensive field-based information on the extent of peatlands is often lacking, particularly in the case of inaccessible tropical peatlands. In such cases, the combined use of remote sensing and field measurements may provide comprehensive peatland distribution maps with reasonable accuracy and quantifiable uncertainties. Lawson *et al.* (2014) identified four features, detectable with the help of remote sensing, which distinguish pristine peatlands (especially tropical peatlands) from surrounding non-peat ecosystems:

- low vegetation species richness;
- distinctive vegetation structure;
- distinctive topography; and
- high water tables.

Pristine peatlands often have a lower vegetation diversity compared with surrounding ecosystems. For example, within the peatlands of South and Central America, some parts of Africa, and on the island of New Guinea, palms are often more dominant than in upland forests, and even sometimes occur as mono-dominant stands. However, in some peatland forests vegetation diversity can also be high (Brady, 1997; Rieley and Page, 2005). As low vegetation species richness cannot be directly detected with remote-sensing systems, distinctive vegetation structure acts as proxy.

The vegetation structure of pristine peatlands is very often (but not always) distinct from that of surrounding vegetation. For example, tropical low-pole peat swamp forests are characterized by more open canopies, low canopy height with thin stems, and high stem density, or no trees at all (Anderson, 1983; Ballhorn, Jubanski and Siegert, 2011; Jaenicke *et al.*, 2008; Lawson *et al.*, 2014; Page *et al.*, 1999; Phillips, Rouse and Bustin, 1997).

Most peatlands occupy a specific topographic or geological setting, such as coastal peatlands in Southeast Asia, subsiding basins, dendritic drainage river networks (many contributing streams), etc. Furthermore, many peatlands, such as Indonesia's tropical peatlands, are dome-shaped and can be detected by elevation data (e.g. Ballhorn, Jubanski and Siegert, 2011; Jaenicke *et al.*, 2008; Lähteenoja *et al.*, 2009; Phillips, Rouse and Bustin, 1997).

Water tables in undrained peatlands lie close to or above the surface throughout the year but can be also subject to natural fluctuation of several decimetres depending on the season - wet or dry.

Low vegetation species richness, distinctive vegetation structure, and topography can directly be detected through remote sensing. Whereas any of these features alone would not be sufficient to definitely detect peatlands, a combination of two or more often leads to much clearer results (Draper *et al.*, 2014). As all key features related to vegetation and high water tables are immediately altered through vegetation clearance and drainage, it is crucial to assess historical remote-sensing data. Finally, all approaches based on remote sensing need a satisfactory set of field data - such as soil sampling - to validate the mapping results.

Box 1

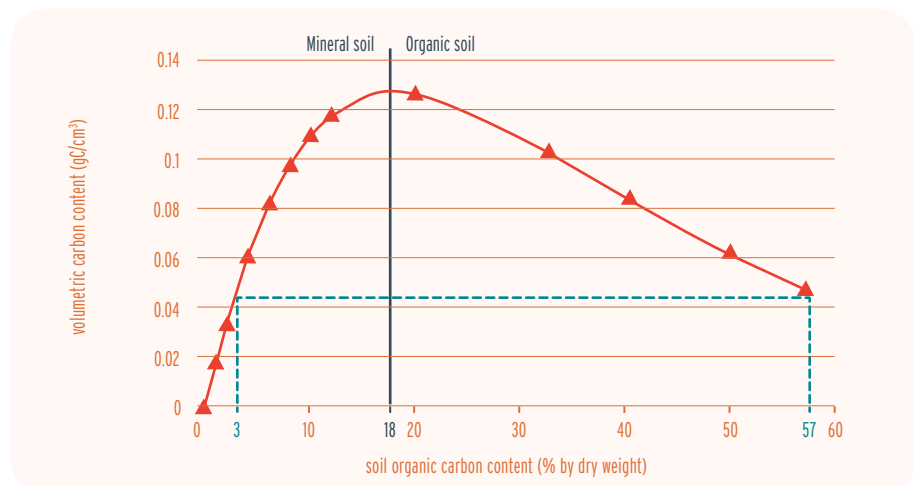
How much soil organic carbon defines peat?

The proportion of organic matter that a soil layer must hold to be called "peat", varies greatly among countries and disciplines. In soil science, peat soils are included in "organic soils", which are distinguished from "mineral soils" based on the dry weight percentage of organic carbon (gram of carbon per gram of soil $\times 100$). The vertical solid line in Figure 4 denotes 18 percent carbon content by weight, which is the threshold above which soil is called "organic". This boundary varies between 12 and 18 percent depending on the proportion of clay in the soil. However, this boundary is not very appropriate from the climate point of view, because the percentage reveals little about the volumetric carbon content (g/cm^3), i.e. the amount of soil carbon that upon drainage is exposed to oxygen and that can thus be emitted as CO_2 .

Pure peat has a high percentage of carbon by weight (approx. 57 percent), but a low volumetric carbon content (Warren *et al.* 2012; Roßkopf *et al.* 2015). In comparison, mineral soil weighs much more and with three percent of carbon by weight can have just as much carbon per volume (Figure 4, based on Ruehlmann & Körschens 2009). After drainage, both soils emit the same amount of CO_2 . The traditional definition of a peat soil based on 18 percent carbon content by weight or higher is thus problematic as many soils with lower carbon content – but equal or higher emission potential – can be overlooked by such standard country definitions.

Figure 4

Volumetric carbon content vs carbon by dry weight in soils in percentages



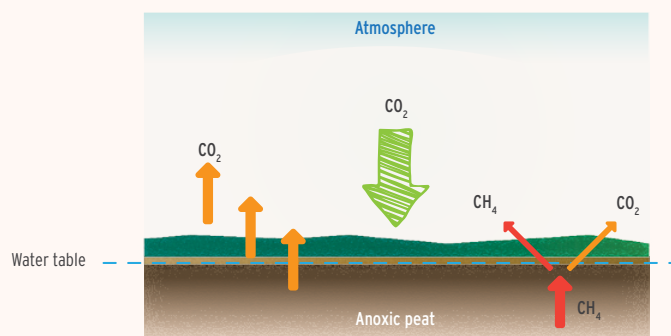
Source: based on Ruehlmann & Körschens, 2009

Box 2

Greenhouse gas emissions from peatland drainage and fires

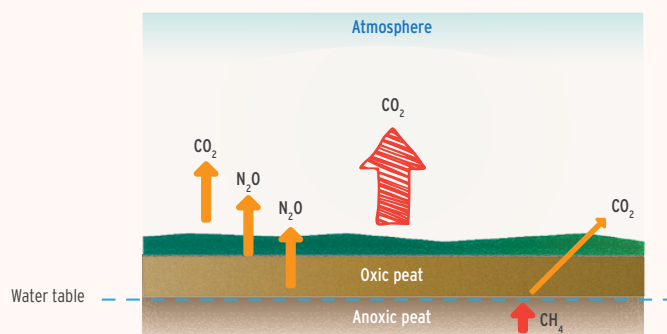
In a pristine peatland, a high water table maintains the anoxic conditions of the peat and the peatland is a net CO_2 sink (Figure 5). When a peatland is drained and water is no longer present in the soil pores, oxygen enters and oxidizes the peat through biological and chemical processes. Drainage also increases the risk of fire. As a result of biological oxidation carbon is lost to the atmosphere, mainly as CO_2 (Figure 6), and as a result of peat fires, a combination of various gases including CO_2 , CO and methane (CH_4) is emitted. Climate and temperature, as well as GWL, have a clear influence on the rate of peatland CO_2 emissions. Both drainage and fire also cause enhanced discharge of carbon as dissolved organic carbon (DOC) and particulate organic carbon (POC) into downstream aquatic ecosystems. Due to losses of organic matter, the peatland surface subsides, and this subsidence can be measured and used as an indicator of carbon losses. CH_4 emissions are also generated in ditches and canals, where plant materials and peat detritus flushed from the land accumulate and decompose under anaerobic conditions.

Figure 5 Carbon dynamic in an undrained peatland



Source: Renou-Wilson *et al.*, 2011

Figure 6 Carbon dynamic in a drained peatland



Source: Renou-Wilson *et al.*, 2011

Non-carbon GHG emissions, mainly nitrous oxide (N_2O) from drained peatlands are a consequence of the mineralization of nitrogen compounds during peat decomposition and are further enhanced by applications of mineral and organic nitrogen fertilizers. Nitrous oxide is an important GHG as it has a global warming potential of 310 times higher than that of CO_2 over a 100-year time horizon (FAO, 2014).

Remote sensing mapping and data sources

In addition to the secondary and field data used in previously developed mapping methodologies, remote sensors have been widely used for peatland identification. Main types are high-resolution optical sensors and radar satellite systems, which differ in the way they function and offer information.

High-resolution optical sensors

Optical remote sensing makes use of visible, near-infrared and short-wave infrared sensors to form images of the Earth's surface by detecting the solar radiation reflected from targets on the ground. Freely available optical imagery from high-resolution satellite sensors (with resolution of 10–30 m; e.g. Landsat, Sentinel-2, etc.) has been primarily used to map peatlands (e.g. Lähteenoja and Page, 2011; Langner, Miettinen and Siegert, 2007; Miettinen and Liew, 2010; Phua *et al.*, 2007; Wahyunto, Heryanto and Widiastuti, 2006; Wahyunto, Ritung and Subagio, 2003, 2004; Wijedasa *et al.*, 2012). The new generation of very high resolution (VHR) multispectral imagery (with resolution of ≤ 10 m; e.g. SkySat [Planet: 0.72 m], Doves [Planet: 3 m], WorldView [2 m], IKONOS [4 m], RapidEye [5 m]), and others might considerably enhance future peatland delineation. However, as these are commercial operations, they come at a price and may not be accessible to developing countries.

Optical sensors are limited by weather conditions and rely upon solar illumination or thermal radiation. To compensate for frequent cloud cover, especially in the tropics, satellite imagery with high temporal resolution should be used (e.g. Sentinel-2).

Radar satellite systems

Radar remote sensing from space has developed greatly over recent decades, in parallel with the development of radar sensors, but also with developments in space technology, computing capacity, image processing techniques and physical understanding of the interaction of radar waves with the terrain. Radar-based satellites are not affected by weather conditions and can penetrate clouds and, to some degree, vegetation.

In 1978, NASA launched SEASAT, equipped with the first space-borne synthetic aperture radar (SAR). This radar satellite used the so-called L-band wavelength of ± 25 cm. Radar wavelengths are much larger than wavelengths used for optical systems and have the capability to penetrate clouds, mist and rain. Moreover, radar is an active system, which means it has its own source of illumination and is independent of solar illumination, allowing imaging radar to observe 24 hours per day, each day of the year.

Besides L-band radar, other radar systems with shorter wavelengths exist, such as C-band and X-band radar (Table 1).

Table 1

Remote sensing tools and their characteristics, useful for peatland mapping

Satellites / sensors	Country	Period of operation	Band	Wave-length (cm)	Polarisation	Spatial resolution (m)	Orbital repeat (days)
ALOS / PALSAR	Japan	2006–2011	L	23.6	Single, Dual, Quad	10–100	46
ALOS-2 / PALSAR-2	Japan	2014–present	L	23.8	Single, Dual, Quad	1–100	14
NISAR	NASA, India	Start in 2021	L	23.8	Single, Dual, Quad	3–10	12
Sentinel-1	Europe	2014–present	C	5.6	Single, Dual, Quad	W–20	12 (6)
RADARSAT Constellation	Canada	2019–present	C	5.6	Single, Dual, Quad	1–100	12 (4)
TerraSAR-X TanDEM-X	Germany	2007–present 2010–present	X	3.1	Single, Dual	1–16	11
PAZ	Spain	2019–present	X	3.1	Single, Dual	1–16	11
COSMO-SkyMed	Italy	2007–present	X	3.1	Single, Dual	1–100	16

The longer the wavelength, the deeper the waves penetrate the forest canopy. L-band radar reflections are mainly caused by trunks and large branches, while the shorter C- and X-band radar are mainly reflected by the leaves of the upper canopy, which means they can help to observe peatland soil moisture only where there are no trees. Radar systems with short waves also have higher spatial resolution. This makes L-band radar more suitable for land cover and forest biomass monitoring, while X-band radar is better for detecting disturbances in the forest canopy at tree level.

Radar systems also differ in the polarization(s) of the waves used. There are systems with single polarization, dual polarization and full (quad) polarization. More polarizations allow better distinction between different types of land cover (Table 1).

Radar satellites are designed with specific applications in mind. The Japanese L-band systems PALSAR-1 and PALSAR-2 cover the entire world systematically, building large archives for the study of continental-scale land cover change and wetland dynamics. The European Sentinel-1 mission utilizes two identical satellites to provide free data at 20 m resolution. The systematic acquisition is done with an observation interval of six or 12 days, depending on geographic location. This interval will be improved into six days in the near future.

The X-band satellites TerraSAR-X and COSMO-SkyMed provide images with much higher resolution but these images cover smaller areas. They are typically used where high or very high resolution is required (see also Lucas *et al.*, 2012; GFC-GOLD, 2013; 2015; GFOI, 2013).

A multisensory¹ and iterative² approach that includes historical remote sensing (see next section) and field data is recommended³. This approach can be split into three phases: Phase 1 for collection and processing of input data; Phase 2 for peatland mapping (including peatland delineation and peat thickness modelling); and Phase 3 for possible interventions and restoration mapping. These phases are described below.

¹ Use of multiple remote sensing systems (including passive and active sensors) in combination (Lawson *et al.*, 2014).

² Peatland mapping based on remote sensing is an iterative process in which different sensor types are used (multisensory approach). The interpreter conducting the peatland mapping should preferably have a background in peatland ecology, local knowledge of the area of interest, and a profound understanding of the different remote sensing systems applied.

³ As with every remote sensing approach, peatland distribution derived from remote sensing must be validated using *in situ* data.

Box 3

Definition of peat and peatland by the IPCC

There are no IPCC definitions for peat and peatland. In the IPCC 2013 Wetlands Supplement, the concept of peatland is considered to be included in "(land with) organic soil". The Supplement follows the definition of organic soils in the 2006 IPCC Guidelines (Annex 3A.5, Chapter 3 in Volume 4):

"Organic soils are identified on the basis of criteria 1 and 2, or 1 and 3, as listed below (FAO, 1998):

- *Thickness of organic horizon greater than or equal to 10 cm. A horizon of less than 20 cm must have 12 percent or more organic carbon when mixed to a depth of 20 cm.*
- *Soils that are never saturated with water for more than a few days must contain more than 20 percent organic carbon by weight (i.e. about 35 percent organic matter).*
- *Soils are subject to water saturation episodes and have either:*
 - a. *at least 12 percent organic carbon by weight (i.e. about 20 percent organic matter) if the soil has no clay; or*
 - b. *at least 18 percent organic carbon by weight (i.e. about 30 percent organic matter) if the soil has 60 percent or more clay; or*
 - c. *an intermediate proportional amount of organic carbon for intermediate amounts of clay."*

According to the IPCC 2013 Wetlands Supplement, it is "good practice" that, when a country uses another definition of organic soil in accordance with its national circumstances, the concept of organic soil (and its possible subdivisions) applied is clearly defined, and that the definition is applied consistently across the entire national land area and over time. Research is continuously contributing to the harmonisation of definitions, however, further research is needed to clarify concepts for different applications. Establishing a national definition for peat and minimum thickness to define a peatland is a crucial step in the definition of mapping methodologies.

Types of radar data

Different types of radar input data are beneficial for peatland mapping:

L-band data: the Japanese Space Agency JAXA acquired large archives of L-band data during the JERS-1 mission (1992-1998) and the PALSAR-1 mission (2006-2011). These data are available free of charge. For data from the current PALSAR-2 mission (from 2014 to the present), this is not (yet) the case. In the near future, free L-band data from the NISAR mission is expected to become available, with systematic coverage at high resolution (10 m), every 12 days.

C-band data: two C-band radar satellite constellations are currently operational. Both provide free data. The European Sentinel-1 covers the land surface regions systematically using one satellite (every 12 days) or combining both satellites, to reduce the observation interval to six days. The RADARSAT, with three satellites, can reduce the revisiting time to four days.

X-band data: the X-band missions (see Table 1) provide very high resolution, but cannot do this systematically. Acquisitions must be planned and are not free of charge.

PHASE 1: COLLECTION AND PROCESSING OF INPUT DATA

The following data should be considered in the course of mapping peatlands during the desktop study phase.

Historical and legal data

Many peatlands have a history of degradation, so are difficult to map with recent remote sensing data. In such cases, peat extent should be delineated from historical optical satellite imagery (e.g. Landsat archive) by interpreting historic drainage and vegetation patterns.

Historical land cover and land use maps may help to interpret historical satellite imagery. In cases where no local historical data on land cover and land use are available, global or regional land (and forest) cover and land use data may be considered as an alternative (e.g. Arino *et al.*, 2008; Bartholomé and Belward, 2005; Friedl *et al.*, 2010; Hansen *et al.*, 2000).

When using global maps and other data, find out the source of the global product and which data have been used to validate it, as this may have been done in a completely different area or climatic region than the country or region of interest, and as such may have a low accuracy. Regional land cover and land use data (e.g. Margono *et al.*, 2014; Miettinen, Shi and Liew, 2016) will probably be more accurate but should also be cross-checked against other data.

The legal status of land is registered in the cadastre of most countries. Spatial plans issued by the government provide information on what type of activity is planned or allowed, for example whether the land is designated as a conservation area, national park, or under a concession.

Current land cover, land use and changes

With the Sentinel satellite constellation with its unprecedented temporal (six days) and spatial (10-20 m) resolution in operation since late 2014, automatic land cover mapping is rapidly starting to become the standard at low cost, especially when utilizing the power of cloud computing platforms [e.g. FAO SEPAL (see Box 7), Copernicus Data and Access Information Services (e.g. Mundi Web Services), Google Earth Engine (Gorelick *et al.*, 2017)] which contain much of the common satellite imagery as well as frequently used classification algorithms such as classification and regression trees, random forest (RF), and support vector machines. VHR satellite imagery may be used to delineate reference datasets to train these algorithms, reducing the need for field measurements and consequent cost and time. The quality of the maps depends on the ability to create a sufficiently cloud-free composite image, which may require at least a year of observations.

Once a good land cover or land use map has been created, disturbances can be monitored at regular intervals. Drainage canals or ditches, logging tracks and roads can be manually digitized from VHR (≤ 10 m) resolution optical imagery. Larger canals and logging tracks can be delineated from high resolution (10-30 m) Sentinel-2 and Landsat imagery, for example using the FAO Open Foris suite.

Elevation model

As peatlands develop under long-term water saturation of the soil, they are found in areas where large amounts of water are available (e.g. coastal environments) or flowing (e.g. depressions, rivers). Elevation models are useful to identify these hydrological landscape units. Further, elevation data help to identify the location of peat domes and to interpret the peat (dome) morphology, which is useful when designing field surveys (see next section). It is, however, important to recognize the limitations of elevation models in detecting peatlands that are not dome-shaped. The still frequently used shuttle radar topography mission (SRTM) data, collected in 2000, provide a surface elevation model - not a terrain model - as they include vegetation height. Furthermore, SRTM data are referenced to the geoid and not to local mean sea level (MSL).

