

ECOLOGICAL REJUVENATION OF SAL FOREST LANDSCAPES: A NATIVE SPECIES-BASED RESTORATION STRATEGY FOR A PRIVATE RESORT IN TANGAIL, BANGLADESH

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Abstract: The ongoing degradation of Bangladesh's Sal (*Shorea robusta*) forests, largely caused by exotic monoculture plantations and unsustainable land use, has led to severe ecological decline, including biodiversity loss, soil degradation, and disrupted ecosystem functions. The present study adopts a site-specific ecological restoration process to rejuvenate native Sal Forest ecology within a private resort in the Madhupur Sal Forest tract and evaluates post-design outcomes to assess intervention effectiveness. The landscape was transformed through an adaptive, phased methodology informed by the Forest and Landscape Restoration (FLR) framework and the guidelines of the Society for Ecological Restoration (SER). The study investigates how SER- and FLR-aligned strategies can recover degraded soils, native vegetation, and ecological processes, and how post-design analysis demonstrates measurable ecological improvements. Restoration interventions included removing invasive monocultures, reintroducing native plant communities, recreating Chala-Baid topography, and restoring ecological processes. The study observed ecological changes also include spontaneous native groundcover regeneration and the return of diverse fauna and pollinators. Post-design soil assessment, based on a comparison between the restored site and the adjacent unrestored reference area, shows that the designed site is trending toward healthy Sal Forest conditions. The restored plot recorded a pH of 6.6 compared to 6.4 in the unrestored area, both within the preferred 5.1–6.8 range. Organic carbon increased substantially on the restored site (0.90% vs. 0.16%), indicating improved soil biological activity, while soil moisture was lower (0.64% vs. 2.18%), reflecting enhanced soil structure, greater root uptake, and better drainage associated with early-stage restoration. This study demonstrates that systematic restoration processes, combined with post-design evaluation, can effectively rejuvenate degraded Sal Forest sites and provide a replicable model for biodiversity-driven land management in tropical regions.

Keywords: *Ecological Restoration, Sal Forest, Monoculture, Native Species, Soil Recovery*

1. Introduction

Plantations serve multiple ecological and economic purposes, including the production of timber and firewood, conservation of soil and water, and carbon sequestration. However, their impact on the environment depends significantly on how and where they are established. When plantations replace natural ecosystem such as forests, grasslands, or shrublands with fast-growing, non-native species, they can cause severe ecological harm. These negative impacts include biodiversity loss, soil degradation, and disruption of wildlife habitats (Rahman M., 2023). Conversely, plantations using native species on degraded or deforested land can enhance biodiversity, restore ecosystem functions, and mitigate climate change by capturing atmospheric carbon (Rahman M., 2023; Doan et al., 2025). In such cases, plantation forestry becomes a tool for ecological restoration, particularly when it promotes self-sustaining ecosystems where natural processes like nutrient cycling, species regeneration, and vegetation succession continue without further human intervention (Kim et al., 2021).

The Madhupur Sal Forest, a key ecological component of the Madhupur Tract in central Bangladesh, exemplifies a fragile ecosystem under threat from unsustainable forestry practices. Ecologically classified as a Tropical Moist Deciduous Forest and dominated by Sal trees (*Shorea robusta*), this forest once covered large areas of the region. Today, it survives only in fragmented patches. The unique topography of the Tract comprising elevated 'Chala' lands and low-lying 'Baid' valleys, creates a mosaic of upland dry and lowland wetland habitats that support high biodiversity (Alam et al., 2008). The Sal Forest was historically managed by local landlords (zamindars), later it came under the jurisdiction of the Bangladesh Forest Department (BFD) in the mid-20th century. Starting in 1974, the government introduced large-scale monoculture plantations under the "Shamajik Bonayon" (social forestry) program, primarily using non-native species like Eucalyptus and Acacia for their commercial value and rapid growth (Davidson & Das, 1985). These plantations, while economically driven, have significantly altered the ecological balance, particularly in regions like Tangail and Madhupur. These species were selected for their rapid growth and adaptability across a range of environmental conditions (Kashem et al., 2016). While economically motivated, these plantations have caused widespread ecological disruption (Haque et al., 2014). The introduction of non-native monocultures has displaced native Sal forests, degraded soil health, and fragmented habitats, leading to a marked decline in biodiversity and ecological integrity (Sahar A & Shehata, 2005; Forrester et al., 2005; Khan et al., 2007).

This design research addresses the restoration of a degraded Sal Forest landscape, focusing on a private resort project

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where monoculture plantations are being replaced with native forest species. The process includes site assessment, identification of restoration goals, design and implementation of interventions, and long-term monitoring of ecological recovery. The study evaluates restoration success by comparing key ecological indicators such as groundcover composition, the presence of native and exotic composition of soil with reference conditions and by analysing the functional recovery of the ecosystem.

By highlighting the environmental degradation caused by monocultures and exploring the potential of native reforestation strategies, this study demonstrates the critical role of ecologically informed landscape design. It advocates for integrating traditional forest management, site-responsive planting, and agroforestry as sustainable and context-sensitive approaches to landscape restoration in Bangladesh.

