

Current Status and Proposed Ecological Solutions for Mangrove forest Restoration in Aquaculture Ponds in Dong Chau Commune, Hung Yen Province

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ABSTRACT: Mangrove forests are a typical ecosystem of tropical and sub-tropical coastal zones, providing sea-dyke protection, storm and erosion mitigation, and nursery habitat for many aquatic species, while directly supporting the livelihoods of coastal communities. This study assesses the current status of, and proposes ecological restoration solutions for, mangrove forests within aquaculture ponds in Dong Chau commune, Hung Yen province (formerly Dong Hoang, Dong Co, Dong Lam and Dong Minh communes, Tien Hai district, Thai Binh province, part of the Tien Hai Biodiversity Conservation Area). Using inherited and newly collected data on soil and water physico-chemical properties, forest-area statistics for 2017-2025, community-interview surveys (40 new questionnaires plus 150 inherited questionnaires) and field surveys, the study finds that the mangrove area of the commune fell from a peak of 173.3 ha in 2021 to 130.41 ha in 2025, that true mangrove species have become scarce within the aquaculture ponds (dominated instead by associated shrub species such as *Acanthus ilicifolius* and *Casuarina equisetifolia*), and that the surviving mangrove stands outside the ponds (about 120.4 ha) are dominated by *Aegiceras corniculatum*, mixed with *Avicennia marina* planted in 1992 and 2008 and *Sonneratia caseolaris* planted in 1997 and 2003. The soil is a light loam with generally favourable nutrient status (rich in available phosphorus and potassium) and the surface water quality is generally within Vietnamese environmental standards (QCVN 10-MT:2023/BTNMT) and suitable for mangrove growth and aquaculture. The main drivers of degradation are unplanned conversion of mangrove area to aquaculture ponds, disease outbreaks, storms, cold spells, sand burial and water pollution. Based on these findings, the study proposes two ecological restoration models suited to the study area: (1) a combined silvo-fisheries (forest-fishery) model, in which mangroves and extensive/improved-extensive aquaculture coexist on the same area at an approximate 60:40 (or 70:30) forest-to-water ratio; and (2) an integrated multi-trophic aquaculture - recirculating aquaculture system (IMTA-RAS) model in which mangrove litter functions as a natural biological filter and nutrient source within a closed-loop water system. These results provide a scientific and practical basis for local restoration planning, ecosystem-service payment schemes, and sustainable aquaculture-linked livelihoods in the Red River Delta Biosphere Reserve area.

KEYWORDS: Mangrove forest, ecological restoration, aquaculture ponds, silvo-fisheries, IMTA-RAS, Dong Chau commune, Hung Yen province.

I. INTRODUCTION

Mangrove forest is one of the characteristic ecosystems of saline wetlands found along tropical and subtropical coastal areas; it plays an important role in reducing the impact of waves and storm surges, regulating the local microclimate, preventing erosion, promoting land accretion, limiting saline intrusion, and breaking down waste to reduce pollution in estuarine and coastal areas. Mangrove forest is also one of the ecosystems with a highly diverse biological system and food chain, and is therefore an important nursery, breeding and rearing ground for many aquatic species such as shrimp, crab, marine fish, clams, mussels, oysters, sea bream, and golden thread seaweed ...; it is also a habitat and feeding ground for many rare species such as crocodiles, water monitor lizards, and sea turtles, as well as a nesting and wintering site for many waterbirds and migratory birds [5]. At the same time, mangrove forest secures natural fishery resources, thereby directly supporting the livelihoods of local communities. According to the Global Mangrove Watch alliance, Leal, Maricé [15], the world's total mangrove area over the past decades, as of 2020, is estimated at about 147,256 km², of which South East Asia accounts for about 33.6% of the world's mangrove area [15]. The main cause of the decline in mangrove area is conversion to ponds and lagoons for aquaculture, which accounts for about 26.7% of aquaculture area [14]. Viet Nam is a country located on the Indochina peninsula, in the South-East Asia region, situated along the Pacific coast, with a coastline of more than 3,260 km and a tropical monsoon climate that helps promote the growth and development of mangrove plant species in coastal areas. According to the Hung Yen Provincial People's Committee [11] Decision No. 143/QD-UBND dated 21 January 2026 of the Hung Yen Provincial People's Committee announcing the results of the survey on forest status in 2025, and the Hung Yen Provincial People's Committee [12] Decision No. 575/QD-UBND dated 27 February 2026 of the Hung Yen Provincial People's Committee announcing the 2025 forest status of Hung Yen province, the Ministry of Agriculture and Environment [1] estimates approximately 4,084.18 ha for the whole of Hung Yen province (the former Thai Binh). The study area is located on the coast of Dong Chau commune, Hung Yen province (the communes of Dong Hoang, Dong Co, Dong Lam and Dong Minh, formerly under Tien Hai district, Thai Binh), situated in the eastern part of the province; it is one of the coastal communes with a tropical monsoon climate with a cold winter and diverse biological resources that create favourable conditions for promoting aquaculture. According to the Hung Yen Provincial People's Committee [11] Decision No. 143/QD-UBND dated 21 January 2026 of the Hung Yen Provincial People's Committee announcing the results of the survey on forest status in 2025, and the Hung Yen Provincial People's Committee [12] Decision No. 575/QD-UBND dated 27 February 2026 of the Hung Yen Provincial People's Committee announcing the 2025 forest status of Hung Yen province, the Ministry of Agriculture and Environment [1] estimates that Dong Chau commune, Hung Yen province, has about 130.41 ha [7],[10],[13]. Mangrove forest offers great potential for the livelihood activities of local resident households and communities in the area. Precisely because of the role mangrove forest plays in livelihood potential that drives the local economy, over exploitation activities and the unplanned conversion of mangrove forest into shrimp ponds by residents and households in the area have occurred. Many studies in the world and in Viet Nam show that the results of over exploiting mangrove forest are soil degradation, water pollution, decline in mangrove cover, and biodiversity and resource loss for many rare plant and animal species at risk of extinction, with many spawning grounds at risk of disappearing, etc. this degradation of mangrove forest directly affects the livelihoods of local communities. Stemming from this reality, the graduation thesis topic "Research on the current status and proposal of ecological solutions for the restoration of mangrove forest in aquaculture ponds in Dong Chau commune, Hung Yen province" aims to ensure both the development of livelihoods linked to biodiversity conservation and the promotion of a green, circular economy, while proposing directions for mangrove restoration in aquaculture-pond areas that are both necessary and urgent.

