Convention on Wetlands

Ramsar

Wetland Restoration for Climate Change Resilience

Purpose

This Briefing Note aims to support wetland managers by highlighting the benefits for climate mitigation and adaptation of restoring wetlands and managing them effectively.

Background

The Scientific and Technical Review Panel (STRP) of the Ramsar Convention on Wetlands recommended in its 2016-2018 work plan the development of a Briefing Note highlighting the reasons and potential for restoring wetlands in the context of a changing climate, building on Ramsar Briefing Note No.4: *The benefits of wetland restoration*. The Standing Committee identified this as one of the STRP's highest priority tasks.

As the climate continues to change, our ability to adapt will depend on our ability to put in place a range of responses. Key among these are the wise use of wetlands and the restoration of degraded wetlands. Harnessing the natural capacity of wetlands to buffer communities against the adverse effects of climate change can increase climate resilience.

This Briefing Note highlights key information from recent reports on wetlands and climate change mitigation and adaptation. It includes assessments of carbon uptake and storage, which find that the continuing loss and degradation of wetlands has resulted in significant losses of their stored carbon to the atmosphere. Evidence of the value of wetlands in reducing disaster risk is reviewed, showing that the loss of wetlands is associated with greater human and ecological impacts, and economic costs. It also includes a discussion of approaches to wetland restoration to help recover these benefits. It uses the term restoration in the broadest sense of the Ramsar Convention, which includes both projects that aim to return sites to their original conditions and projects that improve wetland functions without necessarily promoting a return to pre-disturbance conditions.

Key messages

1. **The wise use and restoration of wetlands is essential to protect stored carbon and reduce avoidable carbon emissions.** Wetlands are globally important carbon sinks, storing vast amounts of carbon and thereby helping to mitigate climate change. Peatlands hold a disproportionate amount of the earth's soil carbon, and coastal wetlands such as mangroves, salt marshes and sea grass beds are vital for the sequestration of "blue carbon". Together, they store more carbon than all of the world's forests combined.
2. **Prioritizing wetland protection and restoration can enhance climate adaptation and resilience.** As extreme weather events such as storms, flooding, droughts and heat waves increase in frequency, wetland protection and restoration increases climate resilience by buffering communities from coastal storm surges, reducing wave damage and floods, and stabilizing shorelines, water supplies and local microclimates. As such, wetlands are a critical part of ecosystem-based adaptation practices designed to build community resilience and reduce disaster risk.

www.ramsar.org

Relevant Ramsar documents

Recommendation 4.1: *Wetland restoration*

Recommendation 6.15: *Restoration of wetlands*

Resolution VII.17: *Restoration as an element of national planning for wetland conservation and wise use*

Resolution VIII.16: *Principles and guidelines for wetland restoration*

Resolution XII.11: *Peatlands, climate change and wise use: Implications for the Ramsar Convention*

Briefing Note No.4: *The benefits of wetland restoration*

3. **Wetlands play a vital role in retaining water on the landscape, maintaining local climate and water cycles and reducing temperature extremes.** Wetlands store water from precipitation and slowly release it to the surrounding environment, which can also recharge groundwater aquifers and maintain atmospheric water cycles. Evaporation and the transpiration of water from vegetation have a local cooling effect. Draining wetlands reduces local water storage and can lead to increases in local daytime temperatures.
4. **Protecting and restoring wetlands to increase climate mitigation and resilience delivers many co-benefits.** Wetland conservation and restoration help protect against the effects of a changing climate. However, there are many other ecological, cultural and socio-economic benefits that wetlands provide that contribute to human wellbeing, such as the provision of food, energy and clean water, support to livelihoods and biodiversity, and sites of spiritual and cultural importance. Identifying and valuing the full suite of wetland ecosystem services provide a strong rationale for restoration.
5. **Protecting and restoring wetlands for climate mitigation and adaptation reflects a key tenet of Ramsar's Strategic Plan and represents progress towards meeting the Sustainable Development Goals and the Paris Agreement on Climate Change.** Efforts to protect and restore wetlands and promote their wise use will help countries achieve Nationally Determined Contributions under the Paris Agreement on climate change, and contribute towards the SDGs, Aichi Targets and other important global policy goals.

Box 1. Key terms used in climate change assessments

Greenhouse gas balance is the contribution of net carbon dioxide (CO2) and methane (CH4) uptake or release to global warming. One molecule of CH4 contributes approximately 34 times as much to global warming as one molecule of CO2 (IPCC 2013a). The greenhouse gas balance is expressed in CO2-equivalents per area and time.

Methane emission rate is the CH4 release per area per time. Methane emission rates vary strongly in time and across ecosystem types. As the production of CH4 is suppressed in the presence of sulfate, saltwater and brackish systems tend to have much lower methane release rates than freshwater systems. In the presence of oxygenated topsoil, methane oxidation may occur, resulting in negative methane emission rates.

Carbon sequestration is the removal of carbon from the atmosphere and its storage in an ecosystem in a given area over a given time. This is caused by biological processes such as photosynthesis.

A *carbon sink* results from the long term (of at least one year) sequestration of carbon by an ecosystem (i.e., more carbon is taken up than is released). Living and dead vegetation, as well as soil carbon, constitute the carbon sink.

Carbon stock is the total carbon stored in an ecosystem, regardless of the time it took to build up this stock.

Introduction

The earth's climate is changing at an unprecedented rate. The effects of a changing climate are many and vary by location, with intensifying storm activity, rising sea levels and more frequent floods and droughts predicted (IPCC, 2013b). Globally, the risks of climate-related disasters are increasing, and an estimated 90% of disasters are estimated to be water-related (UNISDR, 2015). Costs are high: between 2006 and 2015, the proportion of lives lost due to weather- and climate-related disasters increased from 40% to nearly 49% of lives lost due to natural hazards (UNISDR, 2015; see also Kumar *et al.* 2017). The need for strategies to mitigate climate change and adapt to its changing conditions has become urgent.

