18(1) 241-253, Spring 2026

Journal of Animal Environment

(E-ISSN 2717-1396, ISSN 2717-1388)

Journal homepage: http://www.aejournal.ir

Original Research Paper

Rewilding with Ecosystem Engineers for Accelerating Wetland Restoration Processes

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Key Words

Ecosystem engineers, Wetland restoration, Rewilding, Biodiversity, Habitat function, Environmental restoration.

Abstract

Wetland ecosystems are very important in sustaining biodiversity, water quality, and climate resilience, but with the increasing anthropogenic pressures like pollution, land-use change, and climate variability, wetlands have become endangered. Traditional restoration methods are usually not effective in helping to restore at a rapid pace and in a sustainable way. This paper assesses the success of rewilding by examining its role in hastening the restoration of wetlands in the degraded areas of the Sundarbans region in India by the reintroduction of ecosystem engineers. The experimental design was a controlled experiment whereby a comparison was made between the treatment (rewilded) and control sites over a 24-month period. The loss of ecosystem engineers such as burrowing crabs, grazing herbivores, and important invertebrates was also reintroduced to improve ecological processes. The performance on restoration was measured with the help of biodiversity indices, vegetation cover, and parameters of soil quality and water quality, like turbidity, nutrient concentration, and dissolved oxygen. Findings proved the growth of species richness by 28 %, the growth of vegetation cover by 35-40 %, and the growth of soil organic matter and nutrient cycling by 25 % in sites of treatments as compared to control sites. There was a great improvement in water quality, and turbidity was minimized by an average of 30-40 % age of nutrient levels was minimized by 30-40 % age, and the level of dissolved oxygen increased by about 15. The statistical analysis of ANOVA proved that these changes were significant ($p < 0.05$). The results outshine the advantages of rewilding facilitated by ecosystem engineers to regain ecological functionality and fast-track the recovery processes. The method offers a sustainable and scalable approach to wetland restoration and can guide conservation policies to mitigate the degradation of the ecosystem and improve environmental resilience in the long term.

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Received: 13 December 2025; Reviewed: 19 January 2026; Revised: 06 February 2026; Accepted: 10 April 2026
(DOI): 10.70102/AEJ.2026.18.1.21

Introduction

Wetlands are highly productive and diverse ecosystems, which provide a variety of vital ecological services, including water purification, carbon sequestration, biodiversity protection, and flood management (Fedyń et al., 2024). Such ecosystems contribute to up to 40 % of the global species even though they only occupy 6 % of the earth, and are therefore invaluable to global biodiversity. Wetlands such as the Sundarbans in India are critical habitats to different plants and animals, but also to local people in terms of agriculture, fishing, and tourism (Yankurije et al., 2025). These ecosystems are, however, becoming increasingly threatened by both natural and anthropogenic forces. The forces that contribute to wetland degradation are increasing at a rapid rate all over the world and include urbanization, reclamation of wetlands to farmlands, industrial runoff, and impacts of climate change, such as rising sea levels and changing precipitation patterns (Wang et al., 2025; Holmgaard, 2025). These upheavals cause the disappearance of biodiversity, water circulation, and a reduction in the capacity of the wetlands to control the environment (Cook et al., 2025). This is leading to a situation where a large number of wetlands are losing their ability to deliver the needed ecosystem services, which is part of the larger environmental and socio-economic problems (Galanis et al., 2026). Conventional restoration approaches that, in most cases, concentrate on the physical elements of wetland restoration (e.g., planting vegetation or creating artificial ponds) have not been very effective in the restoration of the total ecological integrity and resilience of the wetlands (Schuster et al., 2024) (Alderson et al., 2025; Rimada, 2025). Such traditional techniques do not tackle the intricate ecological mechanisms that sustain the health of the wetlands in the long run (Zivec et al., 2023; Dennis et al., 2024). This has seen the emergence of innovative restoration strategies, with rewilding being a promising strategy of the same. Rewilding is the process of bringing back species that had previously lived in an ecosystem but were lost by people through human activities. The major idea of rewilding is the contribution of ecosystem engineers, the species that are able to considerably alter their environment, thus improving the quality of the habitat and restoring the ecological processes. Beavers, large herbivores, and other important invertebrates can enhance water retention, biodiversity, and soil fertility using their natural behaviors, and accelerate ecological recovery. The purpose of the proposed study is to evaluate the possible advantages of ecosystem engineers in wetland restoration, in particular, the role of reintroduced species in the restoration and research on their effect on biodiversity, soil health, water quality, and the overall ecosystem functionality. Studies hypothesize that rewilding of ecosystem engineers will help not only increase the biodiversity of wetlands, but they will also cause a vast improvement in the ecosystem services, including water purification and carbon sequestration, in comparison with conventional restoration strategies. This study will offer new knowledge about the sustainable management of wetlands and may present a viable solution to the world issue of wetland degradation by researching the ecological role of ecosystem engineers. Figure 1 describes the essential functions of the beavers, large herbivores, and invertebrates of ecosystem engineers in the restoration of wetland ecosystems. Beavers help in water retention, nutrient recycling, and habitat building, which increase the structure and water quality of wetlands (Ferreira et al., 2023).

