CBD Briefing note

Opportunities to address climate change and support biodiversity through better management of ecosystems

Convention on Biological Diversity

UNEP

Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety

About this document

This briefing note is intended primarily for decision-makers and technical staff who are involved in the design of biodiversity policies and are interested in promoting synergies with policies addressing climate change. It may also be of interest to those working on climate and land use policies, and the planning or funding of measures to address these issues. It contributes to the implementation of Decision X/33 of the Conference of the Parties to the CBD, which among other things requests the Executive Secretary to collaborate with relevant international organizations to expand and refine analyses identifying areas of high potential for the conservation and restoration of carbon stocks, as well as of ecosystem management measures that make best use of related climate change mitigation opportunities.

Given that terrestrial forests have so far received the most attention in the climate change debate, and have been studied most intensely, the main focus of the information presented here is placed on other types of terrestrial and coastal ecosystems. Marine ecosystems have not been included in the analysis.

The document is based on the outcomes of a literature review and an expert consultation on the current state of knowledge about the potential of ecosystem-based approaches for climate change mitigation, taking into account the additional benefits that such approaches can provide. The assessment was led by the United Nations Environment Programme World Conservation Monitoring Centre (UNEP-WCMC) on behalf of the Secretariat of the Convention on Biological Diversity (CBD).

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Ecosystems and the carbon cycle

The earth's ecosystems are an extremely important repository of carbon. Terrestrial and coastal ecosystems alone hold more than five times as much of this element as is currently in the atmosphere. Around the globe, living vegetation, dead plant matter and the top 2 m of soils together have been estimated to contain between 2,850 and 3,050 gigatonnes of carbon (Gt C). Significant amounts of carbon (over 2,000 Gt according to some current estimates) are also stored at depths greater than 2 m in peatland soils and permanently frozen ground (permafrost). This compares with around 830 Gt C that are out in the atmosphere in the form of greenhouse gases (see Figure 1) [1]. Land use change and degradation causing disturbance of vegetation and soils currently lead to net carbon emissions of around 0.9 Gt per year, about 10 % of total anthropogenic carbon emissions. At the same time, intact or recovering terrestrial ecosystems remove a net amount of around 2.5 Gt C per year from the atmosphere [1].

The way we use and manage ecosystems has therefore enormous implications for the success of efforts to curb climate change.

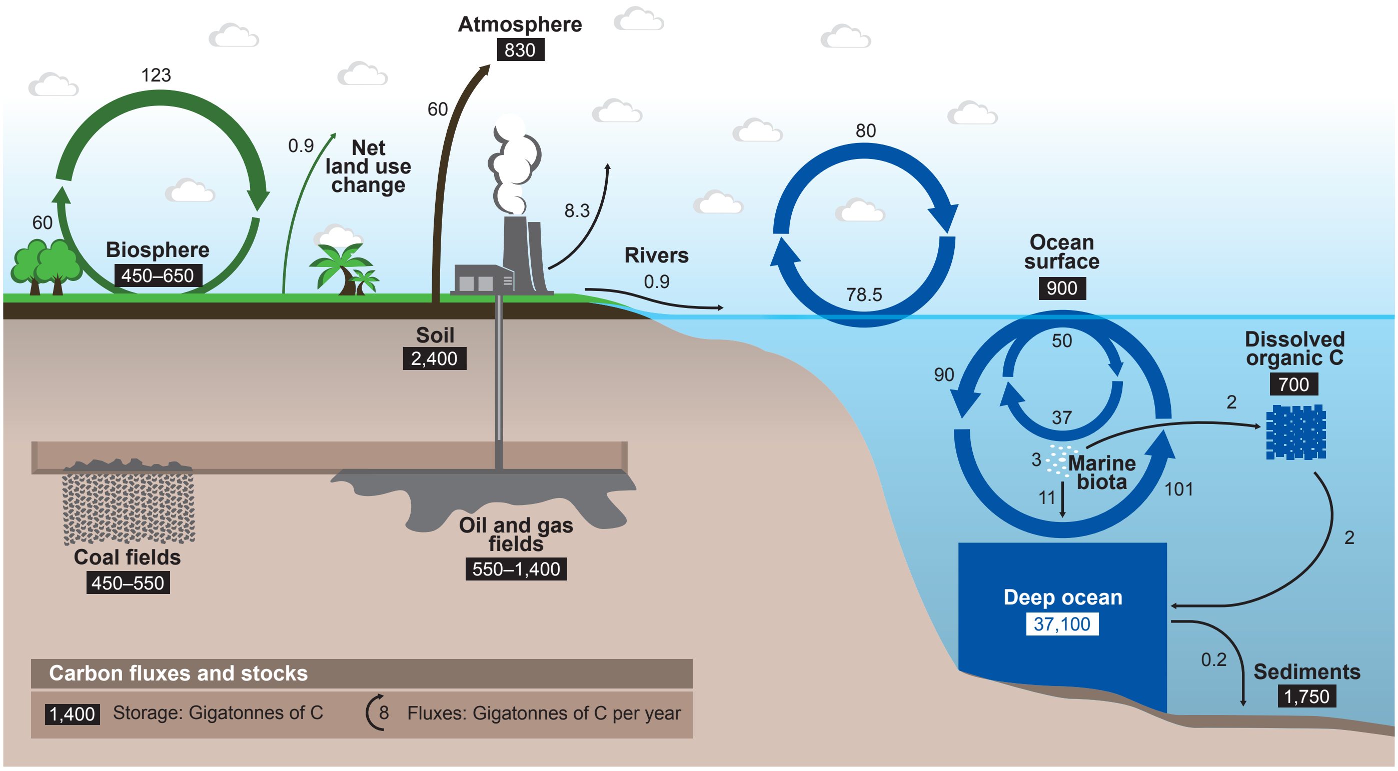

Figure 1: The global carbon cycle **Source:** Diagram from Trumper *et al*. (2009) [5], all figures updated following Ciais *et al*. (2013) [1].

Ecosystem-based mitigation can yield a multitude of benefits

An ecosystem-based approach to climate change mitigation can draw on forms of land use that maintain carbon stocks and allow additional carbon to be taken up from the atmosphere. Often, such forms of land use also support climate change adaptation, disaster risk reduction and sustainable development, and are beneficial for biodiversity. They can thus form a cornerstone of efficient policies for the integrated use of land and natural resources.