II. RESEARCH OBJECTS AND METHODS

2.1. Research objects

Object of study: The mangrove forest ecosystem within aquaculture ponds. Study location: Dong Chau

commune, Hung Yen province.

Spatial scope: The area of mangrove forest within aquaculture ponds in Dong Chau commune, Hung Yen province, lying within the Tien Hai Biodiversity Conservation Area (comprising the former communes of Dong Hoang, Dong Co, Dong Lam and Dong Minh of Thai Binh province prior to the administrative merger of 1 July 2025); coordinates X = 667,840, Y = 2,260,068.

Time scope: Field survey conducted from 22-26 December 2025, 29 December 2025-4 January 2026, 5 January-15 February 2026, and 23 February-22 March 2026.

2.2. Research materials and methods

2.2.1. Materials

The study used secondary data on annual forest development from the Ministry of Agriculture and Environment, provincial forest-protection statistics, and planning and socio-economic reports of the Dong Chau Commune People's Committee, together with data inherited from the state-level research project "Scientific basis and proposal of irrigation-forestry technology solutions combined with the restoration and development of mangrove forests in the Red River Delta Biosphere Reserve" (code ĐTĐL.CN 16/22), including results from 12 soil samples (4 sample plots $\times$ 3 depths) and 30 saline-water samples analysed at the Institute of Agricultural Planning and Design. These data were combined with primary data collected during field surveys and community interviews conducted by the author in the study area during 2025-2026.

Table 1. Analytical parameters and methods used for saline-water quality assessment

No.	Parameter	Unit	Analytical method
1	pH	-	TCVN 6492:2011
2	Salinity	‰	SMEWW 2520B:2017
3	Dissolved oxygen (DO)	mg/l	TCVN 7325:2016
4	Turbidity	NTU	TCVN 6184:2008
5	Total suspended solids (TSS)	mg/l	TCVN 6625:2000
6	Ammonium	mg/l	TCVN 6179-1:1996
7	Lead (Pb)	mg/l	SMEWW 3113B:2017
8	Mercury (Hg)	mg/l	TCVN 7877:2008
9	Arsenic (As)	mg/l	TCVN 6626:2000
10	Total oil and grease	mg/l	SMEWW 5520B:2017

Water and soil quality were evaluated against QCVN 03:2023/BTNMT (national technical regulation on soil quality) and QCVN 10:2023/BTNMT (national technical regulation on seawater quality) [3], [4].