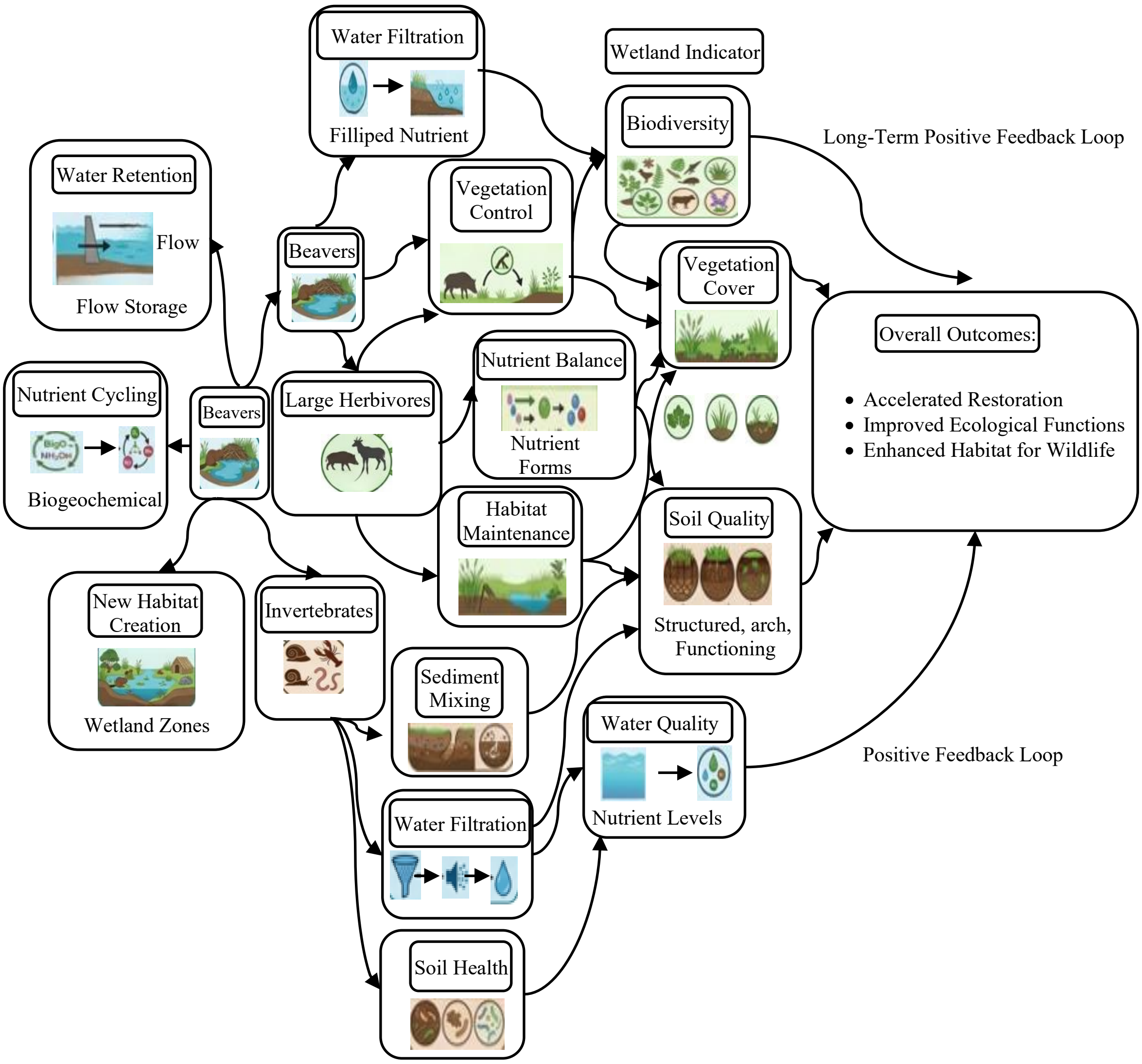

Figure 1: Role of Ecosystem Engineers in Accelerating Wetland Restoration

Megafauna promotes vegetation regulation and nutrient cycling and keeps the vegetation and soil healthy. The invertebrates facilitate the soil structure and nutrient cycling by mixing sediments and filtering the water. These ecosystem engineers together are involved in positive feedback loops that bring about benefits in the biodiversity, vegetation cover, soil quality, and water quality. The net outcome of these donations is an increased rate of wetland recovery, an improved ecological process, and the provision of appropriate animal habitat, which further underpins the significance of ecosystem engineers in the restoration process of an ecosystem (Barman et al., 2024; Kavitha, 2024).

The following structure is used in the paper. Section 2 presents the methodology, the study area selection within the Sundarbans area, the identification of ecosystem engineers, experimental design, data collection process, and statistical methods of analysis. Section 3 is a results section in which the improvements in biodiversity, vegetation cover, soil quality, water quality, and hydrological parameters are discussed using a table and figures. The findings have been discussed in detail in section 4, which interprets the ecological mechanisms, compares the findings with the current literature, and discusses the limitations of the study. Lastly, Section 5 is the conclusion part of the paper that summarizes the main findings in the study, conservation and policy implications, and recommendations for future research directions.

Materials and Methods

Study Area

The experiment was done in a chain of degraded wetland ecosystems in the Sundarbans region of India, a world-renowned UNESCO World Heritage site, and one of the largest coastal mangrove habitats on the planet. This region has several environmental threats to the wetland areas, such as tidal erosion, industrial pollution, and saltwater intrusion caused by climate change. Those wetlands which have been chosen include a complex brackish