Widening our horizons: thinking beyond forests

The role of forests in the global carbon cycle and the part they can play in helping to address climate change are well known, as is their importance for biodiversity and for delivering a wide range of ecosystem services. To date, other ecosystems have received less attention in discussions about climate change. Yet a growing body of evidence shows that they too can have a vital role as active carbon sinks and carbon stores, and in helping us adapt to changed climate regimes. Just as with forests, it is also increasingly clear that appropriate management has the potential to deliver not just climate benefits but other important ecosystem and biodiversity-related services.

A review of the current state of knowledge on some of these ecosystems, including peatlands, grasslands, tundra, coastal and agro-ecosystems, reveals just how important they can be and indicates approaches expected to deliver maximum benefits.

Fast facts

Peatlands (p.5)

- An average peatland holds about 1,500 tonnes of soil carbon per hectare – 10 times as much as a typical mineral soil [2].
- Conversion of peatlands to agricultural use can lead to emissions on the order of 25 t of C per hectare per year [3].
- Global carbon emissions from fire in drained peatlands can reach up to 2 Gt C in some years, and also pose a severe risk for human health [2] [4].

Grasslands and savannahs (p.7)

- Grasslands play an important role in the terrestrial carbon balance because of their large area, as they occur over around 40 % of the earth's land mass [5] [6].
- Many grasslands are seriously overgrazed, and their restoration could potentially lead to a significant uptake of carbon – up to 45 million tonnes per year [7].
- Soil carbon stocks have been shown to decline by up to 60 % following the conversion of grasslands to agriculture [8].

Mangroves, saltmarshes and seagrass beds (p.9)

- Coastal ecosystems characterized by mangrove, saltmarsh or seagrass vegetation have particularly high rates of carbon sequestration and can take up between 1.4 and 1.6 t of C per hectare per year [9] [10].
- All three types of coastal vegetated ecosystems are being destroyed at an alarming rate and between 30 and 50 % of their original area has been lost already [11].
- Coastal vegetation is also of crucial importance for erosion control and disaster risk reduction [12] [13].

Tundra (p.12)

- The permanently frozen soils of the tundra, together with permafrost under boreal forests, are the world's largest reservoir of organic carbon, containing more than 1,700 Gt C [1] [14].
- The physical and chemical processes triggered by melting of permafrost can lead to the release of large amounts of stored carbon as carbon dioxide or methane [15].
- There are no effective means to curb the process of permafrost thawing other than by reducing greenhouse gas emissions to mitigate climate change [16].

Agro-ecosystems (p.13)

- Current agricultural practices deplete soil carbon stocks over large areas; better soil management could reduce net emissions from agriculture by the equivalent of up to 1.4 Gt C each year by 2030 [17].
- Unless agricultural production methods and consumption patterns become more efficient and sustainable, increasing demand for food will lead to further large-scale conversion of grasslands, forests and peatlands [18].
- Around 75 million hectares of cropland went out of use in countries of the former Soviet Union since 1990, leading to a carbon uptake of around 200 million tonnes per year; this land reserve is likely to come under pressure for re-conversion [19].

The ecosystem types addressed in this brochure have been chosen because of their high potential to contribute to climate change mitigation and adaptation, but the list is by no means exhaustive. For example, inland waters and offshore marine ecosystems have not been dealt with, although there is a growing body of evidence demonstrating their importance in climate regulation. The groupings chosen are necessarily generalizations – any classification of the natural world into ecosystems is to some degree subjective, and any given area may have characteristics of more than one ecosystem type: tundra areas and some tropical forests may contain a large proportion of peat soils, for example, and wooded savannahs may be considered forest areas or grasslands depending on circumstances.

For a comparison of ecosystem types according to their area extension and average carbon stocks, see Figure 2 on p.4.

Key lessons learned across all ecosystems

Some general lessons are starting to emerge from experiences with ecosystem-based approaches to climate change mitigation:

1. A perceived lack of knowledge on the potential of non-forest ecosystems for climate change mitigation is often preventing action. However, there is a growing body of information, data and methodologies that can provide the basis for concrete planning and target-setting.
2. Opportunities for ecosystem-based mitigation in the context of sustainable development depend on the social and ecological setting. Optimum results are therefore likely to be achieved through landscape-scale participatory planning involving active engagement of stakeholders across all sectors.
3. Policies and actions targeting forests can provide useful lessons for planning interventions in other ecosystems. Such lessons can concern appropriate institutional arrangements, approaches to the assessment of pressures and options to address them, ways to enhance co-benefits, or social and environmental safeguards.
4. Current incentive systems related to land use do not always favour the best outcomes; reform of these incentives can make transitions to more sustainable forms of ecosystem management financially viable and benefit both local and national economies.
5. Maintaining existing ecosystems is generally a more efficient way to achieve climate, biodiversity and ecosystem service benefits than restoration of those that have been degraded or converted; however, available techniques for restoration are continually improving and can be a good option in areas where little undisturbed vegetation is left and demand for ecosystem services is high.
6. While many ecosystem-based approaches to addressing climate change are likely to benefit biodiversity, there are also risks involved, for example with regard to the development of biofuels and conversion of natural grasslands and peatlands for afforestation.

Smallholder farmers are among the stakeholder groups who should be involved in planning for ecosystem-based mitigation at the landscape level. Here, women from the Mbini Self-Help Group in Machakos, Kenya, show their fields.
Picture by McKay Savage (CC-BY-2.0).