2.2.2. Research methods

a) Overview of research methods

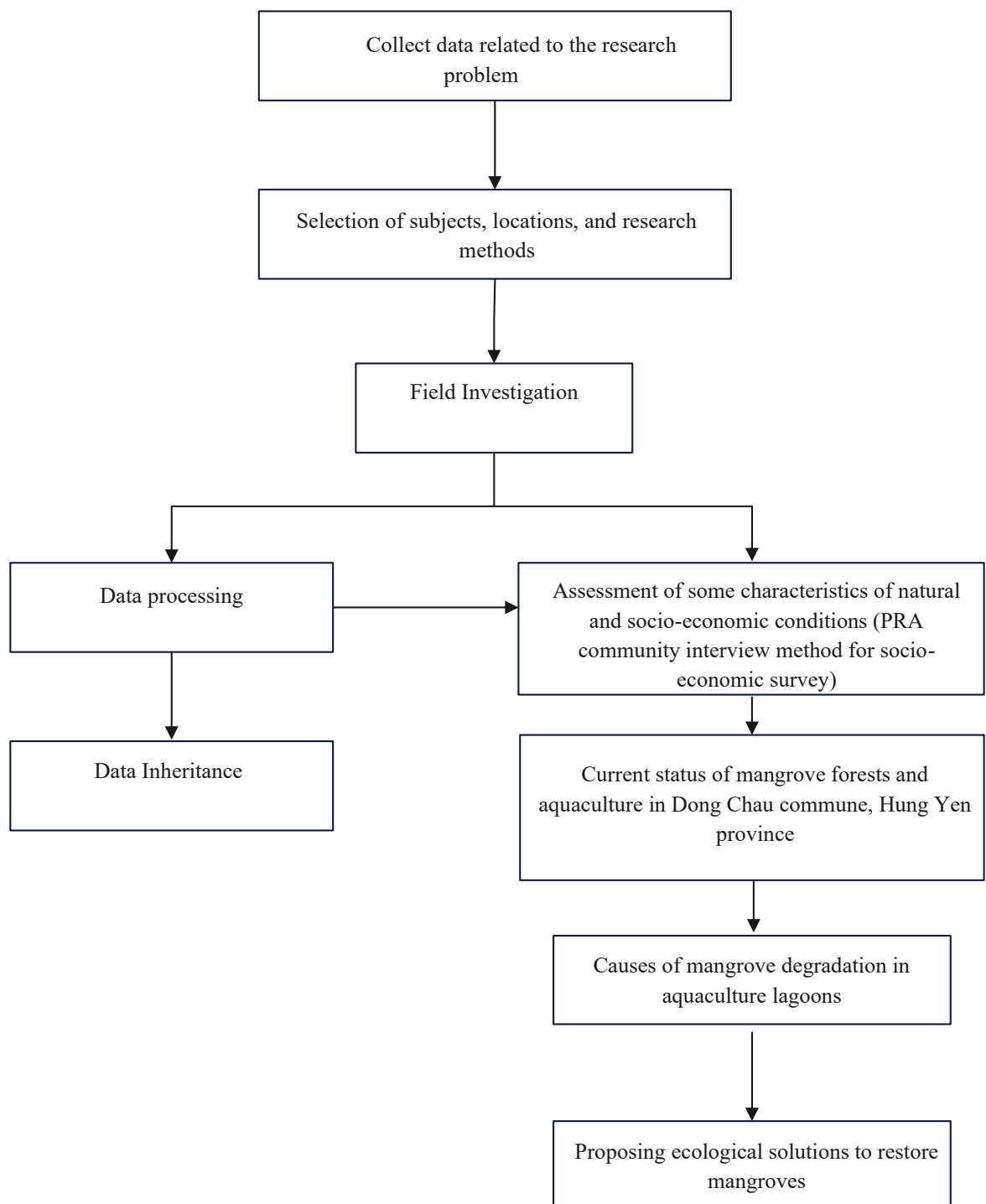


Figure 1. Overview diagram of research methods

b) *Methods of collecting information and inheriting data*

Data collection: Secondary data relevant to the research topic were collected from project reports and scientific studies published in specialized journals and related fields, combined with field surveys and socio-economic data obtained from the Commune People's Committee, as well as reports on the status of coastal mangrove forests from the Center for Biological Dyke Protection - Institute of Ecology and Works Protection. Relevant existing documents, methods, and research content were reviewed and analyzed to select the most appropriate research methods.

Inheritance method: This method was used to synthesize and statistically summarize findings from similar studies and scientific works directly related to the study area or nearby aquaculture ponds in Dong Chau commune, Hung Yen province. The study inherited 150 PRA (Participatory Rural Appraisal) community interviews, along with 3 water samples and 3 soil samples, from the state-level project "Research on Scientific Basis and Proposed Solutions for Irrigation-Forestry Technology Combined with mangrove Restoration and Development in the Red River Biosphere Reserve" (Project code: ĐTDL.CN-16/22; Project Leader: Quy Manh Do, Institute of Ecology and Works Protection), which was then processed to derive the necessary conclusions and gain an overview of the study area. In addition, the study inherited data from the Forestry and Forest Protection Department, the 2025 National Forest Status Announcement published by the Ministry of Agriculture and Environment, and the 2025 Forest Status Announcement published by the Hung Yen Provincial People's Committee.

c) Field Survey Methods

Research in the area with mangrove area in aquaculture lagoon in Dong Chau commune, Hung Yen province of Tien Hai Biodiversity Reserve (including Dong Hoang commune (Tien Hai district), Dong Co, Dong Lam and Dong Minh of Thai Binh province before the merger 01/07/2025). Location coordinates: X = 667840; Y = 2260068 [2],[7].

Conduct the survey through the community interview survey method at coordinates X = 2259146.22, Y = 615155.890.

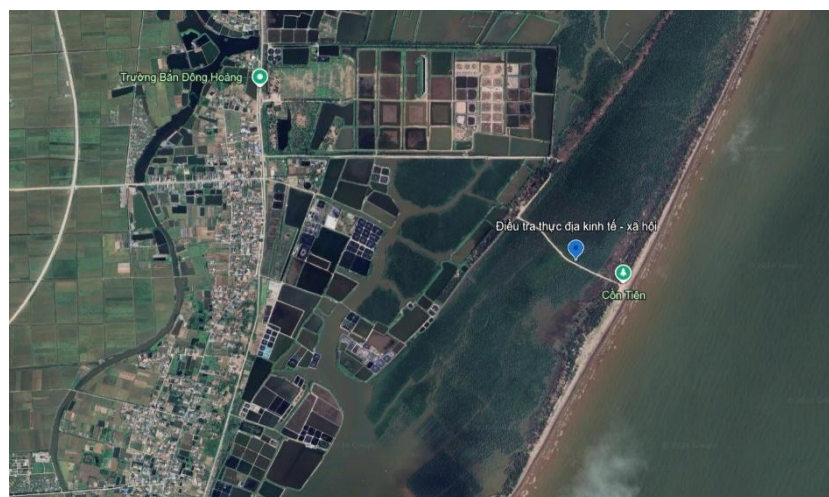


*Figure 2. Map image showing the location of the interview survey participant
(The blue position is the location of interviews with locals)*

d) Community Interview Methods

The PRA community interview method, which stands for the Rural Assessment method with the participation of the people (Secondary data review, group discussion, in-depth interview, direct observation, group interview, face-to-face interview, etc.), with the help of key informants in the community to:

- Identify the current status of traditional aquaculture, aquaculture combined with mangrove development in the locality;
- Identify stakeholders and indicate the level of contribution of each party affecting aquaculture techniques combined with mangrove development in the locality;
- Aquaculture planning, orientations, wishes for participation and functions of local managers and people on aquaculture combined with mangrove development in localities;
- Plan to implement aquaculture combined with mangrove development in Dong Chau commune, Hung Yen province.

