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Assessment of changes in the structure and distribution of mangroves caused by aquaculture activities at the Bach Dang estuary, Vietnam

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ABSTRACT

The development of the movement to change mangroves area for aquaculture has resulted in the loss of a large area of mangroves in Vietnam. The decline of mangroves leads to impacts on natural resources and the environmental and ecological degradation of the area. The aquaculture ponds were built to protect and create a stable environment for livestock, creating a different environment between the inside and the outside of the pond. As a result of the sudden difference in the background, many mangrove species did not adapt quickly leading to death, and many other species came to distribute with new conditions. The paper results are evidence of the impacts of the aquaculture pond filling on the changes in the distribution structure of mangrove vegetation, thereby proposing solutions for sustainable development for the study area.

Keywords: Bach Dang estuary, pond aquaculture, mangrove structure.

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INTRODUCTION

The Bach Dang estuary area has a typical funnel-shaped estuary structure, which is the basis of a part of the Thai Binh river system that flows into the northeast of Hai Phong. This area with an extensive tidal range is shielded by Cat Hai island on the outside, creating a semi-enclosed water body with the main driving force being tidal and low stratification level [1]. Moreover, every year, the Bach Dang estuary receives millions of tons of alluvium and suspended matter from the Thai Binh river system when it reaches the semi-enclosed water body, which is favorable for accretion to create a large area of the intertidal zone. The results of geological tectonics in the area have typical features of funnel-shaped estuaries where the diurnal tidal regime is extensive in amplitude [1].

An estuary area is subject to significant environmental changes because it is the intersection between the river and the sea under tidal activity. The large intertidal zone in the Bach Dang river area is the place to mark the glorious victories of Vietnamese history with three naval battles by strategizing based on the tidal regime here [2]. The Bach Dang estuary has an extensive diurnal tidal range, so the water body has large fluctuations in environmental characteristics. With the evolution and accretionary development of the intertidal zone and human impact, many areas have increased the elevation of the bottom to create residential areas, such as Ha Nam island (Cam La, Lien Vi, Tien Phong and Phong Coc). In the Mac area, the development of aquaculture in extensive embankment farming has created a relatively different environment between the inside and outside of the aquaculture pond. This difference in environmental characteristics has caused the structure of mangrove vegetation to change. However, there isn't a record or research on the changes in the mangrove structure distribution from aquaculture activities to provide essential scientific information for sustainable development while protecting forest areas and developing aquaculture.

The tide strongly influences Bach Dang estuary with the most uniform daily regime. There are one spring tide and one neap tide for 25 days of every month. The tidal range is significant in the Bach Dang estuary, about 3–4 m during spring tide. The highest water level was recorded at 421 cm (October 22, 1985); The lowest water level was recorded at -3 cm (January 2, 1991) [3]. Almost Bach Dang estuary was used for aquaculture by the local people. They are culturing crab and other fisheries; they also manage and protect mangrove plants in their pond. However, the owner controlled the pond water level to supply their aquaculture; their activity has had a significant impact on the mangrove quality and the natural regeneration of the mangrove species. The pond owner often closes the sluice gate to keep water in the pond for aquaculture, leading the water salinity in the pond to be higher 5–6‰ than in the natural channel (outside the mangrove pond). In the Bach Dang estuary, the salinity of water ranges from 3–10‰. There are many kinds of brackish animals and mangrove species that are well developed. But the salinity water in the mangrove pond (15‰) was higher than around the area.

Mangrove vegetation is a pioneer plant group of the intertidal zone; they can live and grow in brackish water to saltwater environments with a muddy bottom [4, 5]. However, each mangrove species is suitable for different habitats (salinity, temperature) and other bottom characteristics. Therefore, the change in habitat and bottom elevation from the creation and embankment of aquaculture ponds has directly affected the survival and the distribution structure of mangrove species. This paper presents the survey results of the survey on the form of mangrove vegetation to assess the changes in the distribution structure due to aquaculture activities at the Bach Dang estuary. The study and assessment of the difference in the distribution structure of mangrove plants due to the impact of aquaculture activities is an essential scientific basis for proposing solutions to ensure the biodiversity of mangroves forest toward sustainable development for the region.

MATERIAL AND METHODOLOGY

Material and study area

The object of the study is the distribution structure of mangrove plants in the Bach Dang estuary, which distribute in the three habitats, including the aquaculture pond, on the dike area of the pond, and along the river bank after here were called the pond, pond-dike, and outside pond habitats, respectively.

The study area is Bach Dang estuary, in the Ha Nam island area, which borders Quang Yen town in the North, Nam Trieu estuary in the South, Rung ferry in the West and Lach Huyen estuary in the East (Figure 1). The Bach Dang estuary is shielded by Cat Hai island and connects to the sea through Lach Huyen and Nam Trieu estuaries. The 2019 satellite image data show that the mangroves area was 1,756.08 ha, of which 1,543.6 were in the pond habitat and 212.48 in the outside pond habitat (Figure 1).

