European Environment Agency

Carbon stocks and sequestration in terrestrial and marine ecosystems: a lever for nature restoration?

Climate change mitigation and nature restoration are two sides of the same coin when it comes to achieving two main objectives of the European Green Deal; climate neutrality and increasing the EU's natural capital. Well-functioning habitats can take up and store large amounts of carbon, reducing atmospheric CO2 levels and greenhouse gas emissions from land use practices. To use nature's full potential, we need to know (1) the carbon storage and sequestration potential of European habitats in their present condition and how much carbon can be used to meet EU emissions policy targets; and (2) the measures available to increase carbon storage in habitats, and the synergies and trade-offs between these measures and ecosystem function. This briefing addresses these questions.

Key messages

- Ecosystems play an important and irreplaceable role in cycling and storing carbon, such as in forests and wetlands, but in many cases implementing measures to increase carbon storage in habitats can have adverse effects on biodiversity and ecosystem services.
- Uncertainties in quantitative estimates of carbon storage and sequestration in many ecosystems are high, making it difficult to quantify the impact of nature restoration on climate change mitigation policies in Europe. This calls for further biogeographical differentiation and validation with data from monitoring and measurements, and for better spatial delineation of habitats across Europe's land and seas.
- Measures to increase carbon storage will need to be carefully considered to ensure that climate change mitigation policy and actions, such as expanding biofuel production, will not result in loss of biodiversity and hence unnecessarily affect conservation and restoration objectives.
- A variety of measures can improve carbon storage in habitats, from stopping the emissions of greenhouse gases from drained peatlands to adjusting the management of forests and agricultural land to increase carbon stocks in vegetation and soil.
- Measures to stimulate and/or safeguard carbon storage in the marine environment need urgent attention, since only a limited number of marine habitats have been considered to date. The success of measures depends on the current condition of the habitat, and they often take decades to take effect, thus realising only a limited amount of carbon sequestration and storage potential within the timeframe of the policy implementation process.

What do we know about the carbon sequestration and storage potential of terrestrial and marine habitats?

Carbon sequestration is the process in which carbon is removed from the atmosphere and stored in the carbon pools of specific habitats, such as above ground biomass, roots and soil. The absolute quantity of carbon held in a habitat pool at any specified time is the carbon stock or store. The rate at which the carbon is stored is referred to as the carbon sequestration rate.

A scoping analysis by the EEA and Wageningen University & Research is the first attempt to classify the different European Nature Information Network (EUNIS) habitat types of terrestrial and marine ecosystems according to their carbon stocks and carbon sequestration capacities. The study aims to create a baseline for further analysis, linking habitat types with carbon storage and sequestration capacities to support nature restoration and conservation, as well as climate mitigation policies. The data and findings presented are based on a literature review, expert knowledge and interpretation of existing studies from inside and, in some cases, outside the 27 EU Member States (EU-27).

According to the scoping analysis, the range of values for the storage and sequestration capacities of each habitat varies because of:

- the variety of natural site conditions of the habitat, such as climate, soil conditions, water and nutrient availability and topography, which affect the growing conditions of the vegetation in that habitat
- the current condition of the habitat and its biological, chemical and physical qualities resulting from its use and management by humans and the pressures that induces, and the stage of its life cycle (e.g. forest age class)
- the fact that most studies describe their observations at the ecosystem level (e.g. pine forest, dry heathland), which differs from the EUNIS habitat type; ecosystem information had to be interpreted to link the information to habitat types using expert judgement, which contributes to the uncertainty
- the uncertainties in the information available for each habitat, depending on the number of studies, the representativeness of the sites investigated in terms of the overall distribution of the habitat, the sites' condition, and the underpinning methods, measurement techniques and modelling approaches used.

The numbers provided are therefore indicative. For habitats with few available data, the ranges may change when new information becomes available. Marine numbers may change significantly for some habitats because new research and evidence becomes available. Nonetheless, this first overview calls for a systematic EU-wide monitoring of carbon sequestration and capacities, taking into account the heterogeneity of habitat condition over space and time.

