The Role of Wetland Ecosystems as Critical Infrastructure for Climate Change Adaptation

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Abstract
Natural areas, and wetlands in particular, have long been recognized for the ecosystem services they provide. However, wetlands have been destroyed for farmland, developments or other human constructs to the degree that an estimated 50 percent have been lost worldwide, and many place have lost much more. As the impacts of climate change are beginning to appear – sea level rise, increased flooding, higher temperatures – the remaining wetlands may become critical in naturally mitigating their effects, providing values similar to that of built infrastructure. This creates motivation to better understand these values, both quantitatively and qualitatively – a process that is often time-consuming and resource intensive. This paper provides an overview of the functions and values of wetlands for climate change adaptation. Further, the paper presents cases in which wetlands have been successfully, or unsuccessfully, employed as infrastructure for climate change adaptation. Finally, this paper discusses limitations of such assessment frameworks, including challenges with quantifying the true value of ecosystem service.

Introduction

Approximately $3.2 trillion USD will be spent globally on transportation, electricity and sanitation infrastructure in 2013, with an estimated $57 trillion USD investment needed by 2030 to accommodate growing populations.[1] Natural areas are increasingly being recognized for their ability to provide functions similar to traditional built infrastructure, while also supplying a range of ecological, economical and social benefits. Wetlands in particular have garnered increased attention for their role in mitigating impacts related to climate change.[2–4] Indeed, wetlands have the capacity to absorb the impacts of floods and storm surges, which can protect shorelines and properties, however the conditions under which wetlands are the best solution to meet these rising challenges are not always clear-cut.[5,6] In fact, managers of wetlands identified as internationally important under the Ramsar Convention on Wetlands often underestimated the functions (i.e., ecosystem services) these areas provide both ecologically and socially.[7]

Understanding both the capacity and value of ecosystem services provided by wetlands is vital for strategic decision-making in terms of restoration, conservation and preservation.[8–12] Further, understanding services could provide information for choosing restoration or conservation over building additional built infrastructure, helping communities to save resources associated with built infrastructure while also benefiting the local environment. This paper describes a set of ecosystem services provided by wetland areas. Each service is illustrated by a case study in which a community or region relies on a wetland for a particular service and the potential interplay between this function and the impacts of climate change. The services identified in this report are not an exhaustive list, but are instead provided as a baseline from which additional examinations could be made.

Wetland Ecosystem Services

Wetlands are commonly found around the world, taking myriad forms, from riparian areas to coral reefs to peatlands and beyond. In fact, wetlands are a vastly diverse ecosystem united mainly by three main factors: hydric soil, hydrophilic plants, and hydrology.[13] They can be hotspots for biodiversity, nurseries for young animals, and in urban areas, one of the last refuges of quasi-wilderness. This report focuses on the functions of wetlands that have the potential to benefit communities facing the impacts of climate change. Table 1 demonstrates a range of climate change impacts, the wetlands functions that could help mitigate, followed by the ecosystem service it represents in the Common International Classification of Ecosystem Services (CICES).[14]

Table 1. Examples of climate change impacts, wetland functions that could assist with their adaptation and mitigation, and the corresponding ecosystem services.

Climate Change Impact	Wetland Function(s)	Ecosystem Service
Change in rainfall timing and amount	Groundwater storage and replenishment	Provisioning service: freshwater
Increased intensity in coastal storms	Shoreline stabilization Storm surge abatement	Regulating service: water regulation
Decreased access to clean water	Pollution uptake and burial	Regulating service: water purification
Increased surface water temperature	Riparian vegetation shades water to reduce water temperature	Regulating service: climate regulation
Increase in algae blooms	Nutrient uptake by plants	Regulating service: water purification
	Water temperature reduction	Regulating service: climate regulation
Excess greenhouse gas	Carbon sequestration by plants Carbon sequestration by soil	Regulating service: climate regulation

The report will focus on a subset of wetland ecosystem services that may be especially useful or relevant in terms of climate change mitigation: the reduction in greenhouse gases, nutrients, and water temperature as well as flood abatement. Each section below will offer a description of the wetland service as well as a relevant case study, or case studies. The case studies chosen do not necessarily represent a success story of wetland infrastructure, but are instead meant to illustrate both the potential and the challenges of this approach.

Greenhouse Gas Reduction

Greenhouse gas emissions continue to rise to unprecedented levels; in fact, between 2000 and 2010, the rate of increase in emissions rose more quickly than the three previous decades.[15] Some wetlands can act as a sink for greenhouse gas emissions, making them an asset for greenhouse gas reduction efforts, while other wetlands can contribute to emissions, sometimes at a very large scale. Wetlands with organic soil, such as peatlands, can emit carbon and methane, in their natural state, but even more intensely when drained or otherwise disturbed.[16]

The most prominent example of emissions from wetlands may be the tropical peatlands of Indonesia. Indonesia's 22 million hectares of peatlands store a vast amount of carbon in their soil and plant matter, with peat in some places up to 11 meters deep.[17] Widespread conversion to agriculture, often through fire, burns not only trees but also the organic matter in the soil. Once the soil is drained and replanted for farms, the soil continues to emit carbon for decades. In Indonesia, this process has been so intensive over the last decades that Indonesia's peatlands, in 2005 alone, emitted over 850 million tons of carbon dioxide – making the country one of the top three global greenhouse emitters.[17]