The steps of information interview under the PRA include:

Step 1. Identify the area and objects of investigation. Area of Dong Chau commune, Hung Yen province. Random subjects in the area are selected according to the criteria of prioritizing subjects with aquaculture activities combined with mangrove forests.

Step 2. Collect information and conduct in-depth interviews with representatives of local authorities, forest owners, aquaculture companies, and professional managers on the current status, planning and orientation for the development of aquaculture combined with mangrove forests.

Step 3. Collect information from households: Direct interviews, whereby the investigator goes to each household and individual directly involved in aquaculture to ask the informant and record all the answers in the questionnaire (Current status of rehabilitation and development of mangrove; People's understanding of the role of mangrove and climate change developments in the locality; People's opinions on current regulations on protection, restoration and development (including advantages and disadvantages); Aspirations of people proposed to management agencies in the restoration and development of local mangrove...). Form form in the appendix.

Step 4. Synthesize and process the information. Use the sample size method to calculate:

$$n = \frac{N}{1 + N \times e^2}$$

n : Number of samples to be investigated and surveyed

N : Total number of households in the study area

e : Wrong sample allowed 5%.

Conducting a survey of 40 votes and inheriting 150 votes from the Institute of Ecology and Protection of Buildings to conduct an analysis of human-caused causes of mangrove decline and socio-economic assessment.

e) Data Processing Methods Statistical method:

Collect and statistics data on Excel v.2024, statistics of primary and secondary data on mangrove indicators and biodiversity indicators. Statistically significant differences ($p < 0.05$)

Data processing methods: Using mathematical statistical methods based on biology with the support of software such as, Python to process data, compare and evaluate research results to ensure objectivity and high accuracy.

III. RESEARCH AND DISCUSSION RESULTS

3.1. Assessment of natural and socio-economic conditions of the study area relevant to mangrove restoration and development

3.1.1. Natural conditions

a) Soil physico-chemical properties

Inherited results from the state-level research project (led by Quy Manh Do) show that the particle-size composition of soil in the study area is dominated by sand, averaging 48.45% (range 16.34-80.56%), with silt averaging 35.97% (range 14.80-58.80%) and clay averaging 19.07% (range 6.39-34.99%); the saline soil in the area is therefore classified as sandy-textured, requiring technical measures to improve soil structure and increase silt content.

pH_{KCl} at the aquaculture ponds of Dong Chau commune averaged 7.82 (range 7.66-8.05), within the recommended range of 6.5-9.0. By comparison, a related study of the coastal saline soils of Hung Yen (formerly Thai Binh) recorded pH_{KCl} ranging from 6.9-7.2, averaging 7.07 within the aquaculture area - a moderately alkaline value.

Average salinity in the aquaculture area was $31.06 \pm 4.35\text{‰}$ at 0-20 cm depth and $32.19 \pm 3.71\text{‰}$ at 20-60 cm depth.

Total N, P and K averaged 0.10% (max 0.24%, min 0.03%), 0.16% (max 0.21%, min 0.10%) and 1.95% (max 2.17%, min 1.32%) respectively - moderate-to-rich levels for the study area [6]. Available K_2O and P_2O_5 , calcium and magnesium averaged 69.3 mg/100 g, 57.98 mg/100 g, 7.39 cmol/kg and 7.41 cmol/kg respectively. These results indicate that soil conditions in Dong Chau commune are moderately to highly suitable for mangrove regeneration.

Table 2. Physico-chemical properties of soil in the study area, Dong Chau commune, Hung Yen province (formerly Dong Hoang commune, Thai Binh province)

Indicator	Unit	M1	M2	M3	Average
Coarse sand (2–0.2 mm)	%	15.9	0.8	0.6	5.7
Fine sand (0.2–0.05 mm)	%	42	19.2	16.4	25.86
Silt (0.05–0.002 mm)	%	27.3	47.8	49	41.36
Clay (< 0.002 mm)	%	14.8	32.2	34	27
pH (KCl)	–	7.2	6.9	7.1	7.07
Total nitrogen	mg/kg	920	1,220	1,200	1,113.3
Total P ₂ O ₅	mg/kg	1,580	2,020	2,010	1,870
Available P ₂ O ₅	mg/100 g	58	60	56	58
Total K ₂ O	mg/100 g	1,610	2,100	1,920	1,876.67
Available K ₂ O	mg/kg	53	89	92	78
Ca ²⁺	mol/kg	6.1	8.2	6.9	7.07
Mg ²⁺	mol/kg	5.6	5.4	5.8	5.6
SO ₄ ²⁻	mg/kg	710	940	900	850
Cl ⁻	mg/kg	3,640	6,750	7,370	5,920