2. Literature Review

The Bangladesh's forest ecosystems, particularly the Sal Forests of the central region, have experienced rapid degradation over recent decades due to anthropogenic pressures such as unplanned land use, monoculture plantations, and encroachment. Once ecologically diverse and structurally complex, these forests now exist in fragmented and vulnerable patches, raising concerns about biodiversity loss, soil degradation, and declining ecosystem services. This literature review critically examines the historical context, ecological characteristics, and drivers of degradation in Sal Forest ecosystems, with a particular focus on the Madhupur Tract. It further explores current restoration efforts, highlighting the principles and practices of ecological restoration as outlined in global frameworks. By identifying key indicators of ecological recovery, the review aims to inform context-responsive strategies for the restoration and long-term sustainability of native forest landscapes in Bangladesh.

2.1. SAL FOREST IN BANGLADESH

Bangladesh's tree-growing potential spans approximately 2.46 million hectares, or 17% of the country's land area, encompassing public forest land, unclassified state forests, and home gardens (Khan N., 2001). Due to its distinct geographical position, topography, and climatic variations, Bangladesh is home to a wide diversity of forest ecosystems. The country's three primary natural forest types (Figure 1(a)) are: Sundarbans mangroves in the southwest, Sal forests in the central region, and evergreen hill forests in the southeast, illustrate the ecological richness shaped by regional conditions (Khan N., 2001).

Among the forests, the Madhupur Sal Forest, also known as Madhupur Garh ("garh" meaning fort), holds ecological significance. As the third largest forest in the country, it spans approximately 45,565 acres, of which 2,525 acres are officially designated as reserved forest, and 43,039 acres are in the process of being gazetted. Sal forests, classified as tropical moist deciduous forests, are concentrated mainly in the Madhupur Tract, which lies 1 to 10 meters above the surrounding floodplains and historically abundant in medicinal plants, fruit-bearing trees, herbs, creepers, and diverse wildlife. These forests are found in districts such as Dhaka, Tangail, Mymensingh, Dinajpur, and Rangpur (Hossain et al., 2010) The Figure 1(b) shows the natural section of the Sal Forest landscape that contains elevated lands, lowers valleys and layering of plants in the forest. The natural soil of Sal forests is characteristically slightly acidic to neutral sandy loam, shaped by the terrace geology of the Madhupur Tract (Rana et al., 1988; Gangopadhyay et al., 1990). Historically, Sal Forests formed a vast, biologically rich belt across central and western Bangladesh. Today, they are highly degraded and fragmented due to agricultural expansion, unplanned settlements, and monocultural plantation practices (Barua et al., 2020). They now cover only about 124,500 hectares, which is equivalent to 0.81% of the country's total land area and 7.80% of its forested regions and alarmingly, nearly 38% of this forest area has already been encroached upon, leaving behind isolated and degraded patches (Saha et al., 2022).