Peat depth

Peat thickness, together with its carbon content, determines the carbon stock in a vertical peat column, and the potential duration of GHG emissions if this particular peatland is drained. Peat depth distribution data are therefore needed to understand the full carbon stock in a peatland landscape (Parry and Charman, 2013), which can be taken into account for land use planning and management. In many countries, peat depth is one of the key criteria, which defines an area as a peatland, and determines whether it can be converted or not. However, peat depth can vary considerably within and between peatlands, and they emit GHGs as long as the peat is exposed to air. Therefore, the depth of a peatland affects the potential period and total amount for GHGs. There is a considerable lack of peat depth data at local, national and global scales (Parry, Charman and Noades, 2012).

Peat depth strongly depends on the relief of the underlying material (such as rock, sand, clay). This presents a challenge to modelling and usually requires field measurements to establish an accurate estimate of peat carbon stocks. In case of limited resources, therefore, the assessment of peatland extent and status (drainage; plantation; and other activity data) should be prioritized, the more so because emissions depend mainly on the area affected by degradation (oxidation, erosion, fire), and much less on total peat depth.

Peat depth can be measured by (i) manual probing with a peat corer or metal rod to record the probable depth, and (ii) ground penetrating radar (GPR). In the field, manual augers or corers are used for measuring, as shown in Figure 7. Field surveys are recommended to be carried out along transects perpendicular to rivers. A detailed protocol as well as an approach to field survey design for an effective and cost-efficient peat thickness survey has been proposed (Vernimmen *et al.*, 2017, 2018). GPR is a non-invasive geophysical technique that uses radar pulses to image the subsurface base layer

of peat (Parry *et al.*, 2014). A GPR unit consists mainly of transmitting and receiving antennas, a control unit and a display. The transmitting antenna produces short-pulse electromagnetic waves that penetrate the belowground substrate and will be reflected or scattered back to the receiving antenna over time. GPR has been applied successfully to the measurement of peat depth (see e.g. Lowry, Fratta and Anderson, 2009; Mellett, 1995; Murdiyarso *et al.*, 2017).

Where an accurate elevation model is available, peat thickness can be determined by identifying the peat bottom position that is the interface between the peat and the underlying mineral sediment, i.e. the difference between the peat surface and depth of the peat bottom. This is further illustrated in Figure 8, and examples are provided in Vernimmen *et al.* (2017, 2018). Belowground carbon stock of the peat can also be determined (see Key features of peatland delineation p.8). Peat samples at different depths can be taken at the same time as the peat thickness measurement, to determine carbon content and bulk density in the laboratory.

Figure 7

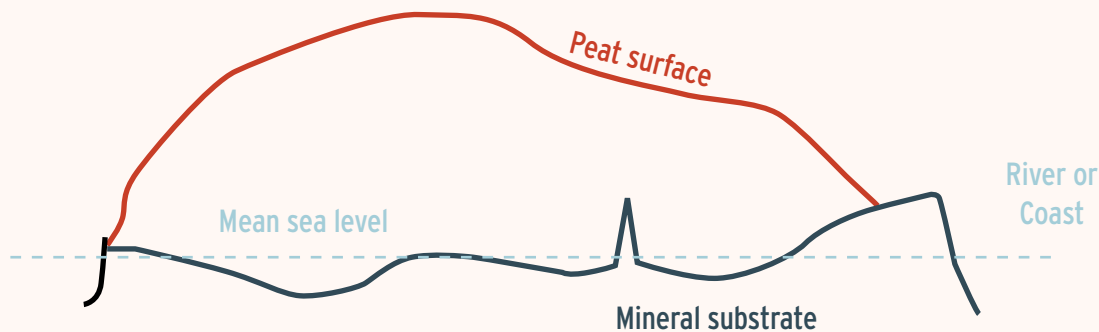
Manual auger used for peat sampling in the field



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Figure 8

How to determine total peat thickness in a domed peatland



Source: Deltares 2017



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Historical fire occurrence and burnt areas

Fires have been monitored routinely from space by the MODIS Aqua and Terra satellites since late 2000 and these data are freely available (Giglio *et al.*, 2003; Justice *et al.*, 2002; Kaufman *et al.*, 1998). Several data products exist including a burnt-area product derived from these satellite data (Giglio *et al.*, 2018). The MODIS hotspot data represent areas of 1 km² in which there is a fire, but this does not

necessarily mean that the entire 1 km² is burning; the actual area on fire may only be a fraction of that (NASA 2020), leading to an overestimation of fire occurrence. On the other hand, MODIS burnt areas have also been found to underestimate actual burnt area (Gaveau *et al.*, 2014; Tansey *et al.*, 2008). Therefore it is preferable to compare with other maps of burnt area, such as those delineated from cloud-free optical or radar satellite imagery (e.g. Gaveau *et al.*, 2014; Lohberger *et al.*, 2018; Tansey *et al.*, 2008).

PHASE 2: PEATLAND MAPPING

Based on an iterative process, peatlands are delineated by an expert incorporating all the above-mentioned input data. More details on delineation methodologies have been developed by Barthelmes, Ballhorn and Couwenberg (2015), Gumbrecht *et al.* (2017), and Bourgeau-Chavez *et al.* (2018) for tropical and boreal peatlands. Other methodologies are also widely available. Personnel mapping the peatlands will need to take the actions described below through field surveys, at least in the main types of peatlands.

Peatland status and socio-economic factors

It is important to map the peatland status, particularly if it has been drained and/or burnt and if different management or other activities are ongoing, and to divide it into different sections according to the type of management. To determine GHG emissions and carbon losses, it is also important to understand hydrological connectivity, i.e. if the effect of drainage extends beyond the area where the GWL has been directly lowered (see Figure 1 and Figure 2).

For reporting on socio-economic issues, as well as improving the sustainability of peatland management, it is important to understand the various ways that people use the peatlands – low-intensity activities such as hunting or gathering non-timber forest products, or activities involving fire or land clearing. It may be useful to disaggregate the collected data by gender and by stakeholder groups to allow a targeted approach, for example for development collaboration. Using geographic information systems it is possible to integrate socio-economic and other data in the peatland maps. National forest inventories (NFIs) are one possible source for land use and socio-economic data acquired through household surveys.

Biodiversity assessments

While accessing the peatlands, it is important to note at least the key plant species that are forming the peat, i.e. the dominant species in the vegetation, such as Sphagnum mosses, grasses, sedges or

trees. For livelihood development, note any natural peatland species that could allow for non-invasive, non-drainage-based livelihood options, if needed. An example of biodiversity assessment for monitoring the United Kingdom's peatlands has been developed by Natural England (2011).

PHASE 3: INTERVENTION AND RESTORATION MAPPING

Through a combined assessment of the above input data (Phase 1: collection and processing of input data) and the results from the peatland mapping (Phase 2: peatland mapping), the areas requiring intervention, such as restoration, are mapped. There will be areas where it is best to only undertake hydrological restoration and allow natural vegetation to return naturally through (assisted) natural regeneration (FAO, 2018, 2019a) or ecological succession, and other areas where both hydrological restoration and planting of native vegetation (rehabilitation) are required (see Figure 9). Planting might be necessary, for example, when peatland fires have destroyed the seed bank, and there are no peatland species growing in the area allowing for natural expansion. Consequently, both rewetting and revegetation should always be planned together, with revegetation achieved either through natural regeneration or, depending on local environmental and socio-economic circumstances, through planting of trees. Increasing tree density by replanting peatland species can help reduce the loss of humidity through evapotranspiration (Limpens *et al.*, 2014).

Revegetation with native peatland tree species is especially applicable to tropical peatlands (see for more: Box 4 and Figure 9). On the other hand, in most temperate and boreal non-forested peatlands, which are dominated by mosses, the removal of tree plantations is, in fact, a restoration challenge on drained sites in the process of restoring native Sphagnum bogs (The Flow Country, 2019).

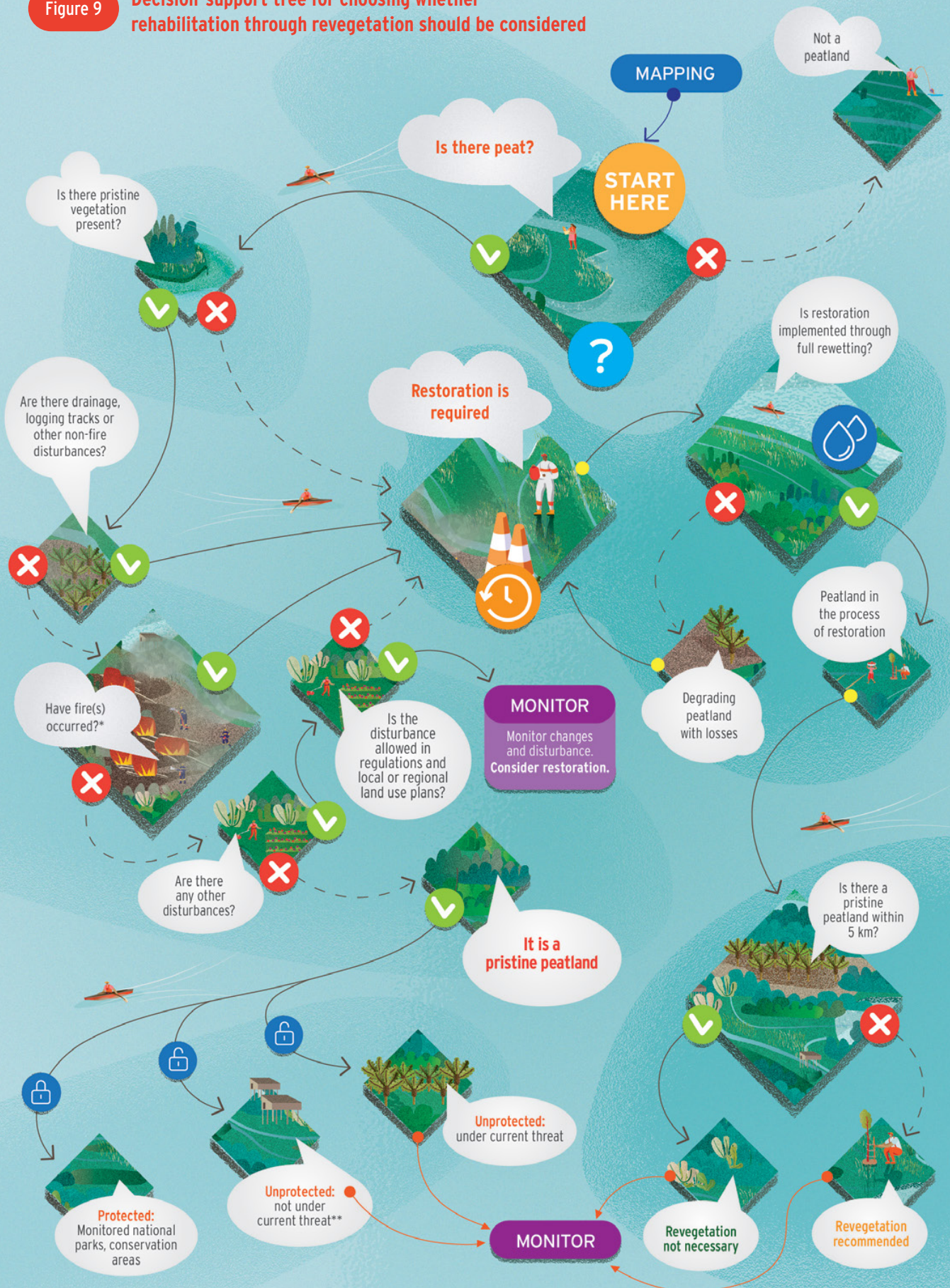
Box 4

Peatland restoration and rehabilitation

The terms peatland restoration and rehabilitation are frequently used and are often conflated. "Rehabilitation" refers to revegetation and is used for activities with the goal of repairing ecosystem processes, without necessarily reverting to the previous state (Society for Ecological Restoration International Science & Policy Working Group, 2004). Note however that without the raised water table, the wetland plants and trees would not be able to return. "Restoration" is mainly used to refer to hydrological restoration, such as canal blocking and associated measures, which would allow the peatland species to return. Peat restoration is best used as a single class to define areas where hydrological restoration is required (see Figure 9).

Figure 9

Decision-support tree for choosing whether rehabilitation through revegetation should be considered



* Include fires due to lighting

** Threat by canal or road development or recent fire occurrences along forest edge within buffer zone of 5 km



Chapter 3

Peatland monitoring

by Ronald Vernimmen, Aljosja Hooijer, Hans Joosten,
Uwe Ballhorn, Maria Nuutinen and Hesti Tata



Chapter 3

Peatland monitoring

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Peatland monitoring is referred to here as the regular and systematic observation of specific variables and their changes over time, within a known peatland area. Monitoring is often used to inform and understand how peatland function and condition is evolving and to assess the effectiveness of water management strategies, restoration interventions, and the risk of fires. To achieve results, a true landscape approach is important:

"By adopting a landscape approach, we learn how to look at landscapes from a multi-functional perspective, combining natural resources management with environmental and livelihood considerations. People and their institutions are therefore perceived as an integral part of the system rather than as external agents operating within a landscape"

(Global Partnership on Forest and Landscape Restoration, 2018)

The landscape approach in the case of peatlands means, in particular, considering water flow and changes, people's livelihoods, and different sectors' impact and activities, sometimes located far from the peatlands but having an impact on them. Other factors to consider are, for example, the buffer zones around peatlands and practices using fire within the landscape.

Peatland monitoring is distinct from peatland mapping, which serves to determine the extent of the peat (see Chapter 2). The purpose of a peatland monitoring system defines the parameters and the relevant data sources and thus the monitoring approaches and tools. Common purposes set by governments are monitoring and reporting



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on peat-related GHG emissions under the GHG inventories and the MRV framework to the Climate Convention, as well as monitoring restoration efforts, and to observe and to be able to make appropriate decisions to control and prevent further deterioration of peatlands.

Chapter 5 covers further frameworks to showcase different monitoring needs, and points out how monitoring could be harmonized to serve multiple reporting requirements.

MONITORING PARAMETERS

Monitoring needs differ depending on the peat condition and the required interventions, defined for example in the mapping phase (see Chapter 2). Examples of tools to measure these parameters are described in Chapter 4. The parameters in Table 2 should be measured to monitor the changing conditions of peatlands and estimate GHG emissions.

Table 2

Examples of parameters for monitoring different types of peatlands, suggested minimum frequency and utility for climate reporting indicators

Peatland's condition	Possible monitoring parameters	Suggested minimum frequency	For climate reporting, indicator of:
All peatlands	Area of peat	Annually	Potential GHG emissions
	Local climate and altitude	Rainfall regimes seasonally	Potential for GHG emissions
	Socio-economic factors	Annually	Sustainability of action
	Peat depth	Once	Carbon storage and potential duration of emissions
Peatlands in temperate and boreal regions	Fertility	Once at different peat depths	Potential for GHG emissions
Temperate peatlands	Vegetation	Regularly, e.g. every five or ten years	Proxy for GHG emissions
Pristine peatlands	Potential land cover or land use change	Annually	Need for preventive action
	Drainage-free land uses	Twice a year	Sustainability of action
	GWL (also through canal water depth)	Seasonally	Adaptive capacity
	Soil moisture	Seasonally	Fire risk in case of reduced moisture
	Fire risk and fire detection during dry periods	Daily	GHG emissions, haze and associated health, economic and political issues
Drained peatlands	Area of each drained peatland hydrological unit or area	Twice a year	GHG emissions
	Land cover change or development of drainage canals or ditches, logging tracks and roads (expansion of network)	Twice a year	Changes in above and below-ground carbon stock; Need for preventive action
	Surface level: subsidence and peat depth	Four times a year	GHG and other carbon loss
	Soil moisture and GWL	Seasonally, twice a year	Fire risk, disaster risk reduction
	Fire risk and frequency of fires	Daily during dry periods	GHG emissions, disaster risk reduction
	Area of burnt peat and frequency of fires	After the dry season	GHG emissions, disaster risk reduction
Restored peatlands	Land cover change: Return of native peatland species	Annually	Success indicator
	Management: Wet peatland uses	Annually	Sustainability of action
	Profitability and gender equity of wet livelihood options	Annually	Sustainability of action
	Fully rewetted area with the entire drainage system blocked	Twice a year	Avoided GHG emissions
	Location and status of dams and other restoration efforts (e.g. blocking of canals and ditches)	Twice a year	Success indicator
	Surface level: subsidence and peat depth	Four times a year	GHG emissions and success indicator
	Soil moisture and GWL (also through canal water depth)	Twice a year	Avoided GHG emissions; disaster risk reduction
	Fire risk and frequency of fires	Daily during dry season	GHG emissions; disaster risk reduction
	Area of burnt peat	After the dry season	GHG emissions, disaster risk reduction

Direct carbon loss measurements

Peat emissions are unique, as they are not calculated based on one off deforestation or degradation events, but when drained, they continue over longer periods until the organic material is fully decomposed (Hooijer *et al.*, 2010). Measuring GHG emissions (CO₂, CH₄ and N₂O) directly at field level has recently become less costly and accessible thanks to portable measurement devices with chamber measurements as well as with flux towers (“eddy covariance method”) (FAO, 2014). In addition, losses of water-borne organic carbon (e.g. dissolved organic carbon) can be measured. Note, however, that the interpretation of such measurement data requires highly experienced personnel.

The requirement for long-term GHG measurements – two years are often required – over different seasons, as well as the need for better equipment, is hindering the development of Tier 2 emission factors that could help countries to estimate their specific GHG fluxes from peatlands. The IPCC 2013 Wetlands Supplement provides standard emission factors for different climatic zones and guidance on how to update the emission factors.

Canal water depth and groundwater level

Measuring the level of the water table in peatlands (often below the peat surface) and in canals is a priority for assessing the changing conditions in the peat, the impact of drainage in various parts of the system (e.g. in a peat dome), and thus likely carbon emissions, restoration requirements and associated results.

GWL, due to its direct correlation with GHG emissions from peatland degradation, is the best parameter to estimate GHG emissions, as also recommended in the IPCC 2013 Wetlands Supplement (IPCC, 2014a). (See the section on Dipwells for water-table depth measurement p. 28.) Canal water depth, sometimes referred to as “freeboard” by water management practitioners, can be used as an indicator of GWL, and accessed directly using light detection and ranging (LiDAR). One of the limitations of LiDAR has traditionally been its high cost. Developments in 2019 allow expecting that the price of monitoring using LiDAR could be reduced in future, for example with the increased use of programmed unmanned aerial vehicles (UAVs) such as drones.

