Ocean and Coastal Research

ORIGINAL ARTICLE

http://doi.org/10.1590/2675-2824071.22117hvt
ISSN 2675-2824

Characteristics of integrated mangrove-shrimp farming systems in Ben Tre Province, Vietnam: preliminary findings for organic shrimp production certification

Huynh Van Thao[1,2], Nguyen Van Cong[1]

[1] College of Environment and Natural Resources, Can Tho University, Campus II, 3/2 Street, Can Tho City 92000, Vietnam
[2] United Graduate School of Agricultural Science, Tokyo University of Agriculture and Technology, Tokyo 183-8506, Japan

* Corresponding author: nvcong@ctu.edu.vn

ABSTRACT

Mangrove forests play a critical role in natural disaster resistance and provide meaningful livelihoods for local communities, especially integrated mangrove shrimp farming (IMSF) systems. Organic shrimp certification actually increases the value chains of shrimp farming in addition to ameliorating mangrove–forest management. Identifying technical issues and assessing environmental risks are the leading concerns when considering organic shrimp production certification. In this study, the technical practices of 30 households were investigated, and surface water and sediment samples were collected in the IMSF models and adjacent rivers in the Thua Duc Forest Management Board area, Ben Tre Province. Data collected from shrimp farming ponds and the environmental background were referred to both the Naturland and National Standards. The results showed that the average mangrove forest and shrimp pond ratio was 56.90:42.70 (%). Two technical issues were highlighted: (i) the use of rotenone, known as a toxin to kill undesirable fish before stocking shrimp, and (ii) annual shrimp pond regeneration causing increased pollution. The data showed that higher concentrations of TSS and P-PO_4^{3-} were detected in surrounding rivers, while surface water in either IMSF ponds or adjacent rivers slightly surpassed the permissible levels of total Fe concentration. All parameters—including heavy metals; toxic and persistent parameters; oil and grease and coliforms analysed in surface water, and sediment samples—were lower than the detection and permissible levels. The results provided evidence that the IMSF's practices and environmental characteristics were suitable for recommending the Naturland Standards. Recommendations and technical interventions for farmers are necessary to help reduce Fe levels and the safe use of rotenone in IMSF systems. An environmental quality monitoring programme at the target area should be applied when launching organic shrimp production.

Descriptors: Mangrove forest, Water and sediment quality, Shrimp farming practices, Vietnamese Mekong Delta.

INTRODUCTION

Mangrove forests, commonly found in tropical and subtropical tidal areas, play a vital role as a fundamental connective factor between terrestrial and marine ecosystems (Nagelkerken et al., 2008; Strauch et al., 2012; Rasyid et al., 2016). As an inseparable component, mangrove forest ecosystems also provide a wide range of suitable habitats and abundant food sources for numerous aquacultural species (Nanjo et al., 2014; Ahmed et al., 2017; Trang et al., 2022). Moreover, mangroves provide valuable ecosystem resources and actions, including reducing natural disasters (e.g. storms, floods, erosion, salt intrusion and climate change); providing wood

Submitted: 23-Aug-2022
Approved: 22-Jan-2023

Associate Editor: Alejandro Buschmann

sources (charcoal, biochar, timber); reserving massive blue carbon sources (13.5 Gt $year^{-1}$ ~ 1% total carbon sequestration); and diversifying local community livelihoods based on coastal aquacultural activities (Alongi, 2012; Brander et al., 2012; Ahmed et al., 2017; Sarathchandra et al., 2018; Chatting et al., 2022). However, anthropogenic activities have greatly affected mangrove forests (Hayashi et al., 2019; Eddy et al., 2021). For instance, aquacultural and agricultural expansion caused an estimated 62% loss of global mangrove forest area between 2000 and 2016 (Goldberg et al., 2020). Therefore, conservation-orientated plans and sustainable exploration strategies need to be developed.