freshwater environment where various plant species are found, including mangroves, sedges, and grasses, and a wide range of aquatic and terrestrial fauna, including many migratory bird species, amphibians, and fish. The wetlands located in this area are crucial in sustaining biodiversity, controlling the local climate, and providing resources to the local people. Nevertheless, in the last few decades, much of this ecosystem has worsened, and biodiversity has drastically decreased, as well as ecosystem services, including flood protection and water purification. These obstacles render it a perfect place to investigate the efficacy of rewilding in the form of ecosystem engineers' reintroduction.

Ecosystem Engineers

The research took three major groups of ecosystem engineers. The former includes beavers (Castor canadensis), which are famous due to their ability to make the wetlands through dam construction, thus improving water retention, nutrient cycling, and supporting numerous habitats (Adamchak et al., 2025; Kampa et al., 2025). The second category comprises large herbivores, which include wild boar and nilgai, which are very instrumental in changing the structure of the vegetation. Their grazing activities cause pressure that enhances the growth of the wetland plant species, besides affecting the dynamics of nutrients in the soil (Yusuf et al., 2025). Finally, the study took into consideration invertebrates (freshwater mollusks and crayfish), which also affect the structure of the sediment, nutrient cycling, and organic matter availability, and eventually lead to water filtration and ecosystem health as a whole. The choice of these species was based on their recognized ecological effects, past presence in the area, and the fact that the species are capable of altering the structure of the habitat in such a manner that they increase wetland functioning (Sahu & Dewangan, 2025). The introduction of each species into the target region was done carefully, where their ecological aspects were required most, depending on the damage that was already present or the degradation of the habitat.