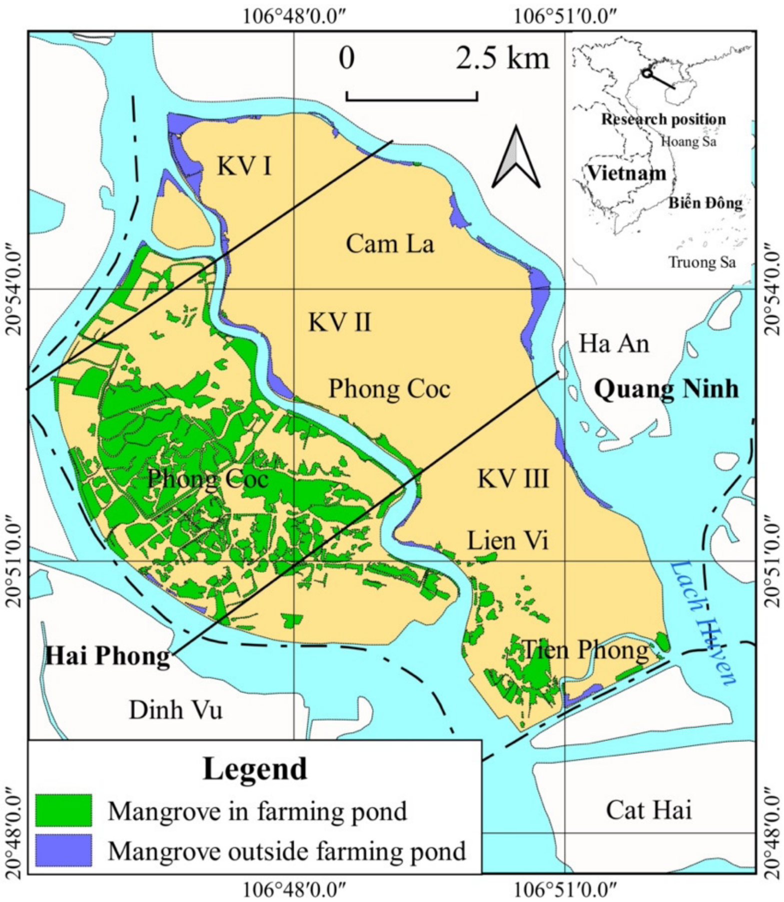

Figure 1. Mangrove mapping in Bach Dang estuary

Methodology

Mangrove structure

Quantitative sample using quadrat

This method is used to determine the current status of the structure of the mangrove flora community in the study area. The quadrat size (10 m × 10 m) was selected according to Phan Nguyen Hong [6]. The 20 chosen quadrats ensure similarity and are representative of the studied habitat.

At each quadrat, mangrove specimens were collected with detailed characteristics of all mangrove species. Each individual's high and diameter at breast high (DBH) were measured.

Quantitative samples

This method is used to evaluate the diversity of mangrove plant species in the study area. All mangrove species were collected in transect at each habitat, following:

Mangrove flora species were collected according to the methodology of Nguyen Nghia Thin [7]. All species encountered in survey routes by habitat were collected to ensure the representativeness of the species composition of each studied habitat.

Mangrove species were identified based on a morphological method based on identifying documents, including the Vietnam plant of Pham Hoang Ho [8–10]; Mangrove of Vietnam of Phan Nguyen Hong [11]; Plant identification of Vo Van Chi and Duong Duc Tien [12].

Salinity measurement

Salinity was measured by a refractometer at all quadrats.

Data analysis

Form the collected data, calculate the following parameters:

$$Frequency = \frac{Total\ number\ of\ segments\ in\ which\ a\ species\ occur}{Total\ number\ of\ segments\ sampled} \times 100$$

$$Relative\ Frquency\ (RF) = \frac{Frequency\ of\ a\ species}{Total\ frequency\ of\ all\ species} \times 100$$

$$Density = \frac{Number\ of\ individuals\ of\ a\ species}{Total\ arrea\ sampled}$$

$$Relative\ Density\ (RD) = \frac{Density\ of\ a\ species}{Total\ density\ of\ all\ species} \times 100$$

$$Basal\ Area = 0.7854\ (diameter)$$

$$Relative\ Basal\ Area\ (RBA) = \frac{Total\ basal\ area\ of\ a\ species}{Total\ basal\ area\ of\ all\ species} \times 100$$

$$Importance\ Value\ Index\ (IVI) = RF + RD + RBA\ (\%)$$

$$Shannon\ Index\ (H') = -\sum_{i=1}^{s} p_i * \ln(p_i)$$

Where: p_i is the proportion of individuals belonging to the i^{th} species in the total individual observation.