Carbon stocks in EU terrestrial and marine habitats

Terrestrial habitats take up and store atmospheric carbon, partly mitigating the increase in atmospheric CO_2 concentration. Wetlands store the largest amount of carbon per unit area, although this varies widely (Figure 1), followed by forests. Forests provide large carbon stocks owing to the high carbon content of the above and below ground biomass. The carbon stocks strongly depend on individual habitats and therefore vary within each biogeographical region and across Europe.

- read scoping analysis

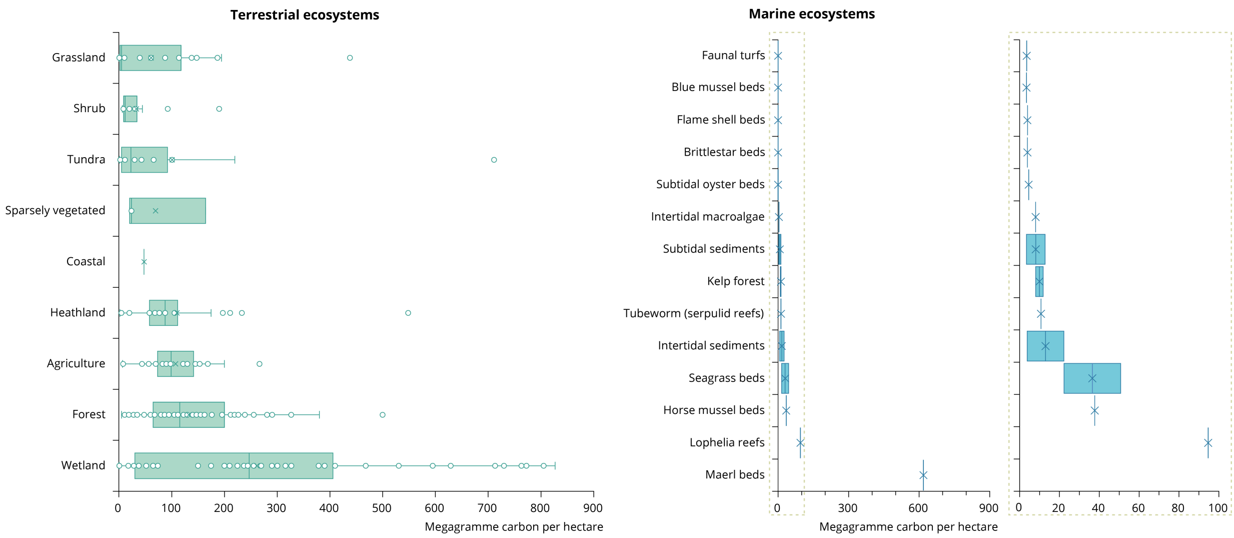
In contrast to wetlands and forests, the carbon storage of agricultural land can be improved using management practices to increase the organic carbon content of soil. However, for heathlands, shrub and semi-natural grasslands, measures to increase carbon storage would reduce their high value for biodiversity, leading to further losses of species richness and abundance. Carbon storage in sparsely vegetated land is highly variable, as it comprises a wide variety of different habitats. Tundra covers only small areas of the EU-27 territory.

Peat soils in terrestrial wetland habitats are important carbon pools. If drained, they may be used for agriculture and forestry. If not drained, habitats on peat soils and salt marshes usually have high carbon storage potential, as organic matter is constantly accumulating because of the wet conditions. Their long-term carbon storage capacity is partly because wetlands rarely burn compared with drier habitats. However, if they are drained, these habitats turn into sources of greenhouse gases, as aerobic conditions lead to the decomposition of the organic substances in the soil.

Marine ecosystems are the largest long-term sink for carbon in the biosphere, storing and cycling an estimated 93% of the Earth's CO_2. Most of the carbon in the oceans is inorganic carbon in the form of bicarbonate, carbonate, dissolved CO_2 and carbonic acid. The highest concentrations of inorganic carbon are found in the North-east Atlantic Ocean, which is estimated to store around 23% of anthropogenic CO_2. A much smaller proportion is organically bound, biologically 'fixed' carbon, i.e. carbon in living organisms or decaying matter in organic compounds in water or in sediments. Approximately 1% of the total organic carbon production at the sea surface is estimated to be buried in the sediment, where it can be stored for thousands and even millions of years.

