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Carbon pools and sequestration potential of wetlands in the European Union

Authors:

Dania Abdul Malak, Ana I. Marín, Marco Trombetti, Sonsoles San Román (Universidad de Málaga - UMA)

ETC/ULS consortium partners: Environment Agency Austria, ALTERRA Research Institute, Department of Remote Sensing, Universidad de Málaga (UMA), Lechner Non-profit Ltd space4environment, GISAT, The International Council for Local Environmental Initiatives (ICLEI), Universitat Autonònoma de Barcelona (UAB), Ecologic

European Environment Agency
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Showing rice cultivation practices in a large wetland in the Ebro Delta (Catalonia, Spain)

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European Topic Centre on Urban, Land and Soil Systems (ETC/ULS)
Environment Agency Austria
Spittelauer Lände 5
A-1090 Vienna/Austria

Tel.: +43 1 313 04
Fax: +43 1 313 04/5400

Web: https://uls.eionet.europa.eu/

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Glossary

Blue Carbon
Organic carbon captured by coastal vegetated ecosystems, mainly mangrove forests, tidal saltmarshes, and seagrass meadows. Both the organic carbon in the living tissues and buried in the sediments are considered Blue carbon. Whether the carbon contained in the form of carbonates is to be considered Blue Carbon, is still a matter of debate within the scientific community. The organic carbon accumulated in other areas of the ocean, in a chemical form or in the sediments, would also be a part of the blue carbon but not typically included in the global inventories (Nellemann et al., 2009).

Black carbon
The complex mixture of particles resulting from incomplete combustion (Nellemann et al., 2009).

Bog
A bog or bogland is a wetland that accumulates peat, a deposit of dead plant material—often mosses, and in a majority of cases, sphagnum moss.[1] It is one of the four main types of wetlands. Other names for bogs include mire, mosses, quagmire, and muskeg.

Brown carbon
Anthropogenic CO_2 emissions from energy use and industry (Nellemann et al., 2009).

Carbon budget
This term refers to three concepts in the literature: (1) an assessment of carbon cycle sources and sinks on a global level, through the synthesis of evidence for fossil-fuel and cement emissions, land-use change emissions, ocean and land CO_2 sinks, and the resulting atmospheric CO_2 growth rate. This is referred to as the global carbon budget; (2) the estimated cumulative amount of global carbon dioxide emissions that is estimated to limit global surface temperature to a given level above a reference period, taking into account global surface temperature contributions of other GHGs and climate forcers; (3) the distribution of the carbon budget defined under (2) to the regional, national, or sub-national level based on considerations of equity, costs or efficiency. See also Remaining *carbon budget* (IPCC, 2018).

Carbon dioxide capture and storage (CCS)
A process in which a relatively pure stream of carbon dioxide (CO_2) from industrial and energy-related sources is separated (captured), conditioned, compressed and transported to a storage location for long-term isolation from the atmosphere (IPCC, 2018).

Carbon dioxide equivalent emission (CO_2-eq)
The amount of carbon dioxide (CO_2) emission that would cause the same integrated radiative forcing or temperature change, over a given time horizon, as an emitted amount of a greenhouse gas (GHG) or a mixture of GHGs. There are several ways to compute such equivalent emissions and choose appropriate time horizons. Most typically, the CO_2-equivalent emission is obtained by multiplying the emission of a GHG by its global warming potential (GWP) for a 100-year time horizon (IPCC, 2019).

Carbon flux
Transfer of carbon from one carbon pool to another in units of measurement of mass per unit area and time (e.g. C $ha^{-1}y^{-1}$).

Carbon neutrality
Achieving net zero carbon dioxide emissions at a global scale through the balance of residual carbon dioxide emissions with the same amount of carbon dioxide removal.

Carbon pool
A reservoir or a system that has the capacity to accumulate or release carbon. Examples of carbon pools are biomass, soils, and atmosphere. An example is the carbon pool living forest biomass, which is composed of various types of compounds synthesized by trees. A group of pools are linked in a cycle with flows among the pools influenced by both anthropogenic and non-anthropogenic processes. The carbon pools that are usually differentiated in terrestrial ecosystems are (above- and belowground) living biomass, dead organic matter and soil organic matter, in which flows are influenced by non-anthropogenic drivers such as plant production and microbial decomposition, as well as anthropogenic drivers such as fertilization, land use, tree harvest and product use. The units are in mass (e.g. Mg C) (IPCC, 2019).

The absolute quantity of carbon held within at a specified time is called carbon stock. Transfer of carbon from one carbon pool to another is called carbon flux. Transfer from the atmosphere to any other carbon pool is said to be carbon sequestration.

Carbon sequestration
The process of storing carbon in a carbon pool. The rate with which the carbon is stored is referred to as the **carbon sequestration rat**e. The units are in mass per time unit (e.g. Mg C * yr^{-1}). See also *Blue carbon*, *Carbon dioxide capture and storage (CCS)*, *Uptake* and *sink* (IPCC, 2018).

Carbon sink
See *Sink*.

Carbon stock
The absolute quantity of carbon held within a pool at a specified time (IPCC, 2018). This could be organic or inorganic carbon. The organic forms can be living or dead debris, both from above and belowground. The inorganic fraction is basically represented by carbonates, largely calcium carbonate.

Conversion from C to CO_2
To convert the sequestration (or loss) of 1 kg of C in a carbon pool to the associated removal (or emission) of CO_2 from the atmosphere, the amount of C is multiplied by 12/44, resulting in 3.66 kg of CO_2 (Hendriks et al., 2020).

Emission factor
A coefficient that relates the activity data to the amount of chemical compound which is the source of later emissions. Emission factors are often based on a sample of measurement data, averaged to develop a representative rate of emission for a given activity level under a given set of operating conditions (IPCC, 2019).

EUNIS
The EUNIS habitat classification is a comprehensive pan-European system for habitat identification. The classification is hierarchical and covers all types of habitats from natural to artificial, from terrestrial to freshwater and marine. The habitat types are identified by specific codes, names and descriptions (Davies CE and Moss D, 2002).

Green carbon
Green carbon is carbon removed by photosynthesis and stored in the plants and soil of natural ecosystems and is a vital part of the global carbon cycle (Nellemann et al., 2009).

IPCC
The Intergovernmental Panel on Climate Change (IPCC) is the United Nations body for assessing the science related to climate change. It provides regular assessments of the scientific basis of climate change, its impacts and future risks, and options for adaptation and mitigation (IPCC, 2018).

Land Use, Land-Use Change and Forestry (LULUCF)
In the context of national greenhouse gas (GHG) inventories under the UNFCCC, LULUCF is a GHG inventory sector that covers anthropogenic emissions and removals of GHG from carbon pools in managed lands, excluding non-CO_2 agricultural emissions. Following the 2006 IPCC Guidelines for National GHG Inventories, "anthropogenic" land-related GHG fluxes are defined as all those occurring on "managed land", i.e., "where human interventions and practices have been applied to perform production, ecological or social functions". Since managed land may include CO_2 removals not considered as "anthropogenic", in some of the scientific literature included in this report (e.g. removals associated with CO_2 fertilization and N deposition), the land-related net GHG emission estimates are not necessarily directly comparable with LULUCF estimates in National GHG Inventories (IPCC, 2018).

Mire
A mire, (also commonly referred to as peatland or quagmire) is a wetland type, dominated by living peat-forming plants. Mires arise because of incomplete decomposition of organic matter, usually litter from vegetation, due to water-logging and subsequent anoxia. All types of mires share the common characteristic of being saturated with water at least seasonally with actively forming peat, while having its own set of vegetation and organisms. is the general term for a wetland area and its associated ecosystem, applied most often to peaty areas and varies from regions and classification systems (Frolking et al., 2011).

Paris Agreement
The Paris Agreement under the United Nations Framework Convention on Climate Change (UNFCCC) was adopted in December 2015 in Paris, France, at the 21st session of the Conference of the Parties (COP) to the UNFCCC. This initiative aimed at bringing for the first time "all nations into a common cause to undertake ambitious efforts to combat climate change and adapt to its effects, with enhanced support to assist developing countries to do so". For the agreement to enter into force, 55 countries representing at least 55% of global emissions had to deposit their instruments of ratification. The EU and its Member States are among the 194 Parties to that have signed the Paris Agreement.

Peatland
The term peatland groups different wetlands habitats from an ecological point of view where the common characteristic is the formation of peat. A peatland is an area with a naturally accumulated layer of peat at the surface (Joosten et al., 2017a, 2017b). Peat is defined as sedentarily accumulated material of which at least 30% (dry mass basis) is dead organic matter. In fact, the presence or absence of vegetation is irrelevant to the definition of peatland. They can develop under a wide range of vegetation types in fresh and saline water, including sphagnum, sedges, reed beds, and shrubs and trees in wet woodland and mangroves.

Radiative forcing
Radiative forcing is the change in the net, downward minus upward, radiative flux (expressed in W / m^2) at the tropopause or top of atmosphere due to a change in a driver of climate change, such as a change in the concentration of carbon dioxide or the output of the Sun. The traditional radiative forcing is computed with all tropospheric properties held fixed at their unperturbed values, and after allowing for stratospheric temperatures, if perturbed, to readjust to radiative-dynamical equilibrium. Radiative forcing is called instantaneous if no change in stratospheric temperature is accounted for. The radiative forcing once rapid adjustments are accounted for is termed the effective radiative forcing. Radiative forcing is not to be confused with cloud radiative forcing, which describes an unrelated measure of the impact of clouds on the radiative flux at the top of the atmosphere. (IPCC, 2018).

Remaining carbon budget
Cumulative global CO_2 emissions from the start of 2018 to the time that CO_2 emissions reach net-zero that would result in each level of global warming. See also *Carbon budget (*IPCC, 2018).

Redox
Redox status of wetland soils dictates many important constituent transformations affecting the chemical phase (aqueous, solid, or gas), mobility of some contaminants, and the reactivity of sorption sites. Reducing or anaerobic conditions arise as soils become water saturated (O›Geen et al., 2010).

Sequestration
see *Uptake*

Sink
Any process, activity or mechanism which removes a greenhouse gas, an aerosol or a precursor of a greenhouse gas from the atmosphere (UNFCCC Article 1.8) (IPCC, 2019).

Soil carbon sequestration (SCS)
The removal and storage of carbon from the atmosphere in soil (being one of the carbon sinks) through physical or biological processes, such as photosynthesis (Millennium Ecosystem Assessment, 2005).

Source
Opposite of sink. A carbon pool (reservoir) can be a source of carbon if less carbon is flowing into it than is flowing out of it (IPCC, 2000).

UNFCCC
The United Nations Framework Convention on Climate Change entered into force on 21 March 1994 and today, has near-universal membership. The 197 countries that have ratified the Convention are called Parties to the Convention. Preventing “dangerous” human interference with the climate system is the ultimate aim of the UNFCCC (UNFCCC website).

Uptake
The addition of a substance of concern to a reservoir. *See also Carbon sequestration and Sink* (IPCC, 2018).

Executive Summary

Wetland ecosystems as defined by the Ramsar convention host a wide variety of wetland habitats across terrestrial, coastal and marine environments. When in good condition, wetland habitats provide many societal benefits and values, among others, they play a crucial role in the carbon cycle because of their capacities to limit the availability of oxygen to soil microbes and decomposition of organic matter. Policies and practices do not sufficiently consider these interconnections and interdependencies in Europe yet due to the fragmented consideration of this ecosystem in their schemes. The findings of this report argue that healthy European wetland habitats have an enormous capacity to contribute to carbon neutrality objectives in Europe. Across the wide array of European ecosystems they belong to, wetland habitats have a role in contributing to the carbon cycle. The most meaningful European wetland habitats to contribute to carbon storage include well-functioning salt marshes, healthy mires, bogs and fens as well as riparian, fluvial and swamp forests. Furthermore, when healthy, terrestrial wetlands namely mires, bogs and fens (where peatlands underly), followed by riparian, fluvial and swamp forests as well as inland marshes ensure a high carbon sequestration potential. If kept in a good condition or restored, the EU wetland related carbon stock capacity of their overall area in Europe (EU 27 and the UK) is estimated to be between 12 - 31 Gt CO_2-eq, corresponding to an overall value ranging between 3 and 8 years of EU GHG emissions[1]. Whereas the Carbon sequestration potential of healthy EU Wetlands per year is calculated to range between 24 and 144 Mt CO_2 eq yr^{-1} (24,352 and 14,3719 kt CO_2 eq yr^{-1}), being a quantity that contributes to “neutralising” between 1 and 4 % of the total GHG emissions registered in the EU27 and the UK (according to 2018 reference year for reported emission). These findings should trigger wetland conservation and restoration to become a high priority for the EU to support reaching climate neutrality by 2050. Climate reporting systems require Parties to report on anthropogenic emissions and removals of greenhouse gases which includes reporting heavily modified peatland habitats only partially and dominantly as a net carbon emitter. Using ecosystem-based approaches to managing reported peatland habitats and re-establishing their ecosystem functioning do transform many of them from climate ‘heaters’ (carbon net sources) into climate ‘coolers’ (carbon net sinks).

1 Reference year is 2018 for the EU-27 and the UK: https://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer/

1 Introduction

Wetland ecosystems, as defined by the Convention on Wetlands of International Importance (Ramsar, 1971), include a wide variety of **inland habitats** such as marshes, wet grasslands and peatlands, floodplains, rivers and lakes, **coastal areas** such as saltmarshes, mangroves, intertidal mudflats and seagrass beds, and coral reefs and other **marine areas** no deeper than six meters at low tide, as well as **human-made wetlands** such as dams, reservoirs, rice paddies and wastewater treatment ponds and lagoons (Ramsar Convention Secretariat, 2016).

When in good condition, wetland habitats provide a wide array of values including many societal benefits. Among their variety of services, wetland habitats are crucial for their capacity to slow chemical decomposition due to anaerobic condition in soils and sediments, and their role in the carbon cycle. Without healthy wetlands, the water, carbon and nutrient cycles are significantly altered, mostly detrimentally, yet policies and practices do not sufficiently consider these interconnections and interdependencies (Russi et al., 2013; Abdul Malak et al., 2019).

Peatlands are a type of wetlands that occur in almost every country on Earth. Peatland refer to the peat soil and the wetland habitat growing on its surface where year-round waterlogged conditions slow the process of plant decomposition to such an extent that dead plants accumulate to form peat. Over millennia this material builds up and becomes several metres thick.

It is worth noting that the term peatland (see Glossary for the full definition) applied most often to peaty areas under a wide range of vegetation types in fresh and saline waters does not cover all wetland habitat types and therefore the ecosystem-based definition of wetland ecosystems should always refer to the Ramsar Convention definition as stated in the first paragraph.

In the light of CO_2 driven climate change, efforts to address this challenge require unprecedented transitions in all aspects of society. Actions are two-fold including on the one hand human-caused emissions reduction as well as measures to sequestering carbon dioxide for stopping the increase or even reduce in atmospheric carbon dioxide concentrations.

The sequestration of CO_2 from the atmosphere and the uptake of CO_2 by terrestrial and marine ecosystems, including **wetland ecosystems** as habitats connecting the **terrestrial**, **freshwater and marine** realms, can **reduce atmospheric CO_2 concentrations** and so contribute significantly to **climate change mitigation** and adaptation efforts (Hendriks et al., 2020).

This report focuses on the role of wetland habitats in the carbon cycle and the ways European instruments, and the ways European instruments report them, specifically by:

i. setting an overview of the relative level of carbon pools and a deeper understanding of the carbon sequestration potential by the wide variety of wetland habitats,
ii. indicating how carbon storage and sequestration can be affected by human use and resource exploitation, and

iii. informing about measures and actions in Europe that would contribute to restoring the capacity of these habitats to sequester carbon.

A meta-analysis was performed to assess the available knowledge and evidence on the carbon pool and carbon sequestration potential of wetland habitats and the influence of their condition in ensuring (or not) these functions entailed a compilation of peer-reviewed publications on carbon storage capacity and sequestration rates. A wide range of assessments of different wetland habitats types around the globe using the Ramsar wetland classification has been considered, including possible study areas in Europe.

In addition to the meta-analysis, more detailed information about the most relevant wetland habitat types as classified for Europe (Maes et al., 2020) are documented in the form of factsheets in Annex III at the end of the report.

2 Wetlands in EU policies

2.1 Typology of European wetland habitats

Wetland habitats are defined according to the Ramsar Convention, signed by all EU-27 parties and the UK, which states that wetlands are "areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salty, including areas of marine water the depth of which at low tide does not exceed six meters". Furthermore, wetlands "may incorporate riparian and coastal zones adjacent to the wetlands, and islands or bodies of marine water deeper than six meters at low tide lying within the wetlands.

Wetlands cover a heterogeneous spectrum of habitats across Europe. The wetland ecosystem assessment (Maes et al., 2020) that defines and assess European wetlands following the Ramsar wetland definition (Box 1.1.) shows that wetland habitats cover an area of 370,000 km^2 in the EU-27 and the UK, comprising 7% of the EU-27 and the UK land surface and a small share of coastal and marine waters.

As represented in Table 1, the European ecosystem assessment (Maes et al., 2020) includes different habitat types belonging ecologically to wetlands but typically classified and reported under other sectoral policies and related land cover and land use classes. Some classification shifts were applied in the assessment previously mentioned to enable the assessment of wetlands using an ecosystem-based approach, including the addition of rice fields (moved from croplands), wet grasslands (moved from grasslands), wet heathlands (moved from heathland and scrub) and riparian forests (moved from forests).

2.2 Wetland habitats and their coverage in EU policy frameworks

Due to the crosscutting nature of the wetland ecosystems, its habitats are the subject of different legislative instruments at European level, overlapping and complementing each other in some cases but also leaving some clear gaps in effectively managing those wetland related habitats that lack proper legislative coverage. As shown in Figure 1, several EU pieces of legislation are relevant to certain wetland habitats namely coastal lagoons, coastal saltpans, lakes, ponds and reservoirs, marine waters less than 6 meters at low tide, river estuaries and estuarine waters of deltas. However, other important wetland habitats are not given the same consideration in these instruments such as in the case of beaches, sand, inland marshes, intertidal flats, open mires, rice fields, riparian fluvial habitats, managed or grazed wet meadow or pasture, and wet grasslands. This partial coverage by European legislation on the wetland habitats is perceived as a major gap in terms of their adequate monitoring, assessment, management, and governance.