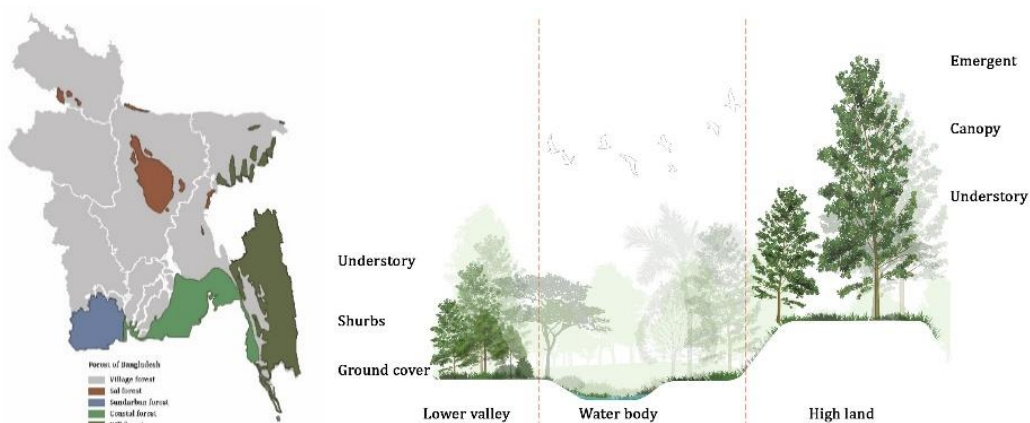


Figure 1: Location of Sal Forests in Bangladesh and its' topography

The Sal Forest ecosystem is known for its floristic and faunal diversity. Sal (*Shorea robusta*) is the dominant species, accompanied by native trees like Banyan (*Ficus bengalensis*), Ashwath (*Ficus religiosa*), Koroi (*Albizia spp.*), Ajuli (*Dillenia pentagyna*), Sonalu (*Cassia fistula*), and Jarul (*Lagerstroemia speciosa*). Fruit-bearing trees such as Mango (*Mangifera indica*), Jackfruit (*Artocarpus heterophyllus*), Guava (*Psidium guajava*), Pineapple (*Ananas comosus*), Lime (*Citrus aurantiifolia*), and Grapefruit (*Citrus maxima*) are also prevalent. In total, 63 plant species from 36 families have been commonly identified in Sal forests (Chowdhury, 2006). A specific survey recorded 40 plant species: 21 trees, 9 herbs, 5 shrubs, and 5 climbers, along with 17 animal species including 9 birds, 3 amphibians, 2 reptiles, and 3 mammals (GOB, 2007). An example of a relatively intact Sal Forest ecosystem is Bhawal National Park, which spans over 5,000 hectares. It consists of tropical moist deciduous forest, grassland, and wetland zones. The park's dense Sal-dominated vegetation supports a range of biodiversity, including hardwoods like Teak, grasslands that provide nesting areas for species such as the Blackbuck, and wetland habitats essential for aquatic and migratory birds. The accumulation of leaf litter in these deciduous forests enriches the soil, supporting the regeneration of medicinal plants and other native flora. Despite its ecological importance, the park faces threats from climate change, habitat degradation, and the decline of several native species. Once home to Bengal tigers and peacocks, it now supports fewer species such as spotted deer and native birdlife (Bala, 2024).

Overall, the Madhupur Sal Forest and similar ecosystems play a critical role in regulating the local climate, supporting biodiversity, and maintaining ecological balance. However, increasing environmental pressures and human interventions underscore the urgency of their protection and restoration (Paul et al., 2013).

2.2. SAL FOREST EXTINCTION

The natural forests and biodiversity of Bangladesh are under severe threat due to habitat destruction, overexploitation, land use changes, pollution, and poaching, further worsened by poor forest management, weak law enforcement, and frequent natural disasters (Khan N., 2001). As one of the most densely populated countries in the world, Bangladesh has very limited natural forest cover (Sarker et al., 2022). The pressure from rapid population growth, urbanization, and industrial expansion has intensified deforestation and ecosystem degradation (Barua et al., 2000). In response to declining forest resources, the Bangladesh Forest Department (BFD) launched the 'Shamajik Bonayon' (social forestry) program—a community-based afforestation initiative aimed at increasing tree cover by planting trees on underutilized public lands, such as roadsides, embankments, and fallow fields (Rahman M., 2022; Kashem et al., 2016). Under this program and the Thana Afforestation and Nursery Development Project (TANDP) initiated in 1989, the BFD targeted the development of 16,188 hectares of woodlot plantations within Sal Forest areas. To meet the rising demand for timber and fuel, fast-growing non-native species such as Eucalyptus camaldulensis, *AcaCia mangium*, and *Acacia auriculiformis* were widely introduced (Afrin et al., 2010). While these exotic species were chosen for their adaptability and rapid growth on degraded land, they have caused multiple ecological disruptions. These trees do not provide edible fruits or nectar, thus failing to support local wildlife populations (Mowla, 2005). Moreover, species like Eucalyptus and Acacia have been shown to reduce biodiversity, deplete soil nutrients, consume excessive groundwater, and release allelochemicals that inhibit the growth of native plant species (Rahman M., 2023; Sahar A & Shehata, 2005). In sensitive forest areas like Tangail's Sal Forest, the long-term consequences of monoculture plantations—including habitat fragmentation, reduced faunal presence, and degradation of soil health are clearly evident (Rahman et al., 2021).

In addition to plantation activities, forest areas in Madhupur are facing ecological pressure from the expansion of commercial agriculture. Many forest-dependent communities, motivated by quick economic returns, have converted large areas of forest into banana, pineapple, and papaya plantations. These crops, although lucrative, are often cultivated using heavy applications of fertilizers and pesticides, leading to soil erosion, chemical runoff, and declining land productivity. Alarming, the Bangladesh Forest Industries Development Corporation (BFIDC) has actively leased forest land to support such cultivation, accelerating the degradation of forest ecosystems (Gain, 2025).

Given the adverse ecological impacts of both nonnative monoculture plantations and unsustainable agricultural encroachment, there is an urgent need to revise restoration strategies. Conservation efforts should prioritize native Sal Forest regeneration and promote mixed-species plantations. Such approaches are vital for maintaining soil health, supporting biodiversity, and ensuring long-term ecological sustainability (Rahman et al., 2021).

2.3. DEGRADATION OF SAL FOREST ECOSYSTEM

Monoculture or non-native plantations significantly contribute to the loss of biodiversity by replacing complex native ecosystems with uniform tree species. This simplification of the ecosystem reduces plant diversity, which in turn limits food sources and habitat for a wide range of wildlife particularly birds, insects, and small mammals that are closely adapted to native flora. Historically, regions like Madhupur were rich in both flora and fauna, with established populations of elephants, Indian tigers (various sub-species), bears, and diverse bird species. Today, most large mammals are locally extinct, and only a few species such as monkeys, deer, and langurs remain. Native floral and fruiting plant species like haldu (*Haldina cordifolia*), korai (*Albizia lebeck*), chhatim (*Alstonia scholaris*), ronia (*Aphanamixis polystachya*), kadam (*Neolamarckia cadamba*), dewa (*Artocarpus lacucha*), neem (*Azadirachta indica*), jam (*Syzygium cumini*), palash (*Butea monosperma*) and shimul (*Bombax ceiba*) are still present but increasingly rare (Paul et al., 2013). The introduction of foreign tree species has also contributed to a sharp decline in bird populations, especially those reliant on insects, nectar, or fruit, which are largely absent in monoculture environments. Moreover, such plantations fragment natural habitats, impeding wildlife movement,