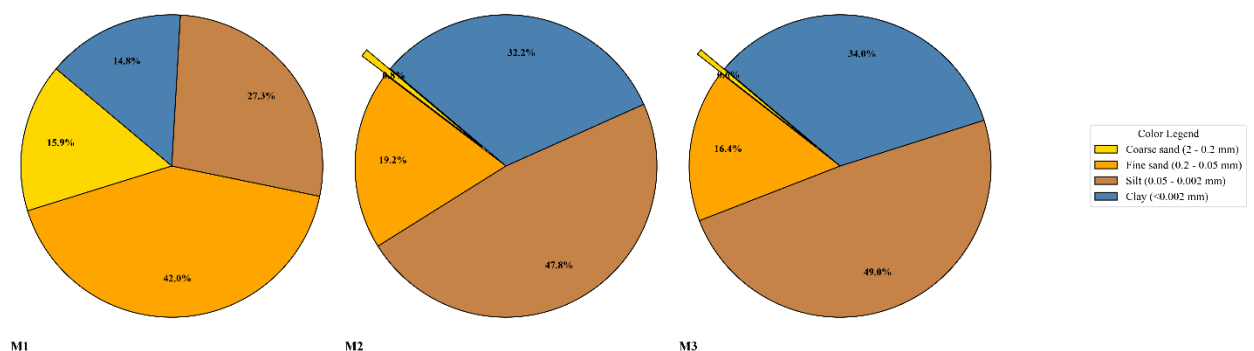


Figure 3. Chart showing the percentage of mechanical composition in samples M1, M2, and M3

b) Surface-water physico-chemical properties

The study area lies within the Gulf of Tonkin, characterised by a fairly uniform diurnal tidal regime. The average tidal amplitude ranges from 1.0-2.0 m (minimum 0.2-0.5 m), with a maximum amplitude of 3.0-3.5 m occurring mainly in January, June, July and December, when water levels can reach up to 4.0 m and fall as low as 0.02 m.

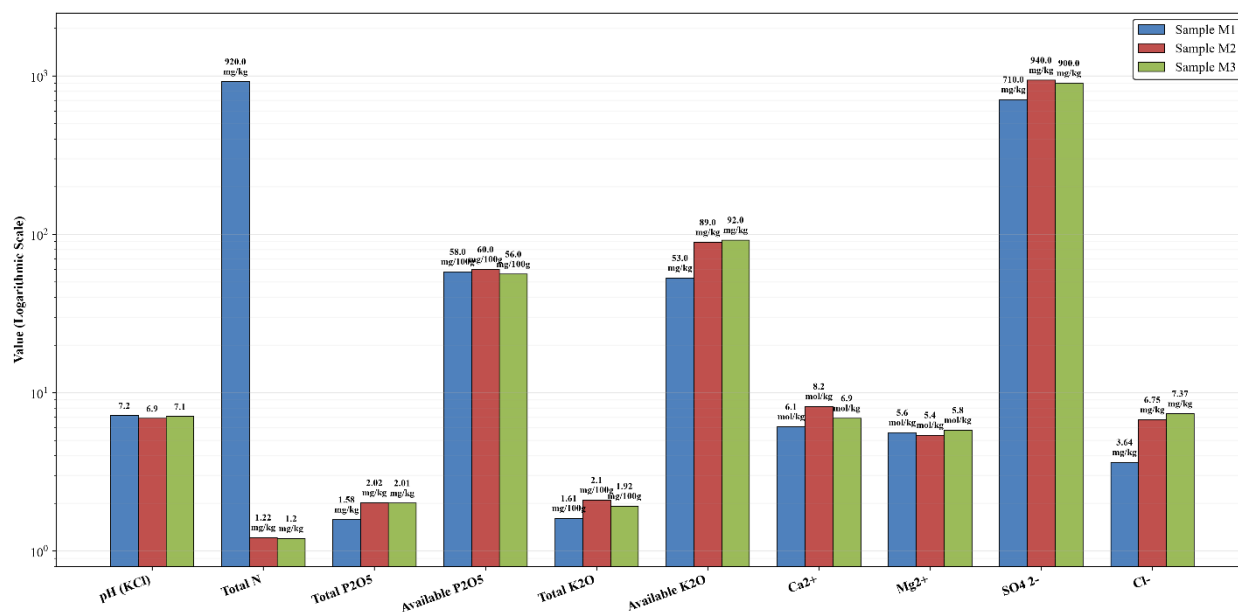


Figure 4. Graph showing the composition of nutrients present in the soil

Physico-chemical characteristics of surface water in the study area were as follows: pH ranged from 5.5-6.3; salinity from 12.9-23‰; dissolved oxygen (DO) from 8.5-10 mg/l; turbidity from 19.5-378.4 NTU; total suspended solids from 79-178 mg/l; ammonium from 0.03-0.13 mg/l; and mercury from 3×10^{-4} to 7×10^{-4} mg/l. Lead, arsenic and total oil-and-grease concentrations were all below the limits of QCVN 10-MT:2023/BTNMT (lead < 0.001 mg/l; arsenic < 0.002 mg/l; total oil and grease < 0.3 mg/l) [4], [6]. Overall, these physico-chemical parameters are relatively favourable for growing mangrove species such as *Rhizophora stylosa* and for multi-species aquaculture.

3.1.2. Socio-economic assessment

A community survey identified the main causes of mangrove decline as aquatic-disease outbreaks, limited community understanding of mangrove ecosystems, environmental pollution, and unplanned conversion of mangrove land into aquaculture ponds, broadly consistent with the natural and anthropogenic causes examined in Section 3.3.

