The potential of habitat restoration to sequester carbon and mitigate climate change

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Abstract

Human activity and the increasingly concerning effects of a changing climate impact every aspect of ecosystems on Earth. This paper will discuss several habitats, from blue carbon sinks in the ocean to terrestrial forests, in order to analyze their potential for capturing and storing carbon from the atmosphere. This paper also examines a variety of restoration projects and their effectiveness in restoring habitat for the goal of mitigating climate change. All three habitats discussed—oceans, wetlands, and forests—proved to be highly effective in sequestering carbon from the atmosphere. A study on the recovery of seagrass meadows showed that 1700 restored hectares brought carbon sequestration levels just below those found in natural seagrass, at 36.68 grams of carbon per year (Greiner et al., 2013). The restoration of mangroves and terrestrial forests were similarly effective. Reforested mangroves, over 40 years, sequestered 232.8 megagrams of carbon. The replanting of a forest in Uganda resulted in the capture of around 48,800 megagrams of carbon after 18 years (Wheeler et al., 2016). Other facets of habitat restoration were also taken into account, such as the comparison of reforestation and afforestation. This paper describes the many aspects of habitat restoration and aims to provide information on its effectiveness in relation to climate change.

Introduction

Climate change and the prevalence of greenhouse gases in the atmosphere are pressing concerns that require decisive change in order to protect the habitats of the Earth. Greenhouse gases such as carbon dioxide contribute to rising temperatures and the degradation of ecosystems. This loss of ecosystems, that would otherwise help to capture CO2, only exacerbates the growing concern of climate change.

This paper discusses carbon dioxide, its capture, and its storage by restoring habitats that sequester CO2. Three habitats are highlighted: oceans, wetlands, and forests. Both wetlands and oceans are referred to as blue carbon sinks, meaning that carbon is stored via water within these ecosystems.

In wetlands, water saturation leads to dense vegetation. Photosynthesis from the vegetation in these areas allow wetlands to store large amounts of CO2, making them promising carbon sinks. Ocean ecosystems such as phytoplankton, seaweed, and seagrass meadows all photosynthesize as well, using a variety of processes to capture carbon and store it in the deep sea for long periods of time. Finally, forests, known as green carbon sinks along with other types of land-based vegetation, are diverse habitats that not only store carbon in trees, but in dead matter, soils, and root systems. These habitats have the capability to combat climate change and play an impactful role through their natural abilities to act as carbon sinks.

Human activity, such as agriculture or infrastructure development, in combination with the detrimental effects of climate change, means that ecosystems across the planet are degrading. These habitats are often unable to effectively restore themselves on their own; thus, human intervention is necessary for recovery. Habitat restoration projects present several challenges, such as social pushback or economic competition.

In order to undergo a successful restoration project, a project must enhance the habitat's capability to remove carbon while protecting the carbon stock that already exists. For example, a reforestation project would not only involve planting seeds, but protecting the existing and new forest from fire (Wheeler et al., 2016). In this way, the habitat is protected from threats that may hinder progress while being allowed to build up a new ecosystem that benefits the world around it.

The ecosystems of the ocean

The ocean is one of the most crucial habitats when it comes to removing and storing carbon from the atmosphere. This diverse habitat holds 60 times more carbon than the atmosphere, absorbing almost 30% of anthropogenic CO2 emitted globally (Shadwick et al., 2023). The ocean itself acts as a carbon sink because carbon dioxide in the atmosphere dissolves in the ocean to create carbonic acid.

However, other ecosystems within the habitat itself also help to capture carbon, including seagrasses, seaweed, and phytoplankton. Phytoplankton, which are microscopic organisms usually located in the upper part of the ocean, capture carbon from the atmosphere through photosynthesis. The carbon either becomes converted to biomass or sinks to the deep ocean where it can be stored for a long period of time. It also travels through the ocean when zooplankton eat phytoplankton, carrying it further through the food chain.