RESULTS

Mangrove species composition

The survey results of the mangrove species composition distributed in the Bach Dang estuary are shown in Table 1. This result indicates 22 species of plants belonging to 18 families, two Phyla (Poyphodophyta and Anglospermae). Mangrove species were divided into 2 groups; the leading group is the true mangrove, resistant species tolerance to a saline environment. They have a mechanism to excrete salt through parts of the stem such as leaves (leaf surface; old leaves fall), stems, roots; the associated mangrove species is a group flora which usually distributes from mean high water mark astronomical high tide area. Bach Dang estuary found 22 mangrove species in three habitats, of which 13 species belong to the actual mangrove group and 9 species belong to the associated mangrove group (Table 1).

The number of mangrove species was different in each habitat studied. The pond-dike habitat found 19 species accounted for 86.36% of total mangrove species in Bach Dang estuary. They mainly belong to the associate mangrove species (Table 1). The pond and outside pond habitat found 10 species (45.45%) and 6 species (27.27%), respectively. Almost all flora species in the pond and outer pond habitats were true mangrove species. The mangrove species in pond habitat were usually found in a high place that is less flooded by tides, such as *R. stylosa* (Đước vòi), *B. gymnorrhiza* (Vẹt dù). In contrast, mangrove species in the outer pond habitat are beginner species which is found in the seaward fringe zone, such as *S. caseolaris* (Bần chua), *A. corniculatum* (Sú), and *K. obovata* (Trang).

Table 1. Mangrove species composition at different habitat in Bach Dang estuary

No.	Taxons	Vietnamese	Species name	Vietnamese	Groups	Habitats		
						1	2	3
	Phylum 1. Poyphodophyta		Ngành Dương xỉ					
1	Pteridaceae	Họ ráng sẹo già	*Acrostichum aureum* L.	Ráng biển	*	x	x	
	Phylum 2. Anglospermae		Ngành hạt kín					
	Class 1. Dicotyledoneae		Lớp 1. Hai lá mầm					
2	Aizoaceae	Rau đắng đất	*Sesuvium portulacastrum* (L.) L.	Sam biển	*	x		
3	Ancanthaceae	Họ ô rô	*Ancanthus ebracteatus* Vahl.	Ô rô biển	*	x		x
4	Amarathaceae	Họ rau dền	*Alternanthera sessilis* L. A.DC	Rau dệu	+	x		
5			*Pluchea pteropoda* Hemsl.	Cỏ lức, sài hồ	+	x		
6	Euphorbiaceae	Họ thầu dầu	*Excoecaria agallocha* L.	Giá	*	x	x	
7	Malvaceae	Họ bông	*Hibiscus tiliaceus* L.	Tra làm chiếu	+	x		
8	Myrsinaceae	Họ đơn nem	*Aegiceras corniculatum* (L.) Blanco	Sú	*	x	x	x
9	Avicenniaceae	Họ mắm	*Avicennia lanata* Ridley	Mắm quăn	*	x	x	
10	Meliaceae	Họ xoan	*Xylocarpus granatum* Koenig	Xu ổi	*	x	x	
11	Fabaceae	Họ đậu	*Derris tripfoliata* (Benth) Barker	Cóc kèn	*	x	x	x
12	Portulacaceae	Họ ram sam	*Potulaca oleracea* L. Sam.	Rau sam	+	x		
13	Rhizophoraceae	Họ đước	*Bruguiera gymnorrhiza* (L.) Lam	Vẹt dù	*	x		
14			*Kandelia obovata* L. Druce	Trang	*		x	x
15			*Rhizophora stylosa* Giff	Đước vòi	*	x	x	
16	Sonneratiaceae	Họ bần	*Sonneratia caseolaris* L.	Bần chua	*		x	x
17	Combretaceae	Họ bàng	*Lumnitzera racemosa* Willd.	Cóc trắng	*	x	x	
18	Verbenaceae	Họ cỏ roi ngựa	*Clerodendrum inerme* L. Graertn	Ngọc nữ biển	+	x		
19	Annonaceae	Họ na	*Annona glabra* L.	Na biển	+	x		
	Class 2. Monocotyledoneae		Lớp 2. Một lá mầm					
20	Cyperaceae	Họ cói	*Cyperus rotundus* L.	Cỏ cú, cỏ gấu	+	x		
21			*Cynodon dactylon* (L.) Pers.	Cỏ gà	+	x		
22	Poaceae	Họ lúa	*Phragmites australis* (Cav.) Trin. ex Steud.	Sậy	+	x	x	x
Total			22 species			20	11	6

Note: **Groups:** *: True mangrove species; +: Associate species; **Habitats:** 1: Pond-dike; 2: Pond; 3: Outside-Pond.