Subsidence

Peat subsidence is a serious issue associated with peatland drainage and often connected with other peatland problems. “Subsidence” means the gradual sinking of an area of land. Most peatland subsidence is associated with a massive and continual loss of carbon via both air and water (Couwenberg and Hooijer, 2013), with the intrusion of saltwater, and with an increased risk of flooding. If

peat subsidence continues and global sea levels continue to rise, vast areas will become permanently flooded. Subsidence rates in drained boreal and temperate peatlands are typically in the range 1–3 cm per year, whilst in drained tropical peat rates are higher (3–6 cm per year) as a result of faster decomposition rates at higher temperatures (Evans *et al.*, 2019). Subsidence rates are generally higher in more deeply drained peat, and in the period immediately following drainage. Large areas of peat in some countries such as the Netherlands and Britain, where drainage began centuries ago, are now below sea-level and require energy-intensive pumped drainage. This approach is unlikely to be feasible for the vast areas of coastal peatland in Southeast Asia that have been drained more recently, and if peat subsidence continues in these regions, and global sea levels continue to rise, these areas will be at increased risk of flooding. Loss of areas where people live (cities, villages) or work (forestry, cropping or grazing) through increased flooding and intrusion of saltwater may cause significant economic and social hardship, and force countries to take extensive adaptation and disaster risk reduction (DRR) action. Subsidence intensifies when proper management is lacking (Saputra, 2019) and often indicates the need for restoration.

Subsidence is also closely associated with carbon loss, with at least half of all subsidence typically resulting from the oxidation of aerated peat and resultant CO₂ emissions. In the IPCC 2013 Wetlands Supplement, subsidence measurements were recommended as a cost-effective method to estimate GHGs for reporting purposes in drained organic soils. As subsidence and raising of the peat surface vary according to the water content of the peat, it can also be used to estimate the success of peatland rewetting. For examples of measurement methods, see sections on Subsidence poles and Subsidence measurements, pages 27 and 28.

Fire occurrence

Fire monitoring is an area of work currently under development. Monitoring peatland condition is relevant for determining fire risk, likely causes, and the GHG emission associated. New emission factors should be available in the near future, making it possible to estimate, for example, emissions due to reduced fire load after several fire events. Fire monitoring should intensify during dry periods (see sections on Historical fire occurrence and burnt areas, p. 15 and on Fire monitoring initiatives, p. 42), and studies have shown the importance to monitor peatland status even after, and between, fire events, due to its relevance for GHG emissions calculations (Lupascu, 2020).

Different methods exist to monitor fire risk and fire events. In most cases, meteorological centres conduct fire danger monitoring, which is closely related to monitoring weather conditions, such as rainfall, wind, and thunderstorms. Large commercial enterprises often have

their own fire risk monitoring systems and teams charged with extinguishing fire. Fire risk monitoring allows the setting of fire warnings, such as prohibiting the use of fire outdoors.

In the humid tropics, the majority of fires are anthropogenic, and - importantly - most fire events can be spotted, and their original location traced. Many countries have made rapid advances in identifying the culprits of intentionally lit fires. In this case, a timely monitoring system can contribute to emergency response and development of strategies to avoid intentional fires.

Canal blocks

Water loss can be controlled by canal blocking⁴ leading to raised GWL and allowing peatlands to restore⁵. In some cases, canal blocks have been damaged⁶ by people who prefer to use the canals for transportation or to keep the water levels low. Canal blocks are also often destroyed by natural causes, such as floods. Therefore, to ensure successful restoration, regular monitoring that the dams remain in place is required. For large areas, high-resolution imagery through remote sensing tools can verify the state of canal blocks, depending on their size.

Other monitoring parameters

Depending on the goal of the monitoring process, biodiversity (e.g. plant and animal species, vegetation structure, connectivity), and socio-economic factors (e.g. local livelihoods, profitability and gender equity of wet livelihood options) could be analysed in order to understand the evolution of peatland status and possible threats. In addition, climate reporting often requires socio-economic data, such as information on safeguards. The results of the mapping phase can be useful to determine which parameters to monitor, but note that any available information on peatland status can be used as a basis for peatland monitoring within a national system.

⁴ Canal block constructions have been built as compacted peat dams, cement structures, box dams, partial canal infilling, and peat dam cascades with positive and negative results (BRG, 2016). After collecting restoration experience from several countries in different climatic zones, the most positive experience has been reported with compacted peat dams. Their particular benefits are persistence even during peak flow, as well as the availability and sustainability of the raw material.

⁵ To achieve full rewetting, stopping peat degradation, reducing fire risk as well as avoiding GHG emissions, the GWL needs to be raised to at least around the peat surface, preferably higher. Canal blockings should be constructed high enough, taking into account the rainy seasons and other periods when water easily breaks dams.

⁶ Compacted peat dams have been noted to be the most difficult to break.

TAKING DECISIONS

The parameters to be monitored depend on the question the monitoring personnel has and may differ among countries. Monitoring requirements can be derived from international frameworks and conventions (see Chapter 5) and/or national legal frameworks or conservation goals and strategies. Table 2 shows possible monitoring parameters depending on the peatland state (for tools to measure these and other parameters see Chapter 4).

The scope of this report does not cover potential issues of data-sharing, institutional arrangements (such as mandates, coordination, capacities, legal basis, budgets, organizational development or other aspects) and processes (such as data handling, quality management, third-party reviews, archiving). In addition, the peatland information is best catered to various stakeholder groups in an approachable manner to allow for social debate, and fact-based decisions to be made. Much can be learned from the experience of countries that have been working on national forest monitoring systems (NFMSS) and GHG inventories as well as national adaptation plans (NAPs).



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Chapter 4

Examples of monitoring tools and approaches

by Andrew Groom, Albert Sulaiman, Dirk Hoekman,
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Chapter 4

Examples of monitoring tools and approaches

by Andrew Groom, Albert Sulaiman, Dirk Hoekman, Laura Villegas, Kai Milliken, Ronald Vernimmen, Laure-Sophie Schiettecatte, Maria Nuutinen and Erik Lindquist

This chapter provides examples of monitoring tools, i.e. those that are currently operational and those that are expected to become operational in the near future. As a key objective is to mitigate climate change by reducing GHG emissions, the descriptions extend beyond observational tools to include analytical tools. Analytical tools focus on those that enable the conversion of monitoring results into GHG emission metrics. The examples are not exhaustive, and only include tools that take into account the specificities of peatland landscapes.

Table 3

Summary of tools for peatland monitoring

Object of monitoring	Type of tool	Tool	Known or expected challenges
Peat surface motion	Ground monitoring	Subsidence pole	Provides limited spatial detail Impractical for monitoring large areas
Peat surface motion	Ground monitoring	Integrated, autonomous subsidence measurement instruments	Some additional cost Impractical for monitoring large areas
Sub-centimetre changes in surface level	Remote observational tool	Interferometric SAR	Variable results linked to vegetation characteristics Update frequencies
Water-table depth	Ground monitoring	Dipwells	Artificial disturbances of peat surface during installation
Canal water depth, ground surface level	Remote observational tool	LiDAR	Cost
Hydrological characteristics, fire, canal detection, forest degradation, etc.	Remote observational tool	Synthetic aperture radar	Cost
Detection of land-use changes, and landscape elements (e.g. canal blockings, deforestation, etc.)	Remote observational tool	High resolution optical imagery	Time needed for interpretation of satellite images
Net ecosystem CO ₂ exchange	Ground monitoring	Flux towers	Cost
Emissions from peat soils under deforestation, fire, and logging	Carbon and GHG balance	AFOLU Carbon Calculator	Some updates needed

Object of monitoring	Type of tool	Tool	Known or expected challenges
GHG balance, temporal carbon trends, and estimation of other climate impacts	Carbon and GHG balance	CarboScen	Availability of GHG emission models
Impact of agriculture, forestry and fishery development projects, programmes and policies on the carbon balance	Carbon and GHG balance	EX-Ante Carbon Balance Tool – EX-ACT	Differentiation of emission factors for areas drained more than five years and less than five years
Carbon stock fluxes (above - and belowground) and GHG emissions derived from land cover change to oil palm	Carbon and GHG balance	Palm GHG Calculator	Identification of further reliable peat emission parameters

OBSERVATIONAL TOOLS AVAILABLE TODAY

Ground-based tools

Subsidence poles

Changes in peat surface elevation (e.g. subsidence) can be measured by inserting a pole made from long-lasting material (e.g. a thick PVC tube) vertically into the peat. It is important to ensure that the subsidence pole is installed firmly into the mineral substrate underlying the peat (to a minimum depth of 50 cm) to guarantee proper anchorage. Upon installation, a permanent marker (PVC collar or another permanent marking) allows a fixed recording of the height of the peat surface. It is relevant to secure that the permanent marker is light enough not to sink in the peat, but heavy enough not to float when flooded. In some instances, it is recommended to fence an area of 2 m × 2 m around the subsidence pole to prevent inaccurate measurements by disturbance of the peat surface, but care should be taken to avoid the fencing activity itself disturbing the measurements.

RSPO (Roundtable on Sustainable Palm Oil) highlights the importance of subsidence measurements, and recommends the installation of subsidence poles with a minimum density of at least one, and preferably two, poles for every 240 ha of oil palm plantations on peatlands for which surface elevation monitoring is required (RSPO, 2018). Subsidence poles should be placed in a representative location (i.e. not close to a ditch or canal) and across a range of representative land use types. Densities may need to be finer for areas with a variety of peat types, depths and drainage conditions.

The RSPO best practice manual requires the peat surface elevation to be recorded at least every quarter year, to adequately capture wet and dry season variability (RSPO, 2018). Regular measurements over a minimum of three years provide reliable subsidence rates.

Dipwells for water-table depth measurement

Dipwells are PVC tubes which may be joined in length depending on the depth of the peat in which they are installed. They enable the measurement of water-table depth below the peat surface. When a dipwell is embedded into the mineral substrate underlying the peat

it can function at the same time as a subsidence pole, allowing the observation of change in peat surface elevation.

To maximize robustness and lifespan potential, the PVC tubes (with an inside diameter of e.g. 3.80 cm or 1.5 inch) should be of the highest quality available, with a preferred wall thickness of 3 mm, as these are more resistant to UV radiation than thin-walled PVC tubes.

Dipwells should be placed at a minimum distance of 10 m from the main transect access path to avoid disturbance and compaction of the peat surface at the monitoring location. They are installed in the peat through boreholes and should be sunk a minimum of 50 cm into the mineral substrate to allow the dual monitoring of peat surface elevation. The top of the tube is sealed with a cap to prevent rainfall from entering the tube (Figure 10, right), while entrance of the groundwater is enabled through a “filter” of 1 mm holes drilled manually into the tube located 5 cm apart (Figure 10, left). During installation, workers should stand on wooden planks to avoid artificial disturbance of the peat surface (Figure 10, right). Installation also provides an opportunity to record peat depth.

Figure 10

Dipwells for water-table depth measurement



Thick-walled PVC pipes with holes to measure groundwater table and an installed dipwell, covered by a removable cap and a PVC collar on the surface of the peat.

© Ronald Vernimmen

Depth to water table is monitored by routinely measuring the distance from the water table in the dipwell to the top of the dipwell. Measuring from the top of the dipwell to the peat surface records any changes in peat surface elevation. Because the peat surface around the dipwell is irregular, the height of the dipwell above the peat surface should be measured to a PVC collar placed on the ground around it (Figure 10, right). As noted above, the material used for the collar should be light enough to float on the peat surface, and heavy enough not to float when the peat surface is flooded.

Good practice also involves photographing the site conditions when readings are taken. These pictures can reveal possible data irregularities that may relate to the conditions of the transect, the equipment, or the data entry.

Figure 11

Automated groundwater level, rainfall and wind measurement point



Automated groundwater level, rainfall and wind measurement point with a solar panel visited by Congolese researcher Dr. Ifo Suspense in Indonesia

© FAO / Maria Nuutinen

Subsidence measurements

Observing changes in peat surface elevation entirely manually and with sufficient frequency is a challenge using subsidence poles or dipwells, particularly on extensive peatlands. Peat surface motion is highly dynamic and thus temporally frequent observations are preferred to understand drainage regimes and related GHG emissions, also to calibrate and validate remote observations.

Automatization reduces the need to access the measurement devices. The Centre for Ecology and Hydrology in the United Kingdom has developed a time-lapse camera system that provides daily observations of peat surface elevation with no requirement for a daily manual reading. The system is designed to be low-cost and easily constructed from materials that can be locally sourced. The tools are robust under field conditions (there are no external moving parts, and similar cameras are widely used in wildlife camera-traps in the region) and able to operate autonomously for long periods (batteries and data storage should allow the system to operate unattended for months).

The British system includes a time-lapse camera mounted on a lightweight platform which “floats” on the peat surface and takes a daily photograph of a target attached to a metal subsidence pole embedded in the mineral substrate underlying the peat. The daily photograph provides a high-resolution (millimetre-scale) measurement of the relative displacement of the camera relative to the target. Software is available to automatically extract these readings from the received photographs.

Greenhouse gas measurements

GHG exchanges between the land surface and atmosphere can be quantified using a variety of methods. The FAO report (2014) describes a variety of methods for direct measurements, summarized here:

CO₂ air-soil measurement: the eddy covariance or “flux tower” method is a micro-meteorological technique employed on a tower with instrumentation typically located above the vegetation. This method determines the surface-atmosphere flux from source areas (hectares to square kilometres) by measuring the covariance between fluctuations in the gas mixing ratio and the vertical wind velocity. A flat, homogeneous topography is a pre-requisite for undertaking these measurements, and steady atmospheric conditions are desirable for more accurate results. In contrast to closed chambers, this method provides continuous, whole ecosystem gaseous flux measurements over relatively large areas. (See for more: FAO, 2014.)

Waterborne carbon: the DOC content is determined by measuring the oxidation of organic matter to CO₂, which is generally accomplished using high-temperature combustion or persulfate oxidation. The spectrophotometric method is used as a complementary method for determining DOC content in the water. To estimate the total loss of DOC, the total discharge also needs to be measured and the catchment area defined. (FAO, 2014.)

In addition, GHGs can be estimated using proxies, as described in the Box 5.



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Box 5

Central European vegetation as a proxy for greenhouse gas fluxes

by John Couwenberg

Vegetation is well suited to indicating GHG fluxes (Couwenberg *et al.*, 2011) because:

- it is a good indicator of the water table, which in turn strongly correlates with GHG fluxes;
- it is controlled by various other site factors that determine GHG emissions from peatlands, including nutrient availability, soil reaction (pH) and land use (history);
- it is itself directly and indirectly responsible for the predominant part of the GHG emissions by regulating CO₂ exchange, supplying organic matter (including root exudates) for CO₂ and CH₄ formation, reducing peat moisture, and providing possible bypasses for methane fluxes via gas conductive plant tissue, or “aerenchymous shunts”;
- it reflects long-term water-table conditions and thus provides indication of average GHG fluxes on an annual time scale; and
- it allows fine-scaled mapping, e.g. 1:2 500–1:10 000.

The approach of estimating GHG emissions through vegetation is currently being applied in the United Kingdom, Germany (Bonn *et al.*, 2014) and the Baltic countries (Sendžikaitė *et al.*, 2018).

In a recent study, the results of a meta-analysis of GHG fluxes were combined with a matrix system of all vegetation types that may occur in Central European peatlands. The analysis then allows for extrapolation and interpolation of measured flux data along various axes of site characteristics (Couwenberg *et al.*, 2011). The resulting greenhouse gas emission site types are currently mainly based on water-table class, vegetation and land use, but also nutrient status and acidity (pH). Additional measurement data are regularly integrated to increase the accuracy of GHG emission estimates.

In order to estimate emission reductions, scenarios of vegetation development must be formulated for the situation with rewetting (“project scenario”) and the situation without rewetting (“baseline scenario”). Emission reductions can be conservatively estimated by applying low estimates for the baseline and by omitting emissions from ditches and of N₂O, while applying high estimates for the project scenario. CH₄ emissions from ditches can be particularly substantial, but are usually emitted from small areas that are expected to be overgrown after rewetting measures, thus reducing emissions. Disregarding emissions from ditches thus means reductions are underestimated. N₂O emissions are erratic, but always negligible when peatlands are wet. Leaving N₂O out of the assessment will result in an underestimation of emission reductions.

Remote observational tools

Changes in peatlands can be increasingly monitored using remote sensing tools (see also Box: 6) and platforms (see e.g. Box 7).

Synthetic aperture radar

Space-borne radar observation is not hindered by adverse atmospheric conditions, such as clouds, smoke and haze, and can be made frequently and repetitively, including in the rainy season. Because of a certain penetration level of the radar waves, observation below the canopy is also possible. Particularly the L-band sensors on board the former JERS-1 and ALOS-1 satellites (Rosenqvist *et al.*, 2007) are superior to all other space-borne sensors for assessment of flooding and drought conditions and thus hydrological cycles.

Moreover, radar signals are sensitive to forest structure and biomass level (Hoekman and Quiñones, 2002; Hoekman, Vissers and Welaard, 2011; Lohberger *et al.*, 2012; Schlund *et al.*, 2014). This offers unique opportunities for applications such as monitoring

peat swamp forest conditions, hydrological integrity and fire susceptibility, as well as fast response to illegal tree logging and canal construction (Hidayat *et al.*, 2011; Hoekman, 2018; Schlund *et al.*, 2015). A near real-time system based on free Sentinel-1 C-band data has recently been demonstrated, allowing forest degradation, deforestation and new canal detection to be monitored. For more accurate information related to hydrology, it is better to integrate these C-band data with L-band data.

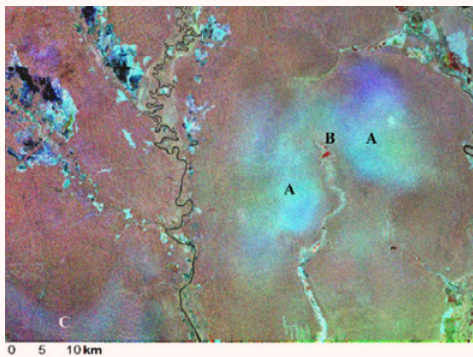
Figure 12 is an apt example of the use of SAR data, which illustrates that temporal dynamics in flooding intensity can be related to the hydrology of ombrogenous⁷ peat swamp forests and indirectly to peat depth (Hoekman, 2007). Light blue areas show flooded parts of the relatively flat tops of two peat domes (“A”); “B” indicates a central depression with a river; and “C”: relatively flat and wet fringe of a

⁷ A peat-forming vegetation community lying above groundwater level: it is separated from the ground flora and the mineral soil, and is thus dependent on rainwater for mineral nutrients.

dry peat dome, which can be better seen in Figure 13. The red area dates back to 7 September 1994, with green and blue representing 12 July 1995 and 4 January 1996 respectively.

Figure 12

Example of SAR data on flooded areas within a complex peat dome in Mawas area, Central Kalimantan and JERS-1 SAR multi-temporal composite image



Source: Hoekman, 2007.

In Figure 13, the time-series of JERS-1 SAR exemplifies the deleterious impacts of underground peat fires and the fast succession of events that resulted in trees falling down at a central area of peat swamp forest. This forest collapse can be accurately depicted, using time-series data to highlight the logical sequence of events. Until 1996, the dome was hydrologically intact, however, in 1997, the construction of a wide canal through the dome became apparent. In the third image of the sequence (September), the canal becomes filled with water and becomes black and distinguished with a small bright area. This bright area grows exponentially through time, until the forest completely collapses in January 1998. To note, the images of figure 13 are from the location “C” in Figure 12.

Soil surface subsidence for this dome was estimated to be approximately two meters (Kool, Buurman and Hoekman, 2006). A pivotal cause of the collapse was the intense drainage caused by the wide canal. That said, the coinciding ENSO period at the time, may have accelerated the process (Hoekman, 2007).

Interferometric SAR

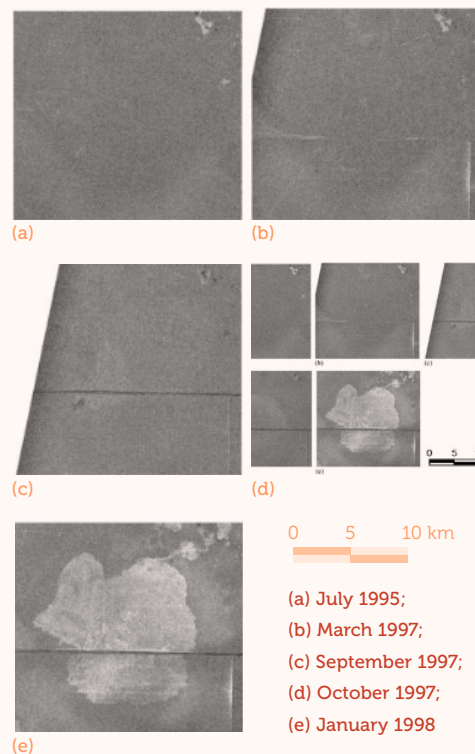
High-precision mapping and monitoring of changes in land surface elevation are also possible using satellite-based techniques, the most common of which is differential interferometric synthetic aperture radar. These techniques exploit subtle changes in the radar signal phase to identify sub-centimetre changes in the line-of-sight position of targets. The two most common times series InSAR methods are PSInSAR (persistent scatterer) and SBAS (small baseline subset), both of which can typically produce very accurate deformation

profiles for urban or rocky, sparsely vegetated areas. However, both methods are considered to be severely challenged over vegetated terrain due to uncertainty of signal penetration - depending on vegetation density and height - and high variability incoherence of the measured signal (Figure 14).

Recent studies have shown that all SAR wavelengths are able to penetrate a forest canopy to some extent. The challenge is to develop a technique that can effectively filter out and exploit the high coherence points and produce meaningful observations of changes in surface elevation. Such a technique, known as ISBAS (intermittent small baseline subset), was developed at the United Kingdom's Nottingham University in 2012 (Sowter *et al.*, 2013).

Figure 13

JERS-1 SAR time series of the collapse of the peat dome in 1995–1998 in Kahiya, Central Kalimantan, Indonesia



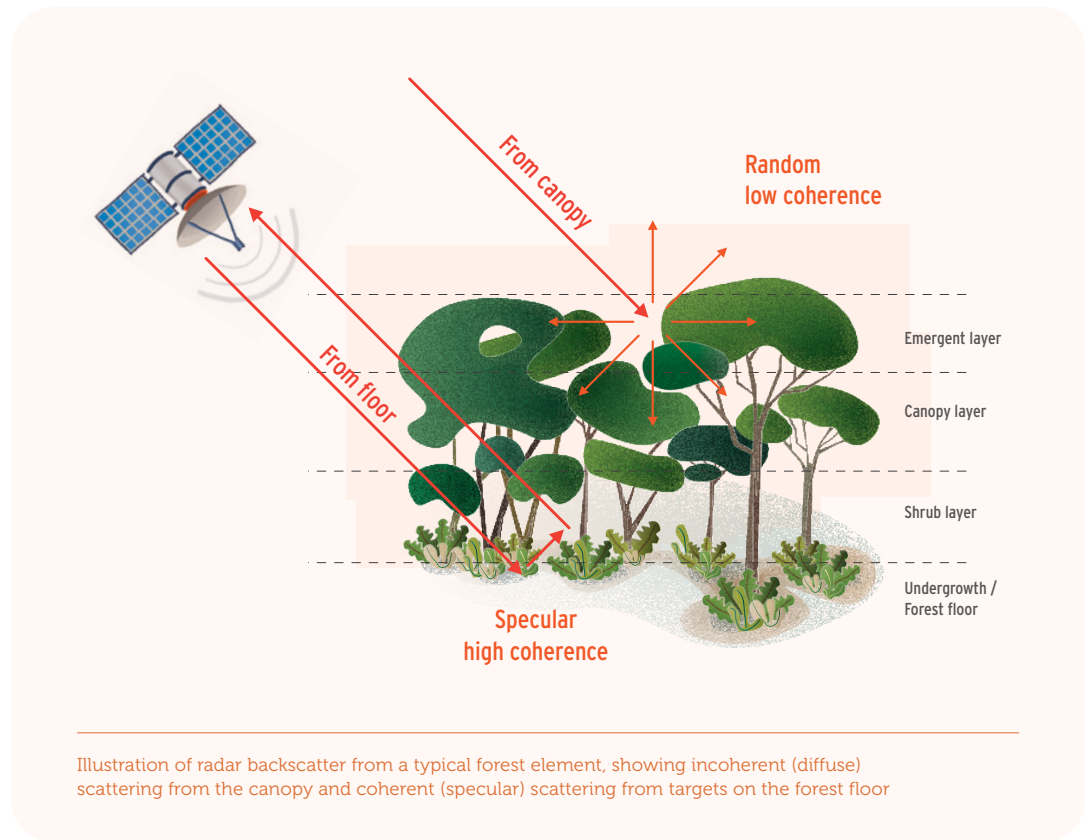
Source: Hoekman, 2007.

ISBAS is imagery intensive, requiring a dense time series of SAR observations in order to allow for the capture of sufficient numbers of high coherent points. The operational Sentinel-1 mission (a two-satellite constellation) captures a new image at least every 12 days over all global landmasses.

This temporal capability, combined with the partial canopy penetration (Sentinel-1 is C-band), enables the generation of land motion measurements over both vegetated and non-vegetated surfaces.

Figure 14

Illustration of radar backscatter from a typical forest element



Source: European Space Agency and Dr Andrew Sowter/Personal communication.

This means ISBAS can be used for almost complete coverage of any landscape, including peatlands.

The technique is able to generate average rates of motion, with 12-month update frequencies, and has been demonstrated to work in all peatland contexts (arctic permafrost, temperate, Neotropical and tropical) (Alshammari *et al.*, 2018; Cigna *et al.*, 2014). It can be used for wide-area surveys of peat surface motion to select priority restoration areas, as well as routine, ongoing monitoring of peat surface motion to test the effectiveness of restoration interventions.

Peat surface elevation changes are known to be linearly related to water-table depth. As water-table depth is also related to GHG emissions, the technique can also be applied to:

- plantation-scale observations to test the effectiveness of water table management strategies;
- regional-scale observations to demonstrate compliance with water table depth regulations; and
- regional-scale observations to inform calculations and monitor GHG emissions in response to land management actions.

Box 6

Landscape-scale observation of peat surface elevation change

LiDAR (light detection and ranging) uses a laser to produce and emit pulses of light, and measures the time it takes for a reflection of this pulse to return. Most commonly, the LiDAR system is carried by a fixed-wing aircraft, and in addition to the laser-emitter-receiver scanner, LiDAR systems are also connected to a global positioning system (GPS), and an inertial measurement unit (IMU). The GPS constantly measures the position of the laser scanner, which is crucial for knowing the location where the light pulses are emitted. The IMU measures the tilting of the aircraft (roll, pitch, yaw), which is crucial for calculating the directionality of the aircraft and hence the directionality of the emitted pulses of light.

The easiest way to understand how LiDAR works is to examine the life of a single emitted pulse of light. The pulse of light is a clump of time-stamped photons emitted with known directionality. As this pulse contacts a surface (e.g. a leaf in the forest canopy), a portion of those photons is reflected back towards the laser. The laser-emitting device recognizes these time-stamped, reflected photons and calculates the time between their initial emission and their reflected return, alternatively called their echo (i.e. an echo was received from the emitted pulse). Next, the device calculates the location from where the echo originated. This is possible because pulse speed (i.e. the speed of light), pulse origin (location of emission), pulse directionality, and pulse travel time are known values, making it a simple geometry problem to calculate the location of the echo.

Light pulses frequently yield multiple echoes because not all of the photons are reflected by the first surface they contact. Instead, some continue through semi-transparent surfaces before contacting something else and delivering another echo. Therefore, whereas the first echo comes from the highest surface encountered by the pulse, for example the top of the canopy, the final echo from a given pulse comes from the last surface hit by the remaining photons. Most often, this is the ground, but in a dense forest, such as in the tropics, the last pulse can come from inside the canopy as well.

In addition to the location, the device also records the intensity of the returning echo. The intensity is higher if the pulse hits a solid surface, because more photons reflect back (ground vs forest canopy). Modern LiDAR systems can emit up to 800 000 pulses per second. Each pulse can yield multiple echoes, and for each of these locations the echo is recorded. The result is generally referred to as point cloud data; a cloud of points, all of which have an XYZ-location (coordinates). When the data are plotted, the structure of the scanned target can be visualized.

LiDAR has the capability to detect both surface water level in canals and ground surface level near canals, allowing the canal water depth to be determined below the land surface. Although water typically absorbs the LiDAR near-infrared wavelength of 1 064 nm (Höfle *et al.*, 2009; Roelens *et al.*, 2016), reflections of the pulse do occur on the water surfaces caused by low incidence angles and water turbidity among other factors, but also by floating debris and/or plants.

Detection of water surfaces is an essential step in many classification workflows for LiDAR, often to remove them from the dataset to create a digital terrain model that should present the land surface only. In a few cases, point cloud LiDAR data have also been used for surface water level measurement in ditches and rivers (Höfle *et al.*, 2009; Hopkinson *et al.*, 2011; Roelens *et al.*, 2016).

These principles can be applied to determine the absolute water surface elevation above MSL, as well as the level below the surrounding soil surface, i.e. the “freeboard” that is a common target parameter in lowland water management.

ANALYTICAL TOOLS TO ESTIMATE CARBON BALANCE AND GREENHOUSE GASES

All the following tools have parts and/or potential applications for different types of peatlands.

AFOLU Carbon Calculator

The AFOLU Calculator by USAID employs IPCC-based accounting methods that allow users to estimate the CO₂ fluxes of eight types of land-based activities: forest protection, forest management,

afforestation, reforestation, agroforestry, cropland management, grazing land management, and forest degradation by fuelwood, in order to develop and support policies. The calculator is designed for forested landscapes with potentially decreasing carbon stock.

The calculator has several parts, and one of them, “AFOLU carbon calculator – The Forest protection tool: underlying data and methods” (Winrock International, 2014), when used for peatlands, computes emissions from deforestation, fire and logging that can then be compared with, for example, a REDD+ conservation scenario. Activity data used for calculations include, as appropriate, annual area deforested or burnt (ha), annual volume of wood illegally extracted

(cubic metres/hectare), percentage area of peat, depth of peat drainage (metres) and depth of peat burning (metres). The carbon stocks include the live tree biomass (above and belowground) and soils (including peat). The technical area of peatland monitoring has developed rapidly since the calculator was published, and therefore some updates would be needed. As two areas for development, the tool should take into account the soil carbon stock after deforestation, as well as including soil carbon in belowground carbon counting.

CarboScen

CarboScen simplifies the quantification of GHG fluxes and allows the study of temporal carbon trends based on land-use data only. CarboScen has a comparative advantage in landscapes with rapid land use change but gradual changes in carbon density, such as in soil carbon if biomass change is sudden, as typically occurs during deforestation. Distinct uses range from educational to rapid expert assessments, typically simulating future carbon stocks in a landscape. CarboScen could be used in future carbon calculations when planning

or releasing advance payments in REDD+ or other programmes aiming to increase ecosystem carbon. The main payments are then typically released only after results are documented in the field. CarboScen could naturally also be used to compute prior landscape carbon dynamics. CarboScen has been used to simulate various land use scenarios for peatland activities in Indonesia.

Access the tool online: www.cifor.org/gcs/toolboxes/carboscen

EX-Ante Carbon Balance Tool

The Ex-Ante Carbon-balance Tool (EX-ACT) is an appraisal system developed by FAO, providing estimates of the impact of agriculture, forestry and fishery development projects, programmes and policies on the carbon balance. The carbon balance is here defined as the net balance of all GHGs from peatlands (CO_2 , CH_4 , N_2O and DOC), expressed in carbon dioxide equivalent (CO_2eq) that are emitted or sequestered due to project implementation, as compared with a business-as-usual scenario.

Box 7

SEPAL – platform for land monitoring

The System for Earth Observation Data Access, Processing and Analysis for Land Monitoring (SEPAL) is an online, open-source platform that allows users to query and process satellite data and undertake a range of geospatial analyses tailored for different needs. Field monitoring data can be processed through SEPAL's integrated tools by combining optical satellite-based time series analysis with radar-based soil moisture estimates and trends. Specific state-of-the-art peatland restoration monitoring modules are being developed by FAO and partners and are accessible in SEPAL.

SEPAL is a powerful cloud-computing platform for autonomous land monitoring, which uses remotely sensed data to readily process satellite data efficiently to generate advanced geospatial and statistical analyses (e.g. uncertainty). Notable innovations of the platform include:

- improved data access;
- system for rapid and standardized image processing;
- cloud-based processing capacity;
- powerful and useful open-source tools; and
- effective user interface that operates smoothly without the latest computers or high-speed internet connection.

Given that SEPAL is based on open-source code, it can easily be tailored for different users and countries, with their own working areas. In Indonesia, tailored modules are integrated into and accessible through SEPAL. The modules include the following workflows based on up-to-date, scientific methodology:

- dam detection with high-spatial resolution optical imagery;
- time-series analysis of field-based observations;
- time-series analysis of optical spectral indices; and
- radar-based surface soil moisture estimates and trends over time.

Access the tool online: <https://sepal.io>

EX-ACT is a land-based reporting system, estimating emissions or sinks of CO₂ in all five carbon⁸ pools as well as GHG emissions per unit of land, expressed in tonnes of CO₂eq per hectare and year. The tool helps project designers to estimate and prioritize project activities with the greatest economic benefit and potential for climate change mitigation.

The tool can be applied to a wide range of land-based developments, as well as other projects concerned with climate change mitigation, watershed development, production intensification, food security, livestock, forest management or land use change. It is cost-effective, requires a comparatively small amount of data, and is equipped with useful resources such as tables, maps and FAOSTAT data. While EX-ACT is mainly used at the project level, it can easily be scaled up to programme or sector level and can also be used for policy analysis. The World Bank and International Fund for Agricultural Development already use EX-ACT to estimate the carbon balance of projects prior to their implementation. For emission factors and carbon stock, EX-ACT primarily incorporates the IPCC 2006 Guidelines, augmented by the 2013 Wetlands Supplement (IPCC, 2014a) and complemented by other methodologies.

Palm GHG Calculator

The Roundtable on Sustainable Palm Oil (RSPO) has guidelines to estimate the carbon stock changes (above and belowground) and GHG emissions that occur with land cover change to oil palm, peat drainage, and emissions from mills and operations. The guidelines see land use, peat oxidation, and chemical fertilizers as the largest sources of GHG emissions in a plantation.

The tool, known as the RSPO PalmGHG Calculator (version reviewed: 2018) is used to quantify annual net GHG emissions in CO₂eq per hectare and per unit of product and is a crucial component of the RSPO GHG Assessment process. It allows oil palm growers to identify crucial areas in their production chain and thereby guide emission reduction opportunities. The tool's manual does not mention emissions from fires on oil palm plantations on peatlands.

All important GHGs (CO₂, CH₄ and N₂O) from peatland degradation are included in the RSPO calculator. Sources of quantified emissions in this tool include peat decomposition, land conversion, manufacture of fertilizers and transport to the plantation, fertilizer application, fossil fuel combustion in the field and mill and palm oil mill effluent. Three classes of emission reduction are addressed: (i) carbon sequestration by oil palm growth; (ii) carbon sequestration by forest/vegetation growth in conservation areas; and (iii) avoided GHG emissions when mill energy by-products are sold to cement industries to displace fossil fuels.

⁸ The five pools include: aboveground biomass, belowground biomass, dead wood, litter and soil organic carbon.



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Chapter 5

Existing frameworks for peatland reporting and verification

by Julian Fox, Kai Milliken, Maria Nuutinen,
Esther Mertens and Marieke Sandker



Existing frameworks for peatland reporting and verification

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Several global frameworks, conventions and multilateral environmental agreements (MEAs) require, or at least encourage, national and other stakeholders to monitor and report on their peatlands. This chapter gives an overview of the specific parameters, indicators and/or reporting requirements of these frameworks. It illustrates the cross-cutting nature of peatlands: nearly all the frameworks overlap, so that the so-called “integrated frameworks” (here covering SDGs, DRR and the Ramsar Wetland Convention), encourage the monitoring of many climate-related peatland topics, as well as the means to tackle fire. Although this report focuses on mapping and monitoring for climate purposes, biodiversity indicators are listed to show the overlaps with both climate change mitigation and adaptation indicators. The multitude of data requirements demonstrates the need for integrated and harmonized mapping and monitoring, which would allow for cost-effective, targeted reporting on peatlands without unnecessarily burdening countries and other stakeholders.

Figure 15

The Sustainable Development Goals that require peatland monitoring



INTEGRATED ASSESSMENT FRAMEWORKS

Sustainable Development Goals: indicators and reporting

In 2015, the United Nations adopted the 2030 Agenda for Sustainable Development, including a set of 17 aspirational SDGs to eradicate poverty, protect the planet, and ensure prosperity for all (UN, 2019b). Peatland monitoring for appropriate management and conservation overlaps with many of the SDGs, but is particularly relevant to:

- **Goal 6:** Ensure availability and sustainable management of water and sanitation for all;
- **Goal 12:** Ensure sustainable consumption and production patterns;
- **Goal 13:** Take urgent action to combat climate change and its impacts;
- **Goal 15:** Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss (Figure 15).

The 17 SDGs encompass 169 targets with 232 indicators monitored through the SDG Tracker (Ritchie *et al.* 2018). The UN invites Parties to collaboratively develop “the most complete and up-to-date sources for tracking global progress to 2030”.

Table 4 gives some examples of SDGs targets, definition of goals, indicators and monitoring parameters that can be fulfilled through peatland mapping and monitoring.

Table 7 (Annex) summarizes how peatland degradation and restoration can hinder or advance the achievement of selected SDGs.

Table 4

Examples of SDG targets, definition of goals, indicators and potential monitoring parameters related to peatlands

SDG	Target	Definition of the goal	Indicators	Potential peatland monitoring parameters
13 Take urgent action to combat climate change and its impacts.	13.1: Strengthen resilience and adaptive capacity to climate-related disasters.	By 2030, strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries.	Number of deaths, internally displaced persons, missing persons, and total numbers affected by natural disasters.	Losses caused by peatland fires and flooding.
15 Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.	15.1: Conserve and restore terrestrial and freshwater ecosystems.	By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements.	The proportion of total terrestrial area designated as protected; The proportion of important sites for terrestrial and freshwater biodiversity that are covered by protected areas, by ecosystem type.	The proportion of all peatlands that is conserved. The proportion of all degraded peatlands that is restored.
	15.3: End desertification and restore degraded land.	By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world.	Proportion of total land area that is degraded.	Proportion of the total original peatland area that is degraded. No data available for monitoring the indicator.

The Sendai Framework for Disaster Risk Reduction

Floods and fires on peatlands are often manufactured issues caused by unsustainable management, particularly drainage. The Sendai Framework for Disaster Risk Reduction 2015–2030 (SFDRR) (UNDRR, 2020) is a voluntary, non-binding agreement that aims to achieve a substantial reduction of disaster risk and losses in lives, livelihoods and health, and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries within 15 years. Related to peatlands, the framework recognizes that:

- poor land management, unsustainable use of natural resources and degrading ecosystems are driving forces of natural disaster risk;
- disasters cause environmental impacts and loss of natural capital; and
- countries should bolster the sustainable use and management of ecosystems for building resilience to disasters.

The SFDRR underlines the need to safeguard and restore ecosystems as a vital strategy to offset natural disasters. Strengthening country capacity to use ecosystems in DRR and management is particularly pertinent to peatlands and other wetland ecosystems, as 90 percent of disasters are induced by water-related hazards (UNDRR, 2015).

Between 1979 and 2015, the area of marine, coastal and inland natural wetlands declined 35 percent (Ramsar, 2018). Loss of peatlands, as well as most other wetland areas, aggravates the risks from storms and floods, whereas well-managed peatlands help to minimize such damage. Coastal peatlands, such as mangroves, protect against flooding and serve as buffers against saltwater intrusion and erosion. Inland wetlands such as floodplains, lakes and peatlands absorb and store excess rainfall, which reduces flooding and delays the onset of drought by storing water (UNDRR, 2017). Peatland fires, in particular, underline the necessity for peatland mapping and monitoring to assess whether the global targets of the Sendai Framework are being reached. The SFDRR is expected to be renewed after 2019.

The Ramsar Convention on Wetlands

The purpose of the Ramsar Convention on Wetlands (Ramsar, 1971) is to ensure “the conservation and wise use of all wetlands through local and national actions and international cooperation, as a contribution towards achieving sustainable development throughout the world”. Currently, the Convention has 170 contracting parties and 2 331 designated wetlands of international importance, which cover approximately 2.1 million km² (Ramsar, 2018). The Convention recognizes the importance of peatlands for climate change mitigation and calls upon countries to minimize degradation and promote restoration and wise management of peatlands and other wetland types that are significant long-term carbon stores or have the ability to sequester carbon. Under the fourth strategic plan, Ramsar Parties are committed to:

- addressing the drivers of wetland loss and degradation;
- effectively conserving and managing the Ramsar Site Network;
- wisely using all wetlands; and
- enhancing implementation.

As a potential start to a peatland monitoring framework, the Parties to the Ramsar Convention approved detailed Guidelines for Global Action on Peatlands (Ramsar, 2002). Related to peatland mapping and monitoring, their recommendations are:

- to establish a global database containing ecological and carbon-related information on peatlands and mires;
- to monitor the quantity and quality of the peatland resources;
- to develop a globally standardized peatland terminology and classification; and
- to review national networks of peatland protected areas to guarantee the conservation of all peatland biodiversity.

The Ramsar Convention offers a framework for describing wetlands, carrying out inventories, assessment, and monitoring and reporting activities for designated Ramsar sites. Its implementation promotes the conservation and wise use of wetlands, as well as cross-border collaboration. The Convention's integrated framework for wetland inventory, assessment and monitoring (Ramsar, 2010) contains very similar monitoring parameters for climate purposes, and mapping is a cross-cutting activity:

- establishing the **location** and **ecological characteristics** of wetlands (baseline inventory); and
- assessing and monitoring over time the **status, trends and threats** to wetlands.

In addition, the framework encourages action to halt negative changes. Parties to the Convention submit national reports once every three years, including information on changes (condition, area, role in adapting to or mitigating climate change) in wetlands (Ramsar, 2016).

THE UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE

The main objective of the United Nations Framework Convention on Climate Change is to prevent dangerous anthropogenic interference with the climate system within a time frame sufficient to allow ecosystems, food and economic systems to adapt to climate change (UNFCCC, 1992). The Convention requires Parties to report on anthropogenic emissions, adaptation actions, as well as the technical and scientific support to other countries in a transparent manner⁹ under a framework of monitoring and reporting requirements that is evolving (UNFCCC, 2019b).

Under the Paris Agreement (Article 5.1), the signatory parties have agreed to “take action to conserve and enhance, as appropriate, sinks and reservoirs of greenhouse gases”. One significant way for countries to integrate peatlands into their climate action is to add them to their nationally determined contribution (NDC) report, which is updated regularly. To date, only a few countries have explicitly integrated peatlands in NDCs: their next revision in 2020 will offer an opportunity to enhance ambition.

Reporting

The IPCC, an independent United Nations body for assessing climate change science, cooperates with the UNFCCC in preparing guidance on reporting methodologies. Regarding peatlands, the key document guiding countries in GHG reporting is the IPCC 2013 Wetlands Supplement (IPCC, 2014a).

The IPCC has suggested that the category of agriculture, forestry and other land use (AFOLU) should be used to report carbon removal as well as reduction of GHG emissions. The AFOLU category would, therefore, cover the majority of peatland-related emissions. Countries are, however, currently reporting their peatland emissions under various means, through yearly GHG inventories under AFOLU, agriculture, or energy categories, or under the REDD+ framework.

⁹ The reporting procedures are being developed in an Enhanced Transparency Framework.

Many, if not all, REDD+ countries contain peatlands, and only a few have reported GHGs attributable to their peatlands either through REDD+ or NDC frameworks (e.g. Burundi, Indonesia, Rwanda, Uganda, and Uruguay). The REDD+ reporting framework requests Parties to also cover economic and social matters through safeguards (e.g. concerning gender and indigenous peoples), as well as environmental co-benefits such as biodiversity conservation and water resource preservation. By 2019, 40 countries had submitted a forest reference (emission) level (FREL/FRL) to the UNFCCC, but only two of these countries, Indonesia and Malaysia, report on emissions from peatland drainage (FAO, 2019). Indonesia reports emissions for the year 2012 at 47 percent of total CO₂ emissions from deforestation and forest degradation, including peatland drainage (MoEF and Government of Indonesia, 2016), illustrating how significant these emissions can be.

The annual emissions from drained organic soils under different land use are estimated to be responsible for 1-2 gigatonnes of CO₂eq, including emissions from microbial oxidation and fires (IPCC, 2014a; Joosten *et al.*, 2016; Leifeld and Menichetti, 2018). However, an update of these data is urgently needed. Following the IPCC 2013 wetlands supplement, the reporting scope includes GHG emissions from drainage-induced peat oxidation¹⁰, erosion, peat extraction and fires, as well as emission reductions achieved through peatland restoration.

The IPCC 2013 wetlands supplement provides:

- a summary of emission factors and supplementary guidance for drained organic soils that can occur under all six IPCC land use categories, as well as an update for fire on organic soils; and
- guidance and emission factors for rewetted organic soils used for forestry, crop production or other purposes. The emission factors are generally stratified by climate (boreal, temperate, and tropical), peat type separated between “nutrient-rich” fen peat and “nutrient-poor” bog peat; drainage level (deep or shallow) and inland and coastal organic soils.

As a major difference to deforestation, peat emissions are unique, as they are not calculated based on a one-off deforestation or drainage event. Rather they continue emitting over longer periods until either the peatland reverts to a water-saturated wetland condition, or the peat material is completely lost to oxidation.

¹⁰ In the first few months or years after drainage, the peat surface subsides rapidly through peat compression (compaction and consolidation) and oxidation. During this transition phase, emissions are far higher than the default emission factors stipulated by the IPCC (Hooijer *et al.*, 2012).

Adaptation and resilience

National Adaptation Plans (NAPs) allow Parties to the Convention on Climate Change to identify medium and long-term adaptation needs and to develop and enact strategic programmes and related budgets to address these needs.

While there are no established indicators under the UNFCCC, for example, to measure vulnerability, adaptive capacity or resilience, the NAP framework contains guidance on how to “monitor and evaluate” the NAPs to ensure that they are addressing key issues in different sectors, including land use, land use change and forestry (LULUCF). Given that peatlands can support ecosystem-based adaptation (EbA), recent developments in EbA monitoring can be helpful to countries, although monitoring is not obligatory.

EbA encompasses the use of biodiversity and ecosystem services into an overall strategy to help society adapt to the deleterious impacts of climate change. It incorporates a variety of ecosystem management activities to increase resilience and reduce vulnerability of people and the environment, including the following, which can include activities on peatlands:

- sustainable water management to provide water storage and flood regulation services;
- disaster risk reduction, such as restoration of coastal peatlands as a buffer against storms and erosion; and
- strategic management of shrublands and forests to limit the frequency and size of fires.

Challenges

Climate reporting is a challenging task and wide capacity-development is ongoing for most sectors for harmonized reporting (FAO, 2020a). Many countries have therefore requested to make the IPCC guidelines more accessible. In addition, the Tier 1 emission reference figures for tropical countries in the IPCC 2013 wetlands supplement were based on relatively few studies¹¹.

¹¹ Different methods can be used to estimate emissions or removals from most source and sink categories. The selection of a particular method will depend on the desired degree of estimation detail, the availability of activity data and emission factors, and the financial and human resources available to complete the inventory. In IPCC terminology, the lowest ranking or simplest method is “Tier 1”, while more elaborate methods are “Tier 2” and “Tier 3”.

There is an urgent need to support countries in (I) measuring GHG emissions to establish relevant reference emissions levels for different areas, and (II) defining national peatland parameters (e.g. drainage levels) to calculate emissions (e.g. using the 2013 wetlands supplement). Simple guidelines, manuals and training materials should be prepared to enhance understanding of the IPCC guidance, and to provide options to move to Tier 2 reporting (which is mandatory when peatland emissions are one of the key categories). Currently, most countries do not report peatland emissions at all, and the latest estimations by Annex I countries¹² vary in approach (see e.g. Barthelmes *et al.*, 2018).

FIRE MONITORING INITIATIVES

There are no specific international agreements on fire. However, given significant peatland fire challenges faced by several countries, different monitoring approaches have been developed over some decades. This section summarizes some potential frameworks and considerations related to the mapping and assessment, as well as monitoring and reporting, approaches.

At the global level, institutionalized frameworks in which peatlands could be incorporated include the Global Fire Monitoring Centre and the Global Wildlife Fire Network, both voluntary networks that provide policy advice and facilitate technology transfer to enable nations to effectively:

- reduce the negative impacts of landscape fires on the environment and humanity; and
- advance knowledge and application of the ecologically and environmentally benign role of natural fire in fire-dependent ecosystems, and sustainable application of fire in land use systems.

The Southeast Asia region (see Case study: Southeast Asian Nations and regional haze monitoring case below), as well as Indonesia, have paved the way. Indonesia coordinates an International Peatland Fire Network under the Regional Fire Management Resource Centre. The overarching aim of the centre is to contribute to evidence-based political decisions and the development of relevant fire policies for Indonesia.

It is important to note that fire on peatlands is not restricted to tropical countries; fires on peat are a widespread occurrence in high-latitude peatlands. Although partly natural, their

frequency and severity are predicted to increase as a result of climate change and the increasing presence of humans within many landscapes (Turetsky *et al.*, 2014). Fire is also used as a land-management tool in some Northern peatlands, such as those in Britain, although this is becoming increasingly controversial (Baird *et al.*, 2019; Marrs *et al.*, 2019).

Fire monitoring needs

The surface of an intact, undrained peatland has a lower probability of sustaining a fire, because it is usually too wet. However, loss of moisture from the upper peat layer, both by natural climatic variation and anthropogenic disturbance, increases the risk of fires. In various peatland locations, fire is used as a management tool, but many peatland fires are a direct consequence of land use change and disturbance of the natural ecosystem, including drainage and land clearing by fire. Drainage, deforestation and abandonment (stopping of active management) greatly increase the risk of ignition and severe burning of both vegetation and peat. Some of the most extensive peatland fires of the past two decades have occurred on peatlands that were either being used for agriculture, or were in the process of being converted to agricultural use – e.g. Russian Federation (UNFCCC, 2020), Canada (McMaster University, 2018) and Indonesia (Page *et al.*, 2002).

Research and observation have already characterized risk factors in peat igniting. The GWL needs to be sufficiently low, and a low rainfall period needs to be sufficiently long, for the surface layer (0–20 cm) of peat to dry out. Fires rarely if ever start deeper in the peat layer. Surface fires burning in heavier and coarser fuels with slower rates of spread and longer (one to two hours) residence times allow fire to move from above ground into the peat (Adinugroho *et al.*, 2005; ASEAN, 2009; Frandsen, 1997; Rein *et al.*, 2008; USUP *et al.*, 2004).

Peat fires are a particularly large source of carbon emissions into the atmosphere when compared with the combustion of aboveground vegetation, because they can persist for long periods (weeks to months) and consume a considerable thickness of peat (0.5 m thick block of peat contains more carbon per square metre than an equivalent area of pristine tropical rain forest on mineral soil, i.e. around 25 kg carbon per m²)¹³. Also important for the type of emission is whether the fire is flaming on the surface or smouldering within the peat. Smouldering fires are particularly difficult to extinguish as they can burn even under snow.

¹² Annex I Parties to the UNFCCC include the industrialized countries that were members of the Organization for Economic Co-operation and Development in 1992, plus countries with economies in transition (EIT), including the Russian Federation, the Baltic States, and several Central and Eastern European states. Most non-Annex I Parties are developing countries.

¹³ Assuming 50 percent carbon content by dry weight and a bulk density of 0.1 g per cm³.

GHG emissions from peat have added complexity due to the way peat burns, what is burnt and what is emitted. The parameters to assess GHG emissions from fires are (i) the area burnt, (ii) the patchiness of the burn, (iii) the fuel load, (iv) the combustion factor (fire intensity), and (v) the emission factors for GHG emitted per unit of dry matter combusted (i.e. actually burnt) (IPCC, 2014a). Fire emissions estimates tend to be simplistic, applying conservative default values for the data required.

Peat fire emissions may pose significant health risks, even at a regional level. Tropical peat fires emit per unit of carbon combusted as much as three to six times more fine, unhealthy particulate matter (“black carbon”) than fires on grasslands and forests (Turetsky *et al.*, 2014), and have been implicated in large numbers of premature deaths from respiratory illnesses (Kopitz *et al.*, 2016). This emphasizes why peatlands should be incorporated in national and international fire frameworks and management programmes to coordinate efforts to prevent peat-related fire hazards and emissions (see more on fire monitoring on p. 42).

Case study: Southeast Asian Nations and regional haze monitoring

In 1997, forest and peatland fires were widespread across Southeast Asia. Around 24 000 km² of peatland were burnt, releasing an estimated 2.9–3.5 gigatonnes of CO₂eq (Page *et al.*, 2002). These fires were the result of the interference of a prolonged period of drought, driven by El Niño–Southern Oscillation (ENSO), with the presence of drained and deforested peat swamp forests. In response

to this widespread environmental crisis, the ASEAN Agreement on Transboundary Haze Pollution (AATHP) was signed in 2002 by ASEAN Member States to reduce haze pollution in the region.

The Regional Haze Action Plan calls for measures to prevent and monitor land and forest fires and increase fire-fighting capacity. It requires neighbouring countries to assist with the mobilization of personnel and equipment to combat ongoing fires and obliges countries where fires originate to respond promptly and provide information and data to other countries.

The ASEAN Specialized Meteorological Centre (ASMC), has been supporting fire monitoring since 1993. Under the ASEAN Regional Haze Action Plan, the ASMC was tasked to monitor and assess land and forest fires and the occurrence of transboundary smoke and haze affecting the region. Peatlands that occur within these nations are particularly vulnerable to fires, under the influence of prolonged drought induced by the El Niño climate cycle and/or in combination with a positive Indian Ocean dipole, which also triggers extended periods of low rainfall in parts of the region (Abram *et al.*, 2008). This highlights the importance of ASMC, in conjunction with national and local meteorological agencies, to identify incipient fires and map high-risk zones using (drained) peat area as a predictive proxy.

The indicators of the implementation of the ASEAN “Haze-free roadmap” consist of:

- an increase in the number of days with good or moderate air quality in terms of defined pollutant standard or air quality index;

Table 5 Peat-related components of the Association of Southeast Asian Nations’ roadmap

Strategy 1	Implementation of the ASEAN Agreement on Transboundary Haze Pollution (AATHP)
Strategy 2	Sustainable management of peatlands for peatland fire prevention
Strategy 3	Sustainable management of agricultural land and forest for large-scale forest and/or land fires prevention
Strategy 4	Strengthening policies, laws, regulations and their implementation, including facilitating exchange of experience and relevant information among enforcement authorities of the parties
Strategy 5	Enhancing cooperation, exchange of information and technology, and strengthening of the capacity of institutions at all levels
Strategy 6	Enhancing public awareness and cross-sectoral and stakeholder participation
Strategy 7	Securing adequate resources from multi-stakeholders for transboundary haze prevention
Strategy 8	Reducing health and environmental risks and protection of the global environment

Source: ASEAN Secretariat, 2017.

- a reduction in the number of hotspots that are below a defined alert level under the ASEAN standard operating procedure on haze; and a decrease in the area subject to transboundary haze pollution.

These indicators are framed in the following strategic components that translate the principles of the AATHP into specific collective actions under a roadmap (Table 5).

Focus of monitoring

The standard operating procedure provides guidelines for the implementation of monitoring and assessment and joint emergency response under the AATHP. Monitoring is focused on (i) all fire-prone area; (ii) all land and/or forest fires; (iii) environmental conditions conducive to such land and/or forest fires; and (iv) haze pollution arising from such land and/or forest fires, following respective national procedures.

Early warning, early action

To mitigate fire-related problems and fire-suppression costs, forest and land management agencies, including landowners and communities, require early warning systems of extreme fire danger conditions that may lead to uncontrolled wildfires. Early warning allows fire managers to systematically implement prevention, detection and suppression before the fire appears. Fire danger information is provided by satellite data that identify hotspots for early detection, in conjunction with spectral data on land cover and fuel conditions. Such information is particularly relevant to peatlands as they hold a combustible fuel load that may support devastating fires and should be incorporated into early action frameworks in countries where peatlands are prevalent.

THE CONVENTION ON BIOLOGICAL DIVERSITY

The Convention on Biological Diversity (CBD) currently monitors the implementation of a Strategic plan for Biodiversity for the 2011-2020 period, including the Aichi Biodiversity Targets. The Strategic plan provides an overarching framework for all biodiversity-related conventions, including the entire United Nations system and all other partners engaged in biodiversity management and policy development. Parties to CBD will negotiate new targets before the end of 2020.

Peatland mapping and monitoring can contribute to monitoring the current Aichi Biodiversity Targets as well as the future framework. Table 6 shows the main indicators that can help to design peatland mapping and monitoring activities.

FOREST AND LANDSCAPE RESTORATION INITIATIVES

There are several initiatives encouraging countries to advance forest and landscape restoration, such as the African Forest Landscape Restoration Initiative; Initiative 20x20 for Latin America and the Caribbean; the UN Decade on Ecosystem Restoration (2021-2030) and the Bonn Challenge. All these initiatives promote the monitoring of landscapes throughout the restoration process, including their ecological and socio-economic characteristics.