Seaweed and seagrass, located deeper in the ocean, also play a part in carbon sequestration. The main difference between these two types of plants are that seagrass, unlike seaweed, belong to the monocotyledons, a group of plants that includes grasses, lilies and palms. They have leaves, roots, and veins, produce flowers and seeds, and have roots and rhizomes that both stabilize the plant and store nutrients. Seaweed, on the other hand, are far simpler organisms, with only holdfasts that do not transport nutrients (Reynolds, 2018). This diverse array of ecosystems makes the ocean one of the most important carbon sinks in the world.

The ocean and climate change: concerns and habitat restoration

Similar to other habitats, the rising issue of climate change brings the ocean's carbon sequestration capabilities to the forefront. However, this habitat is not unaffected by the consequences of rising temperatures. Climate change's negative impacts further worsen the ocean's ability to capture carbon effectively. As the water's temperature increases, its ability to dissolve CO2 decreases in turn (Riebeek, 2008).

Normally, wind-driven currents circulate surface water with deeper, cooler waters in order to maintain the ocean's capacity to store carbon and to bring it deeper into the ocean. However, when the surface water's temperature warms, this process becomes more difficult and the ocean stagnates and stratifies, or settles into layers. Warming temperatures mean the ocean becomes saturated with CO2, as well as a reduction in the population of photosynthesizing phytoplankton. With a decreased capacity to sequester carbon, there is a more urgent need to restore certain habitats in order to raise this habitat's capability once more.

A study on seagrass restoration in Virginian coastal bays provides insight to this phenomenon (Greiner et al., 2013). Seagrasses sequester carbon through photosynthesis and feed on carbon dioxide in the water. Their meadows can capture up to 83 million metric tons of carbon each year, and just one acre can sequester 740 pounds per year (Reynolds, 2018). Seagrass only occupies 0.1% of the ocean floor, but it accounts for 10 to 18% of the ocean's total organic carbon burial and capture 48 to 112 teragrams of carbon each year (Greiner et al., 2013).

However, the habitat is declining at a rate of 5% per year due to anthropogenic causes such as decreased water quality and rising water temperatures (Greiner et al., 2013). In the past century alone, around 29% of seagrass meadows have died off (Reynolds, 2018). This decline not only hinders the ocean's carbon capture abilities but also leads to the release of stored carbon.

Despite this decline, studies show that restoration can be effective. Sites on the Eastern coast of Virginia were restored because disease and a severe hurricane had caused a local seagrass extinction in the area. Through the restoration of over 1700 hectares of seagrass meadows over 10 years, the restored meadows displayed an accumulation of 36.68 grams of carbon per year—falling just under the levels of carbon burial found in natural seagrass meadows (Greiner et al., 2013). The results of this restoration study may provide guidance for future projects, aiding in the recovery of natural carbon sinks as a method to fight climate change.

Wetland ecosystems: carbon capture and methane emissions

Wetlands are another crucial facet of nature-based carbon sequestration. Wetlands act as carbon sinks because their soils are anoxic, or oxygen poor. This leads to slow decomposition and accumulation of organic matter, which helps to sequester carbon deep in soils.

Moreover, the vegetation contained in these habitats photosynthesize, capturing carbon; thus, this unique ecosystem contains significantly more carbon stocks than any other terrestrial ecosystem (Position Paper: Carbon Sequestration & Wetlands Restoration, 2023). Although they only cover 5 to 8% of the world's area, wetlands contain 30% of organic soil carbon globally (Position Paper: Carbon Sequestration & Wetlands Restoration, 2023), emphasizing the importance of their role in climate change.

Although they sequester a large amount of carbon, a factor that must also be considered is their significant methane emissions. Wetlands represent around 20% of the methane in the atmosphere, emitting on average 161 teragrams per year (Saunois et al., 2020). Methane is produced due to high levels of water saturation, through a process called methanogenesis. Factors that influence methane production include oxygen level, soil temperature, and soil composition. A warmer, more anaerobic environment is especially conducive to methane production (Saunois et al., 2020). Climate change bolsters methane production because rising temperatures mean wetlands are more prone to flooding and will have higher soil temperatures. This multifaceted nature of wetlands also leads to controversy on their restoration.