Mangrove structure

From the survey results, the authors divide the mangrove canopy layer in the Bach Dang estuary into 6 different heights, as shown in Figure 2. The division into different canopy layers will help determine the dominant tree layers and the diversity of the canopy layer distribution of the habitats. The proportion of tree canopy layers in the study area is determined by the ratio of individuals belonging to the high altitude group compared to the total number of individuals measured in the study habitat shown in Figure 2. The results show a significant difference in the distribution of canopy layers among the three habitats at the Bach Dang estuary (Figure 2).

There are six canopy layers of mangrove trees high; the canopy layers didn't significantly differ in the percentage of individuals distributed. The portion of canopy layer 50–100 cm is highest (37.12%), and the canopy layer 100–200 cm is 29.36%. They are shrubs under the canopy of *S. caseolaris* (Bần chua) such as *A. corniculatum* (Sú), *P. australis* (Lau sậy) and *A. ilicifolius* (Ô rô). The canopy layers had similar percentages such as 200–400 cm, 400–800 cm and > 800 cm with 4.46%, 5.57% and 5.57%, respectively.

In the pond habitat, there are six canopy layers with significant differences in the percentage of the individual. The layer 200-400 cm had the highest rate (61.42%). It is a true mangrove species group such as *A. lanata* (Mắm quăn), *R. stylosa* (Đước vòi), *L. racemosa* (Cóc trắng), *B. gymnorrhiza* (Vẹt dù), *E. agallocha* (Giá). The layer 100–200 cm accounts for 23.25%) of the mangrove community found in this habitat, including *A. aureum* (Ráng biển), *E. agallocha* (Giá), *A. corniculatum* (Sú) which distribute at a place above the water level of pond range from 10–50 cm. The layer > 800 cm is *S. caseolaris* (Bần chua), it was distributed in the pond habitat with significantly fewer individual and great body size, but there did not found *S. caseolaris* reproduction in this habitat.

Mangrove distribution

Shannon index (*H'*) shows significant differences in distribution characteristics of mangrove vegetation in different habitats in the Bach Dang estuary area.

The biodiversity index *H'* of the studied habitats is shown in Figure 2. This result indicates that the pond habitat has the highest (2.9), followed by the pond habitat (1.88) and the outside pond habitat (1.63).

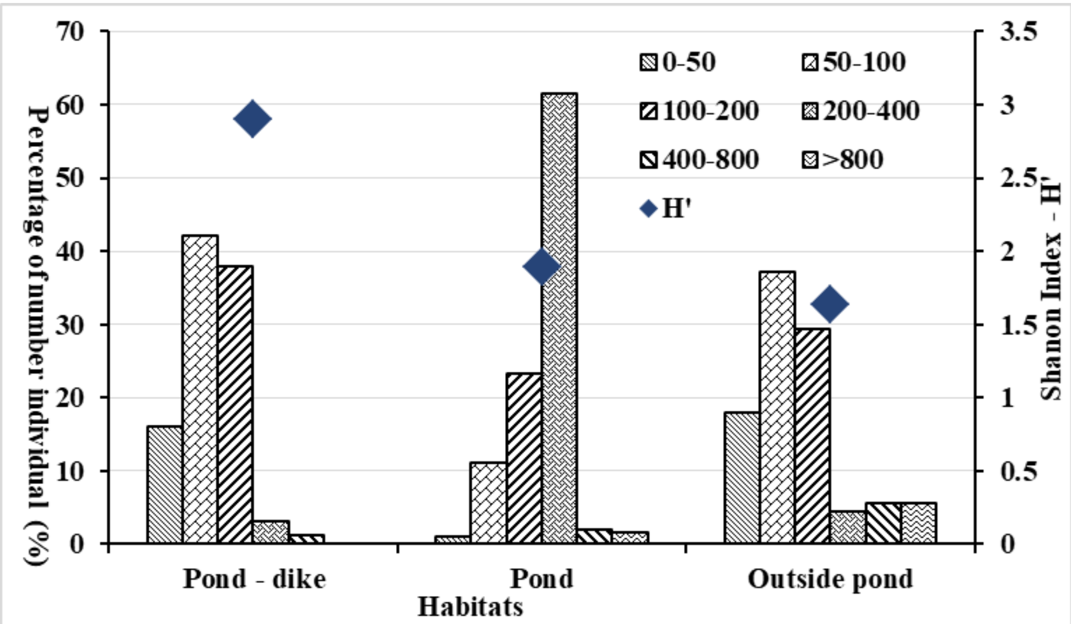

Figure 2. Mangrove structure and Shannon index (*H'*) at studied habitats

Evaluation of the Sorensen Index (SI) similarity between habitats in Table 2 shows that the similarity between the pond and dike-pond habitats is the highest (0.58), the SI is equivalent to the similarity between the pond and outside pond habitats (0.56). At the same time, the SI is relatively low between the outer pond and dike-pond habitat (0.22).