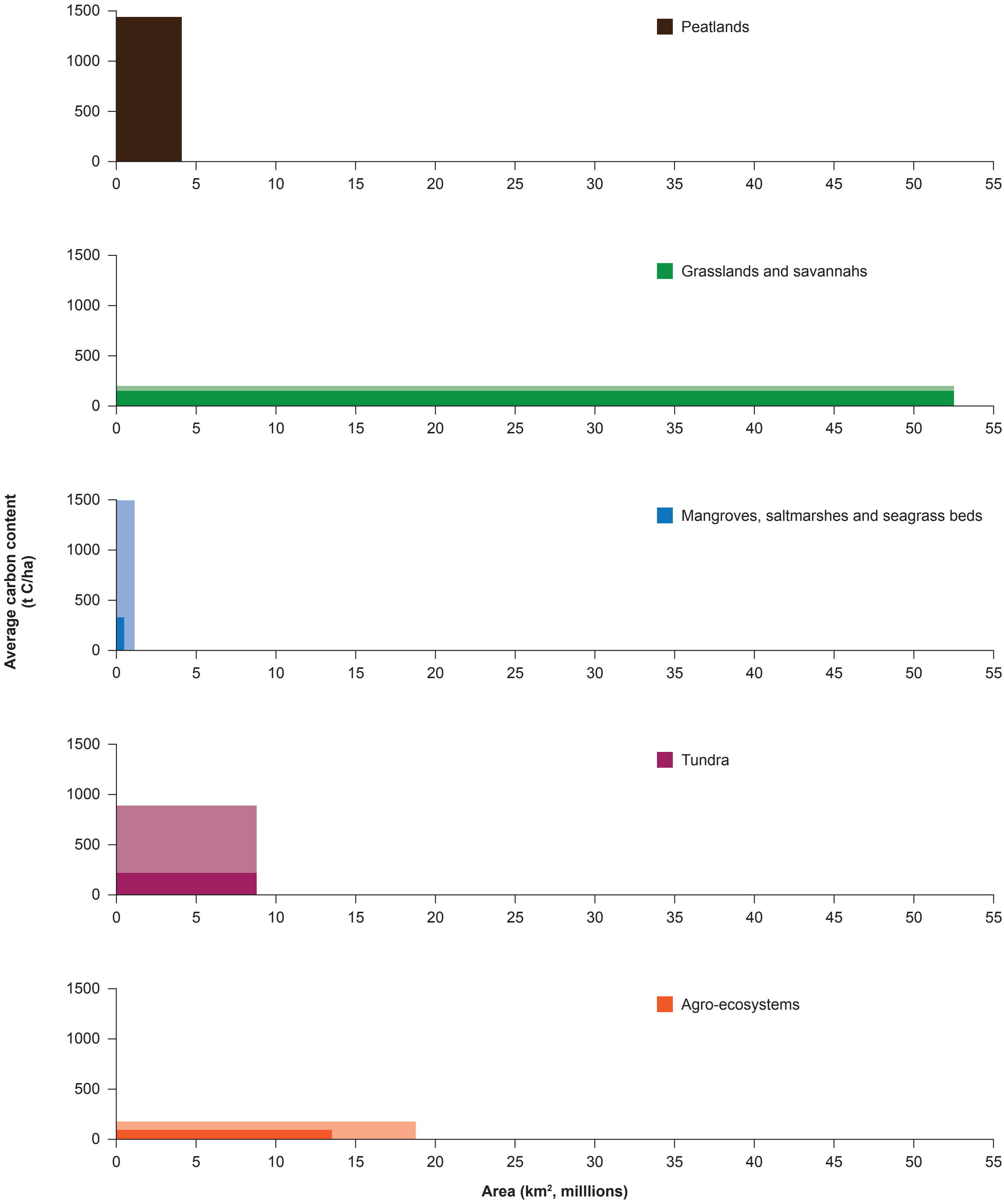

Figure 2: Comparison of major ecosystem types according to their global area extension and average carbon stocks per hectare. Where the sources provide values as a range rather than a single figure, this is indicated by darker shading for the lower estimate and lighter shading for the upper values provided.

Sources: Peatlands [20] [21], Grasslands and savannahs [22] [23] [24] [25], Mangroves, saltmarshes and seagrass beds [26], Tundra [14] [27], Agro-ecosystems [28] [29].

Ecosystems in focus

Peatlands

Role in the climate system

Peatlands cover only around 3% of the global land surface but are disproportionately important for the climate system thanks to the large amounts of soil carbon they contain – estimated at around 1,500 t C per hectare on average [2]. This is about 10 times as much as what is found in typical mineral soils. Some tropical peatland soils can even contain more than twice this amount. In total, known soil carbon reserves in peatlands are currently estimated at over 550 Gt C, and new peat reserves are still being discovered [2]. When in a natural state, most peatlands accumulate carbon, albeit at a slow rate, because dead plant matter is conserved in the waterlogged soils and slowly converted to peat. However, when disturbed, chiefly by drainage, they may become important emitters of greenhouse gases, through decomposition of the peat that is now exposed to air, and through peat fires [4].

Although a large proportion of global peatlands is still in a relatively undisturbed state, the rate of disturbance has been steadily increasing, leading to significant greenhouse gas emissions. Average annual loss of peat carbon is generally agreed to exceed 0.3 Gt per year (which is equivalent to about 3 % of all anthropogenic carbon emissions), while some estimates place the value as high as 2 Gt C for years with a high incidence of peat fires [3] [4] [27]. Global hotspots of anthropogenic greenhouse gas emissions from peatlands are Southeast Asia, where peat is mostly drained for agroforestry and other forms of agriculture, and Europe, where peat is drained for agriculture, livestock grazing and forestry, and peat extraction also plays a role [27] [30].

Climate change is expected to increase carbon emissions from peatlands in some areas but may well lead to enhanced sequestration in others, due to differences in site conditions. It is unclear at present what the balance between the two will be [1] [21] [31] [32]. However, it is likely that peatlands where peat-forming vegetation is intact or has been restored will be more resilient to climate impacts than degraded ones [21].

Options for ecosystem-based mitigation

The most important measures for reducing greenhouse gas emissions from peatlands are avoiding or reversing drainage [5] [18]. Studies have shown that avoiding the conversion of fenlands to agricultural use in temperate regions can prevent between 3 and 17 tonnes of soil carbon per hectare per year being lost, while in tropical regions emission savings on the order of 25 t C per hectare per year are possible where large-scale conversion of peat soils is avoided [3] [31]. Refraining from conversion also means avoiding the emissions that result from the setup, running and maintenance of drainage infrastructure. Reducing other pressures such as peat extraction can also contribute to emission reductions [2] [4].

Undisturbed peatlands can store carbon over very long timescales.
Picture of lowland fen by Peter Wollinga. Used under license from Shutterstock.

When planning mitigation measures, maintenance of intact peatlands is generally likely to be more cost-efficient than peatland restoration as the latter can be technically demanding and may involve long recovery times [4]. If not carefully planned and implemented, measures to raise water levels as part of restoration programmes may even be counterproductive because inundation of fresh or partly decomposed plant matter and nutrient-rich soil layers can lead to initially high emission of nitrous oxides and methane, themselves powerful greenhouse gases. It may take decades for these emissions to be offset by subsequent savings in terms of avoided carbon dioxide emissions [32] [33].

The president of Indonesia inspecting the site of a peatland rewetted as part of measures to address peat fires.
Source: Office of the President of Indonesia.

Where restoration is pursued, options for action will depend on current land use and prevailing socio-economic conditions. Full restoration involving the re-establishment of peat-forming vegetation provides the greatest emission reductions and also has the potential to restore the (naturally slow) process of carbon sequestration. However, where this is not possible, switching to a land use that requires less intensive drainage will also offer benefits. This might involve changing from crop cultivation to pastoral uses, or to cultivation of reeds or tree species that can tolerate high water levels [4] [32].