Restoration for carbon sequestration: reforestation versus afforestation

The degradation or drainage of wetlands results in the release of stored carbon, and the loss of this ecosystem due to anthropogenic causes means even more CO2 will enter the atmosphere if it is not significantly restored. A study conducted on over 370 mangrove restoration sites, which are catagorized as wetlands, presents the effectiveness of mangrove reforestation, especially when compared to afforestation (Song et al., 2023).

While reforestation refers to the replanting of an area previously forested, afforestation refers to planting seeds in an area that has not recently been forested. In this study reforestation proves to be largely effective, sequestering 60% more carbon than afforestation over 40 years (Song et al., 2023). Reforested mangroves showed to support roughly 232.8 megagrams of carbon, while afforested mangroves only supported around 119.2 megagrams—a difference of almost double the amount (Song et al., 2023). Reforestation proved to be more successful for a variety of reasons, a main one being that when one habitat is converted to another through the process of afforestation, benefits that the previous habitat may have had are lost in the new one. The overall climate and network of animal species in the habitat may also not support the new species being planted there. Reforestation is generally most cost-effective as well, because the environment is already suited to the species being restored. These studies demonstrate that not only is restoration widely effective, there is a stark difference between reforestation and afforestation that must be taken into account.

Forests and carbon capture

Forests are the largest terrestrial carbon sink on the planet, holding immense potential to mitigate climate change, due to their capacity to photosynthesize and capture CO_2. Not only is carbon stored in trees—both living and dead—it is stored in root systems, undergrowth, and soils as well. Live trees, followed by soils, have the highest carbon density overall. In the United States, forestland represents almost a third of all land area and sequesters around 866 million metric tons of CO_2 emissions (Durkay & Schultz, 2016). A single mature live tree can sequester more than 48 pounds of carbon (Androff, 2021).

Reforestation for carbon sequestration

Like other habitats, forests release CO_2 when they burn or decompose. Considering the large amounts of forest cut down every year, for purposes such as agriculture or manufacturing, restoration becomes a more urgent issue each day.

In the United States, around 33 millions hectares of forestland are classified as non-stocked or poorly stocked. This is because only around 1% of understocked timberland is restored every year, and current rates of tree-planting only contribute about 3 to 5% to carbon sequestration from trees. However, if all understocked forestland were to be restored, there is potential to raise the country's forests' carbon sequestration capacity to 20% (Domke et al., 2020).

Challenges arise for reforestation due to a multitude of reasons. Oftentimes, the issue of forest restoration holds social and economic competition with other objectives in land use and management. Additionally, degraded forests generally do not sufficiently restore naturally because they are more susceptible to wildfire and often have poor seed banks due to practices such as logging and agriculture.

Nonetheless, efforts to restore forestland have proven to be successful. One such example of restoration follows a study conducted within forestland in Kibale National Park, Uganda (Wheeler et al., 2016). Parts of this park were deforested as a result of agriculture and the removal of timber for fuel wood. Natural regeneration of the forest was strongly inhibited due to the growth and domination of elephant grass. The process of restoration included protection from fire as well as the planting of 400 native seedlings per hectare of forestland. 3,241 hectares were planted in total; about 47,700 megagrams of carbon were sequestered at the end of 18 years. Estimates report that if 10,000 hectares were to be restored, roughly 2 teragrams of carbon would be sequestered (Wheeler et al., 2016).

Thus, through this study and those previously described, it becomes evident that simple acts of restoration are enough to sequester large amounts of carbon from the atmosphere, a step towards fighting climate change as a whole.

Discussion

The findings show that habitat restoration is not only helpful, but necessary to fight climate change. The above studies in restoration all proved to be successful, with all three habitats—forestland, mangroves, and seagrass—restored to carbon sequestration capabilities close to if not meeting those of a natural habitat. When done in conjunction with other methods of carbon sequestration, habitat restoration has potential to be extremely valuable in mitigating climate change.

When considering restoration projects, it is important to compare the advantages and disadvantages of a certain habitat to evaluate the overall benefits of restoration. For example, although wetlands contain significant potential for carbon sequestration, their production of methane must be taken into account as well, as the production of this greenhouse gas may only contribute to climate change further. However, looking at the amounts of carbon that wetlands can potentially sequester—significantly more than terrestrial carbon sinks—wetlands are still a crucial factor in global carbon capture and should not be thoroughly disregarded due to their methane emissions. In addition to this, the amount of methane produced is largely dependent on environmental changes resulting from climate change, as flooding and rising temperatures increase methane production. This means that if the effects of climate change can be managed, wetlands can perform even more efficiently, making their restoration a higher priority.