The protection and restoration of wetlands is a key component of the measures needed to mitigate climate change and reduce disaster risks. Wetlands, particularly peatlands and coastal systems (salt marshes, mangroves and sea grasses), store vast amounts of carbon, both in plant biomass and especially in their soils. The drainage or conversion (loss) of wetlands not only reduces their ability to take up and store carbon, but can cause large quantities of previously accumulated carbon to be lost, moving it from the soil to the atmosphere as carbon dioxide (CO2).

Wetlands also increase the resilience of communities to damage caused by storms and extreme weather. Many types of wetlands, such as mangroves, floodplains, coral reefs and coastal peatlands are natural buffers against weather hazards, and wetland loss and degradation in many regions is strongly linked to increases in climate-related impacts.

Wetland loss and degradation

The global extent of wetlands is estimated to have declined by between 64% and 71% in the 20th century (Davidson, 2014). Over the long term, inland wetlands have declined more rapidly (averaging 61% loss) than coastal wetlands (46% lost). Wetland area has declined in all regions, by 12% in Oceania and as much as 59% in Latin America, and recent data shows that about 35% of inland and marine/coastal wetlands were lost between 1970 and 2015 (Ramsar Convention on Wetlands, 2018). The rate of loss has been increasing, with the rate in the past century estimated to be 3.7 times greater than in previous centuries (Davidson, 2014). Impacts on ecosystem services include decreased rates of carbon sequestration, reduced protection of coastal zones, increasing flood flows, more variable water supplies, and the loss of habitat for fisheries (Duarte *et al.* 2013).

Wetlands as high-carbon ecosystems

Wetland soils contain a disproportionate share of the earth's total carbon. Although they occupy only between 5% and 8% of the earth's total land surface, their soils hold 35% or more of the estimated 1,500 gigatons (Gt, or billion metric tonnes) of organic carbon that is stored in soils (Mitsch & Gosselink, 2015).

Wetlands International, a partner of the Ramsar Convention on Wetlands, has established a fund for community-based peatland restoration initiatives called the Indonesian Peatlands Partnership Fund (IPPF). On the picture: Peatland restoration by local community in Indonesia, blocking drainage channel

Wetland plants take up carbon via photosynthesis and build plant biomass, which can accumulate in the soil as organic matter. Wetlands also release carbon to the atmosphere in the form of the greenhouse gases CO2 and CH4 (methane). The balance between carbon uptake and release varies by wetland type and determines their ability to act as a carbon sink (Table 1).

Figure 1
Carbon take-up and release by coastal wetlands
Intact coastal wetlands (from left to right, mangroves, tidal marshes and sea-grasses) take up carbon (green arrows) where it is sequestered for the long term in woody biomass and soil (red arrows) or respired back to the atmosphere (black arrows). When they are drained, deforested, dredged or converted for agriculture, the carbon stored in the soils is released as CO2. *(Howard et al. 2017)*.

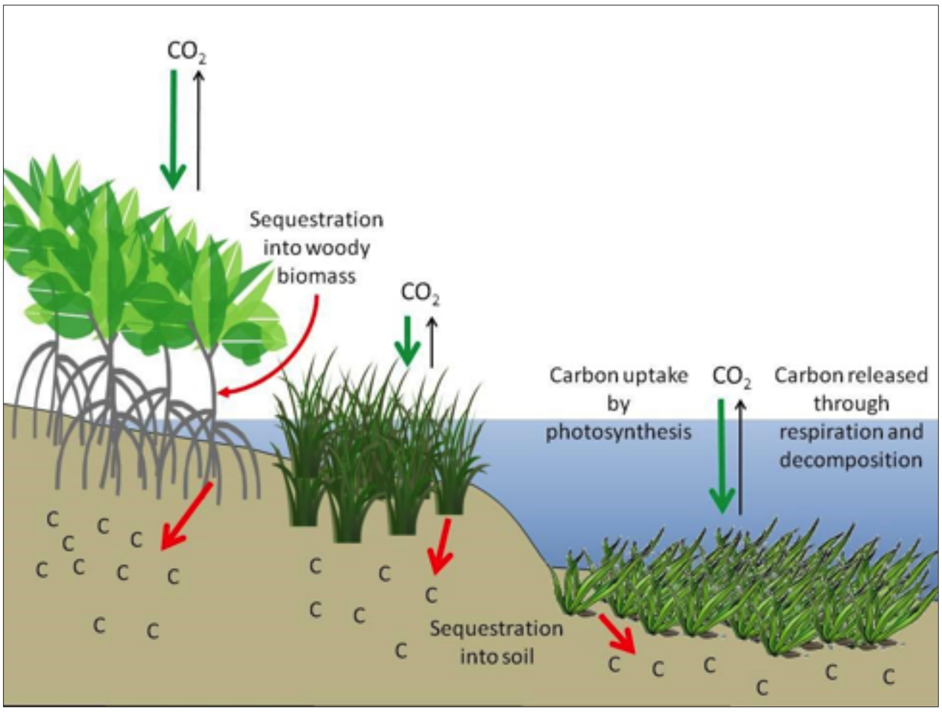


Table 1: **Relative rates of carbon fluxes and capacity to build long-term carbon stocks for different wetland types**

Wetland Type	Soil Carbon Sequestration Rate	Methane Emission Rate	Ability to act as Net GHG Sink	Long Term Carbon Stocks
Salt Marsh	High	Low	High	High
Mangrove	High	Low to High	Moderate to High	High
Freshwater Tidal Marsh	High	High	Low	Moderate
Estuarine Forest	High	Low	High	Moderate
Sea grass Bed	High	Low	High	High
Tropical Peatland	Low	Moderate to High	Moderate	Very High
Temperate-Boreal Peatland	Low	Moderate to High	Moderate	Very High
Inland Freshwater Mineral Soil Wetlands	Low to High	Moderate to High	Low to Moderate	Low to Moderate
Forested Freshwater Wetlands	High	Moderate	Moderate	Very High

Adapted from Crooks et al. 2011. Note that there may be some overlap in the wetland types shown.