The Bonn Challenge is a global initiative to restore 150 million hectares of the world's degraded and deforested lands by 2020, and 350 million hectares of degraded ecosystems by 2030, as well as mitigating climate change. It is underpinned by the forest landscape restoration (FLR) approach that aims to restore ecological integrity while improving human well-being using multifunctional landscapes. Restored peatlands were acknowledged as one of the ecosystems that could be forested under the Bonn Challenge (Besseau, Graham and Christophersen, 2018).

FLR is being monitored using a variety of indicators. Using the Bonn Challenge Barometer, IUCN and partners are looking at a certain set of indicators to monitor restoration, ranging from policies and institutional arrangements to financial flows and planning, and suggest a monitoring and evaluation framework defined by the stakeholders. This might include remote-sensing tools or national restoration monitoring platforms within a national forest monitoring system (NFMS).

Related to peatland restoration monitoring, the Bonn Challenge uses the following indicators of results and benefits achieved:

- hectares under restoration;
- climate impacts both in terms of mitigation¹⁴ and adaptation;
- biodiversity impacts following the Aichi Targets and the World Database of Key Biodiversity Areas and other protected areas where FLR activities take place; and
- socio-economic impacts with a focus on jobs created.

The Bonn Challenge barometer also underlines synergies with existing reporting requirements, aiming to reduce the reporting burden on countries (Dave *et al.*, 2019).

¹⁴ Note that the monitoring and evaluation framework currently considers only cumulative tonnes of CO₂ sequestered through FLR activities since 2010, thereby excluding emissions avoided through peatland restoration.

Table 6 Peat-related Aichi biodiversity targets and relevant indicators

Aichi biodiversity target	Peat-related indicator, trends in:
Target 5: By 2020, the rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation are significantly reduced.	The extent of natural habitats other than forest
	Degradation of forest and other natural habitats
	Extinction risk and populations of habitat specialist species in each major habitat type
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, and integrated into the wider landscapes and seascapes	Area of terrestrial and inland water areas conserved
	Area of coastal and marine areas conserved
	Areas of particular importance for biodiversity conserved
	Areas of particular importance for ecosystem services conserved
	Ecologically representative areas conserved
	Areas with effective and/or equitable management conserved
Target 14 - By 2020, ecosystems that provide essential services, including services related to water, and contribute to health, livelihoods and well-being, are restored and safeguarded, taking into account the needs of women, indigenous and local communities, and the poor and vulnerable	Connectivity and integration of conserved areas
	Safeguarded ecosystems that provide essential services
	Benefits from ecosystem services
	Restoration of ecosystems that provide essential services
Target 15 - By 2020, ecosystem resilience and the contribution of biodiversity to carbon stocks have been enhanced, through conservation and restoration, including restoration of at least 15% of degraded ecosystems, thereby contributing to climate change mitigation and adaptation and to combating desertification	The degree to which ecosystem services provide for the needs of women, indigenous and local communities, and the poor and vulnerable
	Carbon stocks within ecosystems.

Source: CBD, 2016.

The UN Decade on Ecosystem Restoration 2021-2030 is likely to use many approaches currently developed being for FLR, including peatland restoration monitoring and land degradation neutrality (LDN), a new concept introduced by the UNCCD in 2015.

The UNCCD is a legally binding international agreement linking the environment and development to sustainable land management. The Convention specifically focuses on arid, semi-arid and dry sub-humid zones (drylands). The UNCCD 2018-2030 Strategic Framework is a comprehensive global commitment to achieve LDN to avoid new degradation as well as restore the productivity of large areas of degraded land, including all land types while improving livelihoods.

A set of countries are restoring previously drained peatlands as part of their voluntary commitment to achieving LDN. The LDN reporting indicators were still to be finalized at the time of writing, but a draft version contains the indicators and associated GHG emission metrics. The following are related to peatlands: land cover (assessed as land cover change), and carbon stocks (assessed as soil organic carbon, SOC), as in Parties' regular reporting to the UNCCD. In addition, Parties are requested to identify ongoing land degradation, including gully erosion and coastal inundation, for example, and the drivers of land degradation, including unsustainable land use practices, such as overgrazing - both also relevant to peatlands (GEF, 2019).



Chapter 6

Country case studies

by Maria Nuutinen, Felix Beer
and Laura Villegas



Country case studies

by Maria Nuutinen, Felix Beer
and Laura Villegas.

Various countries have advanced with mapping and monitoring peatlands. Progress with peatland mapping methodologies has helped in the discovery and mapping of new peatlands - especially in the tropics - that are significant for climate change mitigation and adaptation efforts. Peatland monitoring, on the other hand, is being explored by a small number of countries that have started the integration of peatlands into national monitoring systems. However, in most cases it is still a work in progress to further define monitoring needs and objectives and choose the most appropriate tools that would allow the continuous improvement of management and restoration strategies.

The country case studies are useful for understanding different approaches to the use of existing peatland information, as well as identifying needs and challenges to be faced while dealing with climate change action in peatland landscapes.

1 INDONESIA: NEW MONITORING METHODS AND CHALLENGES

by Bambang Arifatmi, Muhammad Askary Masjukur, Maria Nuutinen,
Adam Gerrand and Laure-Sophie Schiettecatte

Highlights of peatland mapping and monitoring in Indonesia

- Establishment of an institutional framework for peatland monitoring
- Indonesia has made international commitments, reported to the UNFCCC and has developed policies at various levels.
- The “One Map” policy intends to harmonize different maps into a set of officially acknowledged national maps, including a peatland layer.
- The Indonesian Peat Prize was given in 2018 to a team that had developed a method to map the extent and depth of the country’s peatlands. This method is ready to be applied across all peatlands to support the government to achieve restoration and fire reduction goals.
- Development of the Peatland Ecosystem Protection and Management Plan that guides peatland protection and monitoring.
- Implementation of the peatland monitoring platform to monitor GWL and rainfall, and to understand the progress of peatland restoration.
- Establishment of the Peatland Restoration Agency (BRG) to coordinate and facilitate the restoration.
- BRG is developing the online peat restoration information and monitoring system for its mandate area in 7 Indonesian provinces to both guide restoration activities implemented by various stakeholders and to report the progress transparently and reliably.

Indonesia holds an estimated peatland area of between 149 300 km² and 270 000 km², with the latest area in public sources being 246 700 km² (BBSLP, 2013; Ministry of Environment and Forestry, 2018; Page, Rieley and Banks, 2011). Southeast Asia contains the world's largest tropical peat carbon store (66–70 gigatonnes) (Warren *et al.*, 2017), with Indonesia accounting for 57 gigatonnes of this estimate.

In Indonesia, and Southeast Asia generally, growing agricultural needs have led to the exploitation of lowland peat swamps, especially since the 1990s, by large companies as well as smallholders. A large proportion of these peatlands have thus become degraded with negative environmental and socio-economic consequences. Digging drainage canals to prepare the land for logging, palm oil or industrial forest plantations, and rice farming, have resulted in subsidence and land loss to flooding on the one hand, and dryer peatlands and increased fires on the other. Indonesian peat landscapes have suffered from extensive peat fires since the 1990s. In 2015, 2.6 million ha of land in Indonesia was burnt, including estimated 1.7 million ha of forest and 0.89 million ha of peatland, with related emission estimates varying from 0.71 and 1.75 gigatonnes CO₂eq (Ministry of Environment and Forestry, 2018; Randerson *et al.*, 2017). In response to this disaster, Indonesia has reinforced its governmental commitments to reduce peatland deforestation and fires as well as to rewet and restore degraded peatlands. Government policy mandates concession-holders, in particular, to fully restore peatlands in defined priority areas, and to increase the water table in the peatlands they manage.

Monitoring of peatlands

Indonesian peatland monitoring is guided by a variety of commitments to international conventions, particularly the 2015 Paris Climate Agreement and the NDC under the UNFCCC, other international commitments, such as the Bonn Challenge on Forest and Landscape Restoration, presidential decrees, and policies released by ministries as well as provincial and district administrations. The main responsibility for peatland monitoring lies within the public sector, while many international and private entities have over the years supported the technical development of tools, approaches and systems. Plantation companies are also mandated to monitor and report the GWL in peatlands that have been drained.

Indonesian efforts to improve the management of the country's peatlands have been delayed by the lack of an agreed map. Since 2016, a “One Map” policy¹⁵ has been implemented to integrate different national maps into a set of officially approved maps, including the peatlands. To advance a scientifically solid method to consolidate the peatland layer of the One Map, the Indonesian Peat Prize was awarded in 2018 for the development of a method to measure the extent and depth of the country's peatlands (Ballhorn *et al.*, 2018). This method is expected to be progressively applied across all peatlands to help the government to protect and manage peatlands, accelerate their restoration and support Indonesia's development goals (World Resources Institute, 2018).

As one of the key guiding policies, a Peatland Ecosystem Protection and Management Plan was established by the Ministry of Environment and Forestry to guide peatland protection and management (MoEF, 2018). The plan is improved and revised based on data-driven approaches that help to coordinate restoration efforts by different stakeholders.

A groundwater level and rainfall monitoring database called SiMATAG (MoEF, 2019) in both concession and community areas was presented by the Indonesian Ministry of Environment and Forest (MoEF) in 2019. SiMATAG-0.4m (“information system for peat groundwater level”) is a platform to monitor GWL and rainfall and to understand the progress of restoration activities.

The SiMATAG database displays over 10 300 compliance points across Indonesia, which are updated in real time through a mobile app. SiMATAG is connected to other databases such as the Forest and Land Fire Database, the Database of Meteorology, Climatology, the Geophysics Agency and the National Agency for Disaster Management (MoEF, 2018). The database can be used to determine compliance of concession-holders in adhering to the required water management regulations, and whether the peat is being damaged. Monitoring of parameters such as groundwater table depth (Bechtold *et al.*, 2018) in peatlands is an important process that can point to the state of a system while playing a role in fire prevention by providing the basis for an early warning, early action system for officials to act upon.

¹⁵ Presidential Regulation No. 9/2016 on the acceleration of one map policy implementation at 1:50.000 in scale. Compilation and integration under BIG and synchronization under the Coordinating Ministry of Economic Affairs.

Monitoring of restoration priority areas

In January 2016, the Peatland Restoration Agency (Badan Restorasi Gambut, BRG), was established under the first Presidential Regulation after the Paris Climate Summit in 2016. BRG's mandate is to coordinate and facilitate the restoration of 2.4 million ha of degraded and burnt peatlands by 2030 in seven key provinces (Riau, South Sumatra, West Kalimantan, Central Kalimantan, South Kalimantan, East Kalimantan and Papua). Based on the indicative map of restoration priority, the targeted priority areas for BRG's restoration activities consist of (i) the area burnt in 2015¹⁶, (ii) peat domes with canals (for protection), (iii) peat domes without canals (for protection), and (iv) peatlands with drainage system (canals). BRG supervises, facilitates, assists and coordinates peat rewetting in concession areas and outside of them. BRG must monitor and report its results regularly to the President of the Republic.

A peat restoration information and monitoring system (PRIMS) is being developed by BRG to update and report the progress of peat restoration activities transparently and reliably and provide timely feedback to land managers and policy-makers alike, as well as to facilitate coordination across provinces and institutions. It is a prototype web-based mapping system aided by the World Resources Institute and the Agency for the Assessment and Application of Technology (BPPT) and supported by FAO's land use monitoring tools and systems, such as SEPAL, and other tools within the Open Foris suite (FAO, 2020b). Although still under development, PRIMS has key features that can provide insight into restoration activities, peat degradation indices, peat emission and fire hotspot monitoring, and assess the impacts of restoration efforts, including canal blockings, deep wells, canal backfilling, revegetation, and the economic revitalization of communities.

Challenges and opportunities

Although Indonesia has made important steps to construct various tools for peatland monitoring by different agencies, many challenges persist. In Indonesia's latest forest reference emission level (FREL) submission in 2016, the analysis of peat emissions included only account for drainage, which deals with emissions from peat decomposition. Peatland fire data were not included in the FREL - combustion through fire causes major GHG emissions - as historical activity data were not available. It was also stated that the development of comprehensive emissions factors for fire is complicated and subject to high uncertainties (Agus, Hairiah and Mulyani, 2011). Peatland fire emissions need to be addressed and calculated more accurately to build one functional and holistic system for monitoring and reporting on peatlands for various purposes, including improving MRV for various types of GHG (including REDD+) reporting. The MoEF, tasked on GHG reporting, is working with various partners to further develop the inclusion of peatland emissions in national GHG inventories and update reports.

The lack of an agreed map of Indonesian peatlands negatively affects many efforts not only to monitor but also to restore the target amount of remaining peatlands.

The complexity and cost of peatland monitoring over a large area are important challenges that Indonesia is facing. High temperatures and humid conditions, as well as the risk of fire, pose a threat to the reliability of automatic systems. Collaboration and sharing experiences, data, ideas and methodologies are crucial in overcoming many challenges. The use of satellite data for monitoring peatlands over large areas and with higher frequency is an opportunity that is being explored by the Indonesian Government with support from many of the organizations contributing to this report. These techniques have potential - e.g. on soil moisture (Greifeneder *et al.*, 2019) - but are in relatively early stages of development. All remote sensing tools need to be well-calibrated and validated with field data and have limitations, as outlined in Chapter 4.

¹⁶ Due to the high risk of new fires in the previously burnt areas.



Peat landscape in the Republic of the Congo

© FAO / Maria Nuutinen



2 THE DEMOCRATIC REPUBLIC OF THE CONGO

by Jean-Jacques Bambuta Boole, Cleto Ndikumagenge, Amélie Arquero, and Rémi d'Annunzio

Highlights of peatland mapping and monitoring in the Democratic Republic of the Congo

- The Ministry of Environment and Sustainable Development has established a Peatland Unit.
- The Unit has started consulting stakeholders to define priority needs for peatland mapping and monitoring, including assessments of extent, carbon storage, ecosystem services, and institutionalization of monitoring approaches.
- Different organizations, including national academia, have advanced with peatland mapping and data generation mainly in the Cuvette area (see Map 1), including peat soil sampling.
- The capacity of national institutions has been developed with a pilot integration of a few peatland sites into the national forest inventory.

The Central Congo Basin peatlands are estimated to be the world's most extensive, continuous peatland complex¹⁷ in the tropics. They are also among the most carbon-dense ecosystems, with an average of 2 186 tonnes of carbon per hectare. Approximately 29 percent of the total tropical peat carbon stock is currently estimated to be found within the Cuvette Centrale (Map 1). In terms of both peat area and peat carbon stock, the Democratic Republic of the Congo (90 800 km² of peat equivalent to 19.1 Pg C) and the Republic of the Congo (54 700 km² of peat equivalent to 11.5 Pg C) become the second and third most important countries in the tropics for peat areas and carbon stocks, after Indonesia. It is estimated that there are also other peatland areas around the Cuvette region in the northeast of the DRC (see e.g. Map 1).

Map 1

The extent of peatlands in the Cuvette Centrale, Congo Basin



Source: Dargie et al. (2017).

¹⁷ Note that Indonesian peatlands have a larger area, but are divided between different islands, and therefore not connected to each other like the peatlands within the Cuvette Centrale.

Most of these peatlands remain pristine and undrained. However, they also face various threats: drainage for various types of economic activities, mainly oil concessions, cropping, and potential infrastructure development, as well as declining regional precipitation with more extensive dry periods among them. The drainage and/or poor management of these extensive areas of carbon-rich soils can lead to the release of one of the biggest carbon stocks in the tropics. Therefore, the peatland system in the Congo Basin plays a key role in the global carbon cycle. (Dargie *et al.*, 2018)

Urgent need for peatland monitoring

The Peatland Unit and stakeholders have defined four priority needs for peatland action

- identify the distribution, status (pristine, drained, burnt, cropped, and grazed) and carbon storage of peatlands, including an approximate assessment of the depth of these deposits and their concentration of soil carbon;
- assess the importance of the identified peatlands' ecosystem services, such as sheltering unique biodiversity, water regulation, provision of food and other socio-economic and cultural benefits;
- develop and institutionalize a stakeholder engagement process, and
- integrate peatlands into the country's national monitoring system utilizing state-of-the-art peatland monitoring tools and approaches.

(ministerial source, private communication, July 2019.)

Monitoring is justified for a fundamental reason – peatlands in the Democratic Republic of the Congo are hitherto intact and protected because they are regularly flooded and difficult to access. However, they remain fragile over time, particularly if regional rainfall changes or hydrology is affected by land conversion.

Land use monitoring system and peatlands

At the time of writing, no countrywide peatland maps exist at the national level in the Democratic Republic of the Congo. However, with international support, efforts have been made to rectify this, including peat soil sampling and a pilot integration of some peatland sites into the NFI, including household surveys inquiring about potential drainage practices.

As a result of the activities under the REDD+ framework, the country has an NFMS (Democratic Republic of the Congo, 2020), accessible online and currently being operationalized, which requires capacity-development activities. The NFMS, managed by government agencies¹⁸, aims at assessing the state and evolution of forest resources, as well as meeting the requirements of the UNFCCC for participation in REDD+. With the support of FAO, the satellite land monitoring system will assess land use and land cover changes, and the NFI will measure forest carbon stock and the GHG inventory to report GHG emissions from the AFOLU sector. The collected data, as well as the analyses and results will be published online on the NFMS web portal.

Challenges of peatland management

Stakeholders are asking how peatlands can contribute to the country and its people, including sustainable livelihoods. The Democratic Republic of the Congo is looking forward to finding answers and value its peatlands but the country must overcome various challenges. The first challenge relates to the establishment of financial mechanisms to generate benefits from peatlands with special regard to economic development at national and provincial levels, including local communities and indigenous peoples, and the definition of different stakeholder roles. The second challenge is linked to the analysis of the desirability of fostering jurisdictional interventions at the provincial level, building also on the country's experience in REDD+. Finally, the third challenge will pertain to the demand and need for capacity-building on peatlands, covering mapping, monitoring and approaches to sustainable management. (Ministerial source, private communication, July 2019.)

¹⁸ Direction des Inventaires et Aménagement Forestiers (DIAF); Ministère de l'Environnement et du Développement Durable (MEDD).



Figure 16

Peat landscape in Peru
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3 PERU

by Pedro Raul Tinoco Rodriguez

Highlights of peatland mapping and monitoring in Peru:

- Multiple researcher teams have used remote sensing and field data to map several peatland complexes throughout the country.
- Several mapping and monitoring initiatives are underway
- Peruvian government is coordinating actions and harmonizing the recommended peatland mapping methodology into national guidelines for peatland identification.

Thanks to its varied geography, three types of peatlands can be found in Peru: coastal, Andean and Amazonian. Peat extraction, mining activities and grazing are threatening peatlands in the Andes (Maldonado, 2014). The Amazonian peatlands are mainly threatened by infrastructure for transportation, agriculture, unsustainable forms of *Mauritia flexuosa* palm fruit harvesting, charcoal production, mining, oil, gas, and hydropower production.

