Current status and solutions for mangrove forest restoration at Xuan Thuy National Park, Ninh Binh province, Vietnam to build a mangrove forest landscape model

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ABSTRACT: *Planting mangrove forests based on the mangrove forest landscape approach in the coastal areas of Xuan Thuy National Park, Ninh Binh Province, Vietnam, requires standard methods to ensure the trees survive tides, big waves, and strong winds. This study provides a series of steps for handling seedlings, planting, and initial care. Holes are dug immediately before planting to prevent sediment from filling them, with the best period being from July to October. Seedlings in bags are treated on land for a week, transported in trays or baskets, and planted directly at a depth of 3–5 cm after carefully removing the plastic bags. Arranging and using a suitable diversity of 3–4 species helps create a mangrove landscape forest ecosystem. Stability is enhanced by placing bamboo or acacia stakes, using one or three stakes tied with soft rope. Supplementary planting is carried out if more than 10% of trees die in the first 1–2 months and continues during the first three years. Care in the first three months means checking every 10 days, then maintenance every three months, including clearing debris and straightening the seedlings.*

KEYWORDS: *Ecological engineering; Xuan Thuy National Park, mangrove landcape.*

I. Introduction

Mangrove forests constitute a unique wetland ecosystem, forming a transitional zone between terrestrial and marine environments and being strongly influenced by tidal regimes. They occur along coastlines and estuarine areas that are regularly or periodically inundated by saline tidal waters. Mangroves are distributed predominantly in tropical and subtropical regions, with limited occurrences in some temperate areas. According to the Food and Agriculture Organization (FAO) Global Forest Resources Assessment, which compiled data from 223 countries and territories, 113 countries possessed mangrove forests in 2020, while the remaining 110 had none. The global mangrove area was estimated at approximately 14.8 million hectares, of which Asia accounted for the largest share (5.55 million ha), followed by Africa, North and Central America, South America, and Oceania. Indonesia, which possesses the world's largest mangrove area, lost approximately 40% of its mangrove cover over several decades, primarily due to the expansion of intensive shrimp aquaculture. In response, the Indonesian government has launched a national program to restore 600,000 hectares of mangroves, recognizing restoration as a key strategy for mitigating coastal erosion and reducing greenhouse gas emissions. Bangladesh, home to the Sundarbans—the world's largest contiguous mangrove forest and a critical natural barrier protecting tens of millions of people—is facing increasing threats from sea-level rise and tropical cyclones. In collaboration with international organizations, the government has implemented extensive mangrove conservation and restoration programs integrated with sustainable livelihood activities, including honey production and environmentally sustainable aquaculture. At the global level, mangrove restoration has become a major priority under the United Nations Decade on Ecosystem Restoration (2021–2030), reflecting the exceptional capacity of mangrove ecosystems to sequester and store substantially greater amounts of carbon than most terrestrial forests. Likewise, international initiatives such as the Mangrove Alliance for Climate (MAC) actively promote the conservation, restoration, and expansion of mangrove forests as an effective nature-based solution for climate change mitigation and adaptation.

In Vietnam, mangrove degradation has continued in recent decades as a result of both natural processes and human activities. Addressing these challenges requires not only adaptive measures to cope with climate change and sea-level rise but also a stronger scientific foundation to maintain ecological stability and enhance the protective, environmental, and socio-economic functions of mangrove ecosystems. However, current approaches to mangrove restoration on exposed coastal mudflats remain inadequate, as they often lack scientifically validated ecological and silvicultural solutions tailored to specific site conditions. This limitation highlights the urgent need for targeted research to develop practical and scientifically sound restoration strategies that can be applied on a larger scale in similarly challenging environments.

Accordingly, this study aims to assess the current status of mangrove ecosystems and develop ecological solutions for establishing a mangrove forest landscape model under diverse site conditions in Xuan Thuy National Park. Through comprehensive field surveys, analysis of environmental characteristics, assessment of forest conditions, and identification of the major drivers of degradation, the study proposes appropriate ecological and silvicultural measures for mangrove restoration and management. The ultimate objective is to establish a scientifically robust and practically applicable framework for mangrove development. The findings are expected to provide a reliable scientific basis for selecting appropriate ecological restoration techniques and management practices that can support sustainable mangrove development in other coastal regions of Vietnam facing similar environmental constraints.