Peatlands

Peatlands excel at carbon storage. They are considered carbon “hot-spots”, holding the largest long-term store of carbon of any ecosystem type (Joosten *et al.* 2016). Peat typically accumulates over thousands of years, making it the most space-effective stock of organic carbon in the biosphere. They are found in 90% of the world’s countries. They cover only about 3% of earth’s land surface, yet they hold twice as much carbon as all of the world’s forests combined; estimated at between 180 and 450 Gt globally (Joosten *et al.* 2016). In total, peatlands make up over 30% of inland wetlands (Ramsar Convention on Wetlands, 2018). Northern peatlands are the largest in area (4 million square kilometres (Yu, 2012), concentrated in North America and Eurasia, while tropical peatlands make up at least 10 to 12% of the total peatland resource (Joosten, 2016). Estimates of the extent of tropical peatlands are rising as new areas are discovered, such as the Cuvette Centrale depression in central Congo, where a wetland complex covering 145,500 km2 holds an estimated 30.6 Gt of carbon (Dargie *et al.* 2017). The largest peatland, found in Western Siberia, is the size of France and Germany combined and holds billions of tons of carbon (MacDonald *et al.* 2006). Because they provide an enormous long-term carbon sink, undisturbed peatlands are a critical global asset in the effort to regulate climate.

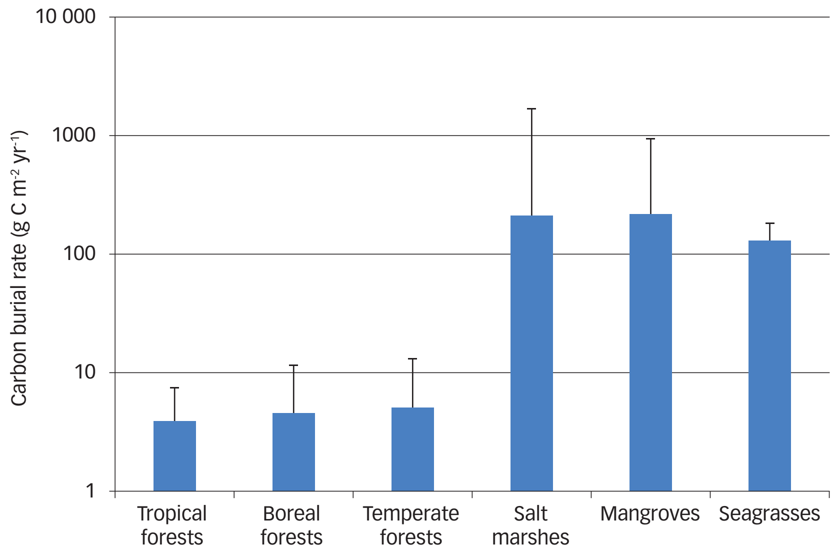
Coastal wetlands and blue carbon

Coastal wetlands (with a focus on intertidal sites) also excel at sequestration, of what is called “blue carbon” (McLeod *et al.* 2011). Blue carbon is the high-density carbon that accumulates in coastal systems as a result of their high productivity and sediment-trapping ability. Estimates show that that the rate of carbon sequestration in coastal wetlands is greater than in all of the terrestrial forests combined, despite forests having a much larger area (Figure 2) (McLeod *et al.* 2011). On average, sea grasses, saltmarshes and mangroves sequester carbon 35 to 57 times faster than tropical forests (Mcleod *et al.* 2011).

The world’s tidal salt marshes store an estimated 437 to 1,210 million tonnes of carbon in their vegetation and soils (Siikamäki *et al.* 2012), while mangroves store an estimated 5 Gt of carbon (Chmura *et al.* 2003).

Carbon storage in mangroves is exceptionally high compared with most forest types. Mangroves may sequester carbon in the form of organic soil and peat. A study of mangroves in desert inlets on the coast of Baja California (Ezcurra *et al.* 2016) shows that organic soils have been accumulating for nearly 2,000 years and harbour an average below-ground carbon content of 1,130 (± 128) metric tonnes of carbon per hectare. Another study found a mean storage of 968 metric tonnes of carbon per hectare, to a depth of 5 meters or more (Murdiyarso *et al.* 2009; Donato *et al.* 2011).

Figure 2
Average annual rates of soil carbon sequestration in terrestrial forests compared to coastal wetlands. Error bars indicate maximum rates recorded for each ecosystem type (note the logarithmic scale on the y-axis; from McLeod *et al.* 2011).



Carbon emissions through wetland drainage and degradation

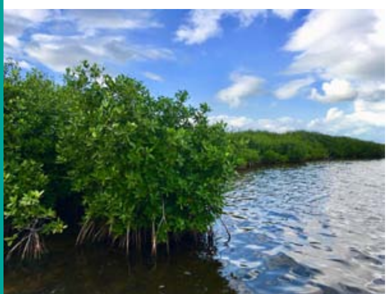
Peatland losses

Drained or damaged wetlands are a major source of greenhouse gas emissions. Human disturbance, particularly drainage, releases carbon in CO_2, leading in years to the loss of carbon that accumulated over centuries or millennia. Current rates of release are equivalent to nearly 6% of global human CO_2 emissions (Joosten *et al.* 2016).

In the tropics, forested peat domes, where peat accumulates into thick, dome-shaped expanses, have been subject to clearing and agriculture, with many deforested for paper production, then drained and replanted with palm oil plantations. This liberates large quantities of carbon and makes them vulnerable to wildfires that, once started, can burn for years (Figure 3; Bell, 2016). Recent peat fires in Indonesia made it the third largest emitter of CO_2 globally, behind China and the United States (Biello, 2009). Approximately 65 million ha (or 15%) of the world's peatlands have been drained due to agriculture, grazing, peat mining and bioenergy production (Biello, 2009). The total CO_2 emissions from drained peatlands, in combination with releases from peat fires (mainly in Southeast Asia, Russia and Canada), are estimated at over 3 Gt of CO_2 per year (Biello, 2009).