The recent advances in knowledge about the location of peatland carbon stocks and the emission reductions that can be achieved through different forms of peatland management provide a good starting point for planning mitigation actions in peatlands. A number of pilot projects have demonstrated both climate and biodiversity benefits, making use of available guidance and standards to assess emission savings (see e.g. [34] [35] [36] [37]). Governments as well as national and international donors should support further work on the creation of enabling conditions for such activities. While the focus on Southeast Asia in current discussions is justified by the particularly high emission rates, the potential for mitigation action in peatlands of other regions should not be overlooked.

Given that agricultural production is a main driver of peatland degradation, actions to support more sustainable forms of management and to direct development towards less sensitive areas are crucial [38]. These could include reforms to subsidies and mechanisms for land allocation, certification schemes, support to local livelihoods and raising awareness among companies and consumers. In the case of biofuel crops, initiatives should ensure that both short- and long-term emissions from soils in the location of production, as well as energy expenditure for drainage, and indirect land use change are included in the calculation of potential emission savings. Considering the full greenhouse gas footprint of biofuel cultivation on peatlands is likely to reveal that it does not provide net benefits for climate change mitigation [2] [4] [5] [39]. Biofuel cultivation on drained tropical peatlands should be avoided.

Potential for synergies with adaptation and other policy goals

Peatland areas can play an important role in regulating the water cycle, for example through buffering water flows and flood control, and in purifying the water that passes through them. These ecosystem services can be highly relevant for adaptation to climate change [2]. Drainage of peatlands not only leads to increased greenhouse gas emissions, but reduces their capacity to fulfil these roles [4]. Drainage also causes subsidence, which occurs when peat decomposition leads to a shrinking of the soil profile and lowering of the soil surface. This makes further drainage increasingly difficult and costly, and can result in more frequent and intense flooding or saltwater intrusion which may eventually cause the loss of habitable and productive land [33]. Agricultural areas on peatlands in the tropics are particularly at risk, as decomposition processes proceed much faster than in temperate or boreal climates [40]. Nevertheless, increased flood risk with severe economic consequences has also been reported from drained peatland areas in North America and Europe [33]. In addition, the peat fires that often result from drainage, with recent catastrophic events occurring in both tropical and temperate regions, can cause severe air pollution, loss of human life and damage to infrastructure [2] [4]

Biodiversity implications

Measures that support the conservation of peatlands will generally have positive impacts on biodiversity, as peatlands harbour a unique array of species, many of which depend on this habitat for their survival [2]. The impacts of measures to restore peatlands, or to start using them in ways that do not involve drainage, will depend on how and where these measures are implemented. Positive impacts can be enhanced if restoration measures are designed to improve habitat conditions for native species and if measures that introduce the cultivation of water-tolerant crops or trees are focussed on degraded areas or areas suffering from subsidence [33]. Where afforestation of naturally treeless peatlands or use of peatlands for biofuel production are considered as mitigation measures, special care should be taken to evaluate the full climate footprint of such measures, to avoid actions that lead to a 'lose-lose' outcome for climate and biodiversity goals, and to assess trade-offs between these goals, as well as consequences for the supply of other ecosystem services.

Natural grasslands and savannahs

Role in the climate system

Temperate, tropical and sub-tropical grasslands and savannahs occur naturally over an area that covers around a quarter of the world's land surface, mostly in regions with a dry climate that cannot support the growth of forests; a further 15% of the land area is taken up by semi-natural grasslands where forests have been cleared for livestock grazing [6] [22] [25]. Levels of carbon in grassland are generally lower than those in peatlands and many forest types, averaging between 150 and 200 t C per hectare, with high variability depending on climate and soil type [23] [25]. However, because they occur over such a large area, grasslands play a significant role in the terrestrial carbon balance [23] [41] [42]. The total amount of carbon stored in the natural grassland biomes is estimated at around 470 Gt C, i.e. around one fifth of the carbon contained in terrestrial vegetation and topsoils worldwide [1] [5]. About 80 % of this carbon is stored in the soil [43].

Among the main processes influencing carbon flows in grassland ecosystems are conversion to agriculture, grazing by wild and domesticated animals, fire, and climate variability and change [6] [18] [41] [42] [44]. In tropical savannahs, harvesting of wood can also be an issue. Many grasslands have fertile soils, and large expanses (around 70 % of temperate grasslands and 50 % of tropical and sub-tropical savannahs) have been cleared for agriculture, notably in North America, South-East Europe and Africa north of the equator [25] [27] [44]. In some parts of Eastern Europe and Central Asia, this conversion trend has partly been reversed following the collapse of the former Soviet Union (see discussion of agro-ecosystems below) [19].

Many grasslands provide the basis for pastoral livelihoods.
Picture of camels on the Mongolian steppe by Oksana Perkins. Used under license from Shutterstock.

Degradation and soil erosion caused by overgrazing is a serious problem in the remaining grasslands of many regions, including sub-Saharan Africa, Central Asia, China and South America [25] [45] [46] [47]. A large part of the world's degraded dryland soils are found in former grassland areas. It is estimated that drylands affected by land degradation currently cover around 4-8 % of the global land area [44], and that around 0.3 Gt C per year are lost from dryland soils as a result of unsustainable agricultural and pastoral practices [27]. As future projections indicate a continued rise in population densities and an increase in frequency and duration of drought in many dryland areas, it is expected that the exposure of natural grasslands to degradation will grow over the coming decades if management practices remain the same [44].

The effects of changes in species composition that will occur due to rising temperatures and CO_2 concentrations and altered precipitation patterns are still hard to predict [32].

Options for ecosystem-based mitigation

Mitigation approaches in grassland ecosystems include adjusting grazing intensity, regulating fire frequency, avoiding conversion to croplands, restoring degraded grasslands, and in the case of savannahs, reducing extraction of woody biomass [25] [48].

Of these, avoiding conversion offers the largest possible carbon savings per hectare, as grassland soil carbon stocks have been shown to decline by up to 60 % following a change to agricultural use [8] [27]. In contrast conversion from cropland back to grassland generally offers a more moderate carbon benefit, but can still lead to an increase in soil organic carbon of around 20 % over a timescale of several decades [8] [49]. This implies that impacts on soil carbon from potential mitigation activities that would involve conversion of grasslands, such as cultivation of biofuels or afforestation, have to be assessed carefully.

The intensity of grazing that is most beneficial for carbon stocks depends on climate, soil and vegetation type. In some grassland systems, especially those dominated by tropical grasses, the greatest rates of carbon sequestration are achieved at intermediate grazing levels, while in others even moderate grazing can lead to loss of soil carbon. If optimum grazing levels for a given location are adopted, annual sequestration rates can be as high as 1.5 t C per hectare [6].