Table 1 The major wetland habitat types constituting the European wetland ecosystem and their relative percentage extent at the level of EU-27 and the UK. [Source: EEA ecosystem layer 2012]

EU wetland habitat type	Sub-habitats considered in the meta-analysis	Share of (%) wetland coverage in Europe	Extent (km^2)
Rivers and lakes	Water courses, lakes, ponds and reservoirs	28.8	109,044
Inland wetlands	Inland marshes, mires, bogs and fens	25.9	98,099
Marine waters	Marine waters less than six meters deep at low tide	15.5	58,685
Riparian, fluvial and swamp forests		13.3	50,180
Coastal wetlands and lagoons	Salt marshes, coastal lagoons, river estuaries and estuarine waters of deltas, coastal saltpans (highly artificial salinas) and intertidal flats	6.7	25,186
Wet grasslands and pasture	Managed or grazed wet meadow or pasture and natural seasonally or permanently wet grasslands	3.7	13,861
Wet heathlands	Belong to heathlands and monitoring work and research analysed does not separate heathlands by their ecology – i.e. no differentiation between the wet and dry heathland habitats	3.6	13,455
Rice fields		1.7	6,530
Beaches, dunes, sand		0.8	2,949
Riverine and fen scrubs		0.2	629
		100	**378,618**

The ***EU Habitats Directive*** (HD)[2] introduced in 1992 aims at achieving a favourable conservation status for different habitats of Community of interest, of which 61 are related to wetlands (see Annex I). The EU Member States report every six years on the conservation status of these habitats through the Habitat Directive which, in spatial terms, cover more than 95% of Ramsar wetland ecosystem surface. Due to the coverage of the geo-spatial information on the distribution of the habitats currently available, this statistic is valid at EU-26 and the UK (with Croatia excluded). Furthermore, the percentage values summarised in Table 2 are considered indicative due to resolution differences, combining the 10 km spatial resolution for the HD data with the 100 m spatial resolution for the wetland ecosystem layer.

The **Natura 2000**[3] is a network of nature protection areas made up of Special Areas of Conservation and Special Protection Areas designated under the Habitats Directive and the Birds Directive, respectively. The Habitats of Community of interest covered by the network of Natura 2000 constitute 41% of EU-27 and the UK level wetlands. Looking at individual habitat types, there is a high heterogeneity in the coverage rates. A high share of coastal wetland habitats (almost 90%) fall within the Natura 2000 network, compared to less than 20% of wetlands linked to riparian, fluvial and swamp coniferous and mixed forests respectively. Furthermore, a very low representativeness in the Natura 2000 network (23%) is assigned to traditional wetland habitats of agricultural interest, such as rice fields (Maes et al., 2020).

The **EU Water Framework Directive (WFD)**[4] adopted in 2000 commits all EU Member States to achieve a good status of all ground and surface waters. Article 2.10 of the Directive provides the following definition of a body of surface water: “Body of surface water means a discrete and significant element of surface water such as a lake, a reservoir, a stream, river or canal, part of a stream, river or canal, a transitional water or a

2 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:31992L0043
3 https://ec.europa.eu/environment/nature/natura2000/index_en.htm

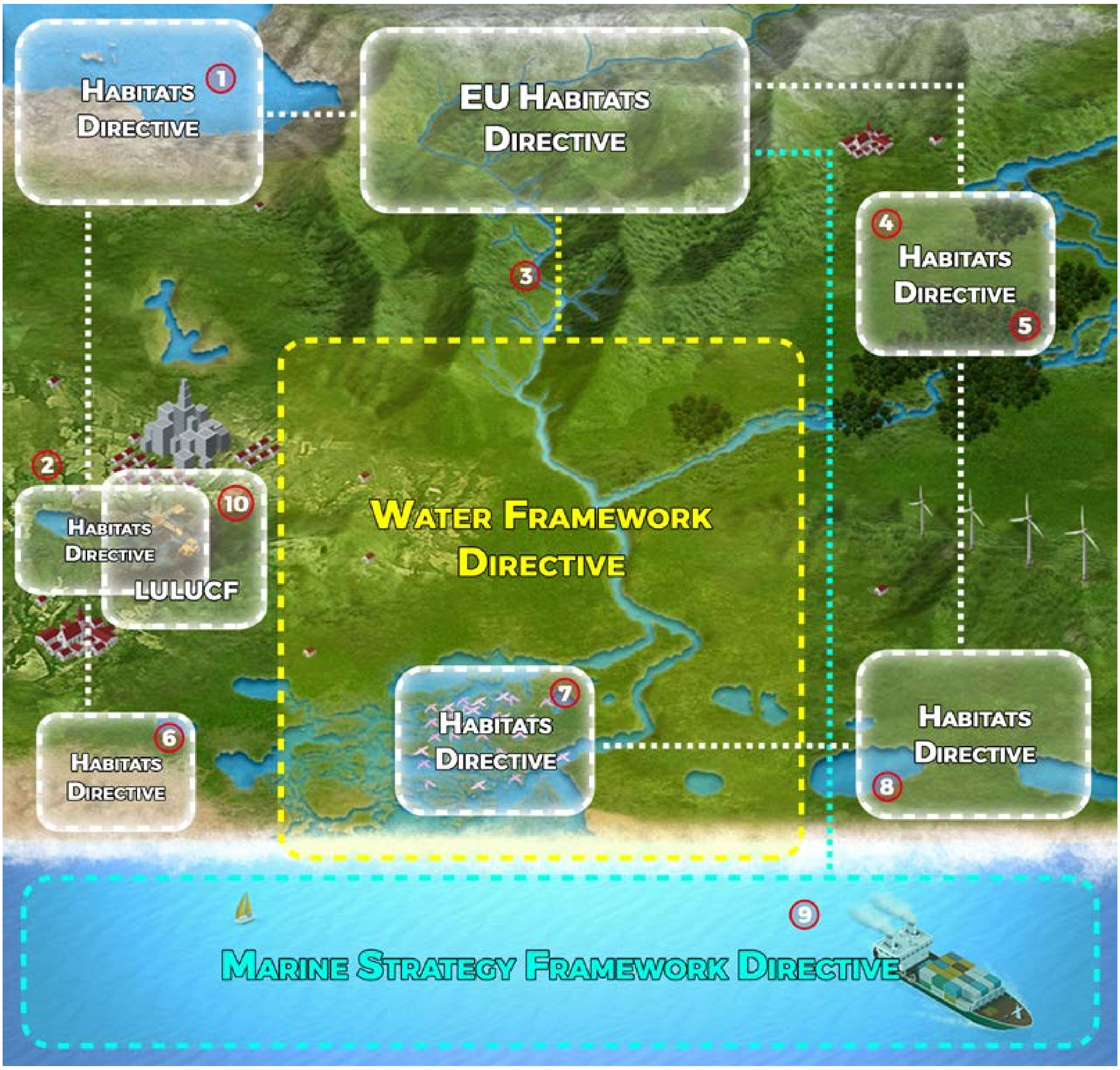


Figure 1 Wetlands and policies in the EU: examples of European habitat types belonging ecologically to wetland ecosystems and the patchy treatment of most relevant EU environmental policies in covering them: 1. Tidal mudflats, 2. Urban wetland, 3. Alluvial meadows, 4. Grasslands, wet meadows, 5. Riparian forest, 6. Dunes, 7. Deltaic areas and 8. Salt meadows and marshes, 9. Marine waters less than six meters deep at low tide, 10. Peat bogs and fens. [Source: Abdul Malak et al. 2019 (adapted)]

stretch of coastal water". This definition includes artificial or heavily modified water bodies, estuaries, and saline waters up to a nautical mile from the marine shore. Though all wetland habitats are identified by the WFD as important components in the assessment of the Ecological Status of associated water bodies and as buffer habitats to be taken into consideration for restoration and management plans, the wetland classes listed in the reporting obligations cover a limited amount of these wetland habitats. Only 44% of Ramsar wetland habitats are covered by the Directive, and for which Member States have the obligation to report, as shown in Table 2.

4 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32000L0060

The **EU Marine Strategy Framework Directive (MSFD)[5]** , adopted in 2008 to "protect more effectively the marine environment across Europe" is the first EU legislative tool dealing with the protection of marine ecosystems and biodiversity and, more concretely, designed with the aim to achieve a good environmental status by 2020. The Directive covers the whole extent of marine wetland habitats being defined by the Ramsar convention as "Marine waters less than six meters deep at low tide". Table 2 shows that the share of wetland habitats covered by the MSFD reporting is around 16%.

The Land Use, **Land-Use Change and Forestry (LULUCF) Regulation 2018/841[6]** comprises one of the pillars for achieving the target of the Paris Agreement and the EU 2030 climate and energy policy framework. This Regulation includes land accounting categories for managed wetlands[7] to be mandatory for the second commitment period 2026 – 2030, as they were not previously included in the LULUCF Decision of the year 2013 (Decision 529/2013/EU, European Commission 2013) and the commitments under the Kyoto Protocol for Annex I Parties[8]. Member States include different definitions of wetlands in the reporting that are normally terrestrial and not always subject to management activities (e.g. flooded lands). The definition that each MS uses in its national inventory reports (NIR) for the wetland land category is compiled in Annex II.

It is to recall that at the EU level, for the year 2018, 71,865 km^2 of wetland areas were reported as "managed" by the EU Member States (MS), while 171,218 km^2 were classified as "unmanaged" (EEA, 2020). This means a total of 243,083 km^2 of land is classified as wetlands under LULUCF.

To compare with the area covered by the Ramsar wetland ecosystem layer for EU-27 and the UK, table 2 shows that 64% of the wetlands are currently reported as wetland LULUCF category in the annual MS greenhouse gas inventories under the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol. Additionally, only 19% is considered as managed wetland and consequently reported in GHG emission and removal accounts.

These figures were not integrated explicitly in Table 2 as the LULUCF reporting done by MS so far does not require the digitisation of the reported data hence their inclusion and the detection of the coverage per habitat type was not possible.

5 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32008L0056

6 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.156.01.0001.01.ENG
https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.156.01.0001.01.ENG

7 Managed wetlands will be restricted to wetlands where the water table is artificially changed (e.g., drained or raised) or those created through human activity (e.g., damming a river). 2006 IPCC Guidelines, Volume 4 (AFOLU), Chapter 7 (Wetlands). Available at: https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_07_Ch7_Wetlands.pdf

8 The United Nations Framework Convention on Climate Change (UNFCCC), in Annex I, listed developed countries and "countries that are undergoing the process of transition to a market economy" whose responsibilities were differentiated from developing, or non-Annex I, countries

Table 2 Percentage coverage of the extent of wetland ecosystems by the EU directives considered [source: Maes et al., 2020 adapted]

Wetland habitat	Percentage (%) of habitat covered by relevant EU Directives*			
	Habitats Directive	Water Framework Directive	Marine Strategy Framework Directive	Natura2000
Beaches, dunes, sand	90			58
Coastal lagoons	92	100		93
Coastal saltpans (highly artificial salinas)	100	100		92
Inland marshes	87			74
Intertidal flats	100			90
Lakes, ponds and reservoirs	93	100		31
Managed or grazed wet meadow or pasture	95			37
Marine waters less than six meters deep at low tide	95	83	100	52
Natural seasonally or permanently wet grasslands	95			47
Open mires	99			33
Rice Fields	84			23
Riparian, fluvial and mixed forest	99			18
Riparian, fluvial and swamp broadleaved forest	94			50
Riparian, fluvial and swamp coniferous forest	99			15
River estuaries and estuarine waters of deltas	100	100		73
Riverine and fen scrubs	97			58
Salt marshes	99			89
Water courses	89	100		51
Wet heaths	99			47
Total	**96**	**44**	**16**	**40**

* Under the LULUCF reporting, there is no spatially explicit assessment required from Member States. Furthermore, each MS chooses their own definition of managed wetland habitats to be included in their GHG reporting. For the purposes of this table, only the coverage of LULUCF for wetland habitats at EU-27 and the UK level is calculated. This figure covers 64% of the area of Ramsar wetland habitats in Europe.

3 Role of wetlands as carbon pools

When assessing carbon pools across ecosystems, oceans have an estimated carbon stock of ~ 40,853 Pg (Petagrams) - the highest carbon pool in the world - followed by terrestrial ecosystems with an approximate carbon stock 10 times lower than the ocean's (~ 3,900 Pg) (Ussiri and Lal et al., 2017).

Concerning wetlands, they cover a heterogeneous spectrum of environments across Europe as shown in Section 2.1., including habitats belonging to terrestrial, freshwater, and coastal/marine realms. The carbon stocks in these wetland habitats at a specific time however depend on several factors and vary across this spectrum. Such variations are affected by landscape positions (inner, transition, toe slope, and upland landscape positions), as well as among land uses and soil depth segments in wetland habitats (Tangen and Bansal, 2020).

The main results collected in this meta-analysis on carbon stocks are summarized in Table 3 showing the ranges, measured as **Mg ha^{-1}**, available in the most relevant terrestrial and marine habitat types.

As highlighted in **bold** in Table 3, the highest carbon pools in terrestrial ecosystems relate to wetland habitats, namely in salt marshes ranging between 225-300 Mg ha^{-1} of carbon stock, and bogs and fens with their high capacity of accumulation peat ranging from 150 to 225 Mg ha^{-1} of carbon stock, followed by forests ranging from 75 to 225 Mg ha^{-1} of carbon stock.

To the same extent, wetland habitats hosted by coastal and marine systems hold high ranges of carbon namely in maerl beds with values higher than 150 Mg ha^{-1} of carbon stock as well as seagrass beds and intertidal sediments storing between 10 – 50 Mg ha^{-1} of carbon stock among others (Table 3).

However, uncertainties in quantitative estimates of carbon stocks across ecosystems remain high, due to methodological restrictions but also because carbon stock is heavily dependent on local conditions and no single set of values can accurately represent all cases.

Table 3 Classification of terrestrial and marine habitats typologies based on their ranges of carbon stocks. [source: Hendriks et al., 2020 adapted]

Broad habitats	Class number	Class range in carbon stocks (Mg ha^{-1}) (based on highest estimates for the marine habitats)	Habitat type
Terrestrial habitats	T1	<75	Sand beach, **coastal dune**, sea cliff, **water body**, ice sheet, glacier, spring brook, watercourse, **tidal river**, rocky grassland, Mediterranean dry grassland
	T2	75-150	**Coastal dune shrub**, coastal dune forest, **bog**, **fen mire**, dry to mesic grassland, wooded pasture, alpine heath, **wet heath**, dry heath, maquis, Fagus-forest, Mediterranean deciduous forest, Mediterranean evergreen forest, plantation forest
	T3	150-225	Coastal dune forest, **bog**, **fen mire**, **helophyte bed**, **mountain hay meadow**, temperate and boreal grassland, Fagus forest, Mediterranean deciduous forests, Taiga Pinus forest, plantation forest
	T4	225-300	**Salt marshes**, **Palsa mire**, **Aapa mire**, **Helophyte bed**, Abies forest, Picea forest, Taiga pinus forest
	T5	>300	**Salt marshes, pals mire, aapa mire**
Marine habitats	M1	<10	**Kelp forest**, **intertidal macroalgae**, flameshell beds, serpulid reefs, brittlestar beds, blue mussel beds, faunal turfs, subtidal shelf sediments. subtidal oyster beds
	M2	10-50	**Seagrass beds**, horse mussel beds, **intertidal sediments**
	M3	50-100	n.a.
	M4	100-150	Lophelia reefs
	M5	>150	**Maerl beds**

3.1 Current knowledge of carbon storage in terrestrial ecosystems

The capacity of terrestrial ecosystems to store carbon is highly variable and dependent on the habitat and its condition. A literature review carried out recently by Hendriks et al. (2020) indicated that their mean value, based on 301 measures, is 143 Mg ha^{-1} but highly variable since values range from 1 to 827 Mg ha^{-1} (Figure 2). This high variability is linked to the diversity of terrestrial wetland habitat types, whose mean value, based on 76 measures, is 252 Mg ha^{-1}.

Driven by their high capacity to **stock carbon**, healthy wetlands are the most important carbon pools in terrestrial ecosystems largely due to their capacity to accumulate carbon in peat. In Europe, peat soils have been accumulating carbon since the retreat of the last glaciers approximately 10,000 years ago (Yu et al, 2010).

In terms of **carbon sequestration** rates, the annual uptake of carbon, forests have by far the highest rates of terrestrial ecosystems, up to about three times those of wetlands and agroecosystems. As shown in Figure 3, for forests the carbon sequestration rate is of 3.17 Mg ha^{-1} y^{-1} with variable values ranging from 0.05 – 9.26 Mg ha^{-1} y^{-1}. For wetlands, the mean carbon sequestration rate is of 1.04 Mg ha^{-1} y^{-1} with values ranging from -0.49 – 6.5 Mg ha^{-1} y^{-1} (Figure 3). These values are significantly lower, but peatlands sequester carbon during very extended time periods where thick peat bogs accumulate carbon for hundreds of years.