Of the biologically 'fixed' carbon in marine habitats, maerl beds have by far the highest carbon stocks (Figure 1). Lophelia reefs and seagrass beds also have high carbon stocks, whereas flame shell beds, blue mussel beds, brittle star beds and faunal turfs all have low carbon stocks. One of the best-studied benthic habitats in terms of carbon storage and sequestration is seagrass beds, where carbon is stored in the plants and the underlying sediments. Accumulation rates and storage depend on the species, sediment characteristics, depth range of the habitat, age of the seagrass bed, depth of the sediment being sampled and remineralisation rates. Carbon storage capacity also varies considerably between geographical areas.

Figure 1. Average levels of carbon storage in the main types of terrestrial and marine habitats



Note: The 'x' in the figure represents the average rate, whereas the green and blue boxes signify the median values and the range is shown by the individual dots. For further explanation of uncertainties, see Box 1. For more detailed information please see data on terrestrial and marine carbon storage and sequestration.
More info...

The type of sediment has a significant influence on carbon storage: subtidal sediments that have a high mud fraction have the greatest potential to store carbon. Anthropogenic activities, such as fishing, dredging and installing offshore structures that affect the mixing of sediments, including disturbing the infauna, will affect carbon storage in shelf sea sediments.

Unlike rooted coastal vegetation, macroalgae do not directly transfer carbon to marine sediments. Nevertheless, seaweed detritus can deliver carbon to sedimentary sites and may provide a source of refractory dissolved organic carbon. Recent studies indicate that globally important amounts of carbon may be involved in these processes.

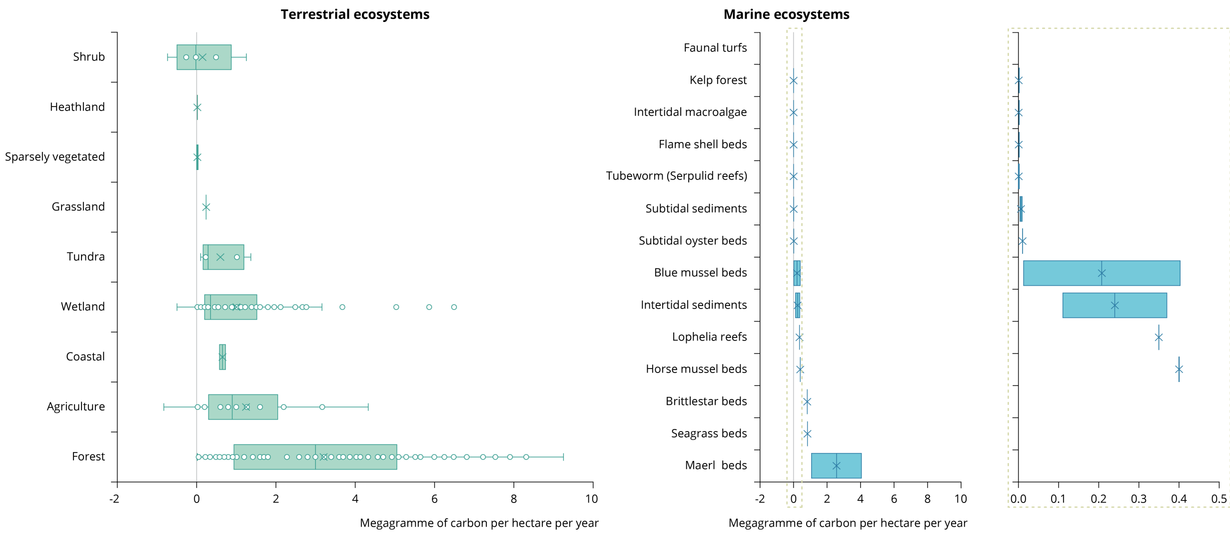
Carbon sequestration rates in EU terrestrial and marine habitats