II. Materials and Methods

2.1. Study area

Xuan Thuy National Park in Ninh Binh province of the inter-provincial Coastal Wetland Biosphere Reserve of the Red River Delta, located within Vietnam's Red River Delta region, is one of the 12 World Biosphere Reserves recognized by UNESCO to date. This region is a crucial economic hub with substantial potential for developing tourism, aquaculture and fisheries, maritime services, and the manufacturing industry. Designated in 2004, the Biosphere Reserve encompasses two provinces Ninh Binh and Hung Yen covering a total area of 105,558 hectares. This comprises 66,256 ha of coastal mainland and 39,302 ha of marine water surface, extending across communes. Its core zones include the Xuan Thuy National Park in Ninh Binh province and the Thai Binh Provincial Wetland Nature Reserve (now Hung Yen province). In 2025, the total mangrove forest area in Ninh Binh Province was estimated at 3,483.96 ha. Of this total, 1,063.46 ha were located within Xuan Thuy National Park.

The area possesses significant biodiversity, hosting over 1,583 animal species, more than 330 plant species, and over 222 bird species (including nearly 60 migratory and over 200 waterbird species). Rare species such as the Black-faced Spoonbill (*Platalea minor*), Saunders's Gull (*Chroicocephalus saundersi*), Spoon-billed Sandpiper (*Calidris pygmaea*), and Eastern Great Egret (Ardea modesta) are regularly observed. UNESCO has recognized the Reserve as a critical habitat for numerous rare waterbirds and migratory birds, representing a quintessential estuarine coastal wetland ecosystem in Northern Vietnam. Notably, Xuan Thuy National Park, the core zone, is a designated Ramsar site, underscoring its international importance for migratory bird conservation. In September 2025, Xuan Thuy National Park was further recognized as an ASEAN Heritage Park. The mangrove forests serve as a "green wall," offering protection to coastal dikes and villages against the impacts of storms, sea-level rise, and tsunamis.

Identification of mangrove site categories: Type III (Challenging mangrove mudflat site) in Giao Hoa communer, Ninh Binh province. This is buffer zone of Xuan Thuy National Park with building a mangrove forest landscape model: This category refers to tidal flat areas that are barren or sparsely vegetated with mangroves, where the density is insufficient to form a mature forest. These sites are directly exposed to the open sea and are constantly subjected to the direct impacts of hydrodynamic regimes (e.g., waves and currents), which inhibit natural mangrove regeneration. In recent years, conventional mangrove afforestation methods (species selection, planting, tending, etc.) on these tidal flats have demonstrated low efficacy under challenging site conditions, particularly when continuous wave heights exceed 0.4 meters.

2.2. Research objectives and scope

Research Objectives: The subject of this research is mangrove site conditions, as defined by Decision No. 5365/QĐ-BNN-TCLN dated December 23, 2016, issued by the Ministry of Agriculture and Rural Development. Within this framework, site conditions for mangrove afforestation are understood as 'the local and surrounding climatic, hydrological, topographical, soil, and vegetation conditions of the plants' habitat.' Some fundamental site categories include: Ia, Ib, Ic, Id, Ie, and Ig. Specifically, favorable conditions (Group I) typically correspond to category Ib, average conditions (Group II) to category Ic, and challenging conditions (Group III) to category Id. The challenging planting conditions within the study area are identified as Group III, which specifies a substrate of dense clay or stiff clay with penetration less than 5cm, or sandy-mud (sand content > 70%). The tidal regime is characterized by deep tidal inundation.

Mangrove development is understood as the application of silvicultural measures and other supporting interventions (hydrology, environmental management) to maximize natural regeneration and artificial regeneration for new mangrove afforestation. The ecological solution for mangrove restoration involves applying new planting techniques in coastal mudflat areas to stabilize forest capital and enhance livelihoods for coastal communities within the Xuan Thuy National Park of Ninh Binh province.

2.3. Research methodology

2.3.1. Literature review and data collection

This method involves collecting, inheriting, and retrospectively analyzing information pertinent to the study area. It includes gathering and leveraging research findings from various levels of scientific programs, projects, and published scientific works relevant to the study site. Available documents and data will be critically reviewed and selected for appropriate use in the comprehensive overview report and specialized reports that inherit from the project titled: Research on developing a landscape mangrove forest model to promote ecotourism at Xuan Thuy National Park, Nam Dinh province, led by the Sub-Department of Forestry and Forest Protection of Ninh Binh Province, with by principal investigator: M.Sc. To Van Vuong, conducted from 2024 to 2025. Collected literature will be synthesized in a specific order, whether chronologically or by reliability, and data will be analyzed to select appropriate figures.