Due to the extent of degradation that has already occurred, grassland soils offer a potentially large carbon sink [48]. It has been estimated that full rehabilitation of the world's overgrazed grasslands, mainly through adoption of appropriate grazing intensities, could sequester about 45 million t C per year [7].

The largest areas of natural steppe vegetation remaining today are located in Central Asia.
Picture of a steppe valley in Kazakhstan by Togzhan Ibrayeva (CC BY-SA 4.0).

Grazing by wild or domesticated animals also decreases fuel loads and can thereby reduce fire occurrence, thus potentially avoiding significant emissions of carbon and nitrous oxides. In some regions, active fire management through the setting of frequent but less intensive fires has been used to reduce carbon emissions [50].

Recently, some initiatives for more sustainable management of grasslands have produced quantified emission reductions and obtained carbon credits from the voluntary market [51]. Experiences from these pilot projects can inform the development of similar initiatives in other regions, or be applied to other types of management interventions. In savannah areas where wood extraction is an issue, approaches from forest-based projects can also be used, for example to support activities that reduce pressure on the tree layer through alternative ways of charcoal production [25] [52].

Given how urgent the sustainable development challenges in many grassland regions are, and what large co-benefits mitigation actions in grasslands can achieve, funding for programmes to improve the management of natural resources in grasslands could be sought from a variety of sectoral budgets, and incentives could be provided in the form of enabling activities, carbon payments or payments for ecosystem services.

Potential for synergies with adaptation and other policy goals

Due to the importance of grasslands for local livelihoods, any change in management that leads to avoided degradation or to the recovery of ecosystems is likely to enhance the sustainability of current economic activities, as well as the capacity of often poor local populations to adapt to future impacts from climate change [48] [53] [54].

Higher soil organic carbon stocks are also linked to greater infiltration capacity and nutrient retention, which may have beneficial effects on water regulation and quality. By avoiding soil erosion and maintaining vegetative cover, climate change mitigation measures in grasslands can also prevent increased sediment loads in rivers and lakes [18] [48].

Trade-offs between climate change mitigation and socio-economic development may be involved where optimal grazing intensities for maintaining or enhancing soil carbon stocks are lower than the carrying capacity of pastures for livestock keeping.

Biodiversity implications

Actions in grasslands to mitigate climate change can potentially have either positive or negative effects on biodiversity. Reduced degradation or conversion of grasslands, as well as grassland restoration (especially through natural regeneration), are likely to benefit biodiversity [53]. By contrast, intensification of management involving fertilization, irrigation or re-seeding with high performance grasses is likely to have negative impacts on biodiversity, as are measures that affect wild herbivore populations.

Biodiversity impacts of mitigation approaches involving fire management depend on the practices used, as well as the natural fire regimes to which species in the area are adapted.

Afforestation schemes, or ‘reforestation’ efforts that are wrongly directed at natural grasslands, present a major potential threat to grassland biodiversity [55]. The risk of negative impacts through displacement of pressures as a result of mitigation activities targeting forests is also particularly high in savannah or steppe ecosystems [56].

In light of the wide range of opportunities and risks presented by mitigation actions in grassland ecosystems, those with an interest in conserving biodiversity should engage with the climate change community to identify mutually beneficial solutions and ways to manage trade-offs where these cannot be avoided.

Mangroves, saltmarshes and seagrass beds

Seagrass beds are found in shallow waters of all continents except the Antarctic on soft-bottom substrates. Although they contain large amounts of carbon, information on their current distribution is still incomplete.
Picture by LauraD. Used under license from Shutterstock.

Role in the climate system

Mangroves, saltmarshes and seagrass beds are the three main types of coastal habitats in which vegetation is periodically or (in the case of seagrass beds) permanently covered by the sea. These vegetated coastal ecosystems are important carbon stores and sinks, despite the fact that their combined overall extent is only about 50 million hectares, or around 0.1 % of the earth's surface [26]. This is because the flooded vegetation can act as a trap for small particles of organic matter, creating sediments that are very rich in carbon [57] [58] [59]. At the same time, the decomposition of organic matter is slowed down in the waterlogged soil, and the high levels of salinity in sea water prevent the formation of methane. The carbon captured in these ecosystems can therefore remain stored for centuries or even millennia [60] [61].

Conservative recent estimates indicate that the amount of carbon stored by the three ecosystem types is between 11 and 25 Gt C in total, i.e. between 0.5 and 1.2 % of the world's biomass and topsoil carbon. Mangroves store the most carbon per unit area, with estimated average stocks in the soil of around 750-800 t C per hectare, and an additional 150 t C per hectare in woody biomass [58] [62]. This compares with around 400 t C per hectare in saltmarshes and around 140 t C per hectare in seagrass beds [63]. Annual carbon sequestration rates are around 1.5 t C per hectare in each case [57] [63] [64].

All three types of ecosystem are under high pressure from human activity. Between 30 and 50 % of the area originally covered by each is believed to have been lost over the last century alone [11]. Current threats include conversion to aquaculture, reclamation and drainage for agriculture and development of settlements and coastal infrastructure, changes in sediment transport due to flood control and coastal defence measures, and pollution from nutrients and chemicals contained in run-off from terrestrial areas [25] [61]. Present rates of loss of the remaining area of each ecosystem are estimated at 1-2 % per year, leading to annual global emissions of 0.02-0.12 Gt C for mangroves, 0.01–0.07 Gt C for saltmarshes and 0.04–0.09 Gt C for seagrass meadows [26] [58]. The reduction in area also entails a loss of potential for continued carbon sequestration in the future [62].

Climate change poses an additional threat to coastal ecosystems, as sea level rise and coastal defence structures together are likely to reduce the area that is available for natural coastal vegetation. Both mangroves and salt marshes can in principle adapt to sea level rise through soil accumulation, as well as through area expansion on the landward side. However, the extent to which adaptation is possible in reality will depend on the rate of change and on the availability of space for a shift towards the land in the densely populated coastal regions [65] [66].

Coastal areas are attractive for a multitude of land uses.
Picture of dwellings and aquaculture installations in Timor Leste by Colin Trainor (CC BY-SA 3.0).

Options for ecosystem-based mitigation

Given the high current rates of loss, the most important option for climate change mitigation in vegetated coastal ecosystems is to address the drivers of conversion, habitat degradation, pollution and siltation. The latter two are particularly important for seagrass beds and may originate upstream in river catchments far away from the ecosystem in question, for example through erosion in areas under agriculture and forestry [67]. Because of the multiple pressures that coastal regions are under in many parts of the world, landscape level, and if necessary transboundary, approaches to management such as Integrated Coastal Zone Management are likely to offer the best chances for success. Such processes should also consider possible future changes in the availability of space for coastal vegetation due to population growth, sea level rise or changes in coastal currents [68].