Coastal wetland losses

Drainage or conversion of coastal wetlands is widespread, particularly for agricultural use. Between 1970 and 2015, 35% of the total global area of mangroves was cleared and drained (Ramsar Convention on Wetlands, 2018). Aquaculture is a driver of wetland loss, as mangrove forests are converted to shrimp ponds that subsequently become emitters of CO_2. Shrimp ponds in Southeast Asia, for example, release an estimated 5.8 to 14 million tonnes CO_2 per year, which is comparable to the greenhouse gas emissions from the conversion of forested peatlands in Indonesia (Sidik &Lovelock, 2013). In total, emissions from mangrove conversion account for nearly one fifth of the total global emissions from deforestation, resulting in damages costing between USD 6 billion and USD 42 billion annually (UNEP, 2014).



Manglares de Nichupté, These dense strips of mangrove protect inland areas against hurricanes and storms. Ecological restoration work has led to an average survival rate of 91% of mangrove introduced through reforestation.

Restoration to reduce emissions and enhance carbon stocks

Peatland restoration

Restoring wetlands using techniques such as rewetting peatlands to raise the water table and re-saturate 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.

Best practices for peatland restoration include the following:

- Rewetting can be accomplished using simple methods to reestablish hydrology. Installing weirs or blocking drains and ditches to prevent water leaving the site can be effective over relatively small areas but can be difficult to accomplish over large, drained peatland expanses. Blocking larger canals and drainage ways within a site can rewet larger areas. Typically, a series of plugs are needed to disperse water (Dommain *et al.* 2010). In any project, the local landscape and hydrology must be integrated into restoration planning.
- Paludiculture[1], or the rewetting of former drained peatlands for wet cultivation, is a means to incentivize restoration by governments and the private sector. Typically, paludiculture focuses on reed mowing and biomass production for fuel, with the protection of peat as the primary goal. Sphagnum farming for horticultural uses may also be permitted on rewetted bogs in order to reduce mining of intact systems. Benefits include protection of stored

1 See Resolution X.25: Wetlands and "biofuels".

More than 150 million mangrove trees have been planted in approximately 500 villages in the Sine Saloum delta and in the Casamance. This result makes it the largest example of mangrove reforestation in the world. In total, almost 12,000 hectares of mangrove have been restored by the people of Senegal.

carbon, the provision of renewable fuels and the protection of biodiversity and cultural practices (Wichtmann *et al*. 2016).

- The benefits of wet cultivation practices in protecting organic soils extend to other wetland types, for example, wet meadows for grazing and mowing, floodplain forestry and reed and willow production.
- The most effective long-term strategy for restoration is community-based engagement, at all stages of a project from the design to implementation. This promotes local stewardship through the use of local knowledge and builds capacity for effective management within communities.
- The Ramsar Convention on Wetlands recognizes[2] the value of peatlands for climate change mitigation, maintaining biodiversity and other ecosystem services, emphasizing that in any restoration plan it is important to incorporate the principles of wise use to promote sustainable management.

Rewetting degraded peatlands significantly reduces carbon emissions from soils as waterlogging slows peat oxidation and allows vegetation to re-establish. Although rewetting may lead to an initial increase in methane emissions, those emissions tend to decrease over the first few years to levels consistent with undisturbed natural sites (IPCC, 2013a; Joosten *et al.* 2016). Rewetting also reduces the emissions of nitrous oxide, another potent greenhouse gas.

Research has shown that, compared to degraded sites, restored peatlands have lower carbon emission rates and over time, can become net carbon sinks (Joosten *et al.* 2016). In a project to restore peat swamps around Moscow that burned in a 2010 heatwave, 35,000 ha are being restored by blocking drains and replanting vegetation, and CO_2 emissions have decreased by 200,00 tonnes of carbon per year as a result (Pearce, 2017).

Table 2. **Reduction of GHG emissions from peatlands drained for different human activities after rewetting**

Human land use on drained peatlands	Reduction in carbon emissions after rewetting (tonnes CO_2 ha^{-1} yr^{-1})	
	Temperate zone	Boreal zone
Forest	6	2
Cropland	28	34
Grassland	20	25
Peat	9	11

From Barthelmes et al. 2015.

Restoring coastal wetlands for blue carbon storage

The restoration of coastal wetlands has the potential to decrease greenhouse gas emissions, increase rates of carbon sequestration and build long-term carbon stocks, as well as provide other ecosystem services related to disaster risk reduction. Research has been underway for several decades, and projects are increasingly extensive (1,000 ha to 5,000 ha; Crooks *et al.* 2011) in order to create substantial regional benefits.

2 See Resolution XII.11: *Peatlands, climate change and wise use: Implications for the Ramsar Convention and Resolution* VIII.17: *Principles and guidelines for wetland restoration.*

Restored coastal marshes begin accumulating carbon almost immediately, at rates equivalent to natural reference sites, although they may lag in total carbon storage, which takes longer to rebuild (Craft *et al.* 2003). The outcomes of mangrove restoration vary, but recent studies show that following mangrove re-forestation, soil carbon concentrations increase significantly with forest age. Soil carbon stocks can reach the level of natural sites within ten years of restoration, despite lower tree biomass in the restored sites (Delvecchia *et al.* 2014).

Best practices for coastal wetland restoration include:

- In tidal marsh restoration, the tidal regime and land elevation are critical parameters because they determine the extent, duration and timing of submergence. This is essential for success because they largely determine how much sediment deposition or erosion will occur, which in turn determines if a site can adjust to rising sea levels.
- Restoring and managing water levels, capturing the full range of tidal exchange to promote vegetation reestablishment and sediment trapping, and planning restoration in the context of the surrounding landscape adds resilience to the restored site and assists in the recovery of the processes that lead to carbon accumulation.