Table 2. Sorensen Index- SI similarity between habitats

Habitats	Pond - dike	Outside pond	Pond
Pond - dike	1.00	0.22	0.58
Outside pond		1.00	0.56
Pond			1.00

Table 3 presents the analysis results of 17 mangrove species found in the quadrats in the studied habitats. The critical index (IVI) results in Table 3 show the dominant level of each species in each habitat. In the dike-pond habitat, there are three predominant species: *D. tripfoliata* (Cóc kèn), *H. tiliaceus* (Tra làm chiếu), and *A. aureum* (Ráng biển) with IVI are 60.11; 56.57 and 49.13, respectively. In the outside pond habitat, *S. caseolaris* (Bần chua) is the dominant species, with IVI being 155.3. The IVI followed by *Phragmites australis* (Sậy) and *A. corniculatum* (Sú) are 56.21 and 38.98, respectively. In the pond habitat, *S. caserolaris* (Bần chua) has the highest IVI (88.97); however, this species has less density (18.18 indiv./ha). While the IVI of *R. stylosa* (Đước vòi) is smaller (60.85) than *S. caserolaris* (Bần chua) but its density is highest in the pond habitat (1,333.3 indv./ha).

The frequency of 17 mangrove species in studied habitats is shown in Table 3. In dike-habitat, the frequency of *E. agallocha* (Giá) and *A. aureum* (Ráng biển) is 76.47% and 70.59%, respectively. In the pond habitat, the frequent of *E. agallocha* (Giá) is also highest (84.85%), followed by *R. stylosa* (Đước vòi) is 72.73%. While the frequency of *S. caseolaris* (Bần chua) is the highest (39.29%) and *D. tripfoliata* (Cóc kèn) is the smallest (3.57%) on the outside pond habitat.

The salinity variation of the studied habitats

The salinity measurements in the studied habitats show that the Bach Dang estuary area can be divided into three areas, as shown in Figure 3. The river area has a salinity range from 0‰ in the rainy season to 4 ± 0.8‰ in the dry season, termed KV III near the Rung ferry upland of Bach Dang estuary. However, the salinity in the pond in the KV III area ranged from 10‰ (rainy season) to 13 ± 1.2‰ (dry season). The KV I connects to the sea via the Lach Huyen and Nam Trieu estuaries (Fig. 1), having a salinity range from 11 ± 0.5‰ (rainy season) to 20 ± 3.0‰ (dry season). The pond at the KV III area has a salinity of 13 ± 2.2‰ and 18 ± 0.8‰ for the rainy season and dry season, respectively. The salinity in the outside and inside ponds at the KV II area is different, ranging between 5‰ and 8‰ (rainy season, outside pond) and 6–16‰ (dry season, inside pond).

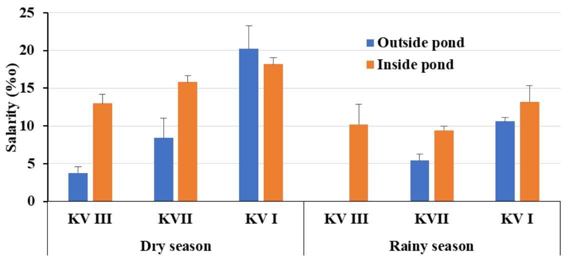

Figure 3. Salinity variation in the study area in different habitats

The salinity distribution in the Bach Dang estuary area shows a significant variation between areas under the influence of tides. Salinity has a big difference outside the pond due to natural water exchange between river and sea. Meanwhile, in the ponds surrounded by the pond, a relatively stable salinity environment has been created, ranging from 9–13‰ (rainy season) and 13–18‰ (dry season).

Table 3. Distribution structure of mangrove plants in the studied habitats at the Bach Bang estuary area