breeding, and gene flow, which weakens the genetic diversity and resilience of native species (Rahman M. , 2023). Monocultures also create ideal conditions for pest and disease outbreaks, as genetically uniform tree stands provide little resistance to pathogens and lack natural predators (Rahman M. , 2023). These pest infestations not only affect the plantations themselves but can also spread to adjacent native forests, further threatening ecological stability. In addition to biodiversity loss, monoculture plantations degrade soil health. Leaf litter from a single species often lacks the diversity of nutrients needed to sustain soil microorganisms, leading to reduced soil fertility and biodiversity (Hossain et al., 2010). Research by Hossain et al. (2010) shows that deforestation causes measurable soil degradation, including a sharp decline in moisture to ~10%, shifts in pH toward less acidic conditions (~5.3). The excessive nutrient uptake of fast-growing trees such as Eucalyptus or Acacia can also result in long-term soil exhaustion. Over time, these practices erode the ecological integrity of the landscape, reduce environmental resilience, and increase the risk of ecosystem collapse (Forrester et al., 2005).

Considering these impacts, large-scale monoculture plantations in ecologically sensitive regions are unsustainable. In the context of Bangladesh, where such practices have disrupted native ecosystems, ecological restoration is urgently needed. This involves not only conserving the remaining patches of native forests but also actively regenerating them through native species replantation and diverse, site-responsive plantation strategies (Rahman M. , 2023).

2.4 ECOLOGICAL RESTORATION

Ecological restoration is defined as the process of supporting the recovery of ecosystems that have been degraded, damaged, or destroyed, with the goal of reestablishing their natural structure, function, and resilience (SERI, 2004). Rather than constructing new ecosystems, restoration aims to facilitate the natural regeneration of native species and ecological processes, allowing degraded systems to recover along their original ecological trajectory.

A central mechanism in ecological restoration is ecological succession, the gradual change in species composition and community structure over time. This process typically begins with pioneer species, which colonize degraded areas and improve conditions for other species by enhancing soil fertility, moisture retention, and microclimatic stability (Wainwright et al., 2018; Walker et al., 2007). As more species establish, biodiversity increases, ecosystem functions improve, and the system becomes increasingly self-sustaining, reducing the need for continuous human intervention (Kim et al., 2021).

Water bodies also play a crucial role in enhancing ecosystem restoration. They not only offer aesthetic and ecological value, but also provide essential ecosystem services, including carbon capture, storage, and nutrient cycling (Pang & Deal, 2024). Lakes and wetlands support ecological balance by offering habitats for aquatic life, birds, mammals, and other wildlife, thus contributing to species richness and functional diversity (Patki, 2025).

In any restoration project, the interaction between biotic components (plants, animals, and microorganisms) and abiotic factors (soil, water, and climate) is fundamental. These interactions determine the survivability of species, the functioning of ecological processes, and the long-term sustainability of the restored system (Mark, 2022)

The Society for Ecological Restoration (SER) provides a conceptual framework for ecological recovery, presenting a continuum of intervention strategies tied to corresponding ecological outcomes (Kim et al., 2021). The SER framework outlines four major stages:

- Reducing Societal Impacts: Minimizing harmful human activities such as land degradation, pollution, and overexploitation to create favorable conditions for recovery.
- Remediation: Addressing specific environmental hazards such as contaminated soils or disrupted hydrological systems to stabilize ecological conditions.
- Rehabilitation: Restoring critical ecological functions like water retention, soil fertility, and vegetation cover, even if full biodiversity has not yet returned.
- Restoration: The most comprehensive intervention, focused on reestablishing native species diversity, ecological processes, and habitat structure.

These stages form a gradient of ecological recovery, ranging from degraded landscapes under pressure to fully functioning native ecosystems. The model offers a flexible and adaptive approach to ecological restoration, acknowledging the varying degrees of degradation and the context-specific nature of recovery pathways (Gann, et al., 2019; FAO, 2021).

2.5. INDICATOR OF ECOLOGICAL RESTORATION

The Society for Ecological Restoration International (SERI) outlines nine key conditions to assess the progress and success of ecological restoration, by following National Institute of Ecology, which is located on Seocheon, central western Korea, the ecosystem was developed. Firstly, the restored ecosystem should include a characteristic mix of native species that resemble those found in the reference ecosystem and form an appropriate community structure. Secondly, it should primarily consist of indigenous species, although in cultural ecosystems, some non-invasive domesticated, ruderal, or segetal species may be allowed. Thirdly, all essential functional groups necessary for ecosystem development and stability should be present or able to return naturally. Fourthly, the physical environment must be capable of supporting self-

replicating populations of key species. Fifthly, the ecosystem should exhibit normal ecological functions for its current stage without any signs of dysfunction. Sixthly, it should be ecologically connected to the surrounding landscape, allowing for natural flows and exchanges. Seventhly, potential threats from the nearby landscape should be reduced or eliminated. Eighthly, the restored system must be resilient enough to endure regular environmental stress events that help maintain ecological integrity. Lastly, the ecosystem should be self-sustaining under current conditions and capable of long-term persistence, allowing for natural changes and development over time (SERI, 2004; Kim et al., 2021).