One way to reduce pressure on coastal areas is to develop more efficient and sustainable practices for major land uses. For example, there is considerable scope for improvement with regard to aquaculture, which is a major driver of habitat loss in coastal areas. Better forms of management could increase the timespan for which aquaculture installations can operate, and reduce their environmental impacts [69].

Restoration methods have been developed for all three ecosystem types, and have proven effective in terms of restoring both the vegetation cover and the soil accumulation processes that are the basis for carbon sequestration [60] [70] [71]. However, successful restoration requires more effort, resources and technical skill than interventions to halt further loss and degradation [11] [61]. It will also fail if the original causes of degradation and loss are not addressed before re-planting or re-seeding is undertaken. Restoration initiatives should therefore mainly be considered for areas where there is a high demand for the ecosystem services that can be re-established, and be planned in a participatory manner [61].

Efforts to establish financial incentives for ecosystem-based mitigation actions in coastal areas can benefit from the high values of carbon stocks and sequestration rates per area, which result in comparatively low cost per tonne of carbon saved [62] [75]. There are also approved accounting methodologies that can be applied. The Wetlands Supplement to the IPCC Guidelines for National Greenhouse Gas Inventories was adopted in 2013, and provides guidance for calculating carbon emissions and sequestration from a range of activities in coastal ecosystems [37]. This information can be used in the design of individual projects, but also for larger programmes. In the case of mangroves, relevant mitigation measures could also be supported as part of countries' emerging REDD+ activities. Opportunities to combine funding from several sources could arise with regard to adaptation, biodiversity conservation, coastal protection and sustainable development.

Surveying a mangrove forest.
Picture by Tappasan Phurisamrit used under license from Shutterstock.

Oyster farming in a mangrove area in Thailand.
Picture by Yongkiet Jitwattanatam used under license from Shutterstock.

Potential for synergies with adaptation and other policy goals

Coastal ecosystems provide a wide range of ecosystem services that are relevant to climate change adaptation, disaster risk reduction, human health, food security and local livelihoods. These are all the more important because many coastal regions have a high density of human settlement [61] [65]. All types of coastal vegetation offer some level of protection for the coastline by reducing wave intensity and stabilizing the ground with their roots, thus reducing coastal erosion [72] [73] [74]. The processes of filtration and sedimentation that are largely responsible for carbon sequestration in coastal ecosystems can at the same time contribute to maintaining or improving water quality. Coastal ecosystems are also important habitats and breeding grounds for animal species used by humans, including fish, molluscs and seabirds. The vegetation itself, if used sustainably, can provide materials for a number of uses, such as roof thatch, fuel, animal bedding, or even, in the case of mangroves, timber [61].

The potential of coastal ecosystems to contribute to climate change adaptation and disaster risk reduction has been documented most clearly for mangroves. These can significantly reduce storm wave intensity, and wide belts of mangrove can attenuate the impacts of storm surges and even tsunamis [61] [66] [72]. The potential of mangroves to provide food, fuel and building materials can also be important for local populations during recovery from an extreme event. The protection and restoration of mangroves, especially if combined with other elements such as early warning systems and hard infrastructure, can thus make a key contribution to strategies for climate change adaptation and disaster preparedness in almost any coastal setting [66].

Biodiversity implications

Actions for climate change mitigation that involve the conservation and sustainable use of coastal ecosystems such as mangroves, saltmarshes and seagrass beds are likely to generate strong benefits for biodiversity, as these systems provide critical permanent and seasonal habitat for large numbers of plant and animal species. In the case of actions aiming to restore lost or degraded coastal vegetation, the biodiversity impacts will depend on the methods applied. Restoration methods that are designed to promote natural species diversity and are suited to the conditions of the site can not only achieve better short- and medium-term outcomes for biodiversity and ecosystem services, but are also likely to enhance the long-term resilience of the restored ecosystems to climate change [61].

Huts in a fishing community in Koh Chang, Thailand.
Picture by Jorg Hackemann used under license from Shutterstock.

Tundra ecosystems

Role in the climate system

Tundra ecosystems cover just under 10 % of the global land area, mostly in the northern hemisphere [27]. Despite their relatively limited extent, their potential impact on the global climate system is large. This is due to the great quantities of carbon stored in their soils, particularly in the permanently frozen layers known as permafrost. The permafrost soils of the tundra and the boreal forest zone together are understood to contain at least 1,700 Gt C, making them the largest reservoir of organic carbon worldwide. The distribution of this carbon is however highly uneven and not yet fully understood [1] [14].

There are serious concerns that tundra ecosystems will turn into a major source of greenhouse gas emissions within the next few decades, as climate change causes continued thawing of the permafrost layer [1] [15] [16]. This is projected to lead to marked changes in the landscape, including the formation or drainage of wetlands and lakes, and to an increase in coastal erosion rates [76]. This, in combination with the rising soil temperatures, is likely to result in the release of a significant share of the stored carbon in the form of carbon dioxide or methane [15]. The problem is exacerbated by the fact that the high latitude and high altitude regions where tundra ecosystems occur are predicted to experience particularly strong warming.

Tundra landscapes are often characterized by extensive water bodies. *Picture by Dr. Andreas Hugentobler (CC BY 2.0).*

Carbon stocks in living biomass in tundra ecosystems are predicted to increase under climate change, as rising temperatures and changes in precipitation allow trees and shrubs to colonise areas previously unsuitable for them [77] [78]. However, most authors expect that these carbon gains will not be large enough to compensate for the losses in soil carbon. Rising temperatures may also lead to a higher risk of fire, potentially affecting both soil and biomass carbon stocks [79].

Pressures from human activity in tundra ecosystems are mostly linked to the extraction of fossil fuels and other mineral resources, and are currently not considered to be a major driver of greenhouse gas emissions due to their limited spatial extent [76]. This may change in the future as demand for resources continues to grow, and tundra areas become more accessible for extractive activities due to reduced sea ice cover and milder temperatures. Growing suitability for forestry use could also increase human impact in the area.