No.	Species	Density (Indv./ha)			Frequent (%)			IVI		
		I	II	III	I	II	III	I	II	III
1	*Acanthus ilicifolius* L.	-	-	278.57	-	-	10.71	-	-	26.51
2	*Acrostichum aureum* L.	988.24	581.82	-	70.59	36.36	-	49.13	27.79	-
3	*Aegiceras corniculatum* (L.) Blanco	23.53	218.18	357.14	5.88	24.24	17.86	4.15	14.34	38.98
4	*Annona glabra* L.	47.06	-	-	11.76	-	-	15.13	-	-
5	*Avicennia marina* (Forsk.) Vierh.	-	12.12	-	-	3.03	-	-	2.65	-
6	*Bruguiera gymnorrhiza* (L.) Lam.	47.06	60.61	-	5.88	9.09	-	16.38	11.13	-
7	*Clerodendrum inerme* L. Graertn	188.2	24.24	-	29.41	3.03	-	15.21	1.78	-
8	*Derris tripfoliata* (Benth) Barker	-	12.12	10.71	-	3.03	3.57	-	1.37	4.81
9	*Excoecaria agallocha* L.	847.0	1006.0	-	76.47	84.85	-	60.11	58.32	-
10	*Hibiscus tiliaceus* L.	47.06	-	-	11.76	-	-	56.57	-	-
11	*Kandelia obovata* L. Druce	-	12.12	89.29	-	3.03	10.71	-	2.31	18.19
12	*Lumnitzera racemosa* Willd.	329.4	472.73	-	35.29	39.39	-	23.52	27.47	-
13	*Phragmites australis* Adans., 1763	352.94	72.73	75.0	17.65	3.03	14.29	15.85	3.12	56.21
14	*Pluchea pteropoda* Hemsl.	494.12	-	-	35.29	-	-	24.44	-	-
15	*Potulaca oleracea* L. Sam.	117.6	-	-	5.88	-	-	5.04	-	-
16	*Rhizophora stylosa* Griff.	188.2	1333.3	-	17.65	72.73	-	14.46	60.85	-
17	*Sonneratia caseolaris* (L.) Engl.	-	18.18	339.29	-	9.09	39.29	-	88.87	155.3
	Total 17 species							300	300	300

Note: I: Dike-pond habitat; II: Pond habitat; III: Outside pond.

DISCUSSION

Impact of aquaculture activities on the distribution of mangroves in the Bach Dang estuary area

Changing the forest area into farming ponds has brought about initial economic benefits as the increase in fish production has boosted the economy to develop compared to before. The development of aquaculture in Vietnam in the early 1990s converted a large area of mangroves into intensive and extensive farming ponds. The price of shrimp in this period increased considerably, especially when Vietnam opened international markets such as the US and Europe, so the demand for developing shrimp raw materials was huge, with high profits, so many regions changed the mangroves area into shrimp farms. Especially in the Mekong Delta, such as Bac Lieu, up to 91.1% of the pond area is derived from mangroves [13]. The decline in mangrove areas in the Northern region occurred in the late 1990s and early 2000s due to the movement of deforestation to make aquaculture ponds benefit from aquaculture. The extent of mangroves in the North decreased by 13,221.09 ha between 1990 and 2008 [14]. However, uncontrolled development has led to a polluted environment; production is reduced due to diseases in many places. As a result, a large area of mangroves was lost, the area of farming ponds increased rapidly, and the ecosystem's structure changed.

The process of adapting to changing environmental conditions is a natural adaptation. So is the natural succession process of mangrove species from pioneering new intertidal plants such as species of the Sonneratiaceae family, Avicenniaceae family with a breathing root system on the surface of the sediment helps the tree to survive and tolerant in the muddy and anaerobic environment [15]. The breathing root system also acts as a sediment trap, helping the suspended matter and silt be deposited faster, gradually raising the bottom. When the base is expanded and stiffer, the species belonging to the families Rhizophoraceae (Họ đước) and *A. corniculatum* (Sú) will come and occupy this area. Next-generation species are usually distributed in central areas inundated by tidal for a short time, such as *Bruguiera* genus (Chi vẹt), *Lumnitzera* genus (Chi cóc), *E. agallocha* (Giá), then the community is usually found in the high tide area such as *A. aureum* (Ráng), *E. agallocha* (Giá) and the associated species including *H. tiliaceus* (Tra), *A. glabra* (Na biển) [15].

The embankment of the aquaculture ponds to create a stable environment and keep livestock has changed the environment in the pond and in the wild, the water level in the pond is often kept at a high level. Usually, the mangrove species can tolerate to the inundation by the tide, but the water in the pond was not exchanged by the tide, which has caused many mangrove species that are not able to withstand flooding for a long time to die. The change in mangrove distribution structure also causes other salinity due to mangrove flora being tolerant to salinity conditions, so each species has a different salinity range. Therefore, some species will die when the salinity change. Our result supported this argument.

The *S. caseolaris* (Bần chua) is the dominant species in the wild area (on both sides of the river and the canal connecting the pond to the river), where salinity ranges from 0–15‰. However, the frequency of *S. caseolaris* (Bần chua) was 9.09% in the pond habitat compared to 39.29% in the outside pond habitat (Table 3). Although *S. caseolaris* (Bần chua) was found in the pond habitat, the number of individuals was small (18.18 indv./ha) with a considerable size of the body (diameter > 30 cm) compared to the outside pond habitat. At the same time, our result did not find any seeds or saplings of *S. caseolaris* (Bần chua) in the pond habitat. Thus, in the pond habitat, *S. caseolaris* (Bần chua) remained from the wild habitat before building the aquaculture pond. While, *R. stylosa* (Đước vòi), *L. racemosa* (Cóc trắng) and *E. agallocha* (Giá) are usually found in the high salinity and stable bottom area [4, 16], they were dominant species in the pond habitat. Although the pond and outside pond habitat are very close in Bach Dang estuary, the difference in salinity is a cause of the difference in species composition among these habitats.