3. Methodology

This study employs a site-based ecological restoration approach to examine the recovery of degraded Sal Forest ecosystems within the Madhupur Tract of Bangladesh. The restoration design was developed using the principles of Forest and Landscape Restoration (FLR) and the guidelines of the Society for Ecological Restoration (SER), which offered a structured yet flexible framework for diagnosing site degradation, identifying intervention priorities, and designing context-appropriate restoration actions. To evaluate the outcomes of this design, the study incorporated a combination of field surveys, landscape diagnostics, and spatial analysis. Post-restoration assessments included on-site surveys of groundcover composition, the presence of native and exotic species, and comparative soil testing.

Landcover change was analyzed using satellite images from different years to track shifts in vegetation density and canopy cover over time. Soil monitoring was conducted using a comparative site-based approach rather than a traditional Before–After design. Samples were collected on 1 September 2025 from a depth of 0–15 cm at two georeferenced locations shown in Figure 9: one (Soil-01) within the designed site where multiple restoration measures have been implemented, and the other (Soil-02) from an adjacent, untouched area with no restoration or design interventions. This approach allows for a direct comparison between restored and non-restored conditions, providing a meaningful baseline for evaluating the effectiveness of the implemented ecological restoration strategies. Laboratory analysis conducted at the Soil Resource Development Institute (SRDI) measured soil pH, moisture, and organic matter content. Together, the design and evaluation methods provided a transparent, evidence-based framework for assessing early-stage ecological recovery.

3.1. CASE STUDIES

A notable case of Sal Forest restoration aligned with ecological principles is the participatory agroforestry initiative undertaken in the Madhupur Sal Forest Tract, led by Japanese researcher Kimihiko Hyakumura and his team from Kyushu University. This project focused on restoring degraded Sal (*Shorea robusta*) forest landscapes through the reintroduction of native plant species in collaboration with local communities. The initiative aimed to improve soil fertility, promote biodiversity, and support local livelihoods by integrating indigenous ecological knowledge with scientific agroforestry practices. It serves as a practical demonstration of how native species-based restoration, coupled with community participation, can offer sustainable alternatives to monocultural plantations. The project aligns closely with the goals of this study, particularly in demonstrating that ecosystem recovery in Sal-dominated landscapes is possible through native species selection, careful zoning, and the reinforcement of biotic and abiotic processes. The Madhupur case reinforces the argument that restoring ecological balance in degraded forests requires moving away from exotic monocultures toward context-specific, culturally and ecologically rooted landscape strategies (Islam et al., 2024).

3.2. SITE ANALYSIS

The Iramon Private Resort project site (24°09'11.0"N, 90°10'57.3"E) is in Tangail, within the Madhupur Sal Forest tract one of the last remaining fragments of moist deciduous forest in central Bangladesh. Positioned in this ecologically sensitive zone, the site presents a concerning example of landscape degradation resulting from unsustainable land use practices. Historical satellite imagery and land-use analysis reveal dramatic changes in vegetation cover over the past decade.



Figure 2 Changes of site tree cover over the time

In 2013 (Figure 2a), the site was covered with a dense canopy of native Sal and associated species, supported by a healthy understory characteristics indicative of a functioning, biodiverse forest ecosystem. However, by 2016 (Figure 2b), much of

this native vegetation had been cleared and replaced with monocultures of non-native, fast-growing species such as *Acacia auriculiformis* and *Eucalyptus camaldulensis*, largely for aesthetic enhancement and short-term economic gain. Although by 2019 (Figure 2c), the canopy appeared denser due to the rapid growth of these exotic species, the forest floor remained barren, with minimal ground cover. A closer inspection of the current site (Figure 3) reveals signs of ecological stress: low soil moisture, increased termite activity, and a dry, exposed forest floor. These symptoms are consistent with the allelopathic effects and hydrological disruptions commonly associated with *Eucalyptus* and *Acacia*. These species release phytotoxins that inhibit native seed germination and aggressively deplete soil moisture, preventing the reestablishment of understory vegetation and reducing soil fertility.



Figure 3 Soil and ground cover inspection of site

From a Forest and Landscape Restoration (FLR) perspective, this site reflects a shift away from ecological integrity. Instead of restoring native biodiversity, ecosystem functions, and structural complexity, the landscape has been simplified and degraded. The current dominance of non-native monocultures violates key FLR principles, including the use of native species, enhancement of ecosystem services, and support for natural regeneration. This trajectory compromises biodiversity weakens ecological resilience and accelerates processes such as soil degradation and pest colonization.

To realign with FLR objectives, the site requires targeted ecological interventions. These include the phased removal of invasive species, restoration of native plant communities, and the use of Assisted Natural Regeneration (ANR) or enrichment planting strategies. Engaging local stakeholders throughout the restoration process will be essential to ensure both ecological recovery and long-term socio-economic sustainability.