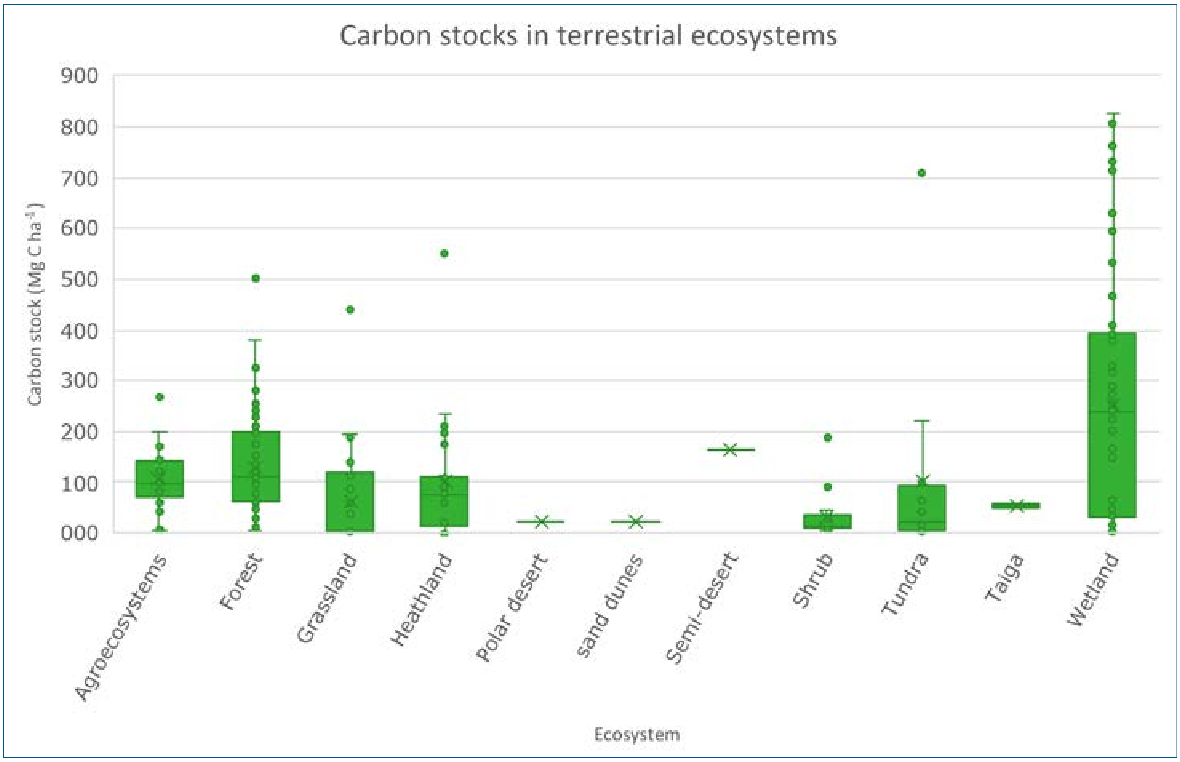


Figure 2 Carbon stocks of terrestrial ecosystems (from Hendriks et al., 2020)

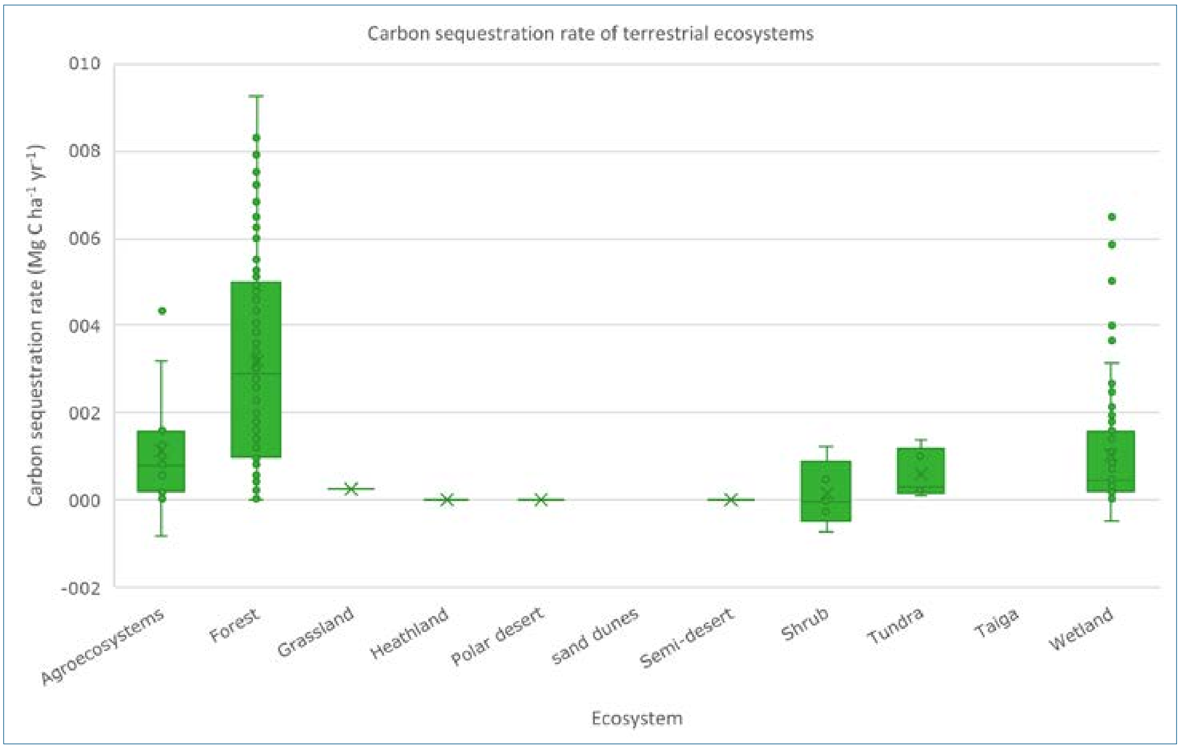


Figure 3 Carbon sequestration rate of terrestrial ecosystems (from Hendriks et al., 2020)

3.2 Current knowledge of carbon storage in coastal and marine ecosystems

Coastal and marine ecosystems have a high storage capacity of carbon per unit area comparable, and in some cases higher than terrestrial forests and are now being recognised for their role in mitigating climate change. Coastal and marine wetland habitats, when healthy, hold high and varied ranges of carbon namely that alter between 50 - 150 Mg ha^{-1} of carbon stock.

Carbon stored in coastal and marine ecosystems is referred to as blue carbon. In Europe, saltmarshes and seagrass carbon storage represents about 1.5 – 4% of existing global "blue" carbon from coastal vegetated habitats (Nellemann et al., 2009).

3.3 Current knowledge of carbon storage in wetland ecosystems

Wetlands hold between 20 and 30% of the estimated global soil carbon (~ 3,900 Pg) (Lal, 2008; Lal et al., 2018) despite occupying only 5–8% of land surface (Mitsch and Gosselink, 2007). The anaerobic conditions, characteristic of wetland soils, slow the decomposition of organic matter and lead to its long-term accumulation as high amounts of carbon stock (Figure 2). In addition, plant vegetation in semi-natural wetlands also sequesters carbon and contributes to the potential of these habitats to add to wetlands' carbon sequestration capacity when not harvested and removed (Figure 3).

As shown in Figure 4, the sequestration potential of wetland habitats depends on many factors and is site-specific varying with age, operation, and the environmental boundary conditions such as location and climate (Kayranli et al, 2010), hydrogeomorphic characteristics and vegetation community (Bernal and Mitsch, 2012) and anthropogenic disturbances (Lolu et al, 2020).

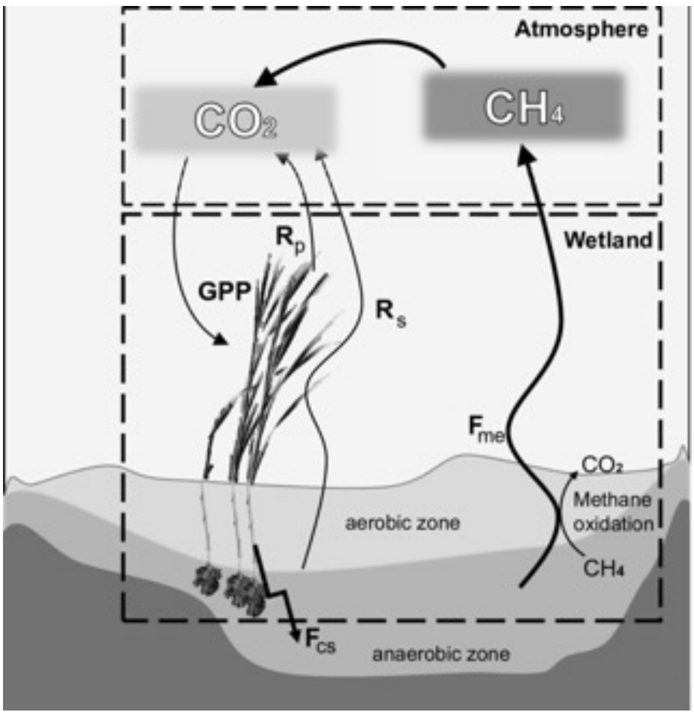


Figure 4 A typical wetland carbon cycle. Modified from Mitsch et al., (2013). Abbreviations: CH_4 = methane, CO_2 = carbon dioxide, GPP = gross primary productivity, Rp = plant respiration, Rs = soil respiration, Fcs = carbon sequestration, Fme = methane emissions

More precisely, **landscape level** practices such as location, watershed size, and adjacent land use activities influence wetland habitats while **wetland scale** processes, such as water and sediment inflows, retention time, and hydroperiod affect plant community structure, site hydrology and morphology. At **process scale**, redox status of wetland soils dictates several constituent transformations affecting the chemical phase (aqueous, solid, or gas) and the mobility of contaminants subsequently controlling productivity and carbon sequestration capacity.

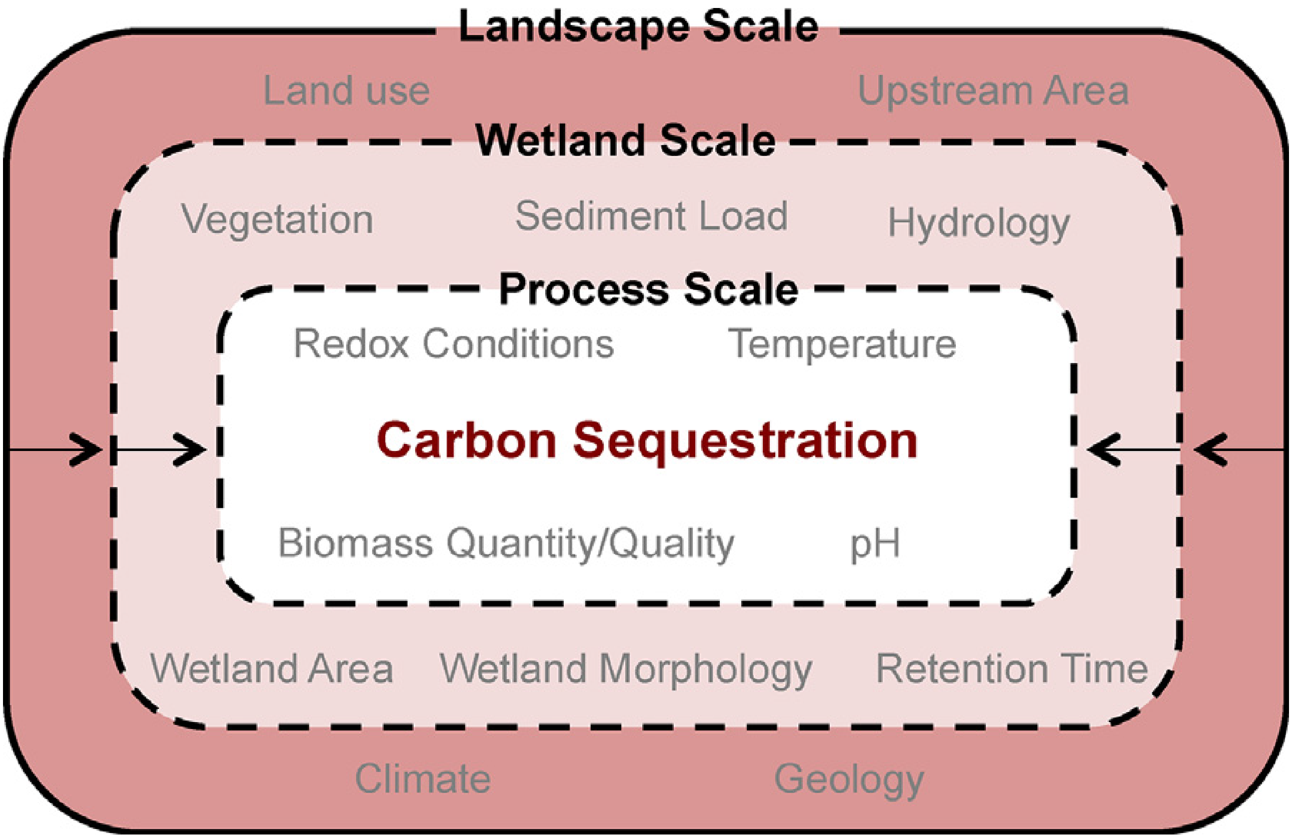


Figure 5 Carbon sequestration is affected by proximal and distal drivers across scales of influence (i.e., process level, site level, landscape level). This case focuses on land use described through measures of wetland condition, sediment load, hydrologic metrics (e.g., wetness and flashiness), and floristic quality of the vegetation (modified from Trepel and Palmeri, 2002)

3.4 Effect of wetland management on Greenhouse Gas emissions

As a common management practice affecting wetlands, hydrologic disturbances such as drainage and shortened hydroperiods tend to increase soil drying and organic carbon oxidation, resulting in the release of carbon dioxide and methane to the atmosphere (Kroeger et al., 2017; Bridgham et al., 2006). On the other hand, vegetation persistence in the system is another important factor that contributes to the carbon sequestration potential of wetland habitats, hence when vegetation is extracted, the potential sequestration capacity of wetland habitats is reduced (Whitaker et al., 2015).

Wetland degradation and destruction are significant factors disturbing wetland habitats and their capacity to mitigate climate change effects by converting them into greenhouse gas emitters to the atmosphere, often reverting wetland ecosystems' roles from carbon sinks into sources (Nahlik and Fennessy, 2016; Hemes et al., 2018).

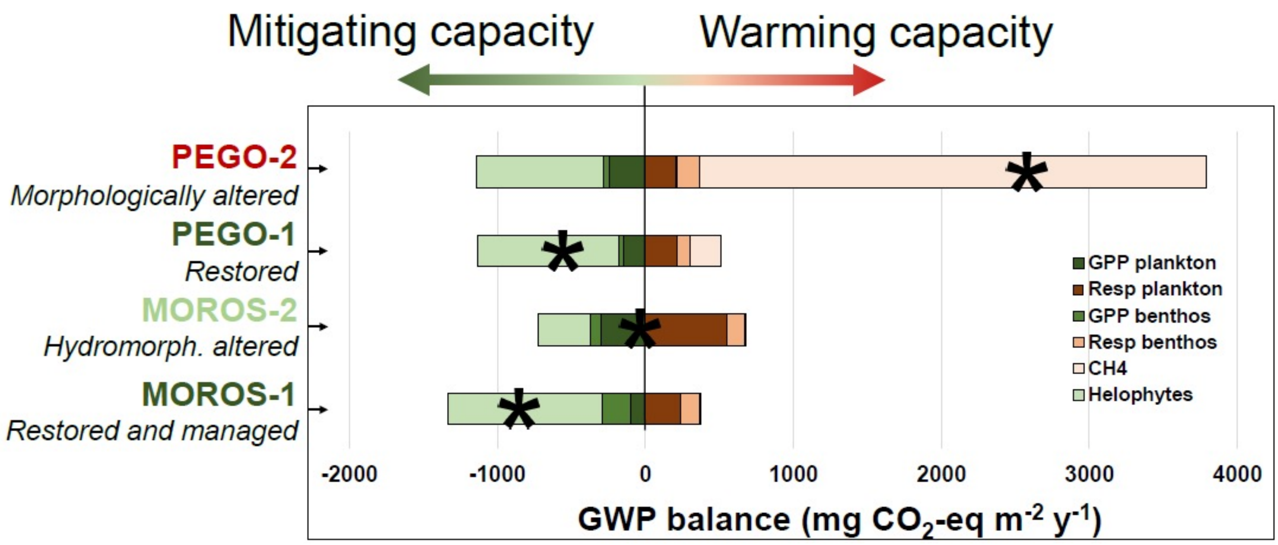


Figure 6 Warming Potential Balance in coastal Mediterranean Freshwater and brackish Wetlands: Annual Global Warming Potential (GWP) balance (stars) and relative contribution to the warming potential (or warming mitigation for C capturing) of each of the C processes (in CO_2-eq) obtained after extrapolation of rates measured every 2 months. Sampling sites on the Valencian coast (eastern Spain): 2 restored (Moros-1 and Pego-1) and 2 altered (Moros-2 and Pego-2) (from Morant et al., 2020).

Nevertheless, the results of dynamic modelling of carbon flux from a wide range of case studies of wetland habitats across the globe (Hemes et al., 2019; Mitsch et al., 2013; Bridgam et al., 2006) demonstrate that long-term (several decades) methane emissions become unimportant compared to carbon sequestration in wetlands, proving that these habitats become net carbon sinks as carbon sequestration rates are outbalancing methane emissions.

Through site level experiments, Morant et al. demonstrate that management practices resulting in instability of the organic sediments favour degradative metabolism in freshwater and brakish wetland habitats, with release of stored C accompanied with increases in CH_4 emissions.

Their results indicate that the hydromorphological alterations in such habitats may convert healthy ecosystems contributing to C sequestration and climate change mitigation into C-emitting ecosystems. (Figure 6).

This demonstrates that healthy natural wetlands as well as the long-term restoration of their habitats can ensure their potential to sequester carbon, thereby confirming their core contribution to the climate change mitigation and adaptation efforts once correctly restored and effectively managed.

Yet, to ensure an integrated management system for wetlands, there is an urgent need to agree on using the right classification system of their habitats and a pre-agreed monitoring scheme that considers wetland extent to ensure their effective and holistic management across various scales.

3.5 Carbon sequestration research and data gaps

3.5.1 Worldwide overview

Literature review clearly shows, that the knowledge about carbon sequestration capacities across wetland types is not homogenous and that research efforts over the last decades had focused mainly on oceans (Sabine et al., 2004; Nellemann et al., 2009; among others) and terrestrial forests (Houghton et al., 1990; Luyssaert et al., 2014, among others), and to a lesser extent and most recently, on coastal systems (Mcleod et al., 2011; Lavery et al., 2013; Macreadie et al., 2013). There seems to be a general agreement among researchers that globally carbon fluxes and pool sizes vary widely among wetland types, the latter determining, together with their naturalness or the level of degradation, their capacity and the degree to which they can act as a carbon sink. As for the important role in climate change mitigation, this table confirms that particular wetland habitat types coincide in their high capacity to act as net GHG sinks, namely forested freshwater wetlands, estuarine forests, salt marshes, seagrass beds and mangroves (with less certainty over mangroves as not all studies coincide). The capacity of these particular habitats ensures high soil carbon sequestration rates and at the same time low methane emission rates (moderate in the case of forested freshwater wetlands), with their soils acting as long-term carbon stocks (moderate in the case of tropical forests). This fact makes these wetland habitats very efficient constituting a nature-based solution to mitigate climate change effects by their ability to act as net greenhouse gases (GHG) sinks.

Table 4 provides an overview of the existing knowledge on the ranges of carbon sequestration in soils and sediments classified per wetland habitat type. It provides evidence on the important role of wetlands in climate change mitigation but also on the variability of the carbon sequestration capacity of their soils and on their capacities to build long-term carbon stocks (Crooks et al., 2011).

Particularly forested freshwater wetlands, estuarine forests, salt marshes, seagrass beds and also mangroves ensure high soil carbon sequestration rates and at the same time low methane emission rates (moderate in the case of forested freshwater wetlands), with their soils acting as long-term carbon stocks (moderate in the case of tropical forests). This fact makes these wetland habitats very efficient constituting a nature-based solution to mitigate climate change effects by their ability to act as net greenhouse gases (GHG) sinks.

Concerning inland wetlands, knowledge is often limited to site-specific studies and very commonly focused on peatlands (Turunen et al., 2002; Joosten et al., 2017a, 2017b; Bernal and Mitsch, 2013), which, if in good condition, are the most space-effective stock of organic carbon on the planet due to the thick layers of carbon rich peat accumulated over thousands of years.

Table 4 Relative rates of carbon sequestration and capacity to build long-term carbon stocks for different wetland types. Note that there may be some overlap in the wetland types shown. Source: Crooks et al. 2011.

Wetland type	EU Wetland classification	Soil carbon sequestration rate	Methane Emission rate	Ability to act as Net GHG Sink	Long-term Carbon Stocks
Salt Marsh	Coastal wetlands and lagoons - Salt marshes	High	Low	High	High
Mangrove	-	High	Low to High	Moderate to High	High
Freshwater Tidal Marsh		High	High	Low	Moderate
Estuarine Forest	Riparian, fluvial and swamp forest	High	Low	High	Moderate
Seagrass Bed	Coastal wetlands and lagoons -Seagrass meadows	High	Low	High	High
Tropical Peatland	-	Low	Moderate to High	Moderate	Very High
Temperate Boreal Peatland	Mires, bogs and fens	Low	Moderate to High	Moderate	Very High
Inland Freshwater Mineral Soil Wetlands	Inland marshes	Low to High	Moderate to High	Low to Moderate	Low to Moderate
Forested Freshwater Wetlands	Riparian, fluvial and swamp forest	High	Moderate	Moderate	Very High

Other wetland types, namely freshwater tidal marshes and inland freshwater mineral soil wetlands including marshes and swamps, though having high sequestration rates of carbon, have in contrast a lower ability to act as GHG sinks due to their high methane emission rates to the atmosphere. These wetland habitats are nevertheless an important refuge for flora and fauna.

Coastal flats and sand dunes have sparse vegetation, resulting in a more limited carbon turn-over, nevertheless, they are unique habitats for a wide range of epifauna (or epibenthic organisms including crabs, cockles, mussels and other shellfish) and infauna (including molluscs, worms, crustaceans among others) which are depending on the good condition of these habitats.

Moreover, there is great uncertainty in the role and estimation of carbon rates of other inland waters such as lakes, streams, and rivers, etc., that move vast amounts of carbon as dissolved organic carbon (DOC) from the land into the oceans (Raymond et al., 2013).

3.5.2 In depth review on carbon sequestration capacities of wetlands

Though wetland habitats are very diverse, the results of the meta-analysis highlight the wetland habitat types or sub-types that have the most significant capacity to sequester carbon as potential Nature-Based Solutions for biodiversity and climate resilience in Europe.

Table 5 provides a summary of an extensive review covering 75 independent studies assessing the carbon sequestration ranges of wetland habitats, and synthesising site-level research results extracted from 34 studies. The remaining 41 studies did not provide additional information and were therefore not integrated in the table but used for broader references across the report. The grouping of available knowledge about wetland habitats was developed as far as possible according to the Ramsar classification system (Ramsar Convention Secretariat, 2016). The geographical focus was on European studies, though in some cases global references or references from other regions were added to complement the European studies.

The scientific literature analysed contained a wide range of both qualitative and/or quantitative information on carbon sequestration rates, on approaches used to gather the information and, in some cases, also including uncertainty analysis. Additionally, most of the publications identified describe the studied habitat type aligned neither with the wetland classification used for this study (i.e. the Ramsar classification), nor EUNIS types, but focused on certain wetland linked species and habitats (e.g. peatlands, seagrass meadows). To enable a synthesis of these variable data, the interpretation of the carbon sequestration results in wetlands was in some cases interpreted using independent expert judgement to align the information with the Ramsar wetland classes.

The most relevant extensive results of the meta-analysis were organized in a database classified by habitat type. More detailed information is presented as factsheets for each habitat type and added as an annex to this report (Annex III).

The main results presented in **Table 5** inform about the wetland type studied with a focus on the most relevant for Europe, the dominant biogeographical region of consulted studies, the number of measures in the field taken in each study analysed, the carbon sequestration rate reported (as mean and standard deviation), as well as the reference list. Table 5 is followed by **a synthesis of the main outcomes for the most representative and significant wetland habitats for Europe.**

Table 5 Summary of Carbon sequestration rates by wetland type based on the meta-analysis of 34 peer-reviewed studies

Broad habitats	Wetland classification	Biogeographical region	N of measures	C sequestration rate (g C m^{-2} yr^{-1})		Reference
				Mean	STD	
Terrestrial habitats	Riparian, fluvial and swamp forest	Forested mires (Boreal/Arctic region)	8	23	± 4.3	Turunen et al., 2002
	Riparian, fluvial and swamp forest	Pine bog (Boreal/ Arctic region)	8	25	± 7.28	Turunen et al., 2002
	Riparian, fluvial and swamp forest	Global	15	176	*	Villa and Bernal, 2017
	Inland marshes	Global / Temperate	11	173	± 117.6	Bernal and Mistch, 2012
	Mires, bogs and fens	Subartic	2	7	±5	Aurela et al., 2002
	Mires, bogs and fens	Boreal	17	34	±28	Turunen et al., 2002 ; Tolonen and Turunen, 1996; Alonso et al., 2012; Soini et al., 2010 ; Friborg et al., 2003
	Mires, bogs and fens	Atlantic / Temperate	14	57	±34	Koehler et al., 2011; Ratcliffe et al., 2018; Sottocornola et al., 2005; Beverland et al., 1996; Alonso et al., 2012; Yu et al., 2009; Helfter et al., 2015.
	Rice fields	Asia	5	-246		Nasser et al., 2020; Koizumi 2001
	Dunes- Vegetated grasslands (main vegetation types include dune grassland and dune slacks, with dune heath on some acidic sites)	Atlantic	4	56	±13.7	Jones et at., 2008; Beaumont et al., 2014
	Wet heathlands	No information on wet heathland encountered	-	-	-	-
	Coastal wetlands and lagoons - Salt marshes	Global	6	282	±99	Ouyang and Lee 2014; Chmura et al., 2003; Adams et al., 2012.
	Coastal wetlands and lagoons - Salt marshes	Mediterranean	6	166	±83	Morant et al., 2020; Morris et al., 2013 ; McLeod et al., 2011.
	Coastal wetlands and lagoons - Salt marshes	Atlantic	4	263	± 151	Brix et al., 2001, Beaumont et al., 2014
Marine habitats	Coastal wetlands and lagoons -Seagrass meadows (Zostera Marina)	Atlantic	11	43**	±64	Jankowska et al., 2016 ; Novak et al., 2020
	Coastal wetlands and lagoons -Seagrass meadows (Posidonia Oceanica)	Mediterranean	23	52**	±50	Mateo and Serrano, 2012; Serrano et at., 2016; Gacia et al., 2002, Mazarrasa et al., 2017; Mateo et al., 2006; Mateo et al., 1997; Cebrian et al., 1997.

*Standard deviation unknown. The 25th (Q_1) and 75th (Q_3) quartiles, respectively 89.5–563.3

** Net carbon accumulation

3.5.2.1 Riparian, fluvial and swamp forests

Riparian, fluvial and swamp forest habitats cover 13% of the wetland habitats in Europe and include the following classes:

- Forested peatlands, whose main characteristic is the presence of a peat layer and
- Freshwater, tree-dominated wetland flooded forests that are either permanently or seasonally inundated with freshwater.

The carbon sequestration potential of forested wetlands (i.e. riparian, fluvial and swamp forests) varies significantly and is closely linked to the carbon balance between the vegetation and tree types in these habitats, their soil condition, moisture, and salinity among others.

Swamp forests include forested peatlands where the presence of a peat layer in addition to trees boosts their carbon sequestration capacity. Due to their wetland - forest duality, these ecosystems have a high capacity to sequester carbon. The results presented in Table 5 show that site-based studies indicate high carbon sequestration in riparian/fluvial and swamp forests assessed at global scale followed to a lesser extent by pine bog and forested mires in boreal and arctic regions. In Europe, forested and afforested peatlands, if adequatly managed, prove to contribute to soil carbon stocks, giving clear greenhouse benefits (Laine et al. 1997; Hargreaves et al. 2003) and confirming the importance of keeping, through conservation and returning forested peatlands (through restoration) to their saturated state (Cannell et al, 1993).

On the other hand, riparian and fluvial forests usually have favourable growing conditions (e.g., due to soil moisture), and may accumulate carbon stocks at a greater rate than upland forests (Matzek et al., 2018; Naiman et al., 2010), contributing more to rapid carbon sequestration in the short-term. Due to the continuous water and nutrient supply, riparian forests are among the richest forest habitats when it comes to carbon as they store a large amount of carbon in the aboveground (leaves, branches, and stems) and belowground (roots) biomass.

As the LULUCF Regulation offers Member States the accommodation of their different national classification systems, countries consider riparian, fluvial and swamp forests as either forests or wetlands, depending on the systems and definitions each country uses. The compilation of data for these habitats into the LULUCF reporting at EU level is therefore difficult due to fact that MS use country specific definitions (EEA, 2020). Most of the EU countries do not differentiate between «wet forest» and forest, and when considered as forests, the stratification of these habitats is based on age, tree species or forest type (broadleaves or coniferous), degree of management, and type of soil (organic/inorganic).

These wet forests have accelerated but shorter sylvigenetic cycles, due to the natural recurrence of scouring floods. Indeed, riparian forests do not grow very old, unless they are disconnected from the river dynamics. This parameter, fundamental for wet forest function, has suffered major alterations in the past by river containment and flood regime control. Re-naturalising river flows and ensuring free-flowing rivers should be more present in the future due to the increased frequency of intense climatic events and the restoration of river continuity.

Therefore, from a climate change mitigation perspective, decisions and best practices to ensure a good condition of these habitats makes sense entailing reducing wood extractions from these habitats through sustainable management mechanisms in addition to their protection and restoration when needed. If well, conserved, these habitats have a dual benefit serving as biodiversity hubs due to their particular biota and as carbon sinks.

The restoration of riparian, fluvial and swamp forests is a valuable strategy for providing both rapid carbon sequestration capacity and long-term ecosystem services returns (Dybala et al., 2019). Best practices such as maintaining and restoring the groundwater and subsurface connections will ensure co-benefits for biodiversity by maintaining plant species richness and for climate mitigation.

For more details, please see Annex III- **Wetland type: Riparian, fluvial and swamp forests (focus on Forested wetlands).**

3.5.2.2 Coastal / Marine wetlands and lagoons

Coastal wetland and lagoon habitats cover 7% of the wetland habitats in Europe and include five classes according to the Corine Land Cover inventory: saltmarshes, salines, intertidal flats, coastal lagoons, and estuaries.

Marine waters belonging to Ramsar wetlands cover 15% of the wetland habitats in Europe and include marine waters less than 6 meters at low tide, river estuaries and estuarine waters of deltas.

Coastal wetlands encompass salt marshes, salines, intertidal flats, coastal lagoons, and estuaries while marine waters belonging to wetlands (as defined by Ramsar) include marine waters less than 6 meters at low tide, river estuaries and estuarine water and deltas. These wetland-related habitats are the ecologically sensitive interface between land and sea where seagrass beds are a common habitat that occurs abundantly. Due to their highest carbon sequestration capacities, the in-depth analysis of this section focused on salt marshes and seagrasses (for more details, check Annex III).

Salt marshes occur on the extreme upper shore of sheltered coasts and are periodically covered by high tides with vegetation developing on a variety of sandy and muddy sediment types. Salt marshes are widespread along all the coastlines of Europe and have a very high carbon sequestration capacity if their functional capacity is ensured. The carbon sequestered, stored in, or released by salt marshes (that normally host seagrass meadows) and known as Blue Carbon, places these wetland habitats among the most productive ecosystems in the world. Indeed, **they represent the globally most important coastal blue carbon storage sink and service benefitting both living and organic-rich soils** (Fourqurean et al., 2012). This is primarily due to the high capacity of seagrasses to trap particles by reducing water flow, wave energy and sediment resuspension (Fonseca and Cahalan, 1992; Gacia and Duarte, 2001; Gacia et al., 2002; Agawin and Duarte, 2002; Koch et al., 2006; Bos et al., 2007; Hendriks et al., 2008). Despite being a carbon sink, once these habitats lose their natural functional capacity due to anthropogenic impacts, salt marshes can become net emitters of methane.

Although the carbon stored in coastal wetlands was not considered directly in the Kyoto Protocol, the 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands (Wetlands Supplement)" provides new and supplementary guidance on estimating and reporting greenhouse gas emissions and removals from lands with organic soils and wet and drained mineral soils in Wetlands and all the other IPCC land-use categories with these soil types that are subject to human activities ('managed'). This supplement supports countries in reporting properly on GHG emissions and removals from all wetlands.

Tools for the accounting and crediting of carbon payments now exist for coastal wetland conservation, restoration and creation, under the voluntary carbon market (Macreadie et al., 2019). In fact, Australia was one of the first countries that voluntarily decided to include blue carbon ecosystems in its national greenhouse gas (GHG) accounts within the Australian Government's Emissions Reduction Fund (ERF) (Kelleway et al., 2017).

Blue carbon strategies build on the opportunity to avoid or mitigate GHG emissions through the conservation and restoration of blue carbon ecosystems (Nellemann et al., 2009; McLeod et al., 2011). Good practices to maintain and restore the natural function of coastal wetlands include the protection against erosion and the anthropogenic pressures generated in land towards the sea through better coastal management. Research has shown that tidal restoration in salt marshes will have greater potential for emission reductions per unit area as a climate change intervention than the creation of new salt marshes or rewetting of terrestrial peatlands to cease the high rate of CO_2 emissions from drained peatland soils (Kroeger et al., 2017). Additionally, the restoration of salinity conditions is important to maintain the methane emissions low (Camacho et al., 2017; Poffenbarger et al., 2011).

Protection, conservation and restoration of Blue Carbon ecosystems will facilitate the maintenance of the benefits they provide, including fisheries, coastal protection, and related ecosystem services that support coastal communities and their livelihoods (Duarte et al., 2013), while contributing to achieving the goal of keeping global warming under 2°C by 2050 (UNFCCC, 2016).

For more details, please see Annex III- **Wetland type: Coastal / Marine wetlands and lagoons (focus on salt marshes and seagrass)**.

3.5.2.3 Inland wetlands

*Inland wetland*s cover 26% of the wetland habitats in Europe and are predominantly water-logged specific plant and animal communities supporting water regulation and peat-related processes. This class includes to a major extent (89%) natural or modified peat bogs hosting mires, bogs and fens, as well as peat extraction sites and inland marshes (11%).

3.5.2.3.1 Peat bogs (mires, bogs and fens)

Peat bogs cover 89% of the inland wetland habitats in Europe with the water table at or above ground level for at least half of the year, dominated by herbaceous or ericoid vegetation which naturally accumulates layers of peat at the surface (Brar et al., 2013) and can include other ecosystem types like swamp and marsh (Bernal and Mitsch, 2012).

When in good condition, peat bogs and mires stock big amounts of carbon making peatlands climate coolers. As shown in Table 4, peatlands are not the wetland habitat type that has the highest rate of carbon sequestration, however the important role of healthy peatland habitats is linked to their high capacity to stock carbon for thousands of years, making them a long-term nature-based solution to the climate crisis. These habitats undergo a series of processes accumulating vegetation litter over thousands of years as peat because of the water saturated conditions. This later restricts the oxic decomposition processes hence promoting slow accumulation in anoxic conditions, converting a small share of the carbon to methane (CH_4).

Even so, peatlands are under high pressures in Europe. This is mainly due to unsustainable management and overexploitation of peat and bogs that alter their carbon flux and threaten their hydrology, leading to a bigger emission of carbon and warming up of the atmosphere (Loisel et al., 2014; Charman et al., 2013).

Climate reporting systems namely the United Nations Framework Convention on Climate Change, its Kyoto Protocol and Paris Agreement require Parties to report on anthropogenic emissions and removals of greenhouse gases which includes reporting peatland habitats only partially. Countries include only the managed peatlands in their inventories which predominantly are reported as carbon emitters. Changes in ecosystem functioning do transform many of them from climate 'coolers' (carbon net sinks) to 'heaters' (carbon net sources) (Harenda et al., 2018).

The management of mires, bogs and fens must shift towards their protection and restoration, dominantly through site specific rewetting mechanisms that are suitable to the local site conditions to ensure re-establishing their hydrological function. Rewetting peatlands has been identified as a cost-effective measure to curb emissions but re-establishes the emission of methane (CH_4) (Smith et al., 2014; Joosten et al., 2017). These restoration efforts would ensure: 1. reducing or avoiding carbon emissions, thus preserving the carbon they currently hold; and 2. rebuilding carbon stocks by recreating the processes that lead to carbon sequestration (Gonzalez et al., 2014; Wilson et al., 2016; Croon 2013).

For more detailed information on peatlands, check Annex III. Wetland type: Mires, bogs and fens (peatlands)

3.5.2.3.2 Inland marshes

Inland marshes are defined as low-lying land usually flooded in winter, and with grounds somehow saturated by freshwater all year round. This habitat type is characterized as non-forested areas with dominantly herbaceous vegetation that is liable to flooding by fresh running or stagnant water; and marsh vegetation located in margin zones of raised bogs. Compared to peat bogs, that cover most of the inland wetlands in Europe, inland marshes have a poor carbon sequestration potential and were therefore not prioritized for assessment in this study.

3.5.2.4 Rice fields

Rice fields cover 2% of wetland related habitats in Europe and are typically classified under croplands. They have been included in this assessment as a wetland habitat type.

Rice fields are defined as inundated or floodable fields used for the cultivation of rice (Oryza sativa). This wetland habitat type is considered a heavily managed wetland type that uses controlled flooding and drying of wetlands to produce rice. The management practices convert rice fields into net carbon emitters.

Rice cultivation is one of the biggest sources of GHG emissions in crop cultivation (Table 5). The emission is the net result of opposing bacterial processes: production in anaerobic microenvironments, and consumption and oxidation in aerobic microenvironments, both of which can be found side by side in flooded rice soils. Global scientific research in the last decade has proven that the water management practices and the level of fertilizer application in rice cultivation are directly linked to the emission of greenhouse gases mostly methane and nitrous oxide (Naser et al., 2020; Khosa et al., 2012; Bayer et al., 2014,2015; Zhang et al 2014). It is to note that references analysed refer to studies done outside the EU.

Nevertheless, when not too heavily treated, rice fields may provide substitution habitats for some wetland fauna particularly bird species including ducks, rails and herons, and could become carbon neutral if managed appropriately. Studies from outside Europe indicate that best management practice could neutralize this methane emission and turn rice fields to GhG neutrality. In fact, several environment-friendly agricultural management practices such as conservation tillage, rice seedling transplanting or direct line seeding, alternate wet and dry irrigation (AWDI), mid-season drainage, soil amendments with biochar, vermicompost, silicate slag and phospho-gypsum, site specific rice based cropping patterns and integrated plant nutrients system (IPNS) exist and should be applied to ensure food security, while mitigating greenhouse gas emissions and global warming potentials (Tarlera et al., 2016; Naser et al., 2020).

Recommendations for more sustainable management include:

- Ensuring more research on best practices to be implemented in the EU rice field plantations to develop a framework for more sustainable practices transferable across the EU.
- Setting rules and criteria to adequate management practices in the EU to reduce the impacts on the functional capacity of this habitat type, and to boost co-benefits by improving its biodiversity and carbon sequestration capacity because of reducing the intensity of current management practices (see previous section).

For more detailed information on rice fields, check Annex III. Wetland type: **Rice fields**

The remaining wetland types as classified in the extended wetland typology (Figure 6) are shortly described below though no in-depth assessments were implemented, namely:

- Wet grasslands and pastures cover 4% of wetland related habitats in Europe and are defined by EUNIS as humid grassland and tall herb communities. The scarce studies show that their carbon sequestration potential is quite high and comparable to the capacities of mires and fens.
- Wet heathlands cover 3% of wetland related habitats in Europe and are classified by EUNIS within the heathland, scrub and tundra category. They are defined as vegetation dominated by shrubs or dwarf shrubs of species that typically do not exceed 5 m maximum height. Wet heathlands are a heathland category that belongs ecologically to wetland habitats and is considered as such in this report following the Ramsar definition. As indicated in Table 5, no information on the level of carbon sequestration registered by these habitats was found in literature, being another knowledge gap identified in this study.
- Rivers and lakes include lakes, ponds, reservoirs, and water courses forming a network that links land to the sea. They cover 29% of the wetland-related habitats in the EU. Specifically, rivers are characterized

by running water (lotic habitats) whereas lake ecosystems are characterized by standing waters (lentic habitats). The interfaces between water bodies and their catchment, including riparian zones, floodplains, and lakeshores are also an important part of the freshwater ecosystem.

3.6 Potential carbon stock and sequestration capacity of European wetland habitats

This analysis shows that, despite the relatively small **coverage of wetlands** in Europe (around 8% EU and the UK land areas), if all major European wetland habitats assessed in this study are maintained healthy in the European Union, their carbon stock capacity is enormous. If kept in a good condition or restored, the EU wetland related **carbon stock capacity** of their overall area in Europe is estimated to be between 12 - 31 Gt CO_2-eq, corresponding to an overall **value ranging between 3 and 8 years of EU GHG emissions**. Moreover, the **carbon sequestration potential of healthy EU Wetlands per year** is calculated to range between 24,352 and 143,719 kt CO2 eq yr^{-1}, equivalent to **“neutralising” between 1 and 4 % of the total GHG emissions** registered in the EU27 and the UK (Table 6).

Despite the limited share of **coastal and marine wetland** habitat areas, covering **23% of the total wetland ecosystem** (Maes et al. 2020), their overall blue carbon stock and sequestration capacities are very high (Table 6). Well-functioning salt marshes and seagrass meadows for example store and sequester quantities of carbon per unit area comparable to terrestrial forests. Among the benefits to humans, coastal and marine wetlands have demonstrated their key role as nature-based solutions. They mitigate climate change impacts and ensure coastal resilience by reducing the risks of erosion and hosting a rich and fragile biodiversity that provides livelihoods and a high recreational value.

Inland wetlands including **healthy mires, bogs and fens** (i.e. when not drained), covering around **26%** of the share of wetlands **in Europe** (Maes et al. 2020) contribute largely to the overall European wetlands’ capacity to store carbon. The carbon stock capacity of these habitats when healthy in Europe is especially high particularly in the Boreal region (Table 6). Given the carbon role of these habitats and their capacity to mitigate climate impacts, these should be clear incentives to protect, sustainably manage and restore these ecosystems when degraded.

Riparian, fluvial and swamp forest habitats cover around **13% of EU´s wetland** share (Table 6) and their Good Environmental Status needs to be ensured by the WFD by limiting the exploitation of wet forests in Europe to maintain the capacity of these wet forests to act as a carbon sink contributing to the climate mitigation efforts in Europe.

Although uncertainties remain, the findings presented in Table 6 provide a rough estimate of the potential of European wetland habitats’ contribution to the EC’s agenda for a climate-neutral EU by 2050. However, and seeing the unfavourable trends observed over the past decades, to benefit from this potential, proper mechanisms need to be put in place to acknowledge the role of wetlands both at land and sea as Nature-based Solutions for Europe. For this, investments in a proper ecosystem understanding and management for the protection and conservation of healthy wetlands together with the restoration of those degrading need to be committed.

The remaining wetland types are important habitats for their function as connecting systems and for their high biodiversity values. These habitats, namely wet grasslands and pastures, wet heathlands and rice fields, are heavily managed systems that are exposed to high pressures and are underrepresented in protection measures.

Wetland classification		Biogeographical region	Area (km^2)*	Carbon stock (MgC ha^{-1})	Carbon sequestration rate (g C m^{-2} yr^{-1})	Carbon stock EU (Gt CO_2-eq)	Carbon sequestration EU (kt CO_2-eq yr^{-1}) Range [A]	Limitations /Uncertainty
Terrestrial wetlands	Riparian, fluvial and swamp forest	Rest of EU riparian forest	46,102	356± 35 to 474 ± 61 (2)	90–563 **	6.02 - 8.02	15,129 – 95,171	Low number of studies in Europe specific to riparian forests
	Riparian, fluvial and swamp forest	Mediterranean	4,077	122 to 201 (3)		0.18 - 0.30	1,338 – 8,417	
	Inland marshes	-	10,716	150 to 330(4)	173 ± 118	0.59 - 1.30	2,177 – 11,419	High variability of carbon stocks and carbon sequestration rates by the high influence of environmental conditions. Low numbers of studies
	Mires, bogs and fens	Boreal	53,381	186 to 883(4)	34 ±28	3.64 - 17.30	1,174 – 12,135	High variability of carbon stocks by the influence on environmental conditions. High number of studies
	Mires, bogs and fens	Rest of EU mires, bogs and fens	34,002	74 to 259(4)	57 ±34	0.92 - 3.23	2,867 – 11,345	
Coastal/Marine wetlands	Coastal wetlands and lagoons - Salt marshes	Rest of EU salt marshes	955	200 to 400(4)	282 ±99	0.28 - 0.57	641 – 1,334	High variability of carbon stocks and carbon sequestration rates by the high influence of environmental conditions. High numbers of studies
	Coastal wetlands and lagoons - Salt marshes	Mediterranean	1,664		166 ±83		506 – 1,519	
	Coastal wetlands and lagoons - Salt marshes	Atlantic	1,256		263 ± 151		516 – 1,907	
	Coastal wetlands and lagoons -Seagrass meadows (Zostera Marina)	Atlantic / Baltic	757(1)	141 ± 73 (4)	43 ±64***A	0.02 - 0.06	≈1 - 297	High variability of carbon stocks and carbon sequestration rates by the high influence of environmental conditions and species composition. High numbers of studies. Uncertainties on area covered by seagrass
	Coastal wetlands and lagoons -Seagrass meadows (Posidonia Oceanica)	Mediterranean	468 (1)	380 ± 38 (4)	52 ±50***A	0.06 - 0.07	3 - 175	
	Total					**11.73 - 30.85**	**24,352 – 143,719**	
	Sub-total Terrestrial wetlands					11.36 - 30.15	22,686 – 138,487	
	Sub-total Coastal/Marine wetlands					0.37 - 0.70	1,666 – 5,232	

*Area calculated from EEA extended wetland layer and Europe 2016 - The biogeographical regions dataset (https://www.eea.europa.eu/data-and-maps/data/biogeographical-regions-europe-3)
** Average value 176 g C m^{-2} yr^{-1}. The 25th (Q1) and 75th (Q3) quartiles, respectively 89.5–563
*** Net carbon accumulation
[A] minimum and maximum values of the range calculated by mean ± std
Conversion factor from carbon (C) to carbon dioxide (CO_2) 44/12 or 3.67
1 Mg C (megagram) = 10^6 g C
1 Gg (Gigagram) C = 10^9 g C = 1 kt C (kilotonne)
1 Gt = 10^9 Mg C = 10^{15} g C
(1) de los Santos, C.B., Krause-Jensen, D., Alcoverro, T. et al. Recent trend reversal for declining European seagrass meadows. Nat Commun 10, 3356 (2019). https://doi.org/10.1038/s41467-019-11340-4
(2) Cierjacks A, Kleinschmit B, Babinsky M, Kleinschroth F, Markert A, Menzel M, Ziechmann U, Schiller T, Graf M, Lang F. 2010. Carbon stocks of soil and vegetation on Danubian floodplains. Journal of Plant Nutrition and Soil Science 173: 644– 653. DOI: 10.1002/jpln.200900209
(3)Fernandes MR, Aguiar FC, Martins MJ, Rico N, Ferreira MT, Correia AC (2020) Carbon Stock Estimations in a Mediterranean Riparian Forest: A Case Study Combining Field Data and UAV Imagery. Forests.11(4) 376 https://doi.org/10.3390/f11040376
(4) Hendriks K, Susan Gubbay S, Arets E, Janssen J (2020) Carbon storage in European ecosystems; A quick scan for terrestrial and marine EUNIS habitat types. Wageningen, Wageningen Environmental Research, Internal Report. 66 pp.; 22 fig.; 22 tab.; 77 ref

Wetlands

Ecosystem types, threats and recommendations

Riparian, fluvial and swamp forests

Covering in Europe:
- Forested peatlands
- Freshwater, tree-dominated wetlands flooded forests

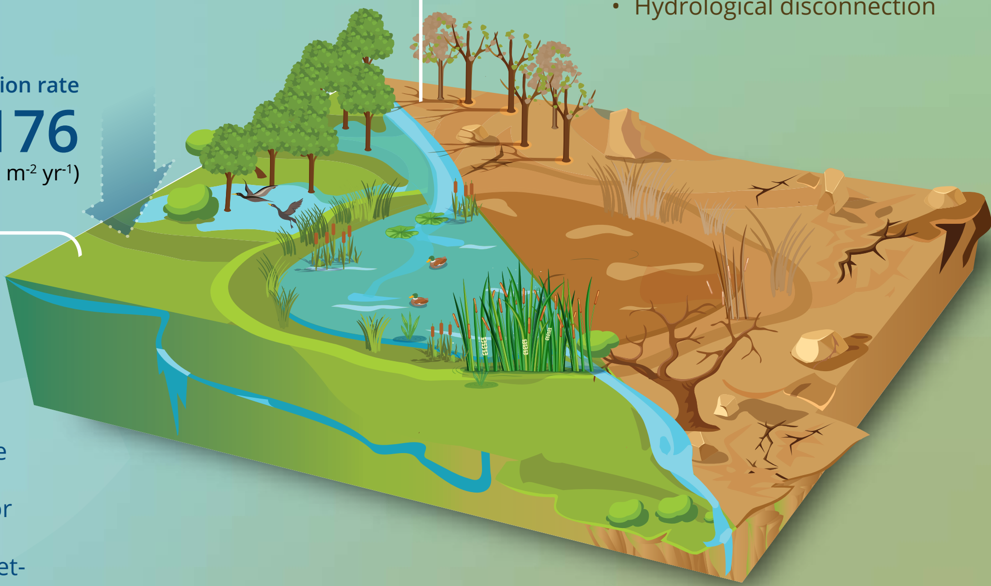
Threats

- Unsustainable management
- Deforestation
- Nitrogen deposition
- Alteration of groundwater flows
- Hydrological disconnection

Carbon sequestration rate

23 - 176

($g\ C\ m^{-2}\ yr^{-1}$)



Management options

- Limit harvesting and exploitation of these "low productivity" forests
- Regulate a strict protection framework for "wet forests" categories
- Restore "forested peatland" through rewetting practices

Coastal / Marine wetlands and lagoons

Covering:
- Salines, intertidal flats, coastal lagoons, and estuaries
- With presence of seagrass beds

Threats

Saltmarshes
- Modification of the tidal regime
- Run-off from agricultural, industrial and urban development
- Sea level rise

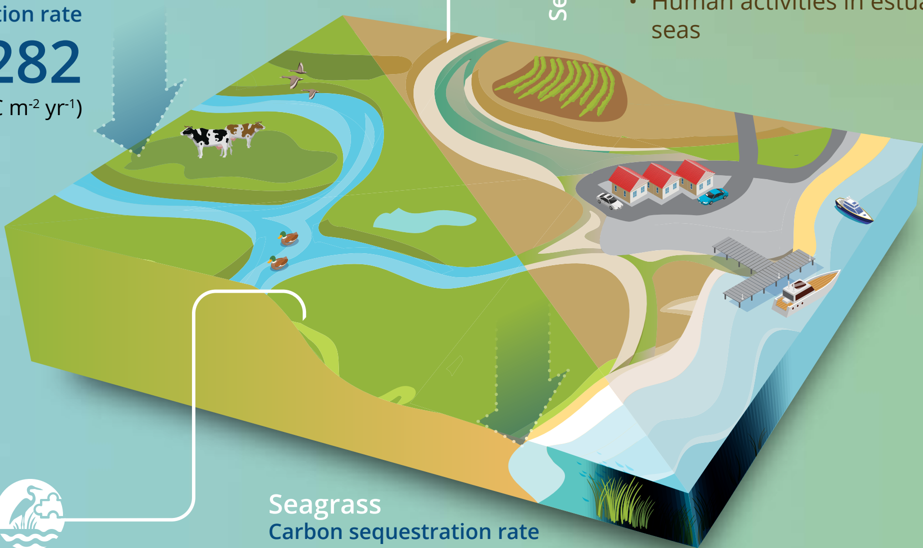
Seagrass
- Run-off from agricultural, industrial and urban regions
- Human activities in estuaries and seas

Saltmarshes

Carbon sequestration rate

166 – 282

($g\ C\ m^{-2}\ yr^{-1}$)



Management options

Saltmarshes
- Protection from erosion
- Tidal restoration
- Maintainance of high salinity levels

Seagrass
- Habitat restoration
- Sustainable coastal management

Seagrass

Carbon sequestration rate

43 - 52

($g\ C\ m^{-2}\ yr^{-1}$)

Wetlands

Ecosystem types, threats and recommendations

Mires, bogs and fens

- Wetlands with a vegetation which usually forms peat
- Have their water table at or above ground level for at least half of the year

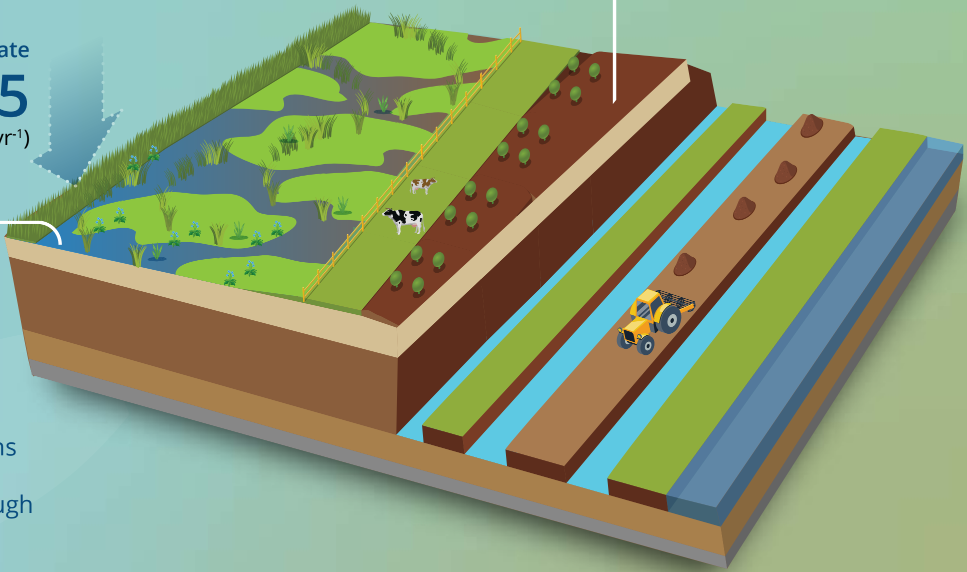
Threats

- Drainage for agriculture and forestry
- Exploitation as domestic fuel source

Carbon sequestration rate

7 - 75

(g C m^{-2} yr^{-1})