The bottom elevation of the pond and dike-pond habitats is higher than the tidal level and rarely flooded, making the environment suitable for species of plants distributed in the high-tide and above-tidal areas such as *E. agallocha* (Giá), *L. racemosa* (Cóc trắng) and *H. tiliaceus* (Tra biển),... and other associated mangrove species. Therefore, in these habitats, there is a diversity of tree species, distributed in species composition as well as canopy structure. Our result supported this argument. The results of the biodiversity index (*H'*) also show that the diversity of species composition in the pond habitat is greater than that of the other two habitats (Figure 2).

The embankment has created a difference in the bottom structure in three habitats, which is the leading cause of the difference in the community structure of mangrove vegetation, due to the mangrove species distribution defense on two factors the height of the bottom and salinity [16, 17]. The diversity index *H'* (Figure 2) and Sorensen similarity (Table 2) showed a transition between the three studied habitats. The similarity index of the outside the pond and the dike-pond habitats are 0.56 and 0.58, respectively, indicating that the mangrove forest in the pond is a transition community between the other two habitats. Thus, The embankment of the pond has caused a significant change in environmental conditions (water and sediment), as well as the height of the bottom, which has led to a considerable difference in the structure distribution of the plant community in three studied habitats at the Bach Dang estuary area.

Solutions for sustainable development for the Bach Dang estuary area

The aquaculture activities have a significant impact on the ability of natural water exchange due to the sluice gates are often closed for aquaculture. The water level in the mangrove pond at the survey time is necessary for the survival and development of the mangroves due to the accretion and shallow process is increasing; therefore, the increasing the water exchange capacity between the mangrove area and the channel system and river also toward the conservation and development of mangrove forests. Because some mangrove species are frequently inundated, such as *R. stylosa*, *A. corniculatum* and *S. caseolaris*, otherwise, this water stored in the mangrove pond will ensure the groundwater in the mangrove area supplies the other mangrove species in the higher area such as *B. gymnorrhiza*, *L. racemosa*, *K. obovate*, *E. agallocha* and *A. aureum*.

The environmental difference between the aquatic pond and the wild is due to the process of the pond's embankment and preventing the exchange of water between the aquaculture pond and the canal system and river through the sluice gates. Therefore, to overcome this difference, it is necessary to create a water exchange between the inside and the outside of the aquaculture pond; it is also essential to develop and expand creeks in the pond to help the water exchange be better. Based on our study result and the geographical structure in the Bach Dang estuary area, we propose solutions to keep mangroves healthy combined with an aquaculture pond.

Construction solutions

Ensure the water exchange and water storage capacity necessary to survive the existing mangrove species described above. The depth of the canal system in the pond is sallow, which ranges from 10–120 cm. In addition, many places with high bottoms sometimes become dry due to water in the pond being a control for livestock, causing the degradation of mangroves in the pond area. Therefore, increasing the water exchange capacity between the mangrove area and the channel system and river also toward the conservation and development of mangrove forests. Because there are some mangrove species frequently inundated, such as *R. stylosa* (Đước vòi), *A. corniculatum* (Sú) and *S. caseolaris* (Bần chua). Otherwise, the water stored in the mangrove pond will ensure the groundwater in the mangrove area supplies the other mangrove species such as *B. gymnorrhiza* (Vẹt dù), *L. racemosa* (Cóc trắng), *K. obovate* (Trang), *E. agallocha* (Giá) and *A. aureum* (Ráng). We propose to build a canal system in the pond habitat as follows:

The canals system for water exchange and storage in the mangrove areas consists of the two-level canal systems, level 1 and level 2

(Fig. 4). Where canal system level 1 is created surrounding the mangrove area in the pond to exchange water to the high bottom area. While canal system 2 is the primary canal system that plays a vital role in water storage in the pond, protects livestock and supplies groundwater for the high area, which is necessary for mangroves in these areas.