It is important to also note the value of inland freshwater wetlands for carbon uptake and storage. Less attention has been paid to freshwater inland sites which, in the United States of America for example, hold about five times as much carbon as the U.S.A.'s coastal wetlands, due to their much larger extent (Nahlik & Fennessy, 2016). On a regional basis, wetlands may contain disproportionately large carbon stocks that might be targets for the implementation of policies related to climate protection.

Wetlands for disaster risk reduction

Coastal wetlands

The frequency of natural disasters has doubled over the past 35 years, and the majority of those disasters are water-related. Coastal communities are among those most at risk from increasingly frequent natural disasters, including storm surges, flooding and inundation from sea level rise. Some 40 million people live in flood-prone coastal cities, and this figure is projected to rise to 150 million by 2070 (Temmerman *et al.* 2013). Salt marshes and mangroves arguably provide the best natural defense. For instance, narrow bands of mangrove forest along a coastline can decrease wave height and energy, by an average of between 13% and 66% over a distance of 100 metres, preventing wave damage and erosion during high tides.

Rates of sea level rise are expected to increase by as much as a metre over the next century (IPCC, 2013b). Because coastal wetlands accrete vertically (accumulating carbon as they do so), they are able to keep pace with rising sea levels, protecting human activities further inland (Church *et al.* 2001).

Wetland restoration and management techniques are critical to ecosystem-based adaptation practices designed to build community resilience and reduce disaster risk. They are generally more sustainable, cost effective and ecologically sound than conventional hard engineering practices (Temmerman *et al.* 2013). The construction of sea walls, groynes or dikes is often seen as the solution to mitigate flood risks. However, their usefulness can be limited by the costs and challenges of maintenance, and the need to expand engineering defenses as storm intensity increases. In addition, these physical structures alter the natural patterns of sediment accumulation, reducing the ability of coastal zones to keep pace with sea level rise, further increasing risk (Temmerman *et al.* 2013).

Wetland restoration not only reduces human vulnerability to weather-related events, but also provides important co-benefits. For example, mangrove restoration not only offers protection from storm surges and enhances carbon sequestration, but it also provides habitat for a wealth of species, increases fish and shellfish production, creating livelihood opportunities and thereby counters poverty (Lo, 2016). Utilization of wetland ecosystem-based adaptation employs the principles of ecological engineering which approach restoration with the goal of "integrating human society with its natural environment for the benefit of both" (Cheong *et al.* 2013, Mitsch & Jorgensen, 1989).

---

3 See: https://www.seacology.org/project/sri-lanka-mangrove-conservation-project/ 2017.

Substantial mangrove restoration efforts are taking place in Sri Lanka, which has the goal of becoming the first nation in the world to protect all its mangroves by protecting 8,815 hectares and restoring 3,880 additional hectares. Funds are also designated to establish a training and microfinance program to support business start-ups by women in local communities in return for their protection of the mangrove forests[3].

Inland wetlands

Inland wetlands (including freshwater peatlands) provide a host of ecosystem services that mitigate climate change and reduce disaster risks, including flood protection and the moderation of local climates, regulation of local water cycles and maintenance of water supplies.

Floodplain and riparian wetlands protect downstream areas from flooding and the erosive impact of storms, by storing runoff and reducing peak flows. Many inland floods are exacerbated by engineering measures to channel rivers and the destruction of wetlands from the surrounding landscape. This leads to shorter river lengths and the loss of wetlands that serve as water retention areas (Mitsch and Gosselink, 2015). The economic benefits of restoring floodplain wetlands can be high. During a recent tropical storm, wetlands and floodplains in the Otter Creek watershed in Vermont, U.S.A., reduced flood damage by an estimated 84% to 95%, saving between USD 126,000 and 450,000 in clean-up costs (Watson *et al.* 2016).

Inland wetlands affect local climate, and their loss and degradation can adversely affect climatic conditions (Figure 4). Draining wetlands and clearing vegetation increases temperatures by lowering the surface albedo (reflectiveness), and so increasing the solar energy absorbed (Foley *et al.* 2003). The evapotranspiration of water from wetlands dissipates large amounts of energy (up to 70% of incoming solar energy is stored in the water vapour in the form of latent heat which is released when water condenses on cooler surfaces) while in dry landscapes the majority of solar energy is transformed into sensible heat. The loss of water storage on the landscape can significantly increase local daytime temperatures and may reduce annual rainfall (Pokorný *et al.* 2010a, b). The impact can be substantial, particularly at higher latitudes (between 45 to 90 degrees), where changing land cover overall may increase warming by an additional 1.6 degrees Celsius above the 3.3 degrees predicted from a doubling of atmospheric CO2 (Costa & Foley, 2000).

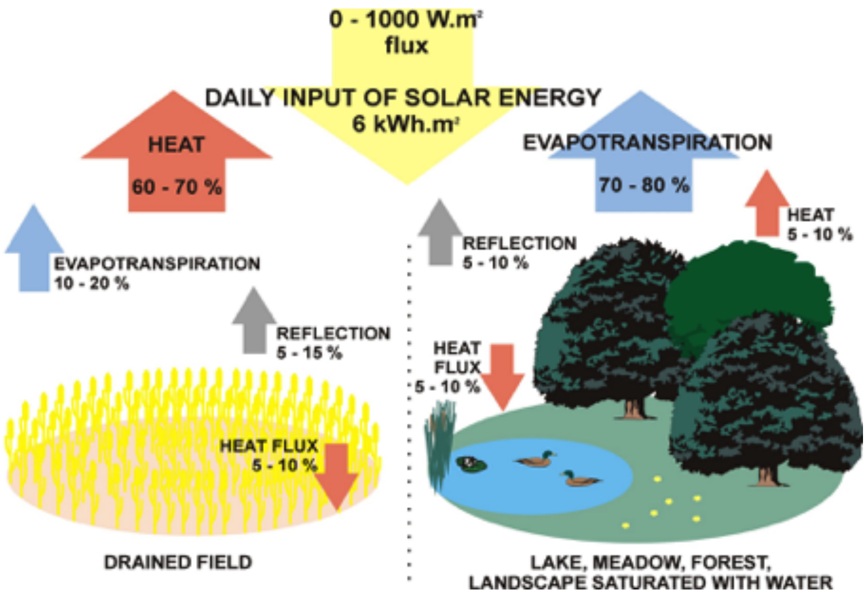


Figure 3
The dissipation of solar energy. A comparison of heat flows over a drained wheat field and a wetland. Note the differences in solar energy transformation into sensible heat, reaching up to 60% to70% over a drained crop field compared to only 5% to10% over an intact wetland. In wetland landscapes, 70% to 80% of heat is dissipated via evapotranspiration. (Based on data measured in Trebon, Czech Republic. Source: Pokorný *et al.* 2010b).