Management options

- Restoration of the hydrological conditions of degraded habitats
- Ensuring sustainable management through rewetting and raising of the water table

Rice fields

- Inundated or floodable fields
- Heavily managed wetlands used for rice cultivation

Threats

- Intensification in water management practices
- Increase in levels of fertilisation

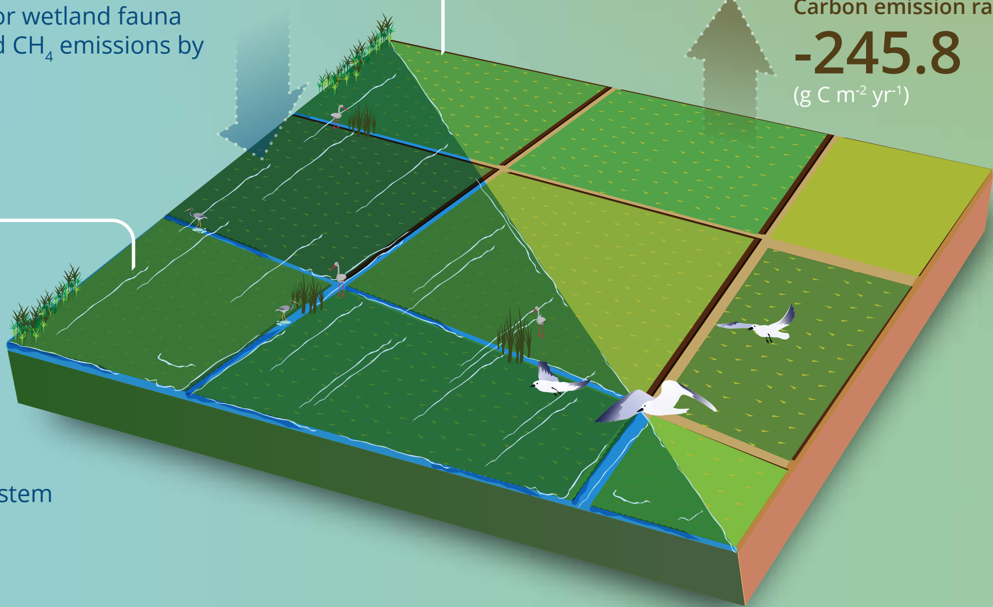
Environmentally friendly practices

- Provide habitat for wetland fauna
- Ensure decreased CH_4 emissions by 48–93%

Carbon emission rate

-245.8

(g C m^{-2} yr^{-1})



Management options

- Implement integrated plant nutrients system
- Alternate dry and wet irrigation cycles

4 Conclusions

Available knowledge

Despite their small share of European land area (8%) assimilated to wetlands, if kept in a good condition or restored, the potential overall carbon stock capacity of the areas covered by major wetland habitat types in Europe is estimated to be between 12 and 31 Gt CO_2-eq. The latter corresponds to an overall value ranging between 3 and 8 years of EU GHG emissions in the EU27 and the UK making wetland conservation and restoration a high priority to be used as nature-based solutions to climate and biodiversity crises that Europe is facing.

Evidence presented in this report shows that these carbon stock potentials are attained when wetland habitats are in a good condition enabling their correct functioning hence their capacity to store and sequester carbon. The most meaningful European wetland habitats to contribute to carbon storage include well-functioning salt marshes, healthy mires, bogs and fens as well as riparian, fluvial and swamp forests whereas wetlands carbon sequestration potential is to a big extent ensured by terrestrial wetlands namely by mires, bogs and fens (where peatlands underly), followed by European riparian, fluvial and swamp forests as well as inland marshes.

On the other hand, research outcomes reveal that heavily managed wetland linked habitats such rice cultivation, drained peatlands, among others, become net carbon emitters and are hence at the core of GHG emissions inventories because of their high degradation and unsustainable management practices that hampers their functional capacity.

Nevertheless, to date, knowledge gaps still exist in understanding the potential of certain wetland-related habitats to sequester carbon because of their poor definition in European systems; namely there is a clear lack of information on the role of wet heathlands in the carbon cycle and its potential to store and sequester carbon, calling for more research needs in that field.

Sustainable practices

The findings collected in this report confirm the importance of ensuring a good conservation status of wetlands to safeguard their climate-mitigating capacity. Shifting schemes of heavily managed wetland habitats into more sustainable practices has proven effectiveness in transforming these systems to mitigate the risk of avoidable contributions to climate change.

Improvements in the condition of heavily managed wetland habitats, through restoration, has proven to bend the curve of carbon emissions converting heavily degraded wetland habitats from net emitters into net carbon stocks (as in the case of peatlands) or to carbon neutral systems (as in the case of unsustainably managed rice fields).

Restoring peatlands by raising the water table and re-saturating soils to reverse the effects of drainage is an effective means to decrease CO_2 emissions and preserve existing carbon stocks. In this type of restoration effort, there are two primary goals: 1. to reduce or avoid carbon emissions, thus preserving the carbon they currently hold; and 2. to rebuild carbon stocks by recreating the processes that lead to carbon sequestration. In terms of GHG management, the maintenance of large stores of C in undisturbed peatlands should be a priority.

In the case of rice fields, shifts into more sustainable management schemes to environment-friendly agricultural management practices include conservation tillage, alternate wet and dry irrigation (AWDI), mid-season drainage, and site-specific rice-based cropping patterns among others. These practices, if followed, would increase biodiversity richness in these areas while maintaining food production as well as mitigating greenhouse gas emissions and global warming potentials.

Depending on which habitat, its sensitivity and its condition, the right tools to ensure a good environmental status need to be identified and applied. This involves actions and decisions affecting the transfer of best practices in management, the protection of under-represented wetland habitats and the implementation of restoration measures depending on the situation in question. To mention some examples, rice-fields need to be better managed whereas riparian forests, wet grasslands and wet heaths need further protection and restoration measures. The implementation of adequate actions in regional restoration plans will bring co-benefits as they can improve the dire status of wetland habitats and the biodiversity they host, guarantee the continuity of the ecosystem services provided and support the EU efforts to reach climate neutrality by 2050.

Prioritization in decisions

Within the EU Green Deal, ecosystem conservation and restoration are clear targets for both climate change mitigation and adaptation and the reduction of biodiversity loss. Our results demonstrate that increasing carbon stock and sequestration potentials must be considered a strong co-benefit of wetland habitat restoration, and that increasing the pace and scale of wetland restoration is a valuable investment providing both immediate carbon sequestration value and long-term carbon storage among several other ecosystem service returns in the EU.

Referring to wetland ecosystem restoration, recent research findings confirm that widescale restoration of seasonal, semi-permanent, and permanent wetlands could help progressively sequester carbon. This nevertheless requires the implementation of long-term restoration actions, of half a century or more, and would ensure prolonged below ground and above ground carbon stocks.

Considering peatland restoration efforts, solutions to limit methane emissions from rewetting practices prove to be feasible through post-controlling measures linked to the effect of biomass harvesting on CH_4 fluxes at local scale. Therefore, management decisions should include the development of nationally specific emission factors that address vegetation composition, being widely lacking at present.

Decisions to effectively conserve and restore wetland ecosystems nevertheless require political will, prioritization in nature-based investments, long-term planning, and firm execution.

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Annex I. List of habitats in Annex 1 of the Habitats Directive associated to wetland ecosystems (61 habitat types)

Code	Description
1110	Sandbanks which are slightly covered by sea water all the time
1120	Posidonia beds (Posidonia oceanica)
1130	Estuaries
1140	Mudflats and sandflats not covered by seawater at low tide
1150	Coastal lagoons
1160	Large shallow inlets and bays
1170	Reefs
1310	Salicornia and other annuals colonizing mud and sand
1320	Spartina swards (Spartinion maritimae)
1330	Atlantic salt meadows (Glauco-Puccinellietalia maritimae)
1340	Inland salt meadows
1410	Mediterranean salt meadows (Juncetalia maritimi)
1510	Mediterranean salt steppes (Limonietalia)
1530	Pannonic salt steppes and salt marshes
1630	Boreal Baltic coastal meadows
1650	Boreal Baltic narrow inlets
2170	Dunes with Salix repens ssp. argentea (Salicion arenariae)
2190	Humid dune slacks
3110	Oligotrophic waters containing very few minerals of sandy plains (Littorelletalia uniflorae)
3120	Oligotrophic waters containing very few minerals generally on sandy soils of the West Mediterranean, with Isoetes spp.
3130	Oligotrophic to mesotrophic standing waters with vegetation of the Littorelletea uniflorae and/or of the Isoëto-Nanojuncetea
3140	Hard oligo-mesotrophic waters with benthic vegetation of Chara spp.
3150	Natural eutrophic lakes with Magnopotamion or Hydrocharition - type vegetation
3160	Natural dystrophic lakes and ponds
3170	Mediterranean temporary ponds
3180	Turloughs

3190	Lakes of gypsum karst
31A0	Transylvanian hot-spring lotus beds
3210	Fennoscandian natural rivers
3220	Alpine rivers and the herbaceous vegetation along their banks
3230	Alpine rivers and their ligneous vegetation with Myricaria germanica
3240	Alpine rivers and their ligneous vegetation with Salix elaeagnos
3250	Constantly flowing Mediterranean rivers with Glaucium flavum
3260	Water courses of plain to montane levels with the Ranunculion fluitantis and Callitricho-Batrachion vegetation
3270	Rivers with muddy banks with Chenopodion rubri p.p. and Bidention p.p. vegetation
3280	Constantly flowing Mediterranean rivers with Paspalo-Agrostidion species and hanging curtains of Salix and Populus alba
3290	Intermittently flowing Mediterranean rivers of the Paspalo-Agrostidion
4010	Northern Atlantic wet heaths with Erica tetralix
4020	Temperate Atlantic wet heaths with Erica ciliaris and Erica tetralix
6410	Molinia meadows on calcareous, peaty or clayey-silt-laden soils (Molinion caeruleae)
6420	Mediterranean tall humid grasslands of the Molinio-Holoschoenion
6430	Hydrophilous tall herb fringe communities of plains and of the montane to alpine levels
6440	Alluvial meadows of river valleys of the Cnidion dubii
6450	Northern boreal alluvial meadows
6460	Peat grasslands of Troodos
7110	Active raised bogs
7120	Degraded raised bogs still capable of natural regeneration
7130	Blanket bogs (* if active bog)
7140	Transition mires and quaking bogs
7150	Depressions on peat substrates of the Rhynchosporion
7160	Fennoscandian mineral-rich springs and springfens
7210	Calcareous fens with Cladium mariscus and species of the Caricion davallianae
7220	Petrifying springs with tufa formation (Cratoneurion)
7230	Alkaline fens
7240	Alpine pioneer formations of Caricion bicoloris-atrofuscae
7310	Aapa mires
7320	Palsa mires
91D0	Bog woodland
91E0	Alluvial forests with Alnus glutinosa and Fraxinus excelsior (Alno-Padion, Alnion incanae, Salicion albae)
91F0	Riparian mixed forests of Quercus robur, Ulmus laevis and Ulmus minor, Fraxinus excelsior or Fraxinus angustifolia, along the great rivers (Ulmenion minoris)
92B0	Riparian formations on intermittent Mediterranean water courses with Rhododendron ponticum, Salix and others

Annex II. Definitions of lands representing wetlands, in the national inventory reports*

* Definitions of lands included under the category 4D, representing wetlands, in the national inventory reports (NIR) of EU 27 and the UK (EEA 2020[9]).

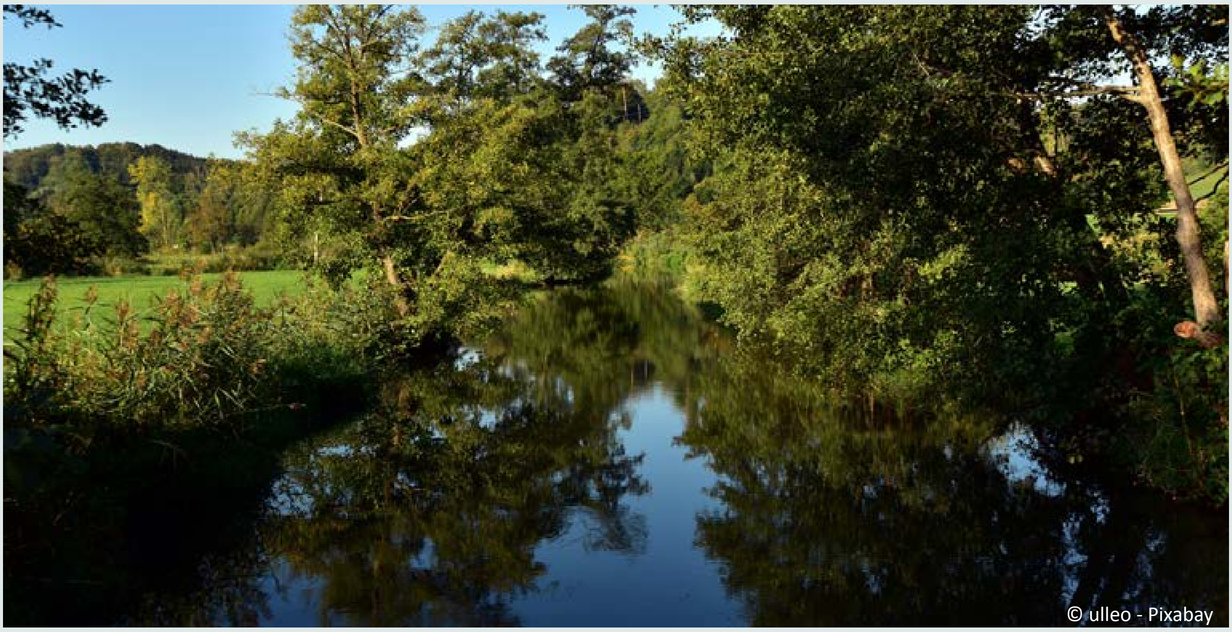
Country	Definition
Austria	Rivers, lakes, mires and peat areas (protected areas, in general) as classified by national statistical system.
Belgium	Land covered or saturated by water for all or part of the year (e.g. peatland) and that does not fall into the other land category. It includes reservoirs as a managed subdivision and natural rivers and lakes as unmanaged subdivisions.
Bulgaria	Wetlands category - wetlands surface water areas are included (wetlands) – covered with water or water saturated lands (throughout the year or partially in the year) which does not fall in the other categories. These are natural or artificial water-courses serving as water drainage channels, natural or artificial stretches of water, coastal lagoons, wetlands areas and peat bogs.
Croatia	Inland marshes, salt marshes, salines, intertidal flats, water courses, water bodies, coastal lagoons
Cyprus	This category contains areas of land that is covered or saturated by water for all or part of the year and that does not fall into the Forest Land, Cropland, Grassland or Settlements categories. In particular, it contains inland and salt marshes, water courses and water bodies.
Czech Republic	Category Wetlands includes riverbeds, and water reservoirs such as lakes and ponds, wetlands and swamps.
Denmark	Permanent wetlands, wetlands for peat extraction and re-established anthropogenic wetlands. Several subdivisions may be distinguished: unmanaged fully water covered wetlands (lakes and rivers); unmanaged partly water covered wetlands (fens and bogs); managed drained land for peat extraction; managed partly water covered wetlands (re-established wetlands on primarily former cropland and grassland).
Estonia	Land permanently saturated by water and/or areas where the peat layer is at least 30 cm and the minimum potential tree height does not conform to the forest land definition. It does include smaller bog holes.
Finland	Inland waters (reservoirs, natural lakes and rivers), peat extraction areas and peatlands which do not fulfil the definition of other land uses.
Germany	Reporting in the wetlands category primarily covers emissions from organic soils that are released during peat extraction, covering: CO_2 losses from extraction areas, and during extraction and spreading of peat. Also, it includes (but they are not estimated) the few non-drained semi-natural bogs that have been largely free of anthropogenic impacts, flooded lands, water-storage facilities (dams, reservoirs, etc.) and settling basins that are used for energy production, irrigation, shipping and recreation, and that are flooded or drained, or that otherwise have large water-level fluctuations.
Greece	Land that is covered or saturated by water for all or the greatest part of the year (e.g. lakes, reservoirs, marshes), river bed (including torrent beds) and that does not fall into the forest land, cropland, grassland or settlements categories.