National mapping and monitoring approaches

The national Peruvian Amazon Research Institute and a team of researchers have recently mapped the largest peatland complex in the Loreto department of the Peruvian Amazon. They used a combination of probability map constructed with the help of remote sensing (both optical and radar data) and soil measurements in the field.

Peru has prepared a national ecosystem map that includes palm swamps, herbaceous-shrub swamps, mangroves, bofedales (a special type of highland peatland) (Figure 16) – all these ecosystems are considered to potentially form peat – estimating a total area of 77 800 km² (7 780 824 ha). In addition, the National Wetland Inventory is being developed within the framework of the National Wetlands Committee, chaired by the Peruvian Ministry of Environment (MINAM). Other institutions have carried out various investigations on the country's peatlands (Chimner *et al.*, 2019; CIFOR, 2017; The Mountain Institute, 2016).

Political frameworks and peatland monitoring

At the time of writing, Peru does not have a nationwide policy framework regulating or protecting all types of peatlands (CIFOR, 2017). Within the framework of the Ramsar Convention for Wetlands, the country has adopted recommendations for the management and monitoring of peatlands. In addition to the multilateral environmental agreements, Peru has several laws, policies and strategies that, although they do not emphasize peatlands, regulate the conservation and sustainable management of the ecosystems that support them¹⁹.

Next steps for peatland mapping and monitoring

At the time of writing, several mapping initiatives are underway and the government is coordinating actions and harmonizing the recommended peatland mapping methodology. This process will define the scope of the country's peatlands considered in the map, and in longer-term monitoring, and it is expected to include the state of the peatlands and their estimated peat depth. In general, there is information on the distribution of wetland ecosystems. The greatest information gaps are related to peatlands' state, the depth of peat in different wetland types and their carbon content, which will require direct assessments and measurements in the field.

¹⁹ These legal and policy frameworks include: the General Environment Law; National Environment Policy; Organic Law for the Sustainable Use of Natural Resources (1997); National Biodiversity Strategy to 2021 and its 2014–2018 Action Plan (2014); National Water Resources Policy and Strategy of Peru (2009); Forestry and Wildlife Law (2015); and National Wetland Strategy (2015).

4 THE UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND

by Rebekka R.E. Artz, Ian Crosher, Andrew Coupar, Emma Goodyear and Chris Evans

Highlights of peatland mapping and monitoring in the United Kingdom:

- The United Kingdom's has mostly over 30 years old peat maps using different mapping methodologies and peat definitions.
- Most recent efforts aim using satellite-data derived models in combination with ground observations to improve the mapping of peat extent.
- Assessment of restored peatland areas have provided evidence of the immediate climate mitigation benefits of peatland restoration efforts.
- Research on GHG emissions from peatlands has increased awareness of the condition and climate impact of country's peatlands, increasing public funding for restoration measures.
- Work is ongoing to incorporate full peatland GHG emissions reporting.
- Current initiatives aim to develop standardized, cost-efficient monitoring methods for evaluating restoration impacts.
- A new citizen monitoring initiative monitors the condition and long-term changes of peatlands and facilitates data collection and sharing through a web application.

Peatland extent and status

Peatlands in the United Kingdom extend from coastal lowland regions to the uplands. The most extensive peatland type is blanket bog, which forms in high-rainfall regions. Blanket bogs have been affected by drainage, grazing, managed burning, conifer plantation forestry, air pollution and erosion. Lowland peats, particularly fen peats, have been progressively drained and converted to agricultural use over centuries, to the extent that most of them are now under cultivation, and large areas have been reduced to thin ("wasted") peat. Lowland raised bogs are less extensive and have been affected by horticultural peat extraction as well as agricultural drainage. The most recent estimated extent of the United Kingdom's peatlands is 2.9 million ha (29 000 km²) (Map 2).

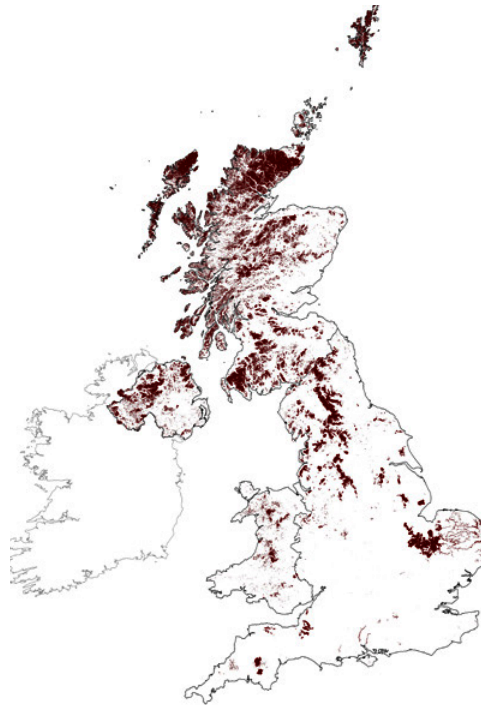
The latest country-wide update on trends in condition on peatland habitats was published in 2013 (Joint Nature Conservation Committee, 2013). This report paints a largely bleak picture of the condition of peatland habitats under nature designation, with the overall assessment of condition status being considered bad across all nine reported peatland habitat types, although six of these habitats showed an overall improving trend in condition status. In both bog and fen, marsh and swamp habitats, a decline in species richness was noted.

National reporting on the condition of the United Kingdom peatlands is largely based on extrapolation of data from designated site monitoring. Various pilot projects have attempted to model peatland condition at local to national scale using satellite-derived data combined with ground observations (see below). There is an ongoing need for traditional field-survey data to support and provide meaningful quantification of remote-sensed and modelled peatland condition assessments at the national scale.

Peatlands undergoing active restoration management largely show significant improvements in ecological conditions, although most sites have been restored only recently and only a handful of publications from early restoration projects exist. However, a recent compilation of the current scientific evidence suggests that halting emissions from degraded peatlands now will have immediate climate mitigation benefits in the short to medium term, with potential long-term benefits for carbon, water and biodiversity (Günther *et al.* 2019).

Map 2

Updated map of the extent of peat in the United Kingdom



Source: James Hutton Institute, 2017.

Mapping and monitoring activities

The United Kingdom's peat maps are reliant on interpolated ground surveys, most of which were undertaken 30 or more years ago, and mapping methodologies (and even peat definitions) vary among the four devolved administrations (England, Northern Ireland, Scotland, Wales). Recent efforts aim to use satellite-data derived models in combination with ground observations to improve the mapping of peat extent.

Peatland mapping and national reporting have traditionally been achieved through upscaling from field-based surveys such as the UK's Common Standards Monitoring programme (Joint Nature Conservation Committee, 2004; 2009). The Programme, however, was not specifically designed to assess peat condition, and only covers legally protected sites so it does not provide a sufficient basis for national-scale assessment of peatland status, function or emissions. Evans *et al.* (2017) combined data from land cover and soil data sources to map peatland extent and provide a broad, habitat and soil-based, condition classification. They used the associated GHG emissions (also compiled in the same report) for these condition categories to estimate current GHG emissions from the country's peatlands. This report was used by the 2018 British Committee on Climate Change report to estimate that 4–11 Mt CO₂eq per annum could be mitigated by restoring peatlands by 2050 (Committee on Climate Change, 2018). Work is ongoing to incorporate full peatland GHG emissions reporting in the British national emissions inventory. Increased awareness of the condition of British peatlands and the emissions arising from them has led to an increase in public funding since 2012, which has resulted in a corresponding increase in the implementation of restoration measures on the ground.

Peatland monitoring is focused on reporting under international biodiversity obligations. Monitoring is carried out using ground-based surveys but is confined to (largely vegetation-based) habitat monitoring and assessments for a limited list of protected species. Remote surveillance options are being tested as lower-cost options. For example, there has now been a sizeable number of efforts to remotely assess the condition and/or degradation features in British peatlands, using aerial photography (Scholefield *et al.*, 2019) or in combination with LiDAR (Carless *et al.*, 2019). Water table and

surface elevation fluctuations have been monitored using interferometric synthetic aperture radar (InSAR) from satellite sources (Alshammari *et al.*, 2018). This method has the potential to provide high-frequency monitoring of peat conditions and a proxy for CO₂ emissions and removals.

At a lower resolution, the condition across the whole of Scotland's peatlands was recently modelled using a time series of satellite data (Artz *et al.*, 2019). Sentinel-1 radar and Sentinel-2 spectral data could be used to produce higher-resolution and repeatable assessments of peatland condition to support national peatland GHG emissions reporting (Lindsay *et al.*, 2019). However, none of these remote techniques has yet been tested at the national scale.

Restoration is not monitored under any formal programme, in spite of its multiple societal benefits. Most, if not all, restoration monitoring includes some form of hydrological monitoring, often combined with assessments of vegetative change. In some cases, changes in GHG emissions or aqueous transport of carbon are being assessed. A review of the state of this monitoring evidence is currently being compiled for the IUCN UK Peatland Programme (unpublished). Current initiatives aim to develop standardized, low-cost monitoring methods for evaluating restoration outcomes and to verify the anticipated emissions reductions, to implement consistent national restoration monitoring systems in the future.

Future initiatives

There are potential benefits in using the power of modern remote-surveillance techniques to implement national peatland monitoring, but further testing of these methods is required to ensure they are fit for purpose for national reporting. Eyes on the Bog (Lindsay *et al.*, 2019), for example, is a newly launched citizen science monitoring initiative for British peatlands. It aims to engage the wider community in monitoring the condition and long-term changes of peatlands and provides a robust, repeatable and accessible monitoring methodology to harmonize basic data-collection across a network of long-term peatland monitoring sites.

The initiative employs cost-effective and simple techniques as well as modern technology to enable useful monitoring information to be collected by peatland community employees or volunteers. The information may be used to inform management interventions and test long-term climate predictions and assumptions about the condition and function of British peatlands. Data collected across multiple independently established sites within the Eyes on the Bog network can be collated in a standardized format by an open-access data hub. For example, PeatDataHub (<https://peatdatahub.net/>) is an emerging peatland-specific web application and database that allows the uploading and sharing of site metadata, datasets, files and images from peatlands around the world.

The aim is to facilitate the collaborative use of shared datasets to address both British and global-scale questions about peatlands in much the same way that Forestplots (<http://www.forestplots.net/>) has been used for tropical forests.

LESSONS LEARNED BY DIVERSE COUNTRIES

While peatland mapping status varies from country to country, most mapping efforts are recognized by academia. Official, nationwide peatland maps are not usually available, especially in tropical countries, where existing gaps are evident. Surveys that support peatland monitoring need to not only consider habitat type, but also the underlying soil characteristics that use harmonized classification methods to support consistent peatland mapping and monitoring approaches. A standardized peatland definition and harmonized mapping approaches would facilitate the creation of one, nationally confirmed peatland map.

Peatland monitoring has also sparked the interest of governments and private organizations. A holistic land use and land use change monitoring system would take into account the diverse needs, goals and institutional frameworks in each country.

Experience on peatland restoration monitoring is increasing. Restoration monitoring has helped to demonstrate the impact of investment. In most cases, current funding for peatland restoration does not provide adequate resources for monitoring and data collection. More coordinated and harmonized approaches are needed to reduce research and monitoring wastage, and to make better use of satellite technologies and citizen science.



Chapter 7

Remaining questions and knowledge gaps

by Maria Nuutinen, Felix Beer,
Laure-Sophie Schiettecatte and Peter Moore



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Mapping and monitoring peatlands can be a challenging task depending on the spatial scale to cover and the number and kind of parameters to be assessed. In the long term, it would be ideal to develop a fully automatic monitoring system – based on a robust and practical mapping procedure – that combines ground and remotely sensed observations providing information on all desired parameters. However, the automatic quantification and upscaling of factors over large areas is not yet fully achieved and requires sophisticated intermediate processing steps, and expert analyses tailored to specific peatlands – a challenge to a wide range of users. Additionally, some parameters cannot directly be derived from remote sensing but depend on ground-point measurements, especially peat occurrence and GWL – one of the most important conditioning factors in peatland GHG emissions. Mapping, modelling and the use of proxies thus require further research to strengthen the scientific basis of their assessment and application.

Mapping methods are already well developed, and research has been carried out on the delineation of almost all types of peatlands. The variety of conditions and characteristics of peatland occurrence makes it difficult to standardize methodologies for peatland mapping at global and even at national levels, which usually increases the cost of field mapping activities on a scale necessary for land planning and management. New approaches and advances with remote sensing technologies are benefiting peatland mapping in a variety of contexts. Continuing to map and develop research on mapping will not only help countries to realize and value their peatland resources, but could lead to efficient and accurate peatland monitoring for conservation and sustainable management. A coherent link between peatland mapping and monitoring needs to be established to avoid wasting resources and institutional capacity.

In addition to the research and data gaps elaborated below, and the general need for capacity-development, constant maintenance of ground equipment and access to data remain crucial in the robust setting up and running of peatland monitoring in countries.

GROUNDWATER LEVEL AND SOIL MOISTURE

Remotely sensed radar-based soil moisture, in combination with GWL field monitoring, can be used as a proxy for GWL modelling (Hashim *et al.*, 2002; Jaenicke, Lohberger and Siegert, 2010). This approach needs further elaboration, as surface soil moisture is quickly changed by events such as precipitation without affecting the GWL. Furthermore, strongly degraded peat at the surface can become hydrophobic, causing surface soil moisture to lose its correlation with the underlying GWL (Wösten *et al.*, 2008). Despite the ability to show trends, and the effect of rewetting activities over time, uncertainties in the consistency of the soil moisture-GWL link require further investigation to robustly quantify the GWL from soil moisture, particularly for emissions estimations.

The appropriate distribution and continuing maintenance of ground observation instruments, to verify soil moisture data from remote sensing and modelling, constitute one of the main challenges to the integration of peatlands into national land use monitoring systems.

RELIABLE SOIL MOISTURE DETECTION

Technically, soil-moisture detection with radar (microwave) satellite systems are based on robust methodologies and has advantages over optical satellite-based approaches (Wang and Qu, 2009). However radar waves can only penetrate ground covering objects up to the size of their wavelength. L-band data with a wavelength of 24 cm that can penetrate vegetation is considered most suitable for remotely sensed soil-moisture assessment regardless of vegetation cover, but needs to be purchased (JAXA, 2020). Freely available X- and C-band data (e.g. Sentinel-1 for C-band) with wavelengths of 3.1 cm and 5.6 cm respectively, can only be applied on bare soils or areas with very light ground cover (e.g. short vegetation). Limited and expensive access to relevant data is a major obstacle to soil-moisture monitoring, as in

the case of entire peat domes in Indonesia. The NASA-ISRO synthetic aperture radar satellite (NISAR) will, however, provide freely accessible L-band data from 2021.

The use of vegetation moisture based on optical sensors as a proxy for soil moisture indicates good results, but also requires further investigation into the moisture dynamics of the different vegetation types and their relation to soil moisture.

GREENHOUSE GAS EMISSION ESTIMATIONS

Integrated systems utilizing data from remotely sensed and field measurements appear to be the best options for estimating GHG emissions and the status of peatlands. However, further measurements would be beneficial to fill the data gaps.

Emissions from decomposition

GHG emissions from peat decomposition correlate well with the GWL and subsidence and depend on land use type, nutrient status and climate zone (IPCC, 2014a). In countries such as Indonesia, where the current peatland management policies favour only partial rewetting (GWL at -40 cm), GHG monitoring should be able to account for emissions from peatlands with different GWLs – to showcase the benefits from raising the water table, even only partially – and on the other hand to emphasize the potential of complete rewetting and restoration for climate change mitigation and disaster reduction. Outside Indonesia, especially in tropical regions, data and models for robust GHG emission accounting on different land use types are largely lacking and require intensive research.

To improve national reporting of emissions from organic soils, the recommendation is to seek the best possible data on activities in the landscape, preferably those that comply with IPCC land use categories, in a spatially all-inclusive (“wall-to-wall”) approach (Barthelmes *et al.*, 2018). It is important to collate and integrate all available information for nationwide, comprehensive coverage of organic soils, use proxy sources to identify possible occurrences of organic soils, and conduct peatland surveys that include fallow land, protected or otherwise not actively used, in particular when it has been drained. Potential proxies can include for example vegetation data, high-resolution elevation data, and data on drainage networks.

Emission factors

Further GHG emission measurements and refinement of emission factors are still needed, particularly in subtropical Africa and Central and South America, including degrading and restored highland peatlands. Decision-makers could benefit from information on peatland emission dynamics to confront a changing climate in the permafrost regions and other potential hotspots.

Land conversion, mainly conversion of wetlands such as mangroves and peatlands, will not only lead to changes in GHG emissions on land once converted and managed but will also export organic and inorganic materials to adjacent water bodies. This material will eventually sustain inland water ecosystem production and ultimately lead to CO₂, CH₄ and N₂O emissions to the atmosphere. Therefore, further research should be conducted to close the carbon budget in the peatlands by investigating more on exported carbon, such as dissolved organic carbon (DOC), dissolved inorganic carbon (DIC) and particulate organic carbon (POC) in drainage canals or ditches. This was already anticipated by the IPCC 2013 Wetlands Supplement, which provides information on the emission factors for CH₄ in the canals. More recent scientific literature also show evidence of fluvial transfer of carbon from managed peatlands which lead to GHG efflux from adjacent water bodies (Cook *et al.*, 2018; Evans, Renou-Wilson and Strack, 2015; Manning *et al.*, 2019).

Gaps in peat fire monitoring and emissions

Estimation of GHG emissions from burning peat is difficult due to the challenge of measuring the variables of (1) burnt area and depth of burn, (2) fuel present on the site (peat as well as aboveground biomass and other surface fuels), (3) fire intensity, (4) amount of fuel (peat) consumed and (5) the GHGs emitted from the burnt peat. The gaps can be set out as follows:

- The difficulty of measuring burnt peat area, fire patchiness and burn depth, is compounded by the fact that fire often smoulders underground. Very little research has been published to evaluate methods of collecting these data²⁰.
- There is also lack of data on peat fuel load, although peat density is sometimes measured.
- Limited information exists on peat fire intensity and severity in smouldering fires. Temperatures are measured in experiments.
- Investigation is required on consumption of peat by fire, although there may not be a lot of variation between burned areas.

There is limited research of trace gases emitted during authentic (non-experimental) peat fires burning at various depths in different peat types (Stockwell *et al.*, 2016). While monitoring systems have been established to detect fires and assess the burnt area, other relevant factors require better understanding and intense research in all peatland regions.

²⁰ One exception is the APFNet project, Improving capacities towards reducing greenhouse gas emissions from peat swamp forest fires in Indonesia.



Chapter 8

Recommendations

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Kai Milliken, Julian Fox and Jukka Alm



Recommendations

by Hans Joosten, Maria Nuutinen, Laura Villegas, Till Neeff, Rémi d'Annunzio, Marieke Sandker, Kai Milliken, Julian Fox and Jukka Alm

Peatland mapping and monitoring need to be approached as a complex and nuanced exercise. The key attributes of an effective monitoring system that includes peatlands will need a synergistic combination of various remote-sensing techniques together with the application of ground-truthing and field measurements, not overlooking the socio-economic factors that remain largely outside the scope of this report. For example, there is evidence that established remote-sensing techniques can be used at a landscape scale to assess land use cover and vegetation conditions, while newer higher-resolution methodologies could monitor the ground water level by detecting soil moisture levels and rates of subsidence.