Restoring floodplain and other inland wetlands as green infrastructure has the potential to decrease flooding and flood damages, improve water quality, and moderate local climates. Strategies for restoration depend on the causes of the wetland loss or degradation. In areas where hydrologic alteration is high it may be necessary to plug ditches, remove agricultural or urban drainage structures, and reconnect wetlands and rivers. Past efforts to dewater the landscape may necessitate the restoration of environmental flows to support the full complement of wetland biodiversity and ecosystem services. Large inland restoration projects are currently underway in all Ramsar regions, for example a project to reconnect wetlands to the Yangtze River to reduce flood damages in China (Kumar *et al.* 2017).

Best practices for inland wetland restoration include:

- Planning for restoration at the catchment scale includes connecting floodplains with their rivers and streams to restore the hydrologic benefits of wetlands by reestablishing the natural pattern of floodplain inundation (Craft, 2016). Restoring wetlands not adjacent to rivers can be planned to take advantage of remnant wetland soils and water sources within a catchment basin to maximize the re-establishment of ecosystem services.
- Where possible, engineering techniques should be minimized. Planning restoration to take advantage of the principles of self-design by allowing natural ecological processes to dominate the restoration process and allowing for passive management can lead to resilient ecosystems and minimize costs (Craft, 2016).
- In urban areas, wetland restoration can form a network of sites that benefit human well-being while mitigating flood and climate risks, and recycling water (Niemela *et al*. 2010).

Authors
Fennessy, S.M., Philip and Sheila Jordan Professor of Biology and Environmental Studies, Kenyon College, and Lei, G., Dean, School of Nature Conservation, Beijing Forestry University, Beijing, China.

Citation
Fennessy, S.M. & Lei, G. (2018). *Wetland restoration for climate change resilience*. Ramsar Briefing Note No.10. Gland, Switzerland: Ramsar Convention Secretariat.