While the story of Indonesia's peatlands may be alarming, similar destruction of wetlands has happened elsewhere. For example, nearly 95 percent of the area or Switzerland's original peatlands are gone, largely to agricultural conversion.[18] As countries strive to meet emissions reduction goals of the Kyoto Protocol or other national policies, there is an opportunity to restore peatlands in order to reduce or reverse emissions. Restoring wetlands by removing artificial drains and supporting the regrowth of native vegetation can rapidly slow emissions. For example, in temperate areas, rewetting the soil can lead to a net sink of carbon -0.55 to -0.34 tonnes of CO_2 per hectare, compared with emissions of over 7 tonnes of CO_2 per hectare for drained peatlands.[19] If trees are included in the revegetation plan for a restored wetland, the net carbon sequestration is even higher.

As such, there is potential for wetlands restoration to be a mechanism for climate change mitigation. This is especially relevant in areas where temperatures are predicted to increase with climate change. For example, if temperatures in Europe continue to rise, there is a potential for peatlands to dry out,[16] which could increase CO_2 and NO_2 emissions, working against reduction targets.[20] Having a clear view on the wetland landscape has the potential to help the government to plan appropriately to mitigate excess emissions over the long term. In some cases, it could be as simple as removing drainage infrastructure, thus could be a relatively low cost project. However, when considering land use conversion, such as between a restored wetland and agricultural areas, maintaining a balance between socioeconomic and environmental factors, such as supporting agriculture-based livelihoods, is an important consideration. In such a case, poorly performing or unused land may be preferable to productive farms, or a conversion to a wetland-friendly farm, such as one that grows water-loving plants like blueberries, could accomplish similar values.

Nutrient Reduction

Increases in temperature coupled with changes in precipitation and high levels of nitrogen influx have the potential to affect the quantity and quality of water. One potentially serious side effect of climate change, the Intergovernmental Panel on Climate Change (IPCC) states, is algae blooms. While algae are present in almost all waters, they thrive in areas with high nutrient levels. Algae can bloom in suffocating numbers when under high temperature conditions combined with stagnant waters, exacerbated by disturbances like drought, storms and floods.[21] Nutrients come from animal and human waste, as well as agricultural areas fertilized organically or chemically. Some algae can bloom in even small concentrations of nutrients, growing even more aggressively in higher concentrations – creating a situation of eutrophication. In eutrophic waters, algae grow in excessive numbers, and sometimes rapidly, choking out native vegetation, clogging waterways and making navigation difficult or impossible. As the algae dies, decomposers multiply to eat the dead algae, consuming the water's oxygen -- sometimes to such a high degree that fish and other aquatic species die off, known as a fish kill.

Algae blooms are a problem worldwide, but In Southeast Asia, where water quality is compromised by poor sanitation, the potential affect could be accentuated, leading to larger algae blooms. For example, Cambodia, with only a few operational wastewater treatment plants, relies prominently on water resources (such as wetlands, streams, rivers and lakes) as a form of wastewater treatment,[22] leading to a discharge of approximately 234 tons of feces, 2,335 m^3 of urine, and 8,154 m^3 of gray water each day.[23] Its largest city, Phnom Penh, depends on wetlands in the south and southeastern parts of the city for wastewater treatment. Untreated urban wastewater and sewage lines are directed to these open wetlands, where they passively filter through before entering the Bassac River.[24]

The natural capacity of wetlands to remove pollutants like nitrogen and phosphorus creates a fairly effective, low cost treatment method for the city. However with little or no monitoring of the resulting water quality, it is unknown how consistent the quality of treatment by wetlands is and how it will react to additional pressures of population growth, industrial wastewater, as well as climate change or additional wetland loss. In fact, across Southeast Asia, wetlands are depended on to "work" for the people, providing vital ecosystem services that may or may not be recognized by the wetlands' neighbors, but will likely grow in importance in the coming years.

In another example from greater South Asia, Colombo, Sri Lanka formalized the protection of the wetland surrounding their city, but their wetland areas continue to suffer. After two decades of rapid urbanization, with associated poor sanitation, lack of planning, poverty, and increased flooding, Colombo's many wetlands began to deteriorate. The city recognized the value of its wetland assets and created a master plan and wetland management plan focusing in the 1990s on 12 priority wetland areas.[25] As the city continues to grow, pressures mount on these protected areas and the quality of protection has become questionable as wetlands continue to shrink due to land use change in the surrounding areas.[26]

Furthermore, at least two-thirds of residents surrounding these wetlands are living without improved sanitation, discharging wastewater directly into the protected areas.[25] Industries also contribute untreated or partially treated wastewater, adding chemicals, sediment, and other by-products. Based on this continued degradation, the International Union for the Conservation of Nature conducted a study to calculate the economic value on one of the 12 priority wetlands, the Mathurajawela Marsh, finding that this marsh alone provides over $8 million per year in benefits such as fisheries, firewood, flood attenuation and wastewater treatment. In fact, the value of the household and industrial wastewater treatment alone was over $2.2 million per year. Placing an economic value on these services adds a meaningful (though limited) perspective for policymakers, providing a compelling argument for strengthened protection of these natural areas.