The following five areas for recommendations give overall suggestions for **national decision-makers and institutions**, in particular, the **ministries in charge of finance, planning, agriculture, environment and forestry, statistical agencies, bodies in charge of conservation, national forest and land use inventories**, as well as **funding, development, cooperation and research institutions**. Similarly, the **scientific community and civil society** can often take a clearer role in advancing peatland protection.

1 ADVANCING WITH PEATLAND MAPPING

Peatland mapping and monitoring should be a priority for all **countries** with peatlands to maintain their carbon and ecosystem services. The support of **research organizations** is needed for the proper integration of information on peatland distribution, extent and status into national maps and monitoring systems. **National governments**, through the relevant ministries or agencies, should focus on consolidating and agreeing national peatland map that can be consistently used by other institutions and stakeholders in territorial planning, land-use management and conservation laws compliance. For the **international community**, coordination and capacity development

to construct a global peatland map are imperative for the future management of restoration and preservation for related resource needs, as well as to collect lessons learned for different peatland types across the globe.

The **national agencies in charge of national forest and other land use inventories** are advised to recall that a harmonized and unified peatland map, that includes location, extent, approximate depth of peat and management status, among other variables, is the basis of effective peatland monitoring. Monitoring focuses on the identification of change of the different variables identified in the mapping phase over time. Remote sensing is extremely helpful in identifying and estimating peatland occurrence, especially where access and information availability is limited (see Chapter 2), but the exact location and extent of peatlands still requires knowledge of ground conditions and soil sampling. Field missions are essential to draw accurate conclusions about the carbon content of the soil and hence better estimates of GHG emissions from peat degradation, so must be budgeted either through national or regional budgets or through research funding.

National academia is in a good position to promote the conservation of these important carbon pools, advocating for the inclusion of shallow peat (widely regarded as a layer less than 50 cm deep) into peatland maps. A peat layer of 15 cm thick – only half the 30 cm depth used by conservative approaches to peatland definition – already holds a larger carbon stock than a high-carbon-stock forest on mineral soil (Barthelmes, Ballhorn and Couwenberg, 2015). For historical reasons, thin peatlands are not classified as peat in many countries. Because of classification issues, shallow peatlands are more often drained and degraded. Their inclusion in national maps would help to ensure that all peatlands were better managed and their emissions accounted for (Lindsay *et al.*, 2019.). Peatlands could be endangered and emissions could considerably increase if monitoring systems were to rely on outdated or inconsequential definitions.

2 FOCUS ON AREA AND COUNTRY-SPECIFIC DEFINITION

The definition of soil carbon content and the minimum thickness necessary to define a peatland, crucial in mapping methodologies, varies between countries. The decisions made in the early stage of definitions through collaboration of the **academia and national institutions** – regarding soil types and classifications, ecological and physical conditions for the identification of an area as a peatland, and key factors for peatland monitoring – will greatly influence a country's peatland delineation methodologies, future conservation strategies and GHG emissions. **International technical agencies** and experts can advise on the standardisation of concept definitions and methods, as well as share technologies in order to speed up the peatlands preservation process.

Peat depth is often mentioned as a critical factor for deciding the conservation value a peatland. However, when deciding on the intervention areas, **national institutions** can find it helpful to consider that many of the most relevant variables to be monitored in peatlands, such as GHG emissions and biodiversity, are largely independent of depth, especially in the short term. Whereas most countries and scientific disciplines specify a minimum depth of peat for an area to be called a peatland, such definitions differ widely and the background to most of them does not relate to monitoring. If the main goal of current monitoring is, for example, to identify GHG emissions and how they change over time, but the peatland definitions are informed by practical agricultural considerations (such as rooting and plough depth) (see e.g. Lindsay *et al.* 2019), a discrepancy between goals and definitions might occur.

The 2006 IPCC Guidelines largely follow the FAO definition of “histosols”²¹, but have omitted the thickness criterion to allow for often historically determined, country-specific definitions of organic soils. As a recommendation for the **IPCC working groups**, a conservative approach to the definition of peatlands, which would serve most monitoring aims, would use a minimum thickness of the organic horizon of 10 cm. (See IPCC, 2014a).

In soil science, a threshold of 18 percent carbon has been established as the boundary above which soils are considered to be organic (Figure 4). This value has been recognised to exclude some soils with high volumetric carbon content – i.e. causing potential high emissions when degraded. From a climate point of view, the boundary between organic and mineral soils could be better drawn at 5 percent carbon, and decided e.g. through **national academia and institutions**. The problem of low-percentage and high-density carbon soils, which has already been recognised by various countries reporting emissions from “peaty soils”, needs more attention from the **scientific community** (Barthelmes *et al.*, 2018).

²¹ A histosol is defined as a soil having a histic or folic horizon, either 10 cm or more thick from the soil surface to a lithic or paralithic contact, or 40 cm or more thick and starting within 30 cm from the soil surface.

3 UPDATING PEATLAND EMISSION FACTORS

The IPCC 2013 wetlands supplement provides emission factors for land use on peatlands for different climate zones, land use types and nutrient status (for boreal and temperate zones). At the time of publishing the Supplement, data from the tropics were limited. An update of the IPCC emission factors is now required to include all measurement data since 2013. The data, as well as available capacity-development approaches, would allow the guidance given in the supplement to be updated and clarified. Also, the **scientific community** could be invited to update the peatland emission references on the *IPCC Emission Factor Database* more systematically. Countries can use those data to increase the accuracy of their inventories instead of using the most simple methods and Tier 1 emission factors.

The **scientific community** should be encouraged to cover gaps in peatland GHG emission factors with the support under various funding mechanisms. Investment in more GHG and other carbon loss measurements on certain peatland types, such as degrading highland peatlands, is recommended.

Peatland fire emissions need to be addressed and calculated more accurately by the **scientific community** to build one functional and holistic system for monitoring and reporting on peatlands for various purposes, including improving MRV for various types of GHG (including REDD+) reporting.

Some countries already have started to integrate peatlands into their national monitoring systems, while others have developed certain elements but still need technical support and capacity development to set up and fully implement integrated systems. Mapping and peatland status update would often require attention and funding from the **development partners**.

4 INTEGRATING PEATLANDS INTO MONITORING SYSTEMS

Countries are increasingly burdened by various types of reporting needs and requests for statistical analysis. The SDG process aims to help manage and prioritize various reporting requirements. For **country decision-makers**, prioritising high-carbon ecosystems, integrating them into existing frameworks, plans, policies and legislation, as well as budgeting, is essential to safeguard, for example, the water services provided by peatlands.

Given that most countries have some forest and agriculture monitoring and reporting frameworks and established processes in place, it is recommended to integrate peatland monitoring into these frameworks. Several gaps still need to be filled to allow countries to improve their peatland mapping, monitoring and reporting for multiple purposes:

- Awareness needs to be raised that peatland-related mitigation and adaptation actions can be significant, similar to action on forests.
- Resources need to be targeted to assess the extent and condition of peatlands, not only for climate purposes but for land use and management planning.

Guidance and capacity can and must be rapidly developed to achieve functional monitoring systems, where confidence is being increased with international harmonisation and mutual quality control, for example through South-South and Triangular Cooperation events with participation of peatland countries.

Peat in national forest monitoring systems

National forest monitoring systems (NFMSs) is an area of work in which countries have already been investing, and which may be able to accommodate peatland considerations. National forest monitoring is a comprehensive process that includes the systematic collection, analysis and dissemination of forest-related data, and the derivation of information and knowledge at regular intervals using both remote sensing and ground data to allow the monitoring of changes over time (FAO, 2017).

An NFMS is one of the elements used by developing country Parties to the UNFCCC implementing REDD+ activities (UNFCCC, 2019a). An NFMS fulfils their obligations to continually develop, monitor and report on forest resources, which may include various land cover classes and soil types, such as peatlands (FAO, 2017). Progress has been made in many countries in this respect (FAO, 2018). These systems and their associated institutional capacities can serve as a starting point when developing specific mapping, measurement and monitoring approaches for peatlands. Ongoing initiatives have gained a wealth of experience on good practices for integrated monitoring, institutional arrangements and data management, which can be adapted to a peatland context bearing in mind that the main ecological consideration of peatlands is that their wetness is the main indicator for degradation.

The information generated by the NFMS can support a variety of land use planning and reporting requirements. Should **countries** choose to voluntarily report REDD+ activities, their NFMS can support the measurement, reporting and verification (MRV) process, through data provision to demonstrate impacts and outcomes of national mitigation policies and measures. Also, the data collected can be useful for forest reference emission levels and/or forest reference levels (FRELs/FRLs) and countries can consider including peatlands in them. Similarly, for peatlands, information derived from an NFMS can serve planning and reporting needs.

However, peat landscapes are diverse and can occur as forested peatlands, as well as other vegetation covers such as herbs, mosses and small shrubs. Besides, when used for productive purposes, they can coincide with diverse categories of land use such as cropland, grazing

land, energy sources. Due to intense soil management practices, such as tillage and fertilization, peatlands under crops are often the source of higher emissions than other land uses. For these reasons, peatland mapping and monitoring should often reach beyond NFMS and its MRV and monitoring processes and needs to rely on cross-cutting data sources from **various government institutions** (see Figure 17).

Mapping of peatlands can build upon tools and methodologies already used in the NFMS, such as the satellite land monitoring system (and national forest inventory (NFI) and its household surveys. Similarly, peatland monitoring can contribute to an NFMS's MRV component as well as national GHG inventories with data such as GHG emissions, emission reductions and enhancement of removals by sinks, as well as reporting on adaptation action such as reduction in vulnerability. In the case of forested peatlands, both mapping and monitoring can contribute to REDD+ reporting through the inclusion of peat emissions and removals originating from forest land (conversion) in the FREL/FRL. It is important for **national agencies** to align peatland monitoring to the existing NFMS for consistency and transparency and to take advantage of existing verification processes.

Learning from experience

Monitoring systems can act as effective mechanisms to learn from the results of interventions on peatlands, modalities of engagement of stakeholders, restoration activities, data collection, among other aspects. The country cases presented in this report are an example of diverse ways in which monitoring systems can provide data on a range of peatland status variables. **Government**-led, application-supported, or community monitoring strategies, among other types, can provide timely updates that can build up to feed international reporting requirements. Finally, ideal monitoring systems should be sufficiently robust to ensure that climate change mitigation efforts are measurable, reportable and verifiable so that emissions and emission reductions are adequately and transparently captured.

5 IMPROVING COORDINATION AND INSTITUTIONAL SETTING

Given the cross-cutting nature of peatlands, various institutions have to collaborate closely in gathering the relevant data through their current or enhanced monitoring practices and systems (Figure 17). A significant challenge is often to have a true and efficient collaboration comprising of data sharing and trust between institutions. For ecosystems that extend over numerous landscapes such as peatlands, improving collaboration across sectors and institutions is a true requirement. **Developing countries** can benefit from enhancing the collaboration, and exchanging best practice through South-South and Triangular cooperation activities.

An example of inter-agency collaboration is the integration of the peat fire monitoring component within the land use monitoring system.

This allows early responses but often requires enhanced governance and coordination. **Land use planners** as well as **units developing and coordinating disaster risk reduction and management plans, strategies, budgets and actions**, would benefit from efficient information sharing on peatlands, their location and drainage status.

As explained in this publication it is possible to build on the lessons learned in different countries regarding the responsibilities and potential support available for MRV, including its institutional setting. As illustrated in Figure 17, to be able to collect and report data on peatlands to different international conventions, **various institutions need to share data with the coordinating unit often located in the Ministry of Environment**. As peatlands are utilized for cropping, grazing, forestry, plantations, infrastructure and extractive industries, institutions in charge of collecting the data (on the right side of the figure) should have peatlands and other high-carbon ecosystems included in their mandates to allow for a country to report on them. **Space agencies and units in charge of disaster risk reduction** will also need to collaborate and offer support.

Capacity development and support on technical and institutional matters can and need to be provided by different **institutions both for collecting as well as combining data** and analysing information both for reporting and for improved management. Capacity should be understood here both as skills, knowledge and other capacities of individuals, organizations as well as their enabling environment, but

also as hardware (tools, laboratories) and software, including land use monitoring and data processing platforms. A systematic review of approaches for covering peatlands within national coordination mechanisms as well as monitoring systems could be beneficial for countries now developing peatland monitoring.

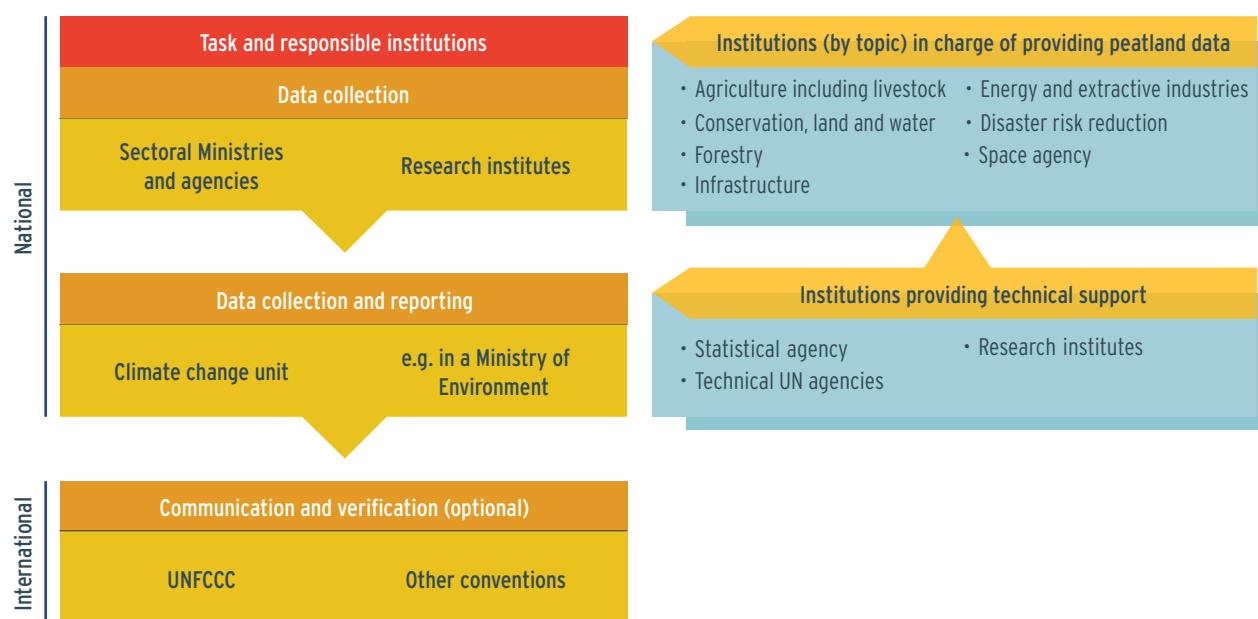
CONCLUDING REMARKS

It is increasingly evident that mapping and monitoring of peatlands are crucial, particularly given the role of peatlands in climate change mitigation. Similarly, understanding the specific national context is critically important to integrate peatlands in the national institutional mandates and land use monitoring frameworks. The rapid development of peatland mapping and monitoring methodologies, guidance and capacity development approaches allow them to be tailored to country-specific context and needs.

As evidenced from the case studies in this publication, much remains to be done in particular to map peatlands before countries can develop reliable peatland monitoring and reporting systems. If resources can be systematically deployed to the work on peatlands, approaches described in this report can help conserve an array of peatland assets that in turn will help in adapting to and mitigating climate change.

Figure 17

Institutional setting and contribution to peatland monitoring and reporting



Annex I: Impacts of peatland degradation on selected SDGs

Table 7

The impacts of peatland degradation and restoration on selected SDGs

SDG	Impacts of peatland drainage and degradation	Impacts of peatland restoration
1. End poverty in all its forms everywhere.	Land subsidence and flooding: land loss, decreased productivity and income (Saputra, Spit and Zoomers, 2019).	Improved management of peatland ecosystems: sustainable livelihoods, alternative streams of income, and food and water security.
	Peatland fires: diminished income, decreased availability of fresh water, timber and non-timber forest products.	Increased resilience to economic, social and environmental disasters from fires, floods, and climate related shocks.
2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture.	Degrading water quality and quantity.	Restored water retention capacity with improved water availability and quality.
	Peat oxidation and land subsidence: flooding and exposed acid sulfate or organic soils decrease available agricultural land (Hoogland, Akker and Brus, 2012), agricultural yields, and food security.	Avoided land loss and better water availability: increased yields, resilient and sustainable food production, reduced hunger and malnutrition.
	Peat soil degradation: pressure on and scarcity of land prevent implementation of sustainable agriculture practices which reinforces monoculture plantation production (Sumarga <i>et al.</i> , 2016).	Sustainable biomass production on rewetted organic soils and peatlands "paludiculture" (Wichtmann, Schröder and Joosten, 2016).
3. Ensure healthy lives and promote well-being for all at all ages.	Reduced biodiversity and environmental quality: reduced food security and well-being.	Improved well-being and livelihoods by reducing risks of social and environmental hazards and diseases ensuring a cleaner environment, and water availability.
	Land subsidence: higher risk from flooding for coastal communities (Andreas <i>et al.</i> , 2018).	
13. Take urgent action to combat climate change and its impacts.	Drained peatlands are currently responsible for 5% of the global anthropogenic GHG emissions (Joosten, 2015).	Attenuated GHG emissions from fire and microbial oxidation.
	Continued drainage of already drained peatlands could leads to the release of 81 Gt of carbon and 2.3 Gt of nitrogen.	Intact peatlands are long-term carbon stores, holding an estimated 644 Gt of carbon globally.
	Peat erosion by wind, water and frost increases carbon losses and GHG emissions (Parry <i>et al.</i> , 2014).	High peatland water tables and revegetation reduce peat erosion.
15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.	Peatland drainage and vegetation damage affect biodiversity and the provision of various ecosystem services (Dieleman <i>et al.</i> , 2015).	Peatland restoration restores the wide variety of ecosystem services that wet peatlands provide (Bonn <i>et al.</i> , 2016; Wichtmann, Schröder and Joosten, 2016).
	Continued drainage-based agricultural crop production leads to further land degradation.	Increased resilience reduces the impacts of environmental disasters and climate regime shifts.

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Peatland mapping and monitoring Recommendations and technical overview

Peatlands have a naturally accumulated peat layer at their surface. In their natural state, peatlands store large amounts of carbon, which is released into the atmosphere if they dry out.

This report gives an overview of key elements for developing peatland maps and integrating them into national land use monitoring systems and reporting processes, describes the advantages and limitations of different choices, and offers practical guidance to facilitate decision-making.

Mapping and monitoring methods are explored to ensure that emissions and emission reductions are measurable, reportable and verifiable. Information is given on other benefits from peatland conservation, restoration, rehabilitation and sustainable management. Country case studies present current achievements. Finally, recommendations are made for the development of robust peatland mapping and monitoring.

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