References

- Alexander, S. & McInnes, R. (2012). *The benefits of wetland restoration*. Ramsar Briefing Note No. 4. Gland, Switzerland: Ramsar Convention Secretariat. Available at: https://www.ramsar.org/resources/ramsar-briefing-notes.
- Barthelmes, A., Couwenberg, J., Risager, M., Tegetmeyer, C. & Joosten., H. (2015). *Peatlands and Climate in a Ramsar Context: A Nordic-Baltic perspective*. Copenhagen, Denmark: TemaNord, Nordic Council of Ministers, Denmark. Available at: http://norden.diva-portal.org/smash/get/diva2:814147/FULLTEXT02.pdf.
- Bell., L. (2016). *SE Asia's damaged peat swamps could release 8.7 gigatons of CO2*. Mongabay Series. Available at: https://news.mongabay.com/2016/05 /se-asias-damaged-peat-swamps-could-release-8-7-gigatons-of-co2/
- Biello., D. (2009). *Peat and Repeat: Can Major Carbon Sinks Be Restored by Rewetting the World's Drained Bogs?* Scientific American. Available at: https://www.scientificamerican.com/article/peat-and-repeat-rewetting-carbon-sinks/.
- Cheong, S.-M., Silliman, B., Wong, P. P., van Wesenbeeck, B., Kim, C.-K., & Guannel, G. (2013). Coastal adaptation with ecological engineering. *Nature Climate Change*, 3(9), 787–791. https://doi.org/10.1038/nclimate1854
- Chmura, G. L., Anisfeld, S. C., Cahoon, D. R. & Lynch, J. C. (2003). Global carbon sequestration in tidal, saline wetland soils. *Global Biogeochemical Cycles*, 17 (12). Available at: file:///C:/Users/BonellsM/Downloads/Chmura_et_al-2003-Global_Biogeochemical_Cycles.pdf.
- Church, J. A., Gregory, J. M., Huybrechts, P., Kuhn, M., Lambeck, K., Nhuan, M. T., Qin, D. & Woodworth, P. L. (2001). Changes in sea level. In Houghton, J.T., Ding, Y., Griggs, D.J. Noguer, M., van der Linden, P.J., Dai, X., Maskell, K. & Johnson, C.A. (eds.). (2001). *Climate Change 2001: The Scientific Basis Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)*. New York: Cambridge University Press. Available at: https://www.ipcc.ch/ipccreports/tar/wg1/pdf/TAR-11.PDF.
- Costa, M. H., & Foley, J. A. (2000). Combined Effects of Deforestation and Doubled Atmospheric CO2 Concentrations on the Climate of Amazonia. *Journal of Climate*, *13*(1), 18–34. Available at: https://journals.ametsoc.org/doi/pdf/10.1175/1520-0442%282000%29013%3C0018%3ACEODAD%3E2.0.CO%3B2.
- Craft, C. (2016). Creating and Restoring Wetlands. Amsterdam, Netherlands. Elsevier Publishing.
- Craft, C., Megonigal, P., Broome, S., Stevenson, J., Freese, R., Cornell, J., Zheng, L. & Sacco, J. (2003). The pace of ecosystem development of constructed *Spartina alterniflora* marshes. *Ecological Applications*, 13 (5), 1417-1432.
- Crooks, S., Herr, D., Tamelander, J., Laffoley, D. & Vandever, J. (2011). *Mitigating Climate Change through Restoration and Management of Coastal Wetlands and Near-shore Marine Ecosystems: Challenges and Opportunities*. Environment Department Paper No.121. Washington, D.C., U.S.A.: World Bank.
- Dargie, G.C., Lewis, S., Lawson, I., Mitchard, E.T., Page, S., Bocko, Y. & Ifo, S. (2017). Age, extent and carbon storage of the central Congo Basin peatland complex. *Nature*, 542, 86-90.
- Davidson, N.C. (2014). How much wetland has the world lost? Long-term and recent trends in global wetland area. *Marine and Freshwater Research*, 65, 934-941. http://dx.doi.org/10.1071/MF14173
- DelVecchia, A. G., Bruno, J. F., Benninger, L., Alperin, M., Banerjee, O. & de Dios Morales, J. (2014). Organic carbon inventories in natural and restored Ecuadorian mangrove forests. *PeerJ* 2:e388. Available at: https://peerj.com/articles/388.pdf.
- Dommain, R., Couwenberg, J. & Joosten, H. (2010). Hydrological self-regulation of domed peatlands in south-east Asia and consequences for conservation and restoration. In *Mires and Peat*, Volume 6, Article 05, 1–17. http://mires-and-peat.net/pages/volumes/map06/map0605.php.
- Donato, D.C., Kauffman, J.B., Murdiyarso, D., Kurnianto, S., Stidham, M. & Kanninen, M. (2011). Mangroves among the most carbon-rich forests in the tropics. *Nature Geoscience*, 4, 293–297.
- Duarte, C. M., Losada, I., Hendricks, I., Mazarrasa, I. & Marba, N. (2013). The role of coastal plant communities for climate change mitigation and adaptation. *Nature Climate Change*, 3, 961-968.
- Ezcurra, P., Ezcurra, E., Garcillán, P. P., Costa, M. & Aburto-Oropeza, O. (2016). Coastal landforms and accumulation of mangrove peat increase carbon sequestration and storage. *Proceedings of the National Academy of Sciences*, 113 (16), 4404, 4409. DOI:10.1073/pnas.1519774113.
- Foley, J., Costa, M., Delire, C., Ramankutty, N. & Snyder, P. (2003). Green surprise? How terrestrial ecosystems could affect earth's climate. *Front. Ecol. Environ.* 1: 38-44.
- Howard, J., Sutton-Grier, A., Herr, D., Kleypas, J., Landis, E., Mcleod, E., Pidgeon, E. & Simpson, S. (2017). Clarifying the role of coastal and marine systems in climate mitigation. *Front Ecol Environ*,15, 1–9. Doi: 10.1002/fee.1451.
- Iftekhar, M. S. & Takama, T. (2008). Perceptions of biodiversity, environmental services, and conservation of planted mangroves: A case study on Nijhum Dwip Island, Bangladesh. *Wetlands Ecology and Management* 16 (2), 119–137. https://doi.org/10.1007/s11273-007-9060-8.
- Intergovernmental Panel on Climate Change (IPCC). (2013a). *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands*. Hiraishi, T., Krug, T., Tanabe, K., Srivastava, N., Baasansuren, J., Fukuda, M. & Troxler, T. (eds). Geneva, Switzerland: IPCC. Available at: https://www.ipcc-nggip.iges.or.jp/public/wetlands/pdf/Wetlands_Supplement_Entire_Report.pdf.
- Intergovernmental Panel on Climate Change (IPCC). (2013b). *Climate Change 2013: The Physical Science Basis, Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V. & Midgley, P.M. (eds.). Cambridge, U.K.: Cambridge University Press. Available at: http://www.ipcc.ch/report/ar5/wg1/.
- Joosten, H. (2016). Peatlands across the globe. In Bonn, A., Allott, T., Evans, M., Joosten, H., Stoneman, R. (eds.). *Peatland Restoration and Ecosystem Services*. Cambridge, U.K.: Cambridge University Press.
- Joosten, H., Sirin, A., Couwenberg, J., Laine, J. & Smith, P. (2016). The role of peatlands in climate regulation. In Bonn, A., Allott, T., Evans, M., Joosten, H. & Stoneman, R. (eds.). *Peatland Restoration and Ecosystem Services*. Cambridge, U.K.: Cambridge University Press.
- Kumar, R., Tol, S., McInnes, R. J., Everard, M. & Kulindwa, A.A. (2017). *Wetlands for disaster risk reduction: Effective choices for resilient communities*. Ramsar Policy Brief No. 1. Gland, Switzerland: Ramsar Convention Secretariat.
- Lo, V. (2016). *Synthesis report on experiences with ecosystem-based approaches to climate change adaptation and disaster risk reduction*. Technical Series No.85. Montreal, Canada: Secretariat of the Convention on Biological Diversity. Available at: https://www.cbd.int/doc/publications/cbd-ts-85-en.pdf.
- McLeod, E., Chmura, G. L., Bouillon, S., Salm, R., Björk, M., Duarte, C. M., Lovelock, C.E., Schlesinger, W.H. & Silliman, B. R. (2011). A blueprint for blue carbon: Toward an improved understanding of the role of vegetated coastal habitats in sequestering CO2. *Frontiers in Ecology and the Environment*, 9(10), 552–560. https://doi.org/10.1890/110004.
- Mitsch, W.J. & Jørgensen, S.E. (1989). *Ecological Engineering: An Introduction to Ecotechnology*. New York, U.S.A.: Wiley.
- Mitsch, W. & Gosselink, J. (2015). *Wetlands*, 5th ed., Hoboken, New Jersey, U.S.A.: Wiley.
- Moberg, F. & Rönnbäck, P. (2003). Ecosystem services of the tropical seascape: interactions, substitutions and restoration. *Ocean & Coastal Management*, 46(1-2), 27–46.
- Murdiyarso, D., Donato, D., Kauffman, J.B, Kurnianto, S., Stidham, M. & Kanninen, M. (2009). Carbon storage in mangrove and peatland ecosystems: A preliminary account from plots in Indonesia. Working paper No. 48. Bogor Barat, Indonesia: Center for International Forestry Research (CIFOR). Available at: https://www.cifor.org/publications/pdf_files/WPapers/WP48Murdiyarso.pdf.
- Nahlik, A.M. & Fennessy, M. S. (2016). Carbon storage in U.S. wetlands. *Nature Communications*. DOI: 10.1038/ncomms13835.
- Niemelä, J., Saarela, S. R., Söderman, T., Kopperoinen,