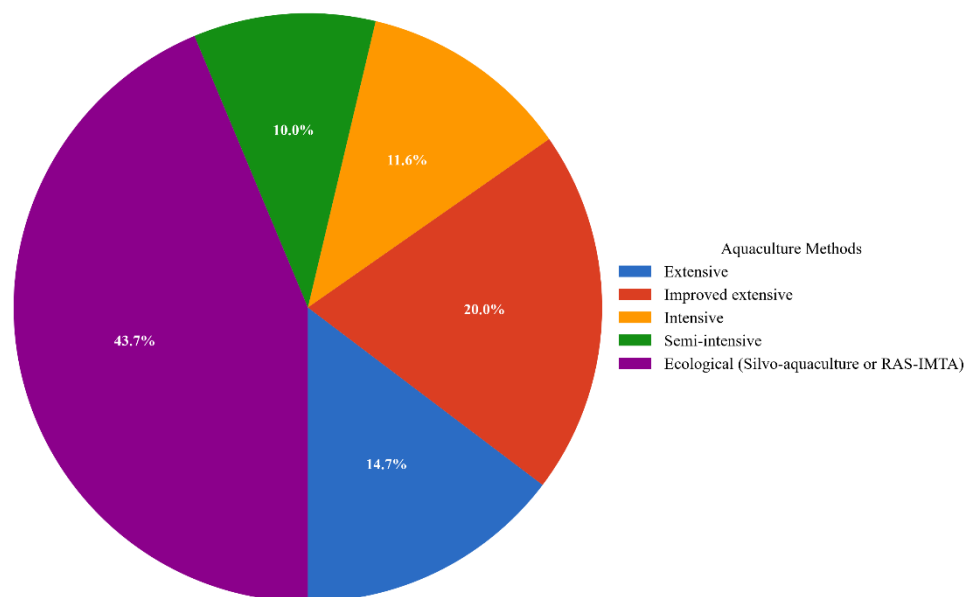


Figure 5. Graph image showing the analysis of types (forms) of aquaculture in Dong Chau commune, Hung Yen province

The structure of aquaculture in the survey area is undergoing a strong shift towards sustainability, in which the ecological farming model (including forestry combined with aquaculture or RAS-IMTA system) occupies an overwhelming position with 43.7%. This shows the high awareness of people in combining production with forest ecosystem conservation and the application of green technology. Forms of nature-based farming such as 20% improved extensive farming and 14.7% extensive farming still play an important role, being a popular choice of households thanks to low investment costs and taking advantage of available natural conditions. Meanwhile, models that require high technical level and investment capital such as 11.6% intensive farming and 10% semi-intensive farming account for the lowest proportion. In general, the aquaculture picture here is very diverse in terms of farming levels, but the biggest bright spot is the priority for eco-economy, reflecting a trend of sustainable development and reducing environmental risks in the livelihoods of local communities.

3.2. Current status of mangrove forest in aquaculture ponds in Dong Chau commune, Hung Yen province

Survey results inherited from the research project show that most of the area of Dong Chau commune has been converted for aquaculture, creating ponds of various sizes; the remaining mangrove area and plant-species composition within the aquaculture zone are sparse, with true mangrove tree species rarely encountered. Only a limited number of associated mangrove species are found, belonging to groups such as ferns, casuarina, Acanthus, sea purslane, amaranth, wood sorrel, screw pine, passion flower, phyllanthus, nightshade and aster, which nevertheless play a stabilising role in protecting pond dikes and contribute to the biological diversity characteristic of the area. Field photographs confirm that vegetation within the ponds is largely absent or sparse, comprising mainly shrub-form species.

Table 3. Changes in mangrove forests in the period 2005-2020

Year	Plantations (ha)	Natural forest (ha)	Total area (ha)
2017	159,14	0	159,14
2018	159,14	0	159,14
2019	163,12	0	163,12
2020	0	0	0
2021	173,30	0	173,30
2022	151,93	0	151,93
2023	151,93	0	151,93
2024	151,93	0	151,93
2025	130,41	0	130,41

(Source: Department of Forestry and Forest Protection, People's Committee of Hung Yen province)

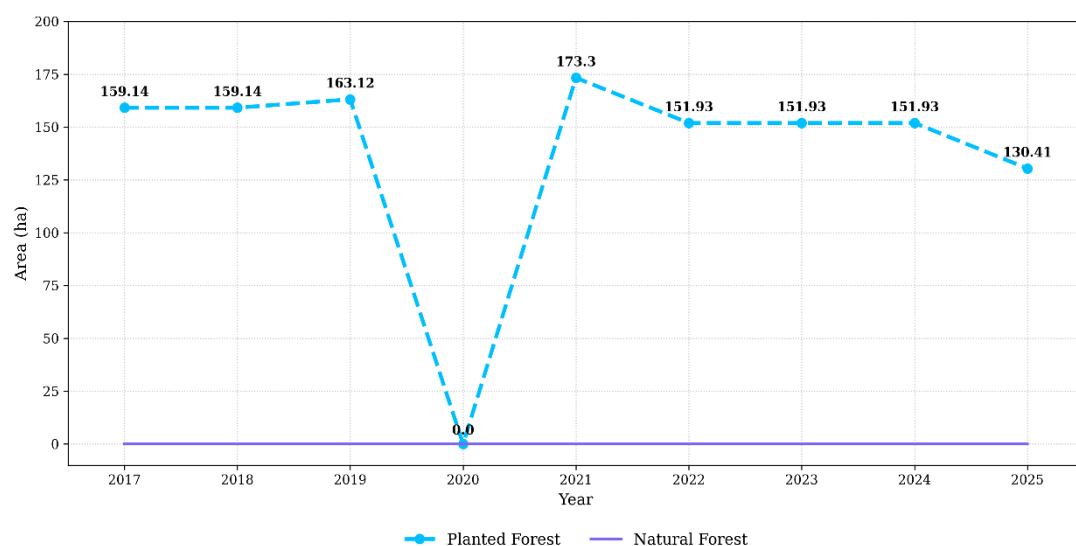


Figure 6. The chart shows the total area of mangrove forests (planted forests) in the period 2017-2025 in Dong Chau commune, Hung Yen province.