Options for ecosystem-based mitigation

The potential for mitigation actions in tundra ecosystems is limited, as no feasible approaches are known that could help to slow the process of permafrost thawing, and the extent of direct human impacts on carbon stocks that can be addressed is relatively small. Climate change mitigation through other activities thus seems to be the only realistic option at present for significantly reducing greenhouse gas emissions from tundra areas [16] [25]. However, given the expected rise in human influence on the tundra, approaches for managing anthropogenic pressures to limit negative impacts on soils, hydrology and vegetation should be developed now. In areas with increasing fire risk, mechanisms to control and manage fires should also be put in place. Generally, the complex nature of the challenges caused by climate change in the remote but resource-rich tundra regions calls for the development of approaches that involve coordination and collaboration across sectors and stakeholder groups and between countries, and that address the anticipated environmental and socio-economic trends.

Potential for synergies with adaptation and other policy goals

Despite the low human population density in the tundra regions, adaptation to the impacts of climate change presents significant challenges both for public and private economic investment and for local communities, many of which are engaged in subsistence livelihoods. This is largely due to the fundamental and only partly predictable landscape changes that are caused by permafrost thawing, as well as to the impacts of climate change on populations of the large mammals that form the basis of many local livelihoods [76]. Strategies to manage the impacts of human intervention in tundra ecosystems on carbon stocks could be designed to take these processes into account and provide synergies with adaptation goals.

Biodiversity implications

The biodiversity of tundra ecosystems is very sensitive to disturbance, mostly because of the long recovery times needed under the harsh climatic conditions. Mitigation approaches that manage the impacts of human intervention on tundra soils are therefore likely to yield biodiversity benefits as well. Risks to biodiversity could result from mitigation options that involve the manipulation of hydrological site conditions or the establishment of tree plantations.

Agro-ecosystems

Role in the climate system

Around 13% of the global land surface is currently used for the cultivation of crops [29]. Most of this land has been converted from what were originally forest or grassland ecosystems [80]. Overall, agriculture accounts for a significant share of current anthropogenic greenhouse gas emissions, mainly through the use of energy for the operation of machinery and the production of agrochemicals, methane emissions from livestock and rice cultivation, emissions of nitrous oxide caused by the application of fertilizers, and soil carbon loss owing to conversion of other ecosystems to agriculture, as well as to soil degradation within existing agro-ecosystems [80].

The conversion of natural or semi-natural ecosystems to agriculture typically leads to a decrease in soil organic carbon stocks of about 50-70 %. It has been estimated that the historical expansion of agro-ecosystems has led to a loss of 40-100 Gt of soil carbon in total [27]. Unsustainable practices have led to the degradation of large areas of land, often to the degree of making them unsuitable for further cultivation [81]. At the same time, changes in management practices can also lead to an increase in soil or biomass carbon stocks on lands that are already under agricultural use [17].

The pressure to convert other ecosystems to agriculture is expected to intensify in the coming decades. Accurate prediction is difficult, but it is estimated that demand for agricultural land will increase by between 320 and 850 million hectares by the year 2050 [82]. The ecosystems most likely to be converted are grasslands and savannahs, tropical forests and peatlands [18]. Cropland expansion is largely driven by the increasing demand for agricultural products that stems from a growing human population and changing consumption patterns. In addition, continuing soil degradation and climate change are projected to adversely affect yields on existing agricultural lands [18]. It is expected that many areas will suffer from declining water availability and greater climatic fluctuations, while some areas at high altitudes or latitudes will benefit from rising temperatures.

Achieving a more efficient and sustainable use of existing agricultural land will be key to limiting the need for further expansion. Efforts towards climate change mitigation in agro-ecosystems thus need to consider not only the potential for reducing greenhouse gas emissions or increasing carbon sequestration per unit of land, but also the impacts on total area requirements for commodity production [82].

Intensive farming methods can lead to soil degradation and erosion.
Picture of a farm field in Iowa by Lynn Betts. U.S. Department of Agriculture, Natural Resources Conservation Service.

Options for ecosystem-based mitigation

For the purpose of this document, only those agricultural management options that address greenhouse gas emissions from, and carbon sequestration in, soils and biomass have been identified as ecosystem-based mitigation approaches. Other approaches to mitigation in agriculture, for example through more efficient use of energy and chemical inputs or through better waste management, are beyond its scope. Nevertheless, it is noted that such technological improvements should go hand in hand with the ecosystem-based approaches.

It has been estimated that the total greenhouse gas mitigation potential that would be technically achievable within agriculture corresponds to a net emission reduction of 1.2 to 1.6 Gt C per year by 2030. About 90 % of the identified potential is linked to measures that would enhance soil carbon sequestration [17]. Among the main options for maintaining or increasing soil and biomass carbon stocks are reduced tillage, addition of organic matter to the soil, adjusting crop rotations to include cover crops and fallow periods, combining different crops on the same field, and agroforestry or the inclusion of hedgerows and forest buffers in agricultural landscapes [17] [82]. These practices have the potential not only to enhance the build-up of organic matter, but also to reduce carbon losses through soil erosion, and to contribute to the restoration of degraded agricultural land. An off-site benefit of agroforestry can be to protect carbon stocks in adjacent forest areas by providing sustainable supplies of woody biomass for a variety of uses, including household energy production and construction [83].

As agricultural expansion tends to be one of the main drivers of deforestation and the conversion of grasslands or peatlands, there are generally great opportunities to link mitigation strategies for agriculture with efforts to maintain carbon stocks in these ecosystems.

A first step towards promoting the uptake of more sustainable agricultural practices can be a review of economic and fiscal incentives, in order to identify any ill-designed schemes that could be reformed to support more climate-friendly land management [84]. The recent progress in methods for measuring or estimating carbon stock changes on agricultural lands can be of use for such efforts [85] [86]. The role of property rights regimes in shaping agricultural practices should be considered when addressing incentive design. Better targeting of incentives can also be aligned with efforts to achieve a more efficient allocation of land to different uses through landscape-level planning.

Potential for synergies with adaptation and other policy goals

Mitigation approaches that maintain or enhance soil and biomass carbon stocks in agricultural lands are likely to provide benefits both for current livelihoods and food security and for adaptation to climate change. Increasing soil organic matter not only improves soil fertility, but also enhances water storage capacity, water infiltration, and resistance to soil compaction and erosion. This can create better conditions for the growth of crops, support groundwater recharge, and reduce sediment loads, pollution levels and flood risk in downstream areas [17] [18]. If techniques for improving soil condition are strategically applied in combination with water saving and harvesting practices in order to prevent or reverse land degradation in drylands, they can provide significant economic benefits. They can further help to avoid the environmental damage and potential social conflicts related to displacement of land use, as has been demonstrated in degraded dryland areas of Africa and Asia [87]. Management practices that increase carbon sequestration in biomass, especially agroforestry, can also support food security, income diversification and livelihood stability, while contributing to the protection of soils and improving microclimates [88] [89] [90].