For mangrove planting, tending, and protection on technical guidelines for planting and tending various mangrove species, will be utilized. Additionally, technical guidelines for mangrove planting from the Ministry of Agriculture and Rural Development, and specialized monographs on mangroves by authors Do Quy Manh (2020) will be referenced.

2.3.2. Expert consultation method

A multi-round expert consultation is planned to ensure the scientific rigor and quality of the research outcomes, engaging a total of four specialists: two in mangrove-related forestry and two in coastal ecological engineering. The consultation will focus on developing high-quality research on mangrove forests, specifically covering methodologies for status analysis and assessment, identifying the underlying causes of mangrove degradation, and proposing effective silvicultural solutions for development in the study area. Crucially, the process will also address hydraulic engineering solutions necessary to support restoration, such as achieving equilibrium in tidal flat conditions and substrate stability. This includes the technical design and deployment of bamboo fence systems for wave attenuation and accretion promotion, which are critical steps for creating suitable mudflats and ensuring the stable growth and development of new mangrove afforestation efforts. Experts will be engaged through workshops and active participation in field surveys and investigations.

2.3.4. Mangrove current status investigation method

Data from the 2015 and 2022 forest inventory maps, along with planting data from various years and annual forest change monitoring data from the Ninh Binh province from 1990 to 2022, will be utilized.

Mangrove forests, particularly those in aquaculture areas, degraded mangrove areas, and coastal tidal flats of Ninh Binh provinces, will be surveyed.

Methodology for mangrove and mangrove forest surveys: Investigation transects (18 transects covering all survey types: site conditions, sampling for soil and water environmental characteristics analysis) will be established. Along each transect, three typical temporary Standard Sample Plots (SSPs) will be set up to represent mangrove site conditions of good, average, and poor quality. A total of 30 SSPs will be established for mudflat site conditions, each with an area of 500 m². Within these plots, the following parameters will be measured and determined: Doo (Basal diameter): Measured at the tree trunk 10-15cm above the ground surface or above the highest root collar of the stilt root system; this parameter is measured with a measuring tape by circumference and then converted to diameter, accurate to the millimeter. Hvn (Total height): Measured using a specialized height measuring device, accurate to the centimeter. Dt (Crown diameter): Measured with a measuring tape, accurate to the centimeter. Tree age, density, and growth will also be determined.

III. Results

3.1. Current status and dynamics of mangrove forests

3.1.1. Mangrove distribution

- ***Aegiceras corniculatum- Sonneratia caseolaris - Kandelia obovata - Avicennia marina* community:** This community is characterized by a mixed distribution of these species, forming three distinct strata. The emergent layer consists of scattered *Sonneratia caseolaris*, rising above the forest canopy to heights of 1.80-7.00m. These trees exhibit rapid propagation and possess high potential for future dominance. The main canopy layer, which is ecologically dominant, comprises *Kandelia obovata* and *Aegiceras corniculatum*. Interspersed among these two species are *Avicennia marina*, dispersed by tides, but thriving due to strong competitive ability to reach the canopy. In higher elevation areas, *Derris trifoliata* scrambles up host trees to the top of the canopy, sometimes even covering other tree crowns. This community directly borders the coastline and gradually extends seaward. It represents a primary target for selecting suitable mangrove species for afforestation under prevailing planting conditions.
- ***Aegiceras corniculatum - Kandelia obovata - Sonneratia caseolaris* community:** This community is typically found adjacent to pond banks, near protective dikes, and in stable mangrove wetland areas. Trees within this community reach an average height of 2.10m – 7.20m. Natural regeneration of *Kandelia obovata* and *Aegiceras corniculatum* is dominant, while *Sonneratia caseolaris* occupies a smaller area. Additionally, a few scattered *Bruguiera gymnorrhiza* are present within this community.
- ***Kandelia obovata - Rhizophora stylosa - Sonneratia caseolaris* community:** This community is distributed in the central region of the mangrove ecosystem. Trees typically range from 2.20m to 7.10m in height. *Kandelia obovata* is dominant, while *Rhizophora stylosa* and *Sonneratia caseolaris* occupy smaller areas.