The Vietnamese Mekong Delta (VMD), located in southwestern Vietnam, has approximately 100,000 ha of mangrove area (Truong and Do, 2018). However, VMD's area of mangrove forests has gradually decreased over the last few decades. Minh et al. (2001) reported that about 161,227 ha were converted into aquaculture and other commercial uses between 1953 and 1995. As a result, the Vietnamese Government changed its policy by leasing a 20-year contract to households while expecting them to ameliorate protection, management, and logging (Ha et al., 2012; Truong and Do, 2018; Trang et al., 2022). Under this approach, 20–40% were allocated to shrimp farming, while 60–80% of the remaining areas required adequate coverage in mangrove forests (Johnston et al., 2000; Bosama et al., 2014; Truong and Do, 2018). Over the years, farmers in VMD's coastal areas have used the allocated forest land to develop integrated mangrove-shrimp farming (IMSF) systems as their main mangrove-engaged livelihood. The IMSF systems have recently received much more attention due to the value of labelled ecological products, thus providing an attractive profit for farmers as well as mangrove forest protection (Baumgartner et al., 2016).

Ben Tre Province, located in VMD's coastal area, accounts for 7.15% of the mangrove forest areas in VMD (Truong and Do, 2018). Therefore, the area contributes a vital mangrove-shrimp-based livelihood source to local communities where diversified livelihoods are limited. The mangrove forest, located at Thua Duc Commune, Binh Dai district, Ben Tre province (Figure 1), had a total of 416.05 ha in 2019, of which 16.36 ha was natural mangrove, while 399.69 ha was the reforested mangrove. The IMSF system is the main livelihood of the majority of poor households in coastal areas. Moreover, it has recently been proposed to develop the area as an organic IMSF, which will likely improve household revenues through higher selling prices. To gain organic IMSF certification, the identification of the IMSF background and environmental quality are two major issues that need to be satisfied. Mangrove coverage in IMSF systems, technical practices, and management all affect shrimp productivity and environmental quality (Trang et al., 2021; Cong and Khanh, 2022). Furthermore, several factors, such as the quality and quantity of shrimp seeds, stocking of post-larvae methods, intake water quality, frequency of shrimp pond regeneration and water exchange, percentage of water surface held in ditches, primary production effectiveness, predators, and leaf litter fall and its decomposition affect shrimp productivity, have been scrutinized and investigated in the IMSF (Clough et al., 2022; Hai and Yakupitiyage, 2005; Johnston et al., 2002; Ha et al., 2014; Truong and Do, 2018; Bosma et al., 2016; Viet and Hai, 2016). However, technical and management issues and surface water and sediment quality in shrimp ponds and surrounding rivers in areas suggested for organic shrimp production have not been thoroughly investigated. Identifying the challenging issues and providing feasible recommendations would offer benefits for facilitating management and necessary interventions to comply with these organic shrimp production regulations. Thus, this study aimed *(i)* to investigate IMSF practices and *(ii)* to examine the characteristics of the water and sediment of shrimp farms and vicinity rivers with the expectation of better management and shrimp production toward environmentally friendly and ecological sustainability.

METHODS

Site description

Ben Tre Province, located in the lower VMD, is divided into seven districts (Cho Lach, Chau Thanh, Mo Cay, Giong Trom, Binh Dai, Ba Tri, and Thanh Phu) plus Ben Tre City (Figure 1). Aquacultural activities account for 44.5% of total