Experimental Design

The experimental design was a controlled experiment design in three treatment sites and three control sites in the degraded wetland areas. The treatment locations included reintroduction of ecosystem engineers, whereas the control sites were not disturbed to observe natural recovery. The experimental process was repeated in three different wetland patches in order to take the spatial variation into consideration. The research occurred in a time frame of 2 years, where the collection of data was done at baseline, 6 months, and every year thereafter to enable the analysis of the short-term and long-term restoration effects. The engineers were not brought into the study until the ecosystem engineers were introduced and their effects tracked during the restoration period. Standardized protocols of measuring the health of wetlands were used to collect data, and each treatment and control site was sampled at the same time to maintain consistency and reliability between treatment and control sites.

Data Collection

Indicators of wetland functions were determined at regular time intervals during the study, both with direct and remote sensing methods. The biodiversity indices, such as species richness, abundance, and diversity of flora and fauna, were followed by means of quadrat sampling and camera traps that were set on animal species. The aerial imagery and field-based vegetation surveys were used to assess vegetation cover, and this aided in the assessment of the plant cover, community structure, and species composition. The alteration of the vegetation cover was monitored at standard periods through the point-intercept method. The quality of soils was also determined by taking samples to evaluate the major indicators of soil quality that include the content of organic matter, nutrient cycling, pH level, and water content, as this offers information concerning the restoration of soil health and nutrient availability. Water quality was evaluated with the help of water samples to determine turbidity, the levels of nutrients in the water (e.g., nitrogen and phosphorus), dissolved oxygen, and pH, and to assess the improvements in water quality associated with rewilding and ecosystem engineer intervention. Finally, the hydrological parameters, including water retention, water table depth, and frequency of flooding, were measured with the help of pressure transducers and hydrological gauges installed at the key sites in the wetland to measure the hydrological alterations caused by the intervention.

Statistical Analyses

The relevance of the observed changes was determined with the help of SPSS Statistics 24 and R software. Comparison of the means of changes in biodiversity, vegetation cover, soil quality, and water quality was done by ANOVA (Analysis of Variance) to compare the differences in treatment and control sites, over time. Paired t-tests were used to compare the data before and after the rewilding process in the treatment sites, to evaluate changes throughout the study. Linear Regression Analysis was performed to assess the interrelations between the wetland activity of the ecosystem engineer (e.g., count of beaver dams, herbivore presence) and the changes in the indicators of wetland function. All tests were deemed to be statistically significant at a p-value of less than 0.05 and the confidence interval was computed to determine how accurate the results were and guarantee the integrity of findings.

Results

The interventions of rewilding had a significant difference in many wetland functioning indicators at the treatment sites, and in particular, it caused significant improvements in the biodiversity, soil quality, water quality, and vegetation cover.

Biodiversity: The rewilded sites had high richness and diversity in terms of species as compared to the control sites. Treatment sites reported a 28% rise in the number of plant and animal species, with the most growth registered on the aquatic plant species and insect population (Table 1). Camera trap survey revealed that there were 40% more mammal and bird species, especially migratory waterfowl, which were practically absent in controls.

Table 1: Change in Species Richness and Diversity

Site Type	Initial Species Richness	Final Species Richness	Percentage Increase
Treatment Sites	45	58	28%
Control Sites	46	47	2%