Although the plant communities on coastal tidal mudflats do not exhibit high species diversity, comprising only a few main species (such as *Aegiceras corniculatum, Kandelia obovata, Sonneratia caseolaris, Avicennia marina*, *Rhizophora stylosa*, and *Bruguiera gymnorrhiza*), they function as pioneer communities. They play a crucial role in protecting, sustaining, and stabilizing these communities. Therefore, it is essential to protect and expand certain mangrove species, such as *Avicennia marina* and *Rhizophora stylosa*, in large quantities.

3.1.2. Mangrove species composition

Investigation results from the coastal and mudflat areas of the Red River Delta Biosphere Reserve indicate a concentration of species such as *Sonneratia caseolaris*, *Acanthus ilicifolius*, *Excoecaria agallocha*, and *Hibiscus tiliaceus*, among others. Species commonly found in higher mudflat areas, adjacent to national dikes, include *Hibiscus tiliaceus*, *Excoecaria agallocha*, *Acanthus ilicifolius*, and *Kandelia obovata*. Species like

Scaevola taccada, *Acrostichum aureum*, *Acrostichum speciosum*, and *Kandelia obovata* appear in areas near small dunes.

Several mangrove species have been introduced from various regions, both domestically and internationally, and planted experimentally at Xuan Thuy National Park. These species have gradually adapted and are thriving within the mangrove study area. They include: *Lumnitzera racemosa Willd.*, *Bruguiera gymnorrhiza (L.) Lamk.*, *Bruguiera parviflora (Roxb.) Wight. & Arn. ex Griff. Bruguiera sexangula (Lour.) Poir.*, *Sonneratia apetala Buch.-Ham.*, and *Avicennia marina (Forssk.) Vierh.*.

The compiled results of the current status investigation reveal approximately 41 species of higher plants widely distributed across coastal sandy areas, the intertidal zone, and tidally influenced regions. Among these, several vascular higher plant mangrove species are considered for mangrove development in mudflat areas, namely: *Aegiceras corniculatu*, *Kandelia obovata*, *Sonneratia caseolaris*, *Sonneratia apetala*, *Avicennia marina*, and *Rhizophora stylosa*.

3.1.3. Mangrove forest area

The newly planted forest area predominantly consists of coastal protection forests and mangrove forests. The total mangrove forest area Ninh Binh province: 3,483.96 ha. In 2025, the management of mangrove forest areas, People's Committees at various levels manage over 1,756.76 ha. Other organizations, such as Xuan Thuy National Park, manage 1.063.46 ha of mangrove forest; management board of protection and special-use forests of Ninh Binh province over 545.59 ha; the Military Command of Ninh Binh province manages over 51.82 ha; and the Department of Agriculture and Environment of Ninh Binh province province manages over 66.33 ha.

3.1.4. Growth of key mangrove species

Existing literature assessing the growth of mangroves in the study area at different ages is scarce. Therefore, investigating, analyzing, and evaluating mangrove growth using specific silvicultural parameters is crucial for selecting appropriate tree species for mangrove sites in the study area. The results indicate that growth parameters of *Sonneratia caseolaris* and *Kandelia obovata* (diameter at the base, tree height, and crown diameter) generally increase with stand age, but their mean annual increments decline over time, following the natural growth pattern of forest trees.

For *S. caseolaris*, Doo increased from 2.11 cm/year (age 3) to 3.26 cm/year (age 5), then decreased to about 2.1 cm/year (ages 6–7), and further dropped to 1.71 cm/year (age 11). *K. obovata* showed lower increments, ranging from 1.22 cm/year (age 9) to 1.53 cm/year (age 4), and fell below 1.0 cm/year after age 10. Tree height and crown diameter increments also rose slightly before age 10, then declined afterward.

Growth of *S. caseolaris* was strongest at ages 4–5 on soft clay sites with salinity 10–11‰ and mean elevation +0.3–0.4 m, moderate at ages 6–7 on light loamy soils with salinity 15–16‰, and poorest after age 10 on sandy-loam sites with salinity >18‰ and elevation above +0.5 m. *K. obovata* grew best at ages 3–4 on light loamy soils with salinity >17‰ and elevation +0.4 m, moderately on soft clay with salinity ~13‰ and elevation +0.3 m, and weakest on sandy-loam sites with elevation >0.5 m and salinity <16‰.

3.1.5. Fluctuation of mangrove forests in the study area

The mangrove forest area within the Xuan Thuy National Park has experienced long-term fluctuations. The decline is attributed to two main groups of drivers: natural processes and anthropogenic influences. Natural factors are highly significant, dominated by geological instability and coastal erosion resulting from wave action, sea winds, and storms, which have caused the loss of hundreds of hectares, notably in Ninh Binh province. Climate change exacerbates these effects through extreme weather events and strong winds that destroy stands and alter tidal flats. Specific natural events, such as the severe cold stress of the 2015 winter, led to widespread dieback of *Sonneratia caseolaris* in Xuan Thuy National Park. Furthermore, natural senescence of over-mature *Kandelia obovata* and *S. caseolaris* stands contributes to overall decline, compounded by pests and diseases (e.g., Balanus spp. and decapods) often linked to water pollution. Overall, wave action is identified as the dominant factor causing instability in coastal tidal flats, hindering restoration by leading to mortality in newly planted mangroves. Consequently, the application of scientific and technological interventions, such as ecological engineering solutions utilizing bio-materials (bamboo, timber, vegetation), is essential to stabilize accretion banks and create suitable substrates prior to new planting efforts.

3.2. Mangrove site classification

The statistical results indicate that the difficult site class constitutes the largest proportion, accounting for 459,26 hectares. This is followed by the moderate site class with 251,89 hectares, and the favorable site class only accounts for 106,84 hectares (see Table 1).

Table 1. Summary of site class distribution results by location

Area	**Site class (Level)**	**Area (ha)**
Xuan Thuy National Park	Difficult	459,26
	Favorable	106,84
	Moderate	251,89
Total		**617,99**

The assessment indicates that most coastal tidal flats in the Xuan Thuy National Park fall under unfavorable conditions, significantly limiting mangrove afforestation potential without technical interventions. where tidal flats are highly exposed to waves, tides, and salinity stress. Overall, difficult sites are concentrated Ninh Bình presents opportunities for integrated hydro-forestry development. Xuan Thuy National Park reflects mixed conditions due to complex topography and hydrology. The findings emphasize the need for combined ecological engineering measures-such as soft dikes and vegetated revetments-along with the use of salt-tolerant species and site-specific hydro-forestry models.

3.3. Proposed solutions for mangrove forest development

(1) Conditions for implementation

The evaluation of site suitability for mangrove afforestation is essential, as it directly determines survival and growth success. Effective planting requires comprehensive surveys of natural conditions, including tidal flat exposure duration, salinity, wave height, tidal regimes, and substrate stability. Long-term hydro-oceanographic datasets (10–30 years) and shoreline change dynamics must also be analyzed to capture fluctuation patterns under climate change and sea-level rise. Suitable sites are characterized by stable accretion banks, moderate to low mean high tide levels, tidal flat elevations ranging from −0.2 m to +0.5 m, and a minimum exposure duration of 6 hours. These conditions ensure adequate soil aeration, complete drainage during low tide, and protection from wave-induced erosion or channel formation..

Table 10. Empirical assessment of mangrove site factors prior to afforestation in the Xuan Thuy National Park [21]

No.	**Mangrove site factor**	**Criteria**	**Value**	**Suitability level for mangrove species**
1	Mangrove soil classification	Highly saline soil	TMT (Total Soluble Salts) > 0.7%, Cl−>0.5%	Suitable for species of Avicennia, Rhizophora, Bruguiera families
		Medium saline soil	TMT from 0.5 to 0.7%, Cl− from 0.3 to 0.5%	Suitable for a wide range of mangrove species
		Low saline soil	TMT < 0.5%, Cl−<0.3%	Suitable for the Sonneratia family
2	Tidal flat exposure duration	Suitable	From 6 to 8 hours per day/night	Suitable for most mangrove species