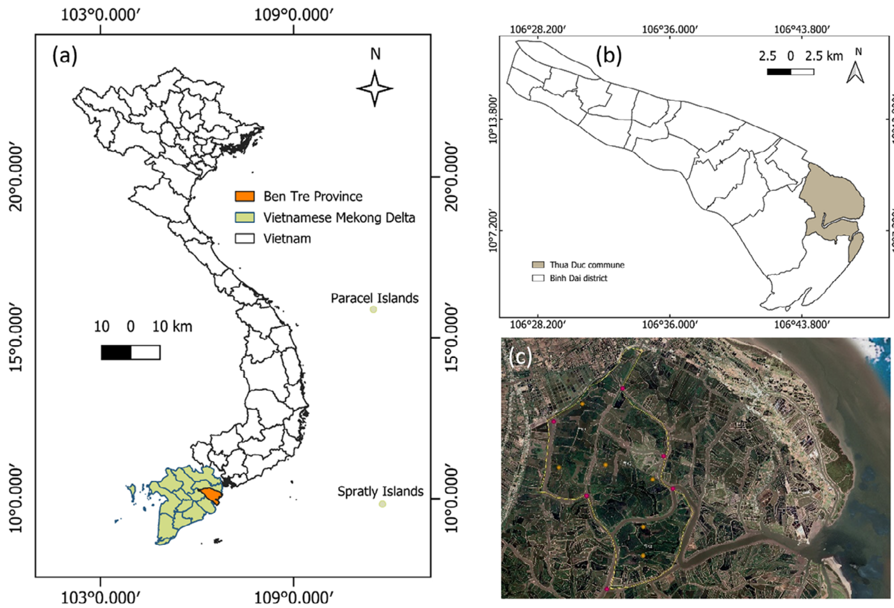

Figure 1. (a) Location of Ben Tre Province in Vietnamese Mekong Delta, Vietnam; (b) study area in Thua Duc commune, Binh Dai district; (c) sampling sites in Thua Duc Forest of the Management Board area. Yellow and red points show in the IMSF and vicinity rivers/canals, respectively.

land use in Ben Tre Province (IUCN, 2015). Binh Dai district has four communes with abundant mangrove forests comprising Binh Thang, Thanh Phuoc, Thua Duc, and Thoi Thuan Communes. This study was conducted in the Thua Duc Forest Management Board, Thua Duc Commune, Binh Dai District, Ben Tre Province. The surveyed area is along the low-lying terrain coast of Ben Tre Province and has been examined for vulnerability to climate change (Can, 2015; Veettil et al., 2019).

The area of mangrove forests in Binh Dai District is 1,385.04 ha, of which Thua Duc Commune shares the most significant portion (416.05 ha) of mangrove forests in the district. Here, mangrove forests are distributed alongside coastlines and river mouths. The study site is in a tropical monsoon climate zone, divided into two distinct seasons with East Sea subcoastal region characteristics. The hydrology regime is impacted by the semi-diurnal tide regime of the East Sea. The largest tidal amplitude recorded was 4.1 m, while the average high tide was 2.6 m. The average temperature varies between 26°C and 27°C. The area records 2,650 mean sunshine hours per year.

Data collection

Collected data included information on forest and pond area ratio, farming technical characteristics (shrimp pond regeneration, water management, aquacultural chemicals, seeds, stocking density, harvest, yields, and net profit), as well as the pros and cons of shrimp farming. Data were obtained from 30 IMSF households through in-person interviews based on structured questionnaires. These IMSF farmers were randomly selected from a list provided by the Thua Duc Forest Management Board. Tiger shrimp (*Penaeus monodon*) is one of the main species stocked in IMSF systems.

In order to examine the environmental background, 12 sampling sites covering the whole study area were selected for collecting water, and 6 sampling sites were selected for collecting sediment in the IMSF systems (Figure 1c). Samples were collected in June 2019 at once. Six sites were in the IMSF, and the other six sites were in water-supply/drainage canals. Water samples were taken 20–30 cm below the water surface, while sediment samples were collected by an Ekman Bottom Grab sampler with three sediment subsamples. The sediment subsamples were then mixed homogeneously to obtain a pooled sample for each site. After collection, the samples were immediately stored in foam boxes with ice and transported to the laboratory within 24 h. A total of 25/25 water-quality parameters were selected based on the National Technical Regulation on Marine Water Quality (QCVN 10-MT:2015/BTNMT), and 15/22 sediment-quality parameters adopted from the National Technical Regulation Sediment Quality (QCVN 43:2017/BTNMT) were also selected and analysed.