3.2.2. Current aquaculture area

According to the Thai Binh (now Hung Yen) Provincial Statistical Yearbook, the total aquaculture area of the former Thai Binh province was approximately 15,268 ha in 2021. Over the past decade, aquaculture area across the province has increased markedly: from 2012-2018 it remained below 15,000 ha, but after 2018 - and particularly in 2020 - it reached a peak of 16,114 ha [7], [8]. A substantial share of low-efficiency salt-production and rice-cultivation land has been converted to brackish and saline aquaculture, which has become a key economic sector, especially along the coast, accounting for 26-33% of the provincial total, owing to highly favourable natural conditions.



Figure 7. Current status of Aquaculture in Dong Chau commune, Hung Yen province (Aquaculture area of Dong Hoang commune in the red zone)

In 2021, the aquaculture area of Tien Hai district reached approximately 5,506 ha, or 33% of the provincial total [9], concentrated mainly in the coastal communes of Dong Hoang, Nam Cuong, Nam Phu and Nam Thinh. Dong Hoang commune had a moderately large aquaculture area of 140 ha (2.5% of the district total), smaller than Nam Thinh (1,230 ha, 22.3%) and Nam Phu (1,039 ha, 18.87%); nevertheless, relative to its own natural area, Dong Hoang's aquaculture area remains substantial. Cultured species are diverse, including black tiger shrimp, whiteleg shrimp, agar seaweed, barramundi, grouper, mud crab and clams. Aquaculture in Dong Hoang is currently practised mainly as improved extensive farming combined with natural harvesting, while some households continue intensive or semi-intensive practices.

3.3. Causes of mangrove degradation in Dong Chau commune, Hung Yen province

3.3.1. Natural causes

Natural degradation of mangrove forest in Dong Chau commune stems mainly from weather- and biology-related factors. Storms frequently cause tree breakage, soil erosion and destabilisation of the forest ecosystem. Prolonged cold spells also negatively affect the growth of many mangrove species, and pest outbreaks on certain tree species have reduced vitality and, in some cases, caused widespread tree mortality, contributing to overall degradation.

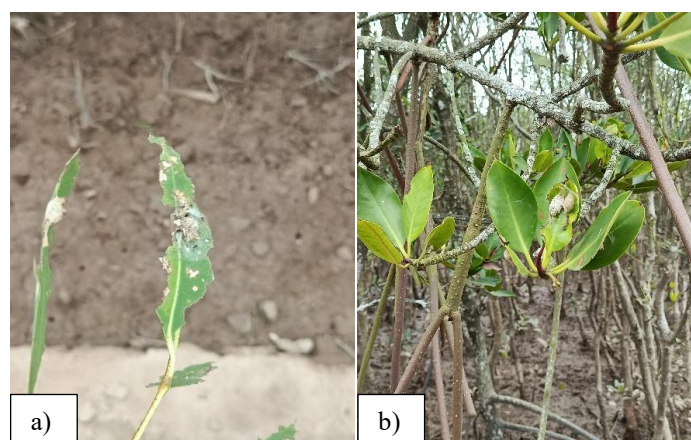


Figure 8. Pests and diseases appearing on mangrove plants
a) Pests and diseases on the leaves of the wingless cork tree
b) Pests and diseases on the leaves of the Mangrove tree

3.3.2. Anthropogenic causes

Numerous anthropogenic factors contribute to mangrove degradation in Dong Chau commune, the most significant being the conversion of mangrove area into aquaculture ponds, which has continuously narrowed and degraded the forest. Over-exploitation of resources - including cutting trees for fuelwood and timber - has further reduced both the quality and extent of mangrove forest. Expansion of agricultural land, infrastructure and coastal residential areas has placed additional pressure on the mangrove ecosystem, while untreated pollution from aquaculture, domestic activities and production has degraded water and soil quality, directly affecting mangrove growth and regeneration capacity. The cumulative effect of these pressures is the ongoing decline of the mangrove ecosystem in both area and quality.