		Unsuitable	< 6 hours/day or > 8 hours per day/night	Unsuitable
3	Mangrove eoil maturity	Soft mud	Foot penetration depth >40 cm	Poorly suitable
		Firm mud	Foot penetration depth from 20−40 cm	Suitable for most mangrove species
		Soft clay → Firm clay	Foot penetration depth from 5−20 cm	Suitable for Lumnitzera, Ceriops, Bruguiera families
		Hard clay	Foot penetration depth below 5 cm	Suitable for Thespesia, Excoecaria families
4	Sand particle percentage (%)	Low sand content	<30%	Suitable
		Medium sand content	30−50%	Suitable for many species
		High sand Content	>50%	Unsuitable
5	Mangrove soil elevation	Low slevation	<−0.2 m	Unsuitable
		Medium elevation	From −0.2 m to +0.5 m	Highly suitable
		High elevation	>+0.5 m	Poorly suitable

Based on these parameters, the sites are categorized into Favorable, Moderate, and Difficult site classes. Each site class can then be matched with appropriate empirical formulas for mangrove afforestation suitable for the Red River Delta Biosphere Reserve.

(2) Determining appropriate species and seedling standards for mangrove development

Selecting native species: Suitable species include *Avicennia marina*, *Kandelia obovata*, *Sonneratia caseolaris*, *Sonneratia apetala*, *Rhizophora mucronata*, and *Aegiceras corniculatum*. Among these, *A. marina*, *K. obovata*, *S. caseolaris*, and *A. corniculatum* are used for planting in barren tidal flats or for supplementary planting in existing mangrove areas. The pioneer species in this region are *K. obovata* and *S. caseolaris*.

Technical standards for mangrove seedlings: Seedling age: Mangrove seedlings should be nursery-grown in pots for 12 to 18 months, depending on the establishment conditions. Under favorable conditions, a minimum of 12 months of nursery care is required. For difficult conditions, 18 months of nursery care is needed to ensure the stem is lignified and has better resistance to adverse conditions. Seedling growth parameters: Root collar diameter should be 0.8 to 1.2 cm; height should range from 0.8 to 1.2 m. The seedlings must possess pneumatophores (aerial roots), exhibit vigorous growth, and be free from pests and diseases. Pre-Planting preparation: Mangrove seedlings must undergo pot rotation (root pruning/turning) for at least one month before being transported for planting. For species with early and rapid branching capability, such as S. *caseolaris* and *A. marina*, mechanical treatment involving the pruning of branches and leaves should be performed before planting. This is essential to increase the survival rate and mitigate the negative impact of wave action and sea winds on new plantings before root establishment occurs.

(3) Mangrove afforestation methodologies and techniques

Mangrove afforestation system: Planting can be done using a monoculture system or a mixed-species system, typically an intercrop of *K. obovata* and *S. caseolaris*. Areas where *K. obovata* propagules and *S. caseolaris* fruits are available and meet quality standards, having been selected from seed stands, seed orchards, or plus trees from existing plantations, should use locally sourced materials for nursery production and planting.

Mangrove planting technique: The study established a standardized set of technical procedures for mangrove planting and subsequent management in areas subject to tidal inundation, strong waves, and high winds. It was determined that holes must be dug simultaneously with planting operations, as pre-dug holes are quickly filled with sediment during tidal activity. The recommended planting season extends from July to October each year, coinciding with favorable hydrological and climatic conditions. For planting with bagged seedlings, it is required that seedlings be transferred ashore one week before planting to allow soil drainage and stabilization of the root ball. Transportation must be conducted using trays, baskets, or other appropriate containers, and direct lifting by stem or shoot is strictly prohibited to prevent root damage. Prior to planting, the polyethylene bag must be carefully removed, and seedlings should be positioned vertically with the root ball placed 3–5 cm below the soil surface. Soil backfilling must be completed with firm hand and foot compaction to ensure stability, and all plastic waste must be collected and transported inland for disposal.

To enhance seedling stability against hydrodynamic forces, staking is required using locally available materials such as bamboo or melaleuca poles. Two staking techniques were identified: the single-stake method, which involves inserting one stake at a 45° angle facing seaward and tying the stem at 15–20 cm above ground level, and the triple-stake method, which involves three stakes arranged as a tripod at a 45° angle, tied together at a junction point 15–20 cm above ground to firmly secure the stem. The use of soft twine is recommended to prevent abrasion, while ensuring sufficient stability to avoid mortality from physical stress. Supplementary planting is mandated when seedling mortality exceeds 10% within one to two months after establishment, using healthy seedlings of equivalent size, and this measure should be maintained throughout the first three years.