Among terrestrial ecosystems and their habitats, forests have the highest carbon sequestration rates, reaching up to three times that of wetlands and agroecosystems (Figure 2). Over the same period, forests take up more carbon above and below ground than other ecosystems, but sequestration by individual forest habitats in each biogeographical region and across Europe is highly variable (read scoping analysis). Wetlands have relatively low carbon sequestration rates but can accumulate carbon over decades and even many centuries; this explains their very large storage capacity, which on average exceeds all other habitats. Although agroecosystems have relatively high sequestration rates, the biomass is mostly harvested, so these habitats make only minor contributions to carbon storage.

Terrestrial habitats are generally a sink for atmospheric carbon (Figure 2). Natural disturbances such as storms, forest fires or droughts release large amounts of the stored carbon into the atmosphere and turn habitats into a temporary source of greenhouse gases. Anthropogenic disturbances, such as harvesting trees from forests, increase the mineralisation of soil organic carbon and reduce the carbon stored in the soil. Agricultural management practices constantly keep the soil carbon contents of arable land at low levels. Furthermore, on drained peat soils in which the rates of peat decomposition exceed the carbon sequestration rate, the habitat becomes a net source of greenhouse gases.

Carbon sequestration rates in marine habitats are usually lower than those of terrestrial habitats. The exception is maerl beds, which have carbon sequestration rates comparable with forests (Figure 2). Kelp forests, intertidal macroalgae and faunal turfs have very low or negligible carbon sequestration rates. Kelp forests and intertidal macroalgae do produce biomass, but this contributes largely to carbon storage in depositional areas rather than in the kelp beds and macroalgae beds themselves.

Figure 2. Average carbon sequestration rates in the main types of terrestrial and marine habitats



Note: The ‘x’ in the figure represents the average rate, whereas the green and blue boxes signify the median values and the range is shown by the individual dots. For further explanation of uncertainties, see Box 1. For more detailed information please see data on terrestrial and marine carbon storage and sequestration.
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Box 1. Uncertainties in Figures 1 and 2

Most of the data for terrestrial and marine habitats refer to the 27 EU Member States (EU-27), but they also include data from outside the EU-27, due to limited data availability. The data from outside the EU-27 are attributed to the respective EUNIS types and therefore can be considered estimates for the EU-27 (see link to study). In some cases, especially for marine habitats, only individual or small numbers of observations are available. These uncertainties call for further validation of the figures.

The ranges indicated are a combination of various habitat types in different parts of the EU-27 under different climatic conditions and management systems, which explain the large variation for both sequestration and carbon stocks per hectare. The average levels of carbon stocks and sequestration include both observations of a single or several subpools and of the total carbon stock in the ecosystem. Use of the observed values therefore also needs to consider European geography and how potentials will vary according to climatic factors and soil types.

Restoration measures in terrestrial and marine habitats

In the context of biodiversity preservation and climate change mitigation, restoration measures should aim to stop net emissions of greenhouse gases and optimise the carbon storage and sequestration potential of habitats while simultaneously maintaining and improving their biodiversity. Management measures in terrestrial ecosystems generally include three types of measures that aim to improve the condition of habitats:

1. measures to conserve a habitat type (e.g. reducing possible negative impacts from management and also impacts from outside the system)
2. measures to restore a habitat type (e.g. improving biotic and abiotic conditions)
3. land use change, increasing the area of a habitat type (e.g. to extend existing habitats,

making them more robust or to connect existing habitats).

In many cases, such as forests and wetlands, there are clear synergies in restoring habitats for biodiversity and at the same time increasing the potential for carbon storage for climate change mitigation. However, nature's capacity is limited both by the life cycles of the vegetation itself and by human requirements for food, timber and other products. Therefore, it is important to put the figures for potential storage and sequestration in the context of the current habitat conditions, including their human use and management.