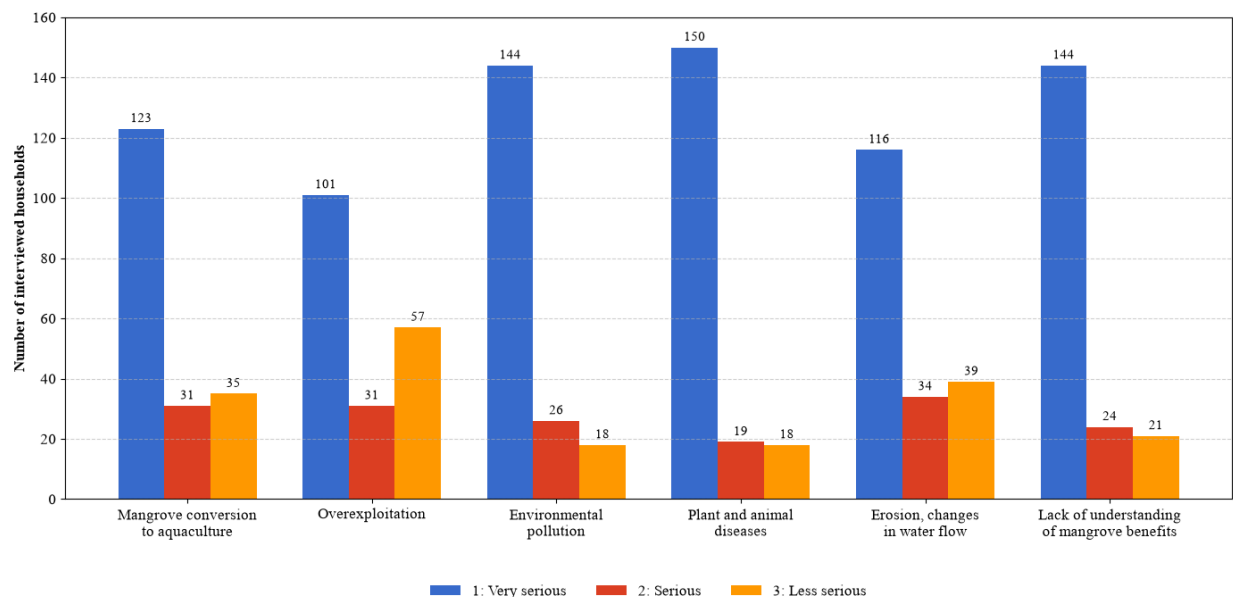


Figure 9. Graphical image showing the causes of mangrove decline in Dong Chau commune through the community interview method

There are many causes of mangrove forest degradation in Dong Chau commune, Hung Yen province, the most notable of which is the conversion of mangrove forest area to the construction of aquaculture lagoons, causing the forest area to shrink and decline continuously. In addition, excessive resource exploitation activities such as cutting down trees for firewood and timber, also contribute to the deterioration of the quality and area of mangrove forests. The expansion of agricultural cultivation areas, infrastructure construction and coastal residential areas also put great pressure on mangrove ecosystems. In addition, environmental pollution from aquaculture, daily life and production activities that have not been thoroughly treated has deteriorated water and soil quality, directly affecting the growth and recovery of mangrove forests. These combined impacts cause the mangrove ecosystem in the region to deteriorate in both area and quality.

3.4. Proposed ecological solutions for restoring and developing the mangrove ecosystem within aquaculture ponds in Dong Chau commune, Hung Yen province

3.4.1. Proposed combined forestry-fishery (silvo-aquaculture) model

The combined forestry-fishery (silvo-aquaculture) model is one of the most effective solutions for restoring and developing the mangrove ecosystem in conjunction with sustainable aquaculture in Dong Chau commune. This model integrates mangrove planting and protection with aquaculture within the same space, ensuring economic benefit while improving the ecological environment. Improved extensive or combined semi-intensive farming should be applied, minimising the use of chemicals and industrial feed while making greater use of natural food sources within the ecosystem. Water management, disease control and environmental protection should be implemented in a coordinated manner to maintain ecological balance within the ponds. In addition, technical outreach and training for local people, together with supportive policies encouraging adoption

of the model, are needed. Scaling up this model would enhance economic efficiency, protect natural resources and support the sustainable restoration of the local mangrove ecosystem.

3.4.2. Proposed integrated recirculating aquaculture model combined with mangrove restoration (IMTA-RAS)

Mangrove leaf litter is an important natural food source that enters the nutrient chain of many economically valuable aquatic species, including shrimp, crab, fish and molluscs. Combining mangrove restoration with an integrated recirculating aquaculture model therefore yields clear ecological and economic benefits. The IMTA-RAS model makes maximum use of nutrients within the culture system through the co-culture of multiple species at different trophic levels: waste from the primary cultured species (shrimp, fish) becomes a food source for extractive species such as molluscs and seaweed, reducing the volume of waste discharged to the environment. The recirculating water system helps maintain stable water quality, limits pollution and reduces disease-outbreak risk. Mangrove forest integrated into the model functions as a "natural biological filter," absorbing excess organic matter, improving water quality and providing habitat for many species. Mangrove belts should be arranged along pond dikes or interspersed within the pond system, prioritising native species with good adaptability. Appropriate management measures - reducing chemical use, increasing the use of biological products, regularly monitoring water quality, and adjusting stocking density - should also be applied, together with technical training and support for local implementation. This model makes efficient use of resources, minimises environmental impact, and contributes to the sustainable restoration and development of the mangrove ecosystem in the study area.

IV. CONCLUSIONS

Mangrove forest plays an important role in the food chain of economically valuable aquatic species such as shrimp, crab and molluscs, thereby supporting local livelihoods and the restoration and development of mangrove forest itself. Specific conclusions are as follows:

1. The study has updated and supplemented data on the current status of mangrove forest within aquaculture ponds in Dong Chau commune, Hung Yen province, showing that only shrub-layer associated mangrove species are present, while true mangrove tree species are rare or absent.
2. The study has assessed the physical and chemical soil and water properties of the study area, providing a basis for selecting mangrove species suited to local soil and water conditions to support silvo-aquaculture models and water-quality improvement for an IMTA-RAS environment.
3. The study has identified the causes of mangrove decline at the time of the survey, comprising two main groups: natural causes (mainly pest/disease outbreaks and cold spells) and anthropogenic causes (mainly conversion of mangrove land to aquaculture).
4. The study has proposed restoration measures, namely a combined forestry-fishery (silvo-aquaculture) model and an integrated multi-trophic recirculating aquaculture model (IMTA-RAS).

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