9 EEA 2020 Annual European Union greenhouse gas inventory 1990–2018 and inventory report 2020 Submission to the UNFCCC Secretariat, May 2020. Available at: https://www.eea.europa.eu/publications/european-union-greenhouse-gas-inventory-2020

France	Lands covered or saturated by water all year long or part of it.
Hungary	Wetland includes the wetlands and water bodies as defined by the CORINE land-cover databases and contain inland marshes (low-lying land usually flooded in winter, and more or less saturated by water all year round), peat bogs (peat land consisting mainly decomposed moss and vegetable matter), water courses (natural or artificial water-courses including those serving as water drainage) and water bodies (natural or artificial lakes, ponds etc.).
Ireland	Natural unexploited wetlands and areas commercially exploited for public and private extraction of peat and areas used for domestic harvesting of peat.
Italy	Lands covered or saturated by water, for all or part of the year, have been included in this category (MAMB, 1992). Reservoirs or water bodies regulated by human activities have not been considered.
Latvia	Wetlands category includes all inland water bodies (rivers, ponds, and lakes), swamps (constantly wet areas where height of trees cannot reach more than 5 m in height and ground vegetation consists mostly of sphagnum and different sword grasses), flood-lands (small areas) and alluvial lands (larger flood-lands).
Lithuania	Wetlands include peat extraction areas and peat lands which do not fulfil the definition of other categories. Water bodies and swamps (bogs) are also included under this category. Peat extraction areas are considered as managed land.
Luxemburg	Land that is covered or saturated by water for all or part of the year (e.g. peat land, reservoirs) and that does not fall into other categories.
Malta	In the Maltese islands wetlands are mostly saline.
Netherlands	Land covered or saturated with water for all or part of the year and does not fall into the other land category. It includes reservoirs as a managed sub-division and natural lakes and rivers as unmanaged, including natural open water in rivers, but also man-made open water in channels, ditches and artificial lakes.
Poland	Wetland consists of: marine internal; surface flowing waters, which covers land under waters flowing in rivers, mountain streams, channels, and other water courses, permanently or seasonally and their sources as well as land under lakes and artificial water reservoirs. from or to which the water course flow; land under surface lentic water which covers land under water in lakes and reservoirs other than those described above, land under ponds including water reservoirs (excluding lakes and dam reservoirs for water level adjustment) including ditches and areas adjacent and related to ponds; land under ditches including open ditches acting as land improvement facilities for land used.
Portugal	Inland wetlands, coastal wetlands, salt marshes, saline and intertidal flats.
Romania	Wetlands includes all lands covered by water (rivers, ponds, dams, swimming pools, etc.) and land affected by humidity (caused by water stagnation, marshy areas, etc.), with the exception of agricultural land. It contains two sections (waters and wetlands) and 11 categories (permanent streams, temporary streams, lakes, dams, floating vegetation, hydrophilic vegetation (stubble etc.), harbours, temporarily flooded areas, bogs, channels and piers.
Slovakia	The wetlands include artificial reservoirs and dam lakes, natural lakes, rivers and swamps.
Slovenia	Wetlands are defined as land that is temporarily or permanently saturated by water. Wetlands include lands such as fens, marshes, bogs and reeds and are not under agricultural use. Inland water bodies (major rivers, lakes and water reservoirs) are also part of Wetlands. Although there are small areas of raised bogs, all Wetlands are assumed managed.
Spain	Includes the lands covered or saturated by water all year long or part of it.
Sweden	Wetlands is assumed unmanaged (mires and areas saturated by fresh water) and managed (cca 10 000 ha used for peat extraction).
United Kingdom	Includes reservoirs and peat extraction sites currently registered for commercial extraction where extraction activity is visible on recent aerial/satellite photographs or by field visits. The areas of inland water exceeding 1km2 are included also in this category.

Wetland habitats factsheet

Riparian, fluvial and swamp forests (focus on Forested wetlands)



Under this category, Riparian, fluvial and swamp ecosystems are included. Concretely, in Europe, it covers:

- Forested peatlands, which main characteristic is the present a peat layer; and
- Freshwater, tree-dominated wetlands flooded forests that are either permanently or seasonally inundated with freshwater.

In Europe, forested wetlands cover 50,179 Km^2 (13% of wetland area) distributed along all Europe. However, swamp ecosystems are mainly circumscribed to sub-Atlantic, Boreal, Artic, and sub-Artic regions since the formation of peat layers need specific climatic and hydrological context.

Classification

- Ramsar classification: Forested peatlands (Xp) and Freshwater, tree-dominated wetlands (Xf)
- Corine land Cover: class 3.1 - Forest
- MAES - Ecosystem types: Forest and woodlands
- Directive habitat / Annex I: 92B0, 92A0, 91, 92C0, 91F0, 91, 9080, 91D0, 91D0, 91D0, 9030
- EUNIS: G1.1, G1.2, G1.3, G1.4, G1.5, G3.D, G3.E, G4.1.

Role in Carbon flux

The importance of forests for sequestering carbon is indisputable. This ecosystem performs a key role as CO_2 sinks and can help mitigate the effects of climate change.

Forested wetlands present two key characteristics, due to their wetland / forest duality, which make these ecosystems very interesting from the point of view of the carbon sequestration services.

Their role in the carbon cycle differs between swamp forest and riparian/fluvial forests.

Forested peatlands present as main characteristic, in relation to carbon, the presence of a peat layer, which is defined as a peatland. Therefore, all the aspects associated with this wetland type, in relation to the carbon sequestration ecosystem service, are like mires, bog and fens. Moreover, under similar climatic and environmental conditions, these wetland habitats present relatively higher carbon sequestration rates since they are dominated by trees and then, above-ground biomass is usually higher than mires, bogs and fens (Turunen et al., 2002).

Riparian and fluvial forests usually have favourable growing conditions (e.g., soil moisture), and may accumulate carbon stocks at a greater rate than upland forests contributing more to rapid carbon sequestration in the short-term (Matzek et al., 2018; Naiman et al., 2010). Due to continuous water and nutrient supply, temperate moist (riparian) forests are among the most productive forest ecosystems. They store a large amount of carbon in the aboveground (leaves, branches, and stems) and belowground (roots) biomass. Additionality, the productivity of riparian forest ecosystems is highly dependent on the flood tolerance of the tree species, sedimentation rates, groundwater and soil moisture availability supplied by inland river water flow (Dybala et al., 2019).

C sequestration range. C seq rate (g C m^{-2} yr^{-1})

N. of measures: 31

Average value: Due to the important differences in term of influence on carbon balance between forest, this assessment shows disaggregated measures:

- Forested mires (Boreal/artic regions): 23.06 ± 4.3
- Pine bog (Boreal/artic regions): 25 ± 7.28
- Riparian / fluvial forests (Freshwater tree-dominated): 176 (89.5–563.3)*

* The 25th (Q1) and 75th (Q3) quartiles. Standard deviation is not known.

References: Turunen et al., 2002; Matzek et al., 2018.

Uncertainty assessment

Uncertainty scale according to the number of studies found, the representativeness and the consistency between the results.

- Red: high uncertainty
- Yellow: moderate uncertainty
- Green: low uncertainty

Status in GHG inventories / LULUCF reporting

The land use, land use change and forestry (LULUCF) Regulation 2018/8411 comprises one of the pillars for achieving the target of the Paris Agreement and the EU 2030 climate and energy policy framework. This Regulation includes mandatorily the inclusion of managed wetlands among the land accounting categories (for the second period 2026 - 2030) that were not previously included as mandatory compared to the LULUCF Decision (Decision 529/2013/EU, European Commission 2013) and the commitments under Kyoto Protocol for Annex I Parties (UNFCCC, 2018).

The IPCC Guidelines set a general frame to define broadly the land-use categories offering to countries the accommodation of their different national classification systems. This leads to a heterogeneity in the types of ecosystems that each country classifies under each land category. In this case two main categories are involved, forests and wetlands, being forest a priority class in the LULUCF hierarchical system.

Then, if these ecosystems are compiled with the LULUCF national definitions for forest land category (in terms of thresholds for patch size, cover density, etc.), these areas are inventoried as forest land instead of wetlands (EEA, 2020). Forest swamp are stratified as forest land/organic soil. Most of the EU countries do not differ between «wet forest» and forest, the stratification is based on age, tree species or forest type (broadleaves or coniferous), degree of management and type o soil (organic/inorganic).

Main threats for altering its role in C flux

Forested wetland is affected for most of the anthropic activities that impact forest ecosystem condition: unsustainable management, deforestation, nitrogen deposition, etc.

Additionally, the hydrological regime, concretely the groundwater regime, is one of the most relevant variables in the C sequestration pattern in forested wetlands since it plays an important role for all the carbon pools (litterfall, fine roots and aboveground biomass) (Rieger et al., 2015).

The alteration of groundwater flows is a major threat in the Mediterranean and semiarid regions intensified by water pumping. Threats exist in other European regions as well where hydrological disconnection also occurs due to direct modification of stream channels and riparian zones. Bank stabilization, riprapping, and lining of channels have similar consequences leading to lowered water tables and restricting water availability in shallow riparian soils (Perry et al., 2012).

Recommendation for management

Mitigating climate change refers to reducing sources or enhancing the sinks of greenhouse gases. Forests can be managed to support both alternatives. Exploitation of forests needs to ensure the implementation of sustainable harvesting means of wet forests in Europe without affecting their drainage status and without damaging tree roots. in Europe. Such good practice is implemented in certain areas and ensures maintaining the capacity of wet forests to act as a carbon sink.

The EU WFD (2000/60/EC) tends to adopt a holistic approach favouring the functionality of aquatic habitats as well as maintaining water quality in a good status. The full application of the WFD, with the achievement of «good ecological status» should contribute to restoring the natural conditions of riparian zones.

Recommendation for habitat restoration for carbon sequestration purposes

Riparian ecosystems have been degraded worldwide. Riparian forest restoration is a valuable strategy for providing both rapid carbon sequestration capacity and long-term ecosystem services returns (Dybala et al., 2005). Practices as bank stabilization, riprapping, and lining of channels have consequents and, importantly, result in lowered water tables, restricting water availability in shallow riparian soils (Groffmand et al., 2003). Best practices to maintain/restore the groundwater and subsurface connections are relevant to maintaining plant species richness and the carbon sequestration rates.

Regarding the forested peatlands, the trade-off is peat extraction, as any peatland, and harvesting vs protection. The wet swamp forests have large soil carbon stores that will continue to grow if the forests are not harvested. They present low-productivity for harvesting wood to substitute fossil carbon. From a climate change mitigation perspective, it is reasonable to put more emphasis on harvesting of forests on well¬-drained soils, which are more suitable for harvesting wood to substitute fossil carbon, and as well as the protection of forests on poorly drained soils due to their carbon soil stocks.

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Wetland habitats factsheet

Coastal / Marine wetlands and lagoons (focus on salt marshes and seagrass)


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Coastal / marine wetlands and lagoons encompass saltmarshes, salines, intertidal flats, coastal lagoons, and estuaries where seagrass beds occur abundantly and are relevant to be included in this study.

Coastal saltmarshes occur on the extreme upper shore of sheltered coasts and periodically covered by high tides. The vegetation develops on a variety of sandy and muddy sediment types and may have mixtures of coarser material. The character of the saltmarsh communities is affected by height up the shore, resulting in a zonation pattern related to the degree or frequency of immersion in seawater. This class includes salt marshes, salt meadows, salines, raised salt marshes; includes tidal brackish and freshwater marshes. Saltmarshes are widespread around all the coastlines of Europe, covering 3,875 Km^2 (1.02% of wetland area) according to the extended wetland layer. Largest areas of European saltmarsh are on the Atlantic and North Sea coasts, particularly in the many estuaries around the coast of Great

Britain and the international Wadden Sea (Netherlands, Germany and Denmark). Large saltmarshes also occur in parts of the Mediterranean Sea, notably in southern France and on the Adriatic and Ligurian coasts of northern Italy (Davidson, 2016).

Four species of seagrass are found in the European seas: Neptune grass (*Posidonia oceanica*), seahorse grass (*Cymodocea nodosa*), eelgrass (*Zostera marina*) and dwarf eelgrass (*Zostera noltii*).

Carbon stored in coastal vegetation (blue carbon) represents the globally most important coastal blue carbon storage sink and service benefit in both living and organic-reach soils (Fourqurean et al., 2012). The seagrass meadows are relevant in the carbon flux for the carbon sequestration and carbon burial rates. Accretion rates of carbon vary from site to site due to currents, growth rates and wave exposure. Carbon burial rates also vary between species of seagrass and the dominant species of seagrass is different in each European sea region.

Classification

Saltmarshes

- Ramsar classification: Intertidal marshes (H)
- Corine land Cover: class 4.2.1 Saltmarshes
- MAES - Ecosystem types: Marine inlets and transitional waters
- Directive habitat / Annex I: 1330, 1630, 1420, 1310, 1320, 2190
- EUNIS: A2.5, A2.6, A2.7, A2.8, A2.9, B1.8

Seagrasses

- Ramsar classification: Permanent shallow marine waters (A), Marine subtidal aquatic beds (B); Estuarine waters (F); Intertidal mud, sand or salt flats (G).
- Corine land Cover: class 5.2 Marine waters
- MAES - Ecosystem types: Marine inlets and transitional waters
- Directive habitat / Annex I: 1110, 1130, 1140, 1150, 1160
- EUNIS: A2.6, A5.5

Role in Carbon flux

Carbon sequestered and stored in or released from coastal wetlands is often referred to as coastal “blue carbon.” (Nellemann et al., 2009).

Salt marshes are among the most productive ecosystems in the world—rivalling that of intensively cultivated agriculture (Odum, 1971). Salt marshes appear to be highly efficient in carbon burial, links to the amounts of dissolved and particulate organic matter (OM) that receive from rivers and estuaries but also to the salt marsh plants (halophytes) that are characterized by, among other things, being extremely productive (Rathore AP et al., 2016).

Therefore, coastal wetlands in general, despite storing large amounts of OM, can be sources of other greenhouse gases (GHG), such as methane (CH_4) and nitrous oxide (N_2O), to the atmosphere (Whalen, 2005; Abril and Borges, 2004). However, the CH_4 emissions are almost negligible due to sulphate inhibition of methanogenesis (Poffenbarger, et al., 2011). Then, saltmarshes are capable of sequestering large amounts of C despite a reduction in the net C sequestration benefit due to the production of CH_4 and N_2O (Adams et al., 2012).

The general behaviour is as carbon sink although (Chmura et al., 2003; Mcleod et al., 2011; Morant et al., 2020; Brix et al., 2001), as all wetland habitats, the C exchange is highly influenced by the anthropogenic impacts that affect the natural functioning of wetlands, being in this case especially relevant due to the role on the methane emission (Turetsky et al., 2014; Bernal and Mitsch, 2012).

Globally, seagrasses are estimated to store as much as 19.9 Pg in organic carbon (Fourqurean et al., 2012). Despite the limited areal extent of seagrass meadows, their contribution to carbon accumulation per unit area is up to three orders of magnitude higher than that of terrestrial soils, primarily due to the high capacity of seagrasses to trap particles by reducing water flow, wave energy and sediment resuspension (Fonseca and Cahalan, 1992; Gacia et al., 2002; Agawin and Duarte, 2002; Gacia and Duarte, 2001; Bos et al., 2007; Koch et al., 2006; Hendriks et al., 2008).

C sequestration range. C seq rate (g C m^{-2} yr^{-1})

Saltmarshes

N. of measures: 16

Average values:
- Global: 282 ± 99
- Mediterranean: 166 ± 83
- Atlantic: 263 ± 151.31

References: Ouyang and Lee 2014; Chmura et al., 2003; Adams et al., 2012; Morant et al., 2020; Morris et al., 2013; McLeod et al., 2011; Brix et al., 2001; Beaumont et al., 2014.

Uncertainty assessment

Uncertainty scale according to the number of studies found, the representativeness and the consistency between the results.

- Red: high uncertainty
- Yellow: moderate uncertainty
- Green: low uncertainty

Seagrass

N. of measures: 34 (Net carbon accumulation)
Average values:
- Atlantic (*Zostera Marina*): 43 ±64
- Mediterranean (*Posidonia Oceanica*): 52 ±50

References: Jankowska et al., 2016; Novak et al., 2020; Mateo and Serrano, 2012; Serrano et at., 2016; Gacia et al., 2002, Mazarrasa et al., 2017; Mateo et al., 1997, 2006; Cebrian et al., 1997. Uncertainty assessment

Status in GHG inventories / LULUCF reporting

The land use, land use change and forestry (LULUCF) Regulation 2018/8411 comprises one of the pillars for achieving the target of the Paris Agreement and the EU 2030 climate and energy policy framework. This Regulation includes as mandatory land accounting categories the managed wetlands (for second five year period 2026 - 2030) that were not previously included as mandatory under the LULUCF Decision (Decision 529/2013/EU, European Commission 2013) and the commitments under Kyoto Protocol for Annex I Parties (UNFCCC, 2018).

The IPCC Guidelines set a general frame to define broadly the land-use categories offering to countries the accommodation of their different national classification systems. This leads to a heterogeneity in the types of ecosystems that each country classifies under the wetlands in terms of area reported under the LULUCF categories. In the case of saltmarshes, these habitats are only specifically included by Bulgaria, Croatia, Poland and Portugal although can be assumed in other countries which wetland definition covers "the lands covered or saturated by water all year long or part of it". Concerning seagrass, it is not specifically included in the national definitions.

However, in terms of the GHG emission and removals accounts, only the managed wetlands are included in the GHG inventory, not being mandatory up to second period of EU regulation 2018/841. This means that most of the saltmarsh are currently excluded from national GHG inventories since according to the reporting information by MS NIRs, less than 30% of land reported as wetlands are managed, being peatlands the most extended wetland type (EEA, 2020).

Apart of LULUCF sectors, but in line with Climate Change commitments, in 2013, the Intergovernmental Panel on Climate Change (IPCC) provided methodological guidance for estimating emissions and removals from mangrove, seagrass and tidal salt marsh ecosystems. These guidelines are intended to support countries improve reporting.

The inclusion of wetlands in the national inventory enables quantification of how mitigation initiatives (e.g., avoiding loss or degradation of wetlands and/or the restoration or creation of wetland habitat) may contribute to country meeting its international GHG commitments.

Main threats for altering its role in C flux

Although saltmarshes are covered by multiple international and national nature conservation designations (Ramsar sites, Biosphere Reserves, declared under the UNESCO Man and Biosphere Programme, etc.), their conservation status is dominantly rated as unfavourable (Davidson 2016).

The role of coastal wetlands in carbon flows and climate change mitigation is majority influenced by the key environmental factors: salinity y trophic status. The eutrophication threats the net carbon sequestration capacity of saltmarsh. Recent studies indicate that the nitrate, a common pollutant of coastal waters, stimulates the decomposition of organic matter in saltmarsh sediments that normally would have remained stable over long periods of time. This increase in decomposition, which releases CO_2, could alter the capacity of salt marshes to sequester carbon over the long term (Bulseco et al., 2019; Kroeger et al., 2017).

Additionally, the alteration or modification of the tidal regime can trigger the decrease of saltmarshes as carbon sink due to the decrease of area or the change of salinity conditions throw an increase of the CH_4 emissions that in good condition are almost negligible due to sulphate inhibition of methanogenesis. Blockage or restriction of tidal flows, through installation of dikes or tide gates, is a common method to protect coastal infrastructure; to drain tidal wetlands for farming, mosquito control, and development; or to raise or manage water tables and reduce salinity for aquaculture, mosquito control, rice production, and wildfowl management (Kroeger et al., 2017).

Obviously, due to the direct effect on temperature and the tidal regimen, these areas are especially vulnerable to climate change impacts, being especially sensitive to sea level rise (DeLaune and White, 2012).