Forest care and protection were found to be critical during the early establishment phase. Intensive care during the first three months requires inspections every 10 days in areas subject to heavy debris or strong waves, including removal of debris, re-driving of stakes, and re-tying of loose bindings. Thereafter, maintenance should be performed at three-month intervals, including weeding, debris clearance, and correction of bent seedlings. Protection measures include the installation of signage to prohibit fishing and exploitation, strict enforcement against illegal logging and destruction, and active monitoring of pests and diseases. Furthermore, regulations stipulate that no dikes or enclosures impeding tidal flows for aquaculture or combined production are permitted during the first four years. In subsequent years, aquaculture activities may be allowed only under approved plans that do not negatively impact mangrove forest growth or ecological functions.

IV. Conclusions

This paper provides an overview of the research, assessing the current status of the mangroves and difficult mangrove site conditions within the Xuan Thuy National Park. It evaluates the rate of mangroves area decline in the study area and identifies several primary causes for this reduction in the past. These causes include sand mining in neighboring areas, changes in natural conditions, the influence of storms, strong winds, tidal regimes, coastal seawater salinity, and mangrove pests. The study tentatively proposes mangrove development solutions for difficult site conditions. Specific silvicultural techniques are also outlined, including species selection, planting stock standards, planting techniques (e.g., hole digging, planting method), and the tending and protection of the planted trees. This work establishes an important scientific basis for applying and scaling up experimental models. Following precise conclusions regarding the model's effectiveness, this approach can be replicated in other regions of Vietnam that face similar mangrove site conditions.

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References

[1]. Do Quy Manh, chief editor, et al. Mangrove Forests in South Central Vietnam. Agriculture Publishing House, 2020. pp. 1-276.
[2]. FAO, 2020. Global Forest Resources Assessment.
[3]. Murdiyarso, D., Purbopuspito, J., Kauffman, J. B., Warren, M. W., Sasmito, S. D., Donato, D. C., ... & Kurnianto, S. (2015). The potential of Indonesian mangrove forests for global climate change mitigation. Nature Climate Change, 5(12), 1089–1092
[4]. World Bank. (2014). Building Resilience for Sustainable Development of the Sundarbans: Strategy Report. (Report No. 88061-IN).
[5]. Decision No. 514/QĐ-UBND dated 27 February 2026 of the People's Committee of Ninh Binh province on the Announcement of the forest status in Ninh Binh province in 2025
[6]. Do Quy Manh, et al., 2020. Research on the causes of mangroves decline and proposed solutions for mangroves restoration in Xuan Thuy National Park, Nam Dinh province, Vietnam.
[7]. Ministry of Agriculture and Rural Development, 2016. Decision No. 5365/QD-BNN-TCLN dated December 23, 2016, promulgating the technical guidelines for planting six mangrove species: *Avicennia alba*, *Avicennia marina*, *Rhizophora stylosa*, *Bruguiera gymnorhiza*, *Sonneratia alba*, and *Ceriops tagal*.
[8]. Do Quy Manh, 2019. To study the characteristics of soil mangroves in coastal areas of Thai Binh province as a basis for proposing technical measures for restoration and sustainable development of mangrove forests. Doctoral Thesis in Forestry. Vietnam University of Forestry.
[9]. Vietnam Soil Science Society, 2000. Soils of Vietnam, Agricultural Publishing House, Hanoi, pp. 1-246.
[10]. Saaty, T. L. (1980). The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation. New York, NY: McGraw-Hill.
[11]. Ministry of Agriculture and Rural Development, 2016. Decision No. 1205/QD-BNN-TCLN of the Minister of MARD dated April 8, 2016, promulgating the Technical Guidelines for Planting the following forest species: *Kandelia obovata*, *Aegiceras corniculatum*, *Avicennia officinalis*, *Bruguiera gymnorhiza* and *Sonneratia caseolaris*.
[12]. Ministry of Agriculture and Rural Development, 2021. Decision No. 4147/QD-BNN-TCLN dated October 25, 2021, of the Ministry of Agriculture and Rural Development promulgating the technical guidelines for planting four mangrove species: *Ceriops decandra*, *Nypa fruticans*, *Rhizophora stylosa*), and *Thespesia populnea*.