If large carbon stocks are pursued in the long term, unmanaged forest might be a good option. Younger forests show higher annual carbon increment in timber than mature forests, but they store less carbon in deadwood and soil. Despite annual increments in stem wood decreasing as forests grow older, they store high amounts of carbon in living biomass, deadwood and soil and are important for biodiversity. Forests are also particularly important in Europe, as they cover approximately 39% of the land surface of the EU-27. If the short-term objective is to rapidly sequester carbon to maximise harvests, then intensive forest management might be an option; however, this comes at the cost of biodiversity and ecosystem services. To sustainably store carbon for the long term would need further sustainable use of the harvested wood and wood products (e.g. for construction applications).

Measures that improve water management and the rewetting of peat soils are straightforward and have positive effects on both biodiversity and the carbon storage capacity of wetland habitats. Although rewetting of former wetlands and peatlands temporarily leads to an increase in methane (CH_4) emissions, the long-term effect on carbon storage is positive and it prevents the emissions of CO_2 associated with drained organic soils.

In many cases, managing habitats to increase their carbon storage and sequestration rates can also create trade-offs. Therefore, decisions should be taken carefully, as many habitats with low carbon storage and sequestration rates have high biodiversity and ecosystem services value. Increasing the carbon storage and sequestration rates of low-productivity habitats, such as semi-natural grasslands, heathlands and shrub, for climate change mitigation would increase their productivity but degrade their biodiversity and is therefore not considered a feasible option.

Many of these habitats in Europe are already at risk due to high nutrient intakes, the CO_2 fertilisation effect, climate change and other pressures such as fragmentation and land take. Measures that aim to maintain and improve habitat quality for species by removing nutrients or biomass from a system (e.g. to restore eutrophicated habitats or maintain habitats with high importance for biodiversity conservation such as heathlands) will not increase carbon sequestration and stocks, and therefore will not contribute to climate change mitigation. Sustainable use of biomass from these habitats is important to reduce the CO_2 footprint of their management.

The marine environment typically offers fewer opportunities for active intervention. Management measures include regulation and guidance on activities to prevent or minimise anthropogenic impacts, as these habitats retain the capacity to recover if left alone. Establishing marine protected areas (MPAs) complements such measures by focusing conservation action in particular locations. MPAs can also act as reference or control areas to study impacts on and changes in the marine environment, including from climate change such as sea level rise and changes in species distribution.

To date, measures to stimulate and/or safeguard carbon storage in the marine environment have considered only a small number of marine habitats, namely benthic habitats, which are also the focus of the scoping study. In this context, it is crucial to note that ecologically degraded ocean waters lose their capacity to support the carbon cycle and will act broadly as a carbon sink. Therefore, measures to promote carbon storage are relevant to habitat protection and restoration.

Of the habitat types reviewed, subtidal sediments with a high mud fraction have the greatest potential to store carbon. Relevant management measures for this habitat either maintain such capacity to store carbon or restore it where it has been degraded. Human activities that affect sediment mixing will reduce carbon storage in shelf sea sediments. Preventing or reducing such disturbance is therefore a solid management option. For seagrass ecosystems, the carbon sequestration rates of created or restored habitats could be substantial, although there is considerable variation between species. Within 12 years of seeding, restored seagrass beds would be expected to accumulate carbon at rates comparable to those of natural seagrass beds. Reducing coastal eutrophication would be essential for using this option.

Finally, both synergies and trade-offs can occur between nature conservation and restoration objectives on the one hand and climate change mitigation actions on the other. These will need to be carefully weighed up to make sure that climate change mitigation policy and related actions will not disproportionately affect nature conservation and restoration objectives, or the other way around.

Uncertainties in the carbon storage and sequestration capacity and the areas covered by different habitats continue to hamper the quantification of the carbon storage and sequestration capacities of European habitats. Nevertheless, this scoping study sets out a baseline for studying the synergies and trade-offs between measures to protect biodiversity and mitigate climate change, with habitats providing the appropriate level of detail for outlining strategies to support both policy agendas.

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