Biodiversity implications

By increasing structural diversity and the diversity of crop species in agricultural landscapes, many approaches for the enhancement of soil and biomass carbon stocks are beneficial for biodiversity, including that of non-cultivated species. Management practices that increase soil organic carbon contents often also support a higher diversity of soil organisms [18]. However, the most important mechanism through which mitigation actions in agro-ecosystems can provide synergies with biodiversity conservation is by reducing pressure on natural ecosystems, as farming on existing agricultural lands becomes more sustainable and yields are maintained or improved. Risks to biodiversity are most likely to arise as an unintended side-effect in cases where the introduction of new and more profitable forms of management eventually provides an economic incentive for further land conversion [91].

Abandoned agricultural lands

Agricultural land may cease to be used for a variety of reasons. It may be required for other purposes, such as housing and infrastructure development; it may become unproductive or unsafe through, for example, loss of topsoil, salinization or contamination; or it may be abandoned for primarily socio-economic reasons. Land abandonment took place at a globally significant scale across large areas of Eastern Europe and Northern and Central Asia following the political and socio-economic changes of the 1990s [92]. It has been estimated that as a result of these, a total of 75 million hectares of cropland went out of use in Russia, Kazakhstan, Ukraine and Belarus. Most of this area has reverted to forest and grassland ecosystems. In doing so it has become an active carbon sink. The average rate of carbon sequestration in vegetation and soils of former cropland during the first 20 years after abandonment has been estimated at 155 million t C per year for Russia and 31 million t C per year for Kazakhstan [93] [94].

If these areas remain uncultivated, sequestration will most likely continue, with a slowly decreasing rate, and carbon stocks close to those of undisturbed forests or grasslands should be reached after about 60–120 years in most regions. However, given that the global demand for agricultural land continues to rise, it is to be expected that many abandoned areas will be returned to agricultural use in the coming decades.

In such a situation, greenhouse gas emissions can be reduced by directing conversion towards areas that have been abandoned more recently and hence had less time to regain their natural levels of carbon stocks. The value of the land for biodiversity and ecosystem services may also be a relevant consideration. Further, there is the potential to avoid emissions by applying sustainable agricultural practices that protect soils and retain soil organic matter as far as possible. Countries with a large share of abandoned lands that are likely to be returned to agricultural use should develop strategies early on to ensure that re-cultivation takes place in an efficient and sustainable way.

Areas for further research

As described above, important progress has been made in recent years in improving the state of knowledge on the global distribution of organic carbon stocks and rates of greenhouse gas flows to and from ecosystems under different land use intensities and in different ecological settings. There are, however, still many areas where better understanding could support the planning of concrete actions that use the potential of ecosystems to contribute to climate change mitigation, biodiversity conservation and sustainable development. Areas for further targeted research include:

- The spatial distribution of soil carbon stocks, especially stocks below 1 m depth in peatlands, permafrost areas and coastal ecosystems;
- The climate impact of non-CO_2 emissions and albedo effects resulting from wildfires, vegetation changes and changes in hydrology, especially in peatlands, grasslands and tundra ecosystems;
- The fate of soil organic matter that is exported from terrestrial and coastal ecosystems as a result of erosion, in particular with a view to assessing the share of eroded carbon that is re-deposited in other locations versus the share that is oxidized and emitted to the atmosphere as carbon dioxide;
- Improvement of models to predict the impacts of climate change and different forms of management on ecosystem services and carbon stocks and flows, both at the global scale and at site level;
- Additional studies to identify good practice for specific approaches to ecosystem-based mitigation, including improvement of land use practices in peatlands that are currently under intensive use, management of grazing by wild and domestic animals in various types of grasslands (also taking into account methane emissions caused by grazing animals), sustainable enhancement of cropland productivity to reduce emissions from agricultural expansion and conversion of other ecosystems, and restoration of mangroves in a way that provides good results for both climate change mitigation and disaster risk reduction;
- Further development of cheap and efficient approaches for estimating and measuring changes in ecosystem carbon stocks for both terrestrial and coastal systems; and
- Scenario analysis of likely impacts on ecosystems of different socio-economic development trajectories, as well as their implications for the feasibility and long-term likelihood of success of ecosystem-based approaches to mitigation.

Working with nature to address climate change – an approach that meets many objectives

A number of international agreements and policy processes related to the environment and sustainable development have called on countries to implement ecosystem-based approaches that contribute to their response to climate change, because this is seen as an important option for achieving their goals. Some examples of relevant decisions include:

- In addition to decisions on mitigation actions in the Land Use, Land Use Change and Forestry sector, the **UN Framework Convention on Climate Change (UNFCCC)** has invited Parties to make use of ecosystem-based approaches to adaptation, and established a database of practical examples.
- The Strategic Plan of the **Convention on Biological Diversity (CBD)** includes a target on contributing to climate change mitigation and adaptation through conservation and restoration of ecosystems; the Conference of the Parties of the CBD has also invited countries to implement ecosystem management activities as a contribution towards achieving the objectives of the UNFCCC.
- The Strategic Plan of the **UN Convention to Combat Desertification** calls on Parties to introduce or strengthen mutually reinforcing measures to address desertification and land degradation and climate change mitigation and adaptation, while also addressing biodiversity issues.
- The **Ramsar Convention on Wetlands** has invited its Parties to undertake action on peatlands and climate change, including by improving the available information on carbon sequestration in peatlands and on good practice in peatland restoration.
- The **Sendai Framework** for Disaster Risk Reduction calls on countries to strengthen the sustainable use and management of ecosystems and implement integrated environmental and natural resource management approaches that incorporate disaster risk reduction.

Because of the many additional benefits that ecosystem-based approaches to climate change can provide, it is likely that actions of the type outlined in this document will also contribute to the implementation of other environmental, social and development-related policies, including at the national and subnational level.

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Terrestrial and coastal ecosystems hold more than five times as much carbon as is currently in the atmosphere. Carbon emissions from land use change and degradation, as well as carbon uptake in intact or recovering ecosystems, are major processes in the global carbon cycle. The way we use and manage ecosystems therefore has large implications for the success of efforts to mitigate climate change.

An ecosystem-based approach to climate change mitigation can draw on forms of land use that maintain carbon stocks and allow additional carbon to be taken up from the atmosphere. Often, such forms of land use also support climate change adaptation, disaster risk reduction and sustainable development, and are beneficial for biodiversity.

This briefing note aims to assist decision-makers and technical staff who are involved in the design of biodiversity policies and are interested in promoting synergies with policies addressing climate change. It may also be of interest to those working on climate and land use policies, and the planning or funding of measures to address these issues.

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