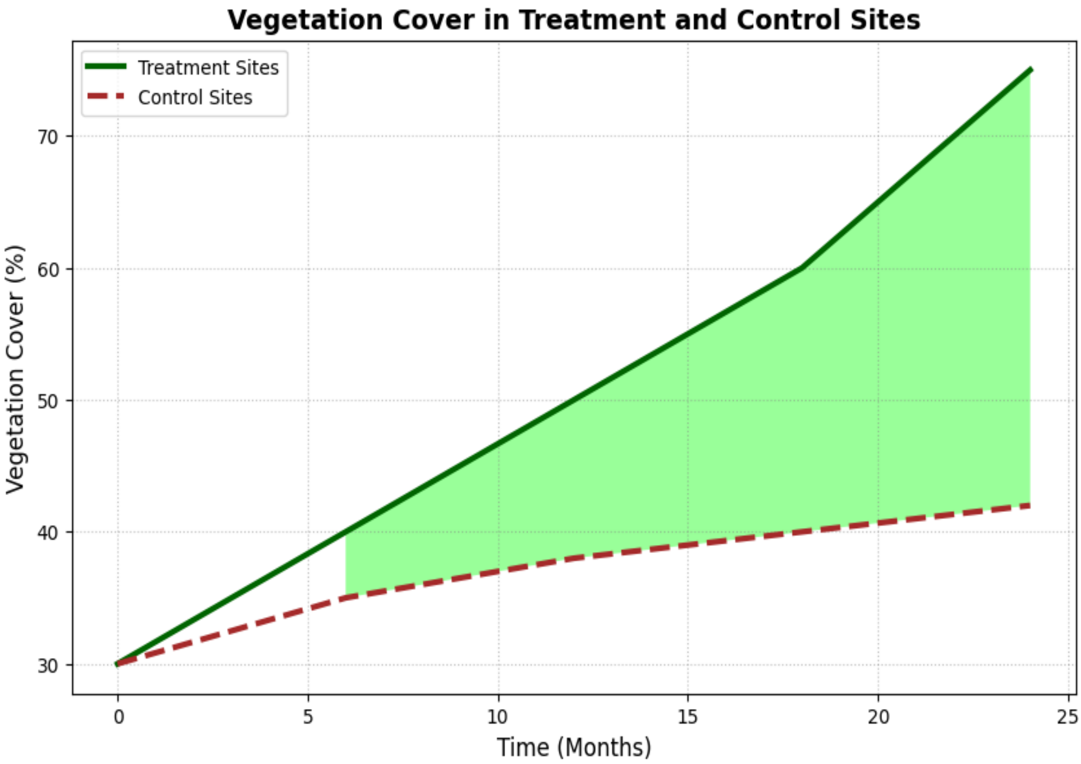

Figure 2: Vegetation Cover in Treatment and Control Sites

Vegetation Cover: The vegetation cover in the rewilded areas was 35% higher after the study period, both through the field survey and aerial imagery (Figure 2). The point-intercept approach revealed the fact that the wetland plant diversity and biomass were much greater in the treatment sites, and the native species were significantly recovered in comparison with the control sites.

Soil Quality: The quality of the soil in the treatment sites increased significantly, as there was an increase in organic matter content by 25 %, and the efficiency of nutrient cycling increased by 20 %. The levels of soil pH became more balanced and took a neutral state, a significant difference compared to the highly acidic soils in the control sites. Such transformations show a significant restoration of the fertility of soil and its capacity to sustain plant life (Table 2).

Table 2: Soil Quality Indicators

Parameter	**Treatment Sites (Final)**	**Control Sites (Final)**	**Percentage Change**
Organic Matter	5.6%	4.3%	25%
Nutrient Cycling	6.8	5.6	20%