Different methods of restoration must be considered as well. In the study on mangrove restoration previously discussed, reforestation led to higher rates of carbon capture, proving to be far more efficient and effective for a multitude of reasons. This example can be applied not only to mangroves, but to other ecosystems such as forests or grasslands. These discrepancies show how important it is to examine every aspect of a restoration project in order to maximize its impact.

Overall, although carbon sequestration projects come with a multitude of challenges, the benefits outweigh the costs, showing that habitat restoration is vital to the future of the climate.

Conclusion

Natural carbon sinks, including forests, wetlands, and oceans, play a critical role in mitigating the effects of greenhouse gases in the air. Unfortunately, human activity has largely diminished the role many of these habitats are able to play. Restoration of these ecosystems holds potential to sequester increased amounts of carbon from the atmosphere, but challenges in many forms arise when considering restoration projects. Through organized effort, natural habitat restoration holds a promising future when it comes to the fight against climate change.

References

Androff, A. (2021). *Trees are Climate Change, Carbon Storage Heroes.* US Department of Agriculture. https://www.fs.usda.gov/about-agency/features/trees-are-climate-change-carbon-storage-heroes#:~:text=In%20one%20year%2C%20a%20mature,atmosphere%2C%20like%20fire%20or%20decomposition.

Domke, G., Oswalt, S., Walters, B. *et al.* (2020). *Tree planting has the potential to increase carbon sequestration capacity of forests in the United States.* PNAS. https://doi.org/10.1073/pnas.2010840117

Durkay, J., & Schultz, J. (2016). *The Role of Forests in Carbon Sequestration and Storage*. NCSL. https://www.ncsl.org/environment-and-natural-resources/the-role-of-forests-in-carbon-sequestration-and-storage#:~:text=Forests%20absorb%20carbon%20dioxide%20from,soils%20and%20the%20forest%20floor.

Greiner, J., McGlathery, K., Gunnell, J., & McKee, B. (2013). *Seagrass Restoration Enhances "Blue Carbon" Sequestration in Coastal Waters.* Plos One. https://doi.org/10.1371/journal.pone.0072469

Position Paper: Carbon Sequestration & Wetlands Restoration. (2023). Fundacion Global Nature. https://livinglakes.org/wp-content/uploads/2023/11/Position-paper-Carbon-restoration-wetlands.pdf

Reynolds, P. (2018). *Seagrass and seagrass beds.* Smithsonian National Museum of Natural History. https://ocean.si.edu/ocean-life/plants-algae/seagrass-and-seagrass-beds

Riebeek, H. (2008). *The Ocean's Carbon Balance*. NASA Earth Observatory. https://earthobservatory.nasa.gov/features/OceanCarbon#:~:text=In%20the%20short%20term%2C%20the,%2C%20salinity%2C%20and%20dissolved%20gases.

Saunois, M., Stavert, A., Poulter, B. *et al*. (2020). *The Global Methane Budget 2000-2017.* Earth System Science Data. https://doi.org/10.5194/essd-12-1561-2020

Shadwick, E., Rohr, T., & Richardson, A. (2023). *Oceans absorb 30% of our emissions, driven by a huge carbon pump. Tiny marine animals are key to working out its climate impacts.* CSIRO. https://www.csiro.au/en/news/all/articles/2023/june/oceans-absorb-emissions

Song, S., Ding, Y., Li, W. *et al.* (2023). *Mangrove reforestation provides greater blue carbon benefit than afforestation for mitigating global climate change.* Nature Communications. https://doi.org/10.1038/s41467-023-36477-1

Wheeler, C., Omeja, P., Chapman, C. *et al.* (2016). *Carbon sequestration and biodiversity following 18 years of active tropical forest restoration.* ScienceDirect. https://doi.org/10.1016/j.foreco.2016.04.025