Seagrass

Seagrasses are a key marine habitat that has been globally declining since the 1930s (Orth et al., 2006). These are predominantly found in shallow coastal waters (although there are some exceptions) and are therefore in proximity to areas most heavily used by humans. Several widespread threats originate from land-based sources, such as run-off from agricultural, urban and industrial regions that carries contaminants into seagrass habitats. There are also many threats from activities occurring in estuaries and seas where seagrass grows like dredging, boating (from propellers and moorings) and shipping accidents, fishing (especially trawling), harvesting, aquaculture, etc (Grech et al., 2012).

The loss of seagrass meadows leads to reduced carbon sequestration and storage capacity and to more CO_2 emissions derived from the remineralization of the soil C deposits. With present rates of loss, seagrasses are estimated to release up to 299 Tg carbon per year (Fourqurean et al, 2012). Like what happens with the degradation of terrestrial carbon sinks, the loss of seagrass ecosystems may significantly contribute to anthropogenic CO_2 emissions and to the acceleration of climate change.

The emissions from global seagrass degradation potentially reaching 0.65 $GtCO_2$ per year (Hoegh-Guldberg et al., 2018), which is roughly equivalent to yearly emissions from the entire global shipping industry.

Recommendation for management

Since saltmarshes and seagrass form part of estuary, coastal bay and often barrier beach systems, the most important impacts are caused by surrounding anthropic uses (DeLaune and White, 2012), with consequences in the degradation of the conservation status and a huge loss of wetlands surface.

Decreases in saltmarsh area are primarily a result of land claim from agriculture and industry, and coastal erosion. The highest impact threats to seagrass are linked to land activities run-off, infrastructure development and dredging (Grech et al., 2012). Additionally, links between coastal/marine habitats in the broader seascape is important for the delivery of ecosystem services or extra-local benefits (see chapter on ecosystem services) (UNEP, 2020).

Therefore, sustainable coastal management is key for coastal conservation. The relationship is bidirectional since good condition of salt marshes help protecting the coasts by stabilising shorelines and protecting them from damage by incoming waves (Shepard et al., 2011)

Recommendation for restoration from Climate Change perspective

Saltmarsh

Protecting saltmarsh from erosion through better coastal management and through reforestation of the low intertidal can enhance the carbon sequestration rates. Emergent plant communities, both helophytes and halophytes, can be helpful for the increase of C-retention.

Research shows that periodic drying of the marsh or the tidal effect can decrease methane emissions to a big extent without reducing carbon uptake by plants. As effective climate mitigation measures, tidal restoration in salt marshes shows to have a greater potential to cease the high rate of CO_2 emissions per unit area than other ecosystem management actions such as the creation of new salt marsh or the rewetting of terrestrial peatland (Kroeger et al., 2017).

Additionally, it is important to control and reduce the impacts reaching from freshwater and brackish systems with high nutrients content, and salinization. The latter favour the settlement of natural communities according to sites' characteristics, and the maintenance of the C-related metabolisms as climate allies.

In the most saline marshes, contrarily, high salinity levels should be maintained, as in natural conditions, as they have potential methanogens in their sediments capable of activating methanogenesis when salinity levels considerably drop (Poffenbarger et al., 2001; Morant et al., 2020).

Seagrass

Seagrass ecosystems have great potential in combating climate change given the carbon storage and sequestration capacity of seagrass ecosystems. The inclusion of seagrass in nationally determined contributions (NDCs) can help nations achieve their targets under the Paris Agreement and the United Nations Framework Convention on Climate Change (UNFCCC). Inclusion of seagrass ecosystems in the post-2020 global biodiversity framework and the Convention on Biological Diversity (CBD) is also critical for protecting the integrity of marine ecosystems and biodiversity. Restoration of seagrasses also provides countries with opportunities to achieve commitments to be made to the United Nations Decade on Ecosystem Restoration 2030.

However, despite the recent recognition that seagrass meadows are important marine carbon stores, the potential of habitat restoration in increasing carbon stocks and sinks in coastal waters is unknown. Recent studies provide evidence of the potential of seagrass habitat restoration to enhance carbon sequestration in the coastal zone within 12 years of seeding, the restored seagrass meadows are expected to accumulate carbon at a rate that is comparable to measured ranges in natural seagrass meadows (Greiner et al., 2013). However, there are still some challenges that prevent the widespread implementation of these strategies, such as the lack of C sequestration rates and stocks for some regions, the lack of accurate seagrass maps, the spatial variability in greenhouse gas emissions derived from seagrass degradation and the uncertainties related to legal aspects such as land tenure, tidal boundaries or legal responsibilities (Herr et al., 2017; Needeelman et al., 2018; Lovelock and Duarte, 2019).

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Wetland habitats factsheet

Mires, bogs and fens (includes the major part of peatlands)

Wetlands, with the water table at or above ground level for at least half of the year, dominated by herbaceous or ericoid vegetation. Briefly, this is a wetland with a vegetation which usually forms peat. In most of the cases, they are called peatlands "A peatland is an area with a naturally accumulated layer of peat at the surface" the definitions of peatlands is independent of the presence vegetation (Joosten et al., 2017b) and can include other ecosystem types as swamp and marsh (Keddy, 2002).

In Europe, open mire wetlands cover 8,738,232 ha (23.11% of wetland area) distributed mainly across sub-continental, sub-Atlantic, Boreal, Artic and sub-Artic regions (Maes et al., 2020).

Classification

- Ramsar classification: U -- Non-forested peatlands; includes shrub or open bogs, swamps, fens
- Corine land Cover: class 4.1.2 Peat bogs
- MAES - Ecosystem types: Wetlands
- Directive habitat / Annex I: 7120, 7130, 7160, 7230, 7320, 7310, 7140, 7150
- EUNIS: D1 - Raised and blanket bogs; D2 - Valley mires, poor fens and transition mires, D3 - Aapa, palsa and polygon mires, D4 - Base-rich fens and calcareous spring mires

* * Note that this class does not cover all the peatlands. Mire, bog and fens cover most of the peat habitats in Europe, but peatland is an area with a naturally accumulated layer of peat at the surface" (Joosten et al. 2017a, 2017b). The next habitats are peat classified under their respective ecosystem wetland type:

- A1.4A: Hydrolittoral peat
- B1.9: Machair
- E3.121: Peat grasslands of Troodos Peat grasslands of Troodos
- F4.1 - Wet heaths
- G1.4 : Broadleaved swamp woodland not on acid peat
- G1.5 : Broadleaved swamp woodland on acid peat
- G3.E5 : Nemoral peatmoss Picea woods
- G3.1C5: Peatmoss montane inner Alpine spruce forests
- G3.415: Peatmoss Caledonian forest

Role in Carbon flux

Peatlands are the soil's most important carbon reserve in land ecosystems. Mires, bogs and fens that are the most extended peatlands in Europe.

Autotrophic vegetation takes up carbon dioxide (CO_2) in photosynthesis and releases it back to the atmosphere in respiration. Although a relatively high proportion of the litter produced by mire plants is decomposed, another part of the litter accumulates as peat due to the wet conditions that restrict the oxic decomposition processes (Clymo, 1984). Decomposition continues even in anoxic conditions where a small proportion of the assimilated carbon is converted to methane (CH_4). Both net CO_2 and CH_4 fluxes between the atmosphere and the mire ecosystem are the result of several processes.

The carbon accumulation process in the peat appears when the rate of organic matter decomposition is lower than the amount of primary production of the ecosystem. In their natural state, peatlands are usually carbon sinks (Turunen et al., 2002; Mäkilä and Saarnisto, 2008) and this feature makes these ecosystems very important elements of the environment in the context of climate change since the absorbed CO_2 is one of the major greenhouse gases.

Peatlands are highly vulnerable and their role in carbon flux are closely linked to the ecosystem condition being especially susceptible to any changes of hydrological (Erwin, 2009).

C sequestration range. C seq rate (g C m^{-2} yr^{-1})

N. of measures: 33

Average values:
- Subartic: 7 ±5
- Temperate/Atlantic: 57 ±34
- Boreal: 33.7 ± 28

References: Aurela et al., 2002; Turunen et al., 2002; Tolonen and Turunen, 1996; Alonso et al., 2012; Soini et al., 2010; Friborg et al., 2003, Koehler et al., 2011; Ratcliffe et al., 2018; Sottocornola et al., 2005; Beverland et al., 1996; Yu et al., 2009; Helfter et al., 2015.

Uncertainty assessment

Uncertainty scale according to the number of studies found, the representativeness and the consistency between the results.

- Red: high uncertainty
- Yellow: moderate uncertainty
- Green: low uncertainty

Status in GHG inventories / LULUCF reporting

The land use, land use change and forestry (LULUCF) Regulation 2018/8411 comprises one of the pillars for achieving the target of the Paris Agreement and the EU 2030 climate and energy policy framework.

This Regulation includes as mandatory land accounting categories the managed wetlands (for second commitment period 2026 - 2030) that were not previously included as mandatory compared to the LULUCF Decision (Decision 529/2013/EU, European Commission 2013) and the commitments under Kyoto Protocol for Annex I Parties (UNFCCC, 2018).

The IPCC Guidelines set a general frame to define broadly the land-use categories offering to countries the accommodation of their different national classification systems. This leads to a heterogeneity in the types of ecosystems that each country classifies under the wetlands. As example, United Kingdom classified fen, marsh, swamp and bogs under the grassland land category (EEA, 2020).

The exploited peatlands are broadly covered by IPPCC guidelines. This means that if mires, bog and fens are exploited, they are currently included in the GHG emission and removals inventories. However, in the case of unmanaged wetlands, the effect as sinks of source of GHG are not accounted. At the EU level (EU-27 and the UK) for instance (see EU CRF tables5), for wetlands area, in 2018, 71,865km^2 Wetlands area was considered managed, while 171,218 km^2 are classified as unmanaged. This means that MS are only obliged to report LULUCF emissions/removals from 29.5% of wetlands, and importantly, only LULUCF emissions/removals from managed lands can be accounted.

Main threats for altering its role in C flux

Mire, bog and fens are a very sensitive and vulnerable ecosystems. The main factors that alter the carbon flux, threat its vegetation community and its stability of carbon stock, and finally lead to bigger emission of carbon and warming up the atmosphere, are the human activity and climate change. They affect the hydrology, land use, temperature (direct and indirect way) and the intensification of extreme weather events. Therefore, drainage induces peatland degradation and alters peatlands, globally, from a net sink to a net source of greenhouse gas (GHG) in the land-use sector (Joosten, 2009; Harenda et al., 2018).

In Europe, peatlands have been drained for agricultural, forest purposes and exploited as domestical fuel source. Estimate of GHG emissions caused by peatlands degradations are around 41 MtCO_2 e/year, 16 MtCO_2 e/year, 8.8 MtCO_2 e/year for respectively Germany, the United Kingdom and the Netherlands (Joosten, 2009; Reed et al., 2013; Gather and Niederhafner 2018).

Additionally, the continued or accelerated warming, threat the most sensitive mires, i.e. Palsa mires that are peat mounds or plateaus with a perennially frozen (permafrost) core and formed primarily in subarctic wetland areas in the northern hemisphere. Studies have reported a drastic decrease in the extent of Palsa mires in Fennoscandia (Luoto et al., 2004; Olvmo et al., 2020).

Recommendation for management

Land use change from wetlands to other habitats results in a net carbon loss – drainage and disturbance of wetlands leading to hydrological shifts causing changes to carbon cycle, decomposition, and fluxes. The management of mires, bog and fens must be toward their protection and restoration, slowing down and stopping the draining effect and the degradation of these ecosystems.

Carbon consequences of some management options in wetlands.(Alonso et al., 2012)

Recommendation for restoration from Climate Change perspective

Peatland rewetting has been identified as a cost-effective measure to curb emissions but re-establishes the emission of methane (CH_4). The resulting climatic effects are, thus, strongly time dependent. Recent research has demonstrated that CH_4 emissions do not undermine the climate change mitigation potential of peatland rewetting (Leifeld and Menichetti, 2018; Günther et al., 2020).

The restoration measures must be site specific; these are dependent of type of peatland, current soil properties, degradation status of the ecosystem.

The most fundamental restoration needs for degraded mires, bog and fens, peatlands in general, is to restore their hydrological functions. Restoration work must strive to re-establish an ecosystem's natural hydrological features (including eg, groundwater regiment) as well as possible because the peatland vegetation, and its biodiversity, can only recover effectively if natural or near natural hydrological conditions are restored.

Restoring peatlands by raising the water table and re-saturating soils in order to reverse the effects of drainage is an effective means to decrease CO_2 emissions and preserve existing carbon stocks. In this type of restoration effort, there are two primary goals: 1. to reduce or avoid carbon emissions, thus preserving the carbon they currently hold; and 2. to rebuild carbon stocks by recreating the processes that lead to carbon sequestration (Gonzalez et al., 2014; Wilson et al., 2016; Croon, 2013).

In Europe, site specific peatland restoration projects have been successfully implemented (Similä et al., 2014; Ramsar, 2019). The Ramsar Technical Report STRP22 Doc.7.2 (Ramsar, 2019) compiles information on restoration and rewetting methodologies to restore degraded peatlands that are based on practical experience from various restoration projects in Northern bogs.

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Wetland habitats factsheet

Rice fields


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Rice fields are defined as inundated or inundatable fields used for the cultivation of rice (Oryza sativa). When not too heavily treated, these fields may provide substitution habitats for some wetland fauna particularly bird species, including ducks, rails and herons.

With more than half of the world's population depending on rice for subsistence (Naser et al., 2020), it is crucial to ensure future rice production.

In Europe, rice fields cover 653,043 ha (2% of wetland area) distributed mainly across Mediterranean biogeographical regions. Rice cultivation in Europe is restricted to a few southern European countries namely: Bulgaria, France, Greece, Hungary, Italy, Portugal, Romania and Spain (Maes et al.,2020).

Classification

- Ramsar classification: Human-made wetlands. (3) Irrigated land that includes irrigation channels and rice fields
- Corine land Cover: Agricultural areas. Class 2.1.2 Permanently irrigated land
- MAES - Ecosystem types: Cropland
- Directive habitat / Annex I: no Annex I habitat type
- EUNIS: I1.4. Inundated or inundatable croplands, including rice fields

Role in Carbon flux

Evidence abounds through numerous studies on the importance of rice cultivation systems in relation to the emission of GHG, especially CH_4 and N_2O, rice cultivation is one of the biggest sources of GHG emissions in crop cultivation (EPA, 2006). The emission is the net result of opposing bacterial processes, production in anaerobic microenvironments, and consumption and oxidation in aerobic microenvironments, both of which can be found side by side in flooded rice soils. Typically, N_2O emissions are low under flooded fields, while CH_4 emissions are high, a trade-off relationship observed which is largely dependent on paddy soil water level, redox status, soil organic matter content, and external sources of organic and inorganic soil amendments.

Global scientific research in the last decade has proven that the water management practices, and the level of fertilizer implementation employed in rice cultivation are directly linked to the emission of greenhouse gases [1, 3, 4, 5, 6] where methane and nitrous oxide emissions are impacted respectively. It is to note that references analysed refer to studies done outside the EU.

C sequestration range. C seq rate (g C m^{-2} yr^{-1})

N. of measures: 5

Average value: -245.8 ± 122.8

References: Nasser et al., 2020; Koizumi 2001

Uncertainty assessment

Uncertainty scale according to the number of studies found, the representativeness and the consistency between the results.

- Red: high uncertainty
- Yellow: moderate uncertainty
- Green: low uncertainty

Status in GHG inventories / LULUCF reporting

The land use, land use change and forestry (LULUCF) Regulation 2018/8411 comprises one of the pillars for achieving the target of the Paris Agreement and the EU 2030 climate and energy policy framework.

Rice fields are productive areas reported under the cropland category. As managed land, the national GHG inventories include the emission and removals link to this land use category.

Ideally rice fields should be inventoried including the seasonally integrated emission factors for each commonly occurring set of rice production conditions in the country developed from standardized field measurements. These emission factors, based on local measurements, would account the specific mix of different conditions that influence on the emissions requiring environmental data on climate zones, soil types, crop types, flooding pattern, water regimen and crop management systems and type and organic amendments [11].

Main threatens for altering its role in C flux

Intensification in rice field management

Recommendation for management

Rice fields are important C source (due to drained /rewetting cycle) but best practice could neutralize this methane emission to neutral behaviour.

Environment-friendly agricultural management practices such as conservation tillage, rice seedling transplanting or direct line seeding, alternate wet and dry irrigation (AWDI), mid-season drainage, soil amendments with biochar, vermicompost, silicate slag and phospho-gypsum, site specific rice based cropping patterns and integrated plant nutrients system (IPNS) should be followed to ensure food security, while mitigating greenhouse gas emissions and global warming potentials (Ali et al., 2019; Naser et al., 2020; Tarlera et al., 2016).

For instance, Bayer et al. (2014, 2015) confirms that biomass incorporation under spring conventional tillage is the main cause of the higher CH_4 emissions. This implies that rice production systems where residue incorporation is excluded (no-till) contribute to mitigation of GHG emissions. Additionally, studies proved that rice fields with silicate fertilization decreased total seasonal CH_4 flux, while maximizing grain yield (Ali et al., 2009). Single or multiple drainages during a rice growing season are reported to reduce CH_4 emissions by 48–93% compared to those observed under continuous flooding systems (Khosa et al., 2012; Zhang et al., 2014; LaHue et al., 2016).

Recommendation for restoration from a Climate Change perspective

The recommendations are to:

- Ensure more research on the practices to be implemented in the EU rice field plantations to develop a framework of action for more sustainable practices transferable across the EU.
- set some rules and criteria to adequate management practices in the EU to reduce the impacts of practices on the functional capacity of this habitat type, and by boost co-benefits improving its biodiversity and carbon sequestration capacity as a consequence of reducing the intensity of current management practices (see previous section).

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European Topic Centre on Urban, Land and Soil Systems (ETC/ULS)
Environment Agency Austria
Spittelauer Lände 5
A-1090 Vienna/Austria

Tel.: +43 1 313 04
Web: http://uls.eionet.europa.eu/

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