3.3. SITE LANDSCAPE PLANNING

Site landscape planning focused on transforming a degraded area into a resilient Sal tract ecosystem through the implementation of four interrelated ecological strategies: Impact Reduction, Remediation, Rehabilitation, and Restoration (Figure 4). These approaches were not applied as fixed or sequential phases but rather as overlapping, adaptive processes, carefully tailored to the site’s ecological conditions and varying levels of disturbance. This integrative framework reflects current best practices in landscape restoration, which prioritize context-responsive, process-driven, and long-term interventions for ecological recovery.

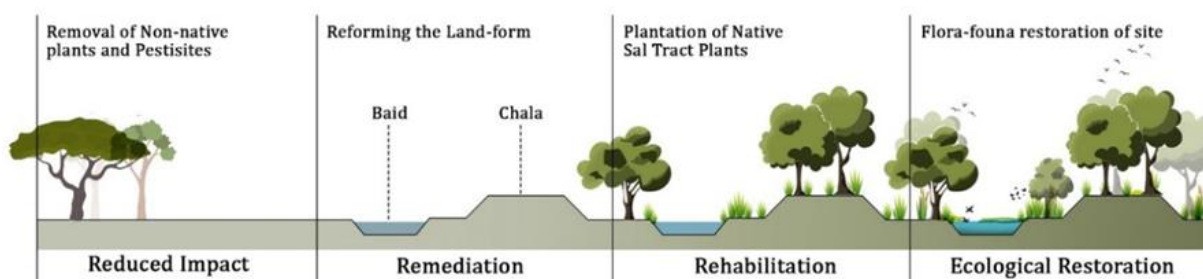


Figure 4 Four interrelated ecological strategies to recover ecosystem

3.3.1 Reducing Impact

The process began with Impact Reduction, targeting the elimination of harmful land use practices. This included removing monoculture plantations of non-native species such as *Acacia auriculiformis* and *Eucalyptus camaldulensis*, which had contributed to ecological simplification and biodiversity loss. Following their removal, Remediation measures were introduced to restore environmental quality by eliminating pests and residual agrochemicals, creating a healthier substrate

for regeneration. With the landscape cleared of invasive species and ecological stressors, the groundwork was established for the next stages: Rehabilitation and Restoration, aimed at reintroducing native vegetation, rebuilding ecosystem functions, and supporting long-term ecological resilience.

3.3.2 Remediation

Following the clearing of invasive species, successful rehabilitation of the Madhupur Sal Forest tract ecosystem necessitates the replication of its characteristic topographical features, particularly the distinct Chala (elevated land) and Baid (low-lying areas). To reestablish this fundamental ecological structure, a lake of approx. 56,900 square feet and an average dept of 12 feet was introduced along the site’s periphery to simulate the Baid, while raised landforms were constructed to represent the Chala (Figure 5). These topographical interventions aim to recreate the natural landscape mosaic that supports native plant communities and facilitates ecosystem processes integral to the Sal tract. The elevated landforms were formed using soil excavated from the newly created lake, enabling a natural redistribution of site materials that closely mirrors the original Chala-Baid topography. This approach not only restores physical heterogeneity but also allows pioneer species to take roots (Figure 8) which is the first phase of successional phases of sal forest (Krishna & Nora, 2006) and necessary for native plant species establishment and long-term ecological resilience (Clément, 2009)



Figure 5 Creating a lake surrounding the site to regenerate the historic landscape formation

3.3.3 Rehabilitation

The site was systematically divided into functional zones (Figure 6) to facilitate the strategic placement of plant species that support ecological restoration and biodiversity enhancement. Along the site boundary, the existing solid wall was replaced with a wire mesh fence to encourage the growth of creepers and climbing plants, thereby enhancing vertical vegetation connectivity. This design also allows for the circulation of small animals and reptiles between the site and its surrounding landscape, promoting habitat connectivity and ecological movement. Around the lakeshore, a variety of herbaceous species were introduced to stabilize the shoreline and prevent erosion. The area between the boundary and the lake was planted with large native trees to create a forest-like environment that supports local biodiversity. Additionally, a dedicated woodland zone was established to further enrich the site’s ecological complexity.