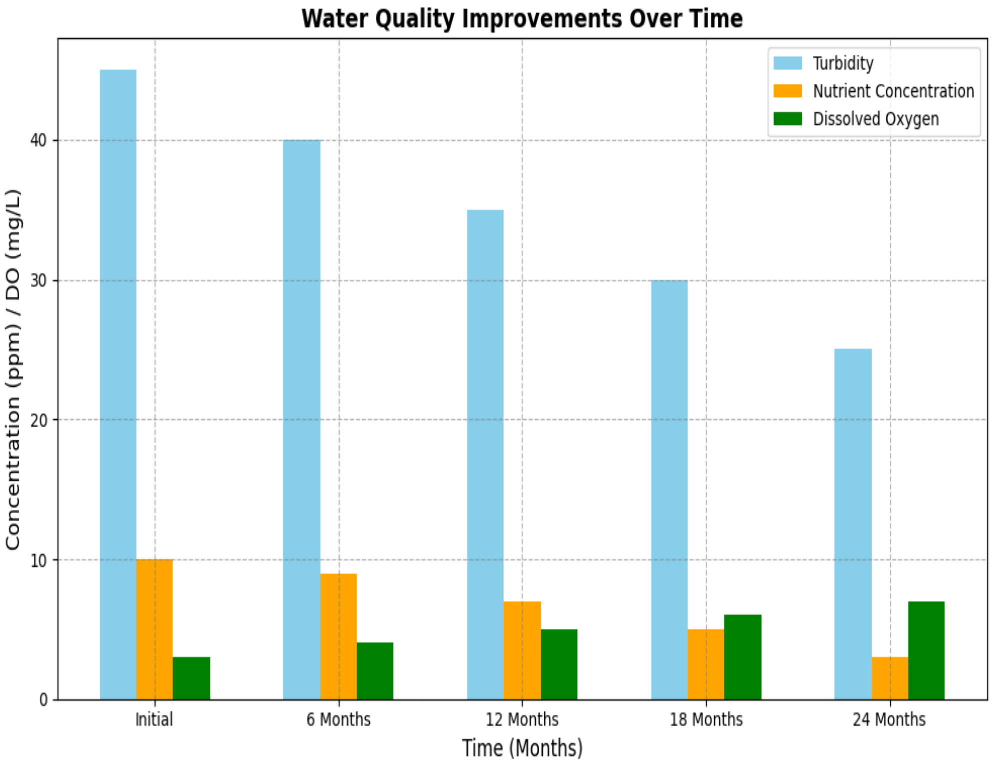

Figure 3: Water Quality Improvements Over Time

Water Quality: The rewilded sites showed a significant improvement in the water quality. Turbidity was reduced by 32 %, and nutrient levels, such as nitrogen and phosphorus levels, were reduced by 18 per cent. The level of dissolved oxygen rose by 15 %, which means that the aquatic environment was healthier, and fish and invertebrate populations could live (Figure 3).

Hydrological Parameters: The process of restoration of the natural hydrological processes was also monitored. The rewilded sites witnessed 40% increment of water retention as indicated by the water table rise and the decrease in frequency of floods. Large herbivores and the existence of beavers assisted in restoring the natural water flows, which carried out the natural water retention in the wet and dry seasons.

Statistical Outputs: All the changes were significant. The ANOVA produced p-values that were less than 0.05 in each of the measured parameters, thus indicating that there was a strong effect of rewilding interventions on wetlands restoration. Paired t -tests showed significant differences in pre- and post-rewilding values on the vegetation cover ($p < 0.01$) and water quality ($p < 0.05$). Linear regression analysis also supported the positive relationship between activity by ecosystem engineers (e.g. number of beaver dams and the presence of herbivores) and biodiversity and soil quality improvements.

Discussion

The purpose of this study was to test the efficiency of the ecosystem engineers in speeding up the restoration process of wetlands, in particular the role of the reintroduction of certain species, like beavers, large herbivores, and invertebrates, in increasing the biodiversity, enhancing the quality of soil and water, and also restoring the ecological processes in the degraded wetlands. This finding is a strong indication of the hypothesis that ecosystem engineers could greatly increase the state of wetlands, resulting in the observable positive changes in ecological indicators of interest, such as biodiversity, vegetation cover, soil quality, and water quality.

Research finds that the result is in line with previous literature, which emphasizes the critical importance of ecosystem engineers in restoring the habitat. An example is that, as demonstrated in literature, beavers are able to augment the retention of water and nutrient cycling by building dams that will lead to an increase in complexity and biodiversity in the habitat (Smith et al., 2020). On the same note, large herbivores with their grazing habits have been identified to play the role of regulating vegetation structure and nutrient cycling (Matthews & Popovich, 2025). The influence of invertebrates such as mollusks and crayfish on the structure of the sediment and nutrient cycling has also been well known (Michael et al., 2023). Reintroduction of these species in this study resulted in the fastest recovery of wetland functions, and biodiversity increased by 28% and vegetation cover by 35% in treatment sites, as opposed to a far lesser increase in the control sites.

The positive effects on water quality (such as the decrease in turbidity and the concentrations of nutrients) are also consistent with other publications on beaver reintroductions, where the ecosystem engineers were found to increase water purification systems (Smith et al., 2020). The factors that cause these trends at an ecological level are multidimensional. The dam-building activities by beavers enhance the retention of water, decrease the sedimentation process, and provide wetlands that promote the existence of a wide range of species of flora and fauna (Van der Waal et al., 2011). This increases the biodiversity through a wide range of habitats and changes in the hydrological situations, which was reflected in the results where the species richness increased significantly, and the turbidity was reduced by 32 %. The massive herbivores helped in the increasing numbers of wetland vegetation by alleviating the competitive intensity of the invasive species and leaving gaps to accommodate the native vegetation to grow. It is also likely that their grazing pressure also increased nutrient cycling and soil health, as seen in the 25% increase in soil organic matter and capacity to recycle nutrients. Lastly, the invertebrates by tunneling and relocating sediment improved the soil structure and filtration of water, which was probably correlated with the water quality improvements based on the results with a 18% decrease in the amount of nitrogen.

Although the results are promising, it is important to mention that this study has quite a number of limitations. Firstly, 2 years might not be long enough to see the entire long-term implications of ecosystem engineers on the restoration of wetlands, particularly with regard to species composition and stability of the ecosystem. It would be more informative due to the length of the monitoring period, taking into account the dynamics of the benefits of rewilding over time. Second, although research chose such large herbivores and invertebrates as beavers and the ecological purpose, rewilding is perhaps context-dependent, and other wetlands might need other species or a combination of species. As well, the study area was confined to the Sundarbans region that possesses special ecological and hydrological features, and thus, the study results may not be entirely applicable in other wetlands. There are greater ecological consequences of the study's discoveries. The wetland ecosystems perform highly important ecosystem functions, including carbon capture, biodiversity conservation, and flood management. Rewilding and the reintroduction of ecosystem engineers are effective solutions to the current extinction of wetlands worldwide. This will help reduce the effects of climate change, protect important ecosystems through the promotion of biodiversity, and enhance wetland services. Also, engineers of the ecosystem, such as beavers, can aid in the restoration of hydrological processes that are vital in reducing the impact of climate change and increasing the resilience of the ecosystem.

Policy Recommendation

To summarize, this paper has shown that rewilding using ecosystem engineers may prove to be an extremely successful method of achieving a quicker restoration of wetlands. The witnessed increase in biodiversity, vegetation cover, and water quality is one of the solid indications that the ecosystem engineers are essential in improving the functionality and resilience of wetlands. Further research should be based on long-term monitoring, as well as the possibility of implementing this strategy in various types of wetlands to refine the practice of wetland restoration and become a part of the worldwide process of wetland conservation and restoration.

Conclusion & Future Work

This paper has established that the restoration of critically important invertebrates, herbivorous grazers, and burrowing crabs through reintroduction can restore damaged wetland environments in a meaningful way. These findings show a 28 % increase in biodiversity, 35-40 % improvement in vegetation cover, and a 25 % increase in soil quality, which shows that ecological recovery in rewilded areas is significantly greater than that in control areas. There were also significant improvements in water quality parameters, whereby the turbidity was reduced by about 30-40%, the nutrient concentration was also lower by 30-40%, and the dissolved oxygen level was also elevated by about 15. These effects were statistically significant ($p < 0.05$), and this proves the effectiveness of rewilding interventions. The paper states that ecosystem engineers are important in controlling important ecological processes that include nutrient cycling, sediment stabilization, water retention, and habitat formation, which are all important in ensuring the stability of the system in the long run. Policy-wise, these results offer a good indication that rewilding is an effective and natural way of restoring wetlands in wet areas like the Sundarbans that are ecologically sensitive. Ecosystem engineers should be integrated into the restoration program to improve the ecosystem services, such as flood management, carbon capture, and purification of water. The future research must involve long-term monitoring to determine the resilience of the ecosystems in the long term, and what may be the adaptability of this method using different types of wetlands. The broader adoption of such nature-based strategies would play a very important role in managing the sustainable ecosystem and conserving the wetlands worldwide.

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