L., Yli-Pelkonen, V., Väre, S., & Kotze, D. J. (2010). Using the ecosystem services approach for better planning and conservation of urban green spaces: A Finland case study. *Biodiv. and Cons.*, *19*, 3225–3243.
- Pearce, F. (2017). *Peat swamps: the forgotten fix for climate change*. Impakter. (Dec. 12, 2017). http://impakter.com/peat-swamps-forgotten-fix-climate-change/.
- Pokorný, J., Brom, J., □ermák, J. Hesslerová, P., Huryna, H., Nadezhdina, N. & Rejšková, A. (2010a). Solar energy dissipation and temperature control by water and plants. *Int. J. Water*,5 (4).
- Pokorný, J., Kv□t, J., Rejšková, A. & Brom, J. (2010b). Wetlands as energy-dissipating systems. *J. Ind. Microbiol. Biotechol.*, 37 (12), 1299 – 1305.
- Seacology. *Sri Lanka Mangrove Conservation Project*. https://www.seacology.org/project/sri-lanka-mangrove-conservation-project/. Accessed 19 September 2018.
- Sidik, F. & Lovelock, C.E. (2013). CO2 efflux from shrimp ponds in Indonesia. *PLoS One* 8, e66329. https://doi.org/10.1371/journal.pone.0066329.
- Siikamäki, J., Sanchirico, J.N., Jardine, S., McLaughlin, D. & Morris, D.F. (2012). *Blue carbon: global options for reducing emissions from the degradation and development of coastal ecosystems*. Washington, D.C., U.S.A.: Resources for the Future. Available at: http://www.rff.org/files/sharepoint/WorkImages/Download/RFF-Rpt-2012-BlueCarbon_final_web.pdf.
- Temmerman, S., Meire, P., Bouma, T. J., Herman, P. M. J., Ysebaert, T., & de Vriend, H. J. (2013). Ecosystem-based coastal defence in the face of global change. *Nature*, 504, 79–83. https://doi.org/10.1038/nature12859.
- The Ramsar Convention on Wetlands. (2015). The 12th Meeting of the Conference of the Parties to the Convention on Wetlands, Punta del Este, Uruguay, 1-9 June 2015. *Res. XII.11: Peatlands, climate change and wise use: Implications for the Ramsar Convention*. Available at: https://www.ramsar.org/document/resolution-xii11-peatlands-climate-change-and-wise-use-implications-for-the-ramsar.
- The Ramsar Convention on Wetlands. (2002). The 8th Meeting of the Conference of the Contracting Parties to the Convention on Wetlands. Valencia, Spain, 18-26 November 2002. *Resolution VIII.17: Guidelines for Global Action on Peatlands*. Available at: https://www.ramsar.org/document/resolution-viii17-guidelines-for-global-action-on-peatlands.
- The Ramsar Convention on Wetlands. (2008). The 10th Meeting of the Conference of the Parties to the Convention on Wetlands, Changwon, Republic of Korea, 28 October-4 November 2008. *Resolution X.24: Climate change and wetlands*. Available at: https://www.ramsar.org/document/resolution-x24-climate-change-and-wetlands.
- United Nations Environment Program (UNEP). (2014). *The importance of mangroves to people: A call to action*. van Bochove, J., Sullivan, E. & Nakamura, T. (eds). Cambrdge, U.K.: United Nations Environment Programme World Conservation Monitoring Centre. Available at: file:///C:/Users/BonellsM/Downloads/DEPI_Mangrove_ES_report_complete_Low_Res.pdf.
- United Nations International Strategy for Disaster Reduction (UNISDR). (2015). *The human cost of weather-related disasters 1995-2005*. Geneva, Switzerland: UNISDR Office. Available at: https://www.unisdr.org/2015/docs/climatechange/COP21_WeatherDisastersReport_2015_FINAL.pdf.
- Watson, K. B., Ricketts, T., Galford, G., Polasky, S. & O'Niel-Dunne, J. (2016). Quantifying flood mitigation services : The economic value of Otter Creek wetlands and floodplains to Middlebury , VT. *Ecological Economics*, 130, 16–24. https://doi.org/10.1016/j.ecolecon.2016.05.015
- Wichtmann, W., Schröder, C. & Joosten, H. (eds.). (2016). *Paludiculture – productive use of wet peatlands, climate protection - biodiversity - regional economic benefits*. Stuttgart, Germany: Schweizerbart Science Publishers. ISBN 978-3-510-65283-9.
- Yu, Z.C. (2012). Northern peatland carbon stocks and dynamics: a review. *Biogeosciences*, 9, 4071-4085. Available at: https://www.biogeosciences.net/9/4071/2012/bg-9-4071-2012.pdf.

Ramsar Briefing Notes are published by the Ramsar Convention Secretariat in English, French and Spanish (the official languages of the Ramsar Convention) in electronic format, and also in printed form when required.

Ramsar Briefing Notes can be downloaded from: **www.ramsar.org/resources**.

Information about the Scientific and Technical Review Panel can be found at: **www.ramsar.org/about/the-scientific-technical-review-panel**.

For more information about Ramsar Briefing Notes or to request information on how to correspond with their authors, please contact the Ramsar Convention Secretariat at: **strp@ramsar.org**.

Published by the Secretariat of the Ramsar Convention.

The Ramsar Convention

The Convention on Wetlands, also known as the Ramsar Convention, is a global inter-governmental treaty that provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources. It is the only global treaty to focus on one single ecosystem.