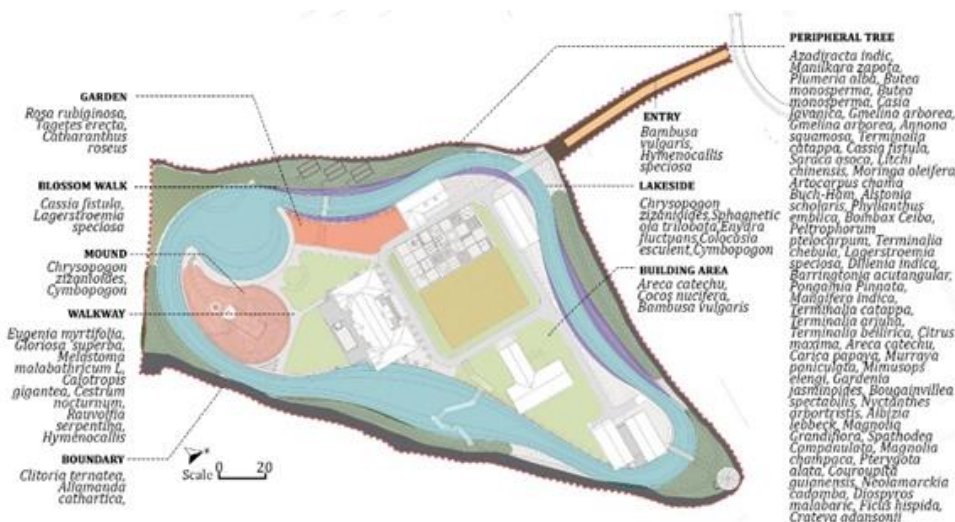


Figure 6 Site zoning and plantation design

A flower garden and blossom walk featuring local flowering trees and shrubs (see figure 6 for the plant list) with vibrant colors and pleasant scents were incorporated to attract pollinators such as bees, butterflies, and birds. Selected areas were planted with fruit trees to promote native species and provide food resources for wildlife, thereby supporting habitat creation. Shrub-like plants were strategically placed near buildings to prevent excessive shading of the built environment. Bamboo plantations flanked the main entry pathway, creating a distinctive and welcoming approach. Throughout the site, groundcover species were used to enhance soil stability and maintain visual cohesion.

Complementing the vegetation, local carp fish were introduced into the lake, and small-scale chicken and duck farming was established to reestablish functional biotic components within the ecosystem. All plant species used in the restoration including trees, shrubs, herbs, creepers, climbers, and groundcovers are listed as shows in Figure 7, with their specific locations mapped according to the site’s zoning plan (Figure 6). The plant palette was carefully selected to mimic the native Sal Forest vegetation, ensuring ecological authenticity and promoting sustainable restoration outcomes (Paul et al., 2013).

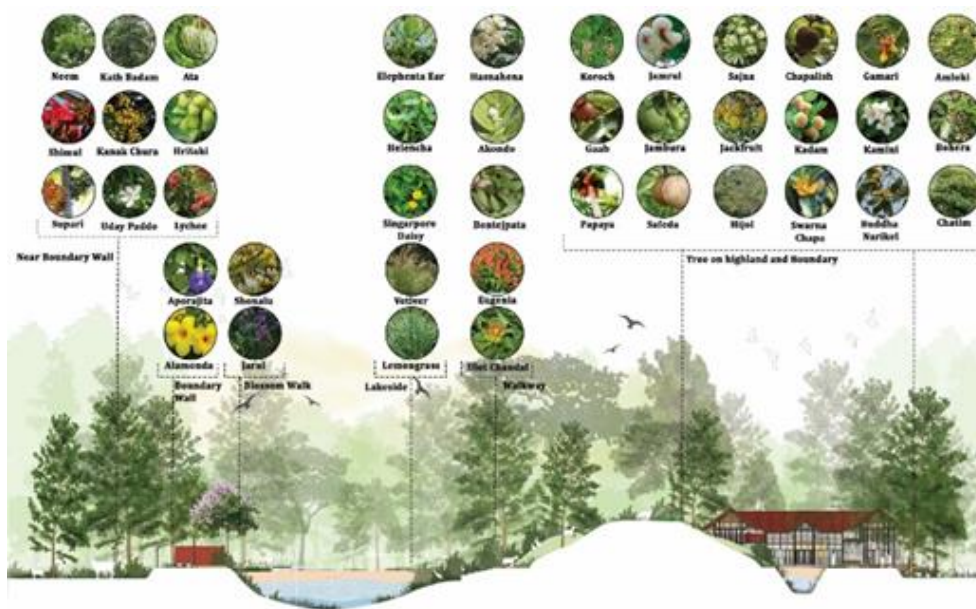


Figure 7 Plantation design of the site in section

3.3.4 Restoration

At this stage, continuous monitoring and adaptive management have been incorporated to ensure the rehabilitated Sal tract landscape progresses toward a self-sustaining ecological system. Key indicators—including the performance of planted native species, soil restoration, water quality in the artificial lake, and the return of local fauna—are systematically evaluated to inform necessary management adjustments. These efforts aim not only to reestablish biodiversity but also to restore the ecological and cultural identity unique to the Sal tract at this site. Through the replication of the Chala-Baid topography, the planting of native Sal Forest species, and the reinstatement of traditional ecological functions such as natural drainage patterns, multilayered vegetation structures, and species-specific habitats. As a result, the site is gradually being transformed into a resilient and functional living landscape.

4. Result and Discussion

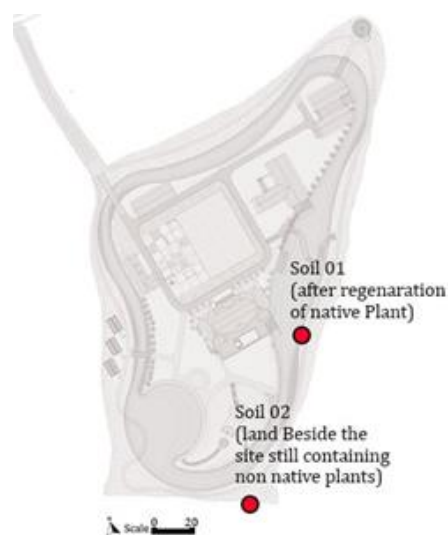
The site’s microclimate, shaped by the complex interaction of biotic and abiotic elements, showed marked changes following the ecological restoration efforts. Initial site analysis revealed dominance by non-native *Acacia* and *Eucalyptus* species, which severely inhibited the growth of native groundcovers and understory vegetation. This resulted in a notable absence of local flora and fauna, leading to a simplified and degraded ecosystem.