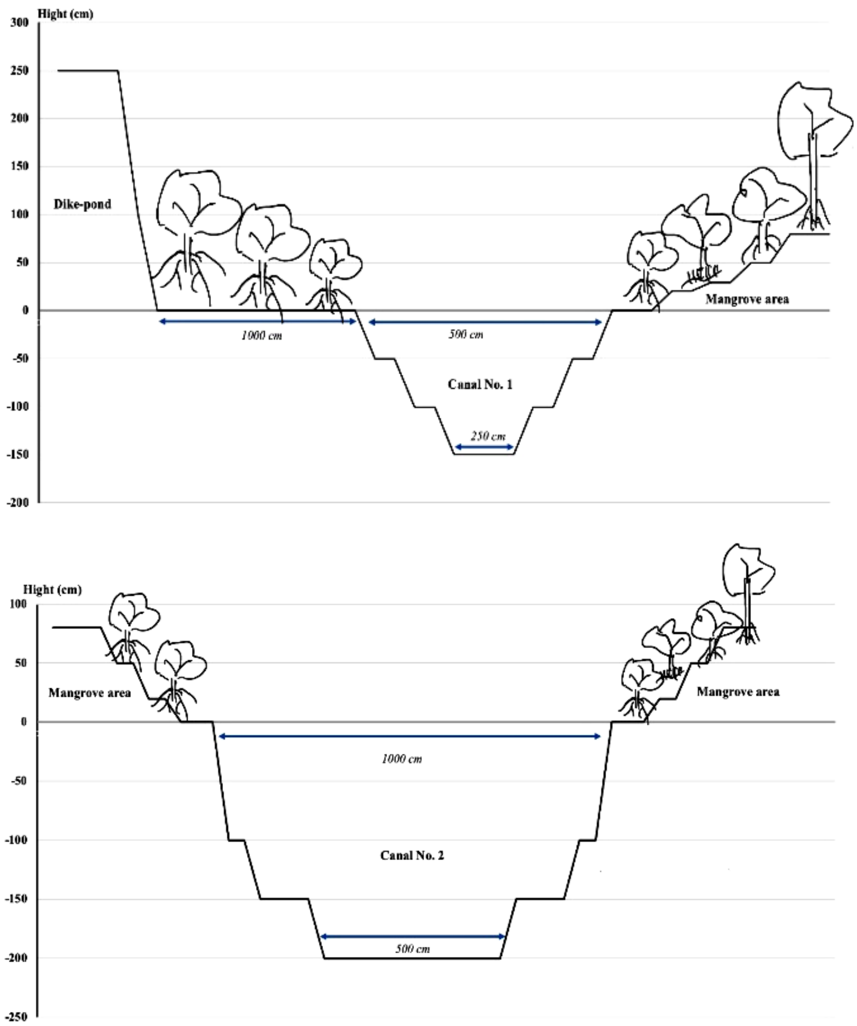

Figure 4. Multi-level canal system solution for water supply and drainage in the pond

Two sluice gates (2.6 × 1.4 m) are set up at two corners where sluice gate number 1 links to the drainage channel and sluice gate number 2 connect to the irrigation channel. Both of these channels are connected to the river (wild environment).

The construction solution helps the water exchange between mangroves pond and outside channels is more favorable, contributes to making an environment in the mangroves area equivalent to the river environment.

Technical solutions

The culture species usually has a small salinity range; thus, the farmers keep stable environmental conditions during the rearing process by storing water in the pond throughout the sluice gates. Therefore, to adapt to the construction solution in creating a similar environment inside and outside the aquaculture pond, it is necessary to select livestock that is suitable for the local environment and develop the source of native organisms. Mud crab

Scylla serrata (Forsk I) is ideal for pond culture in combination with mangroves because The *Scylla* sp., is often farmed in a condition where we call brackish water, in which the salinity range from 10–30‰ between freshwater and seawater [18], capable of adapting to the mangrove environment. The primary food source is small aquatic species with low economic value; this natural seafood source in the aquaculture pond is also a food source for sea crabs, reducing the amount of industrial food. The research results on mud crab farming in mangroves in Quang Ninh province have reduced investment costs by 10–15%, increased farming productivity by 10–12%, and improved the profit margin for crab farming from crab farming 12–15%. 17.5% compared to farming in the pond aquaculture [19]. Raising mud crabs in mangroves has high economic efficiency and contributes to building an aquaculture model combined with the protection and development of mangrove forests because the farming area has mangrove cover from 50–70% of the surface [19].

Legal solutions

It is necessary to develop legal regulations to develop extensive farming models combined with forest tree protection, especially the farming ponds built from the conversion of forests. It is needed to create highly effective and sustainable farming models such as the crab-mangrove and shrimp-mangrove models.

CONCLUSIONS

The research results show that the embankment for aquaculture has been having a significant influence on the distribution of the structure of mangrove flora in the Bach Dang estuary area. There were substantial differences among the three studied habitats (pond, outside pond and dike-pond). There is a transition in the distribution of objects among the three habitats in the direction of ecological succession but forced succession due to marsh filling activities.

To overcome the impacts of aquaculture in the region towards sustainable development, the authors propose three solutions to create similarities in habitat and aquaculture development objects. Which construction and technical solutions need to be researched and deployed soon, thereby protecting the current status of vegetation and combining aquaculture to ensure local socio-economic development.

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