Water Temperature Reduction

In some areas, high temperatures can be considered a pollutant. Thermal pollution, often from the discharge of power plants or industrial operations, can harm or kill temperature sensitive aquatic organisms.[27] As of 2005, nearly 41 percent of freshwater withdrawn in the U.S. was used for cooling power plants (up to 3800m^3 of water per day).[28] In the case of the U.S. State of Oregon, temperature is considered a regulated pollutant in several of its largest river systems due to its impact on endangered salmon species.[29] Young salmon are especially vulnerable to even small changes in temperature.

The State of Oregon recognized the ability of wetlands adjacent to waterbodies, like rivers, streams and lakes, to reduce the temperature of water. The mechanism is simple: trees and shrubs create shade that allows the water to cool. Over a large area, the cooling from this shade can significantly decrease the temperature of water. Of course, the inverse is also true – riparian areas lacking shade can have higher water temperatures. In southern Oregon, the City of Medford needs to cool discharge water from wastewater treatment to meet state pollution standards. One option was a chiller / refrigerator costing nearly one million dollars. Instead, in an innovative program, a 65km tree-planting project along the city's main waterbody, the Rogue River, was determined to meet the temperature reduction requirement for a lower cost than the chiller.[30] Beyond the temperature reduction, the restored wetland areas have additional ecological and socio-economic benefits for the community, as well as a lower carbon footprint, then the chiller option.

While the project has been in action for several years now, it is not without controversy.[31] Issues around the time for trees to establish sufficient canopy to create the required amount of shade / temperature reduction, as well as how temperature reduction, and its inherent uncertainty, can be adequately accounted for continue to be unresolved. So, while the mechanism of trees and shading may be clear, implementing such a project instead of or to replace infrastructure like chillers on a wider scale may still be a way off.

Flood Abatement

Perhaps the most celebrated function of wetland areas is their ability to minimize flooding. Wetland soils, especially those with high peat content, can have a sponge-like quality, absorbing rain or floodwater before it enters rivers or bays.[32] Wetland vegetation can also slow floodwaters as they move downstream, potentially reducing damage. Further, intact stream or oceanside wetlands shield the banks from erosion, minimizing soil loss and protecting property. However, the prime location of these wetlands has contributed to their loss. Development along coastlines and riverfronts often destroys or damages wetlands. Also, the peat contained within these peatlands makes them rich agricultural areas, thus many streamside wetlands are repurposed for rice or other farms.

In Thailand, the farmed wetlands surrounding city of Ayutthaya, Thailand, are being used to take flooding pressure off Bangkok, which lies roughly 80 kilometers south. Sometimes called the "Venice of the East," Ayutthaya sits at the junction of the Chao Phraya, Lopburi and Pa Sak Rivers, which merge into the Chao Phraya on its way into the heart of Bangkok. Draining nearly 35% of Thailand, the Chao Phraya experiences heavy seasonal flooding, most notably in 2011 when flooding shut down many parts of Bangkok for months, causing $47 billion in damages.[33] Nearly all of the river's riparian wetlands have been converted to agricultural or residential areas, leaving very few of the original wetlands intact.[34] Losing wetlands increases the risk of flooding, destroying areas that soak up and slow floodwaters as well as pollution from wastewater, etc. Furthermore, losing some wetlands make the remaining wetlands even more vulnerable to erosion from flooding, further accelerating the rate of loss.

Working wetlands like rice paddies, however, retain some of these functions. The Thai National Water Resources and Flood Policy Committee is implementing many different flood control techniques, including the the Kaem Ling Project, which temporarily repurposes Ayutthaya rice paddies as outlets for excess floodwaters bound for Bangkok.[35] Known as "monkey cheeks," these flood storage areas trap and hold water until the river's depth subsides and it can be safely released. While the project may be effective, the choice of which fields are flooded and which remain dry is a political issue which has resulted in protests from the farming community.[36]

Discussion

Wetlands have a strong potential to help communities adapt to climate change, as illustrated in the case studies for nutrient reduction, local greenhouse gas reduction and flood control. However, growing populations and a need for places to shelter, grow food or take holidays are often more immediate and lucrative needs. As a result, over half of the world's wetlands have been lost, reducing their ability to provde the ecosystem services community's may have come to depend on, whether recognized or not.

As communities continue to grow, considering existing remaining wetlands as infrastructure in development and master planning can help to deliver more cost effective and multifunctional solutions for climate change resilience. To do this, however, the value of the wetlands must be recognized and then balanced with the needs of the community. One avenue for this is through monetizing ecosystem services, such as flood protection or carbon prices. While this can put a price of a wetland area, that may very well be competitive with prices for development, it oftentimes underestimates the true value of these areas. Ecosystem services like biodiversity or recreational values are difficult to quantify with a dollar price, though we may inherently understand their importance. As such, dollar values are something to be wary of, though may be an important factor to consider nontheless, with a grain of salt.

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