Post-restoration, significant ecological improvements were observed. Native vegetation, including a variety of fruit and flowering plants, began to establish and flourish some through deliberate planting, while others regenerated naturally. These positive vegetative changes are documented in Figure 8, highlighting the progressive recovery of plant diversity and ground cover (Figure 8(a, b, c, and f)). The return of fauna was equally encouraging numerous local bird species (common myna, house sparrow, oriental magpie, bulbul, barbet, dove, water hen) were recorded visiting, nesting, and reproducing on site (Figure 8(d) and 8(g)), indicating enhanced habitat suitability. Additionally, the users of the site observed an increase in non-venomous snake species, accompanied by a decline in venomous snakes. The decline in venomous snake sightings may be related to vegetation changes, but this requires targeted monitoring to confirm. Furthermore, areas previously characterized by dry, sparse ground cover experienced the spontaneous regeneration of native groundcover species (*Eulaliopsis binate*, *Oplismenus hirtellus*, and *Arundinella setosa*) throughout the site, including along the reintroduced lake’s edges.



Figure 8 post-restoration observation shows positive changes in ecosystem

The Soil assessment comparison between the restored site and the adjacent unrestored reference area indicates that the site is gradually moving toward the characteristic soil conditions of a healthy Sal (*Shorea robusta*) forest. According to established references, Sal Forest soils typically prefer a slightly acidic to neutral sandy loam with a pH ranging from 5.1 to 6.8 and an organic carbon content of 0.11–1.8% (Rana et al., 1988; Gangopadhyay et al., 1990). The post-restoration soil sample (Soil-1) recorded a pH of 6.6, compared to 6.4 in the pre-restoration condition (Soil-2), placing both within the preferred pH envelope for Sal Forest ecosystems and suggesting a stable chemical environment conducive to native vegetation recovery.



Analytical Result

Lab No.	Sample name and Code	Tested Item	
		Element	Result
S2025-468	Soil 01	pH	6.60%
		Organic Matter	1.55
		Moisture	0.64%
S2025-469	Soil 02	pH	6.40%
		Organic Matter	0.28
		Moisture	2.18%

Note: Both Samples were taken 01 September 2025 (1:00 pm)

Figure 9 Soil sample collection locations and soil test summary

A more notable shift is observed in organic matter content, which increased from 0.28% to 1.55%. When converted to organic carbon (using $OC = OM \times 0.58$), this corresponds to an increase from approximately 0.16% OC (pre-restoration) to 0.90% OC (post-restoration). This positions the restored soil well within the baseline organic carbon range reported for Sal Forest soils. The increase likely reflects the combined effects of mulch decomposition, enhanced litter accumulation from native plantings, and early microbial reactivation expected outcomes in the initial phases of forest restoration. Soil moisture declined from 2.18% to 0.64%, a pattern commonly observed in early restoration stages where improved soil structure, increased root uptake from establishing native species, and enhanced drainage reduce surface moisture (Wei, Zhou, Cai, & Wang, 2021). While this decline does not fall outside expected variation, it highlights the need for continued monitoring, especially during dry seasons, to ensure that moisture levels remain sufficient to support seedling establishment.

Collectively, these results demonstrate that the soil is beginning to align with the known ecological baseline of Sal Forest systems. The findings also show that more work is still needed. We need to keep adding organic matter, increase

groundcover, and continue regular monitoring. These actions will help the soil recover further and stay on track toward healthy Sal Forest conditions.

5. Conclusion

The ecological restoration of the Iramon Private Resort within the Tangail Sal Forest tract exemplifies the effectiveness of native, landscape-based interventions in mitigating the adverse impacts of monoculture plantations. Notable improvements in soil moisture retention, spontaneous regeneration of native groundcover, and the resurgence of diverse fauna demonstrate that restoring indigenous vegetation enhances both biological productivity and ecosystem stability. The soil data indicate early but encouraging shifts toward healthier baseline conditions, although continued monitoring will be required to confirm long-term recovery trajectories. These outcomes align closely with the guiding principles of the SERI, particularly the emphasis on reestablishing native species, promoting functional diversity, fostering ecosystem resilience, and ensuring long-term sustainability. This study highlights the critical need to prioritize indigenous species and site-responsive design approaches within ecological restoration frameworks. Furthermore, the Iramon Private Resort case underscores the integral role of landscape architecture, when integrated with ecological science, in advancing restoration goals even in private or semi-urban settings by rebalancing ecological systems and enriching biodiversity.

In summary, this design research contributes to the ongoing discourse on ecological regeneration in Bangladesh by providing a replicable model for restoring tropical Sal Forest ecosystems. It calls for a paradigm shift from economically motivated monocultural plantations toward ecologically guided, biodiversity-supportive land management. By adopting traditional planting schemes, agroforestry, and restoration-based landscape design, future initiatives in Bangladesh and similar tropical regions can achieve both environmental sustainability and socio-cultural significance.

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