Water temperature, pH, and dissolved oxygen (DO) were measured onsite using a thermometer, pH meter (IM32P; TOA-DKK Corporation, Tokyo, Japan), and DO meter (DO-31P; TOA-DKK Corporation). The chemical properties of water and sediment samples were detected according to the Standard Method for the Examination of Water and Wastewater (SMEWW) (APHA, 2012), International Organization for Standardization (ISO, 1990, 1998, 2002, 2004, 2007), and the Environmental Protection Agency (EPA, 1998) (Table 1).

Data processing

To obtain general information, quantitative variables were aggregated from 30 interviewed households in the targeted area. Data were presented as mean (min–max), n = 30. Water quality data were referred to QCVN 10-MT:2015/ BTNMT (QCVN, 2015), while QCVN 43:2017/ BTNMT was used when analysing the sediment quality data (QCVN, 43). The term "National Standard" used in this article applies to QCVN 10-MT:2015/BTNMT and QCVN 43:2017/BTNMT when referring to water and sediment environments, respectively. The Naturland Standards for Organic Aquaculture (Naturland, 2010) were used to discuss and consider the suitability of an integrated mangrove-shrimp system in the targeted area. The difference between the environmental background of the shrimp ponds and canals was analysed assuming equal variances (Student's t-test) at a significant level of $p \leq 0.05$ (n = 6) after passing the normality test (Shapiro–Wilk) ($P > 0.05$). If the dataset failed the normality test ($p < 0.05$), a Mann-Whitney Rank Sum Test

Table 1. Analytical methods for water and sediment parameters.

Sample	Parameters	Analytical methods
Water	TSS	SMEWW 2540.D:2012
	$N\text{-}NH_4^+$	SMEWW 4500-NH3.F:2012
	$P\text{-}PO4_3^-$	SMEWW-4500P.E:2012
	F-	SMEWW 4500-F -B:2012
	CN-	SMEWW 4500CN- C:2012
	As, Cd, Pb, Cu, Zn and Cr	SMEWW 3120 B:2012
	Cr_6^+	SMEWW 3500-Cr.B: 2012
	Mn and Fe	SMEWW 3111.B:2012
	Hg	SMEWW 3112.B: 2012
	Aldrin, Dieldrin, Benzene hexachloride (BHC), dichlor o-diphenyl-trichloroethane (DDT), Heptachlor and Heptachlorepoxide	EPA (1998)
	Total phenol	ISO 6439:1990
	Oil and Grease	SMEWW 5520.B:2012
	Total coliform	SMEWW 9221.B:2012
Sediment	As	ISO (2007)
	Cd, Pb, Zn, total Cr, and Cu	ISO 11047:1998
	Hg	ISO, 2004
	Chlordane, DDT, dichlorodiphenyldichloroethylene (DDE), dichlorodiphenyldichloroethane (DDD), Dieldrin, Endrin, Lindane, total Polychlorinated Biphenyl (PCB) and Heptachlor epoxide	ISO 10382: 2002

was performed. All computations were performed using R stats (R Project for Statistical Computing, RRID:SCR_001905).

RESULTS

CHARACTERISTICS OF INTEGRATED MANGROVE-SHRIMP FARMING

The results showed that farmers owned an average of 5.62 ha of land (ranging from 1.3 to 12.15 ha) for running the IMSF (Table 2). The area in the IMSF was larger than in shrimp ponds. In particular, the mangrove forest area was 2.4 ha per person, while the shrimp farming area was 0.28 ha per person. The mean forest:pond ratio was 56.90:42.70, of which the 60:40 ratio accounted for approximately 66.67% of interviewed households. Ten percent of households kept 70% of their land in mangrove forests, while 23.3% of households kept 50% of their land in mangrove forests.

Farmers who managed the IMSF regenerated their shrimp ponds once per year. The regeneration schedule ranged from July to September, based on the lunar calendar. About 70% of households in this region chose to regenerate their shrimp farms in August (Table 2). The shrimp pond regeneration process involves four basic steps (Figure 2): *(i)* draining water in the shrimp pond to a depth of 0.5 m; *(ii)* removing deposit sediment layer and reinforcing small border dikes by either excavators or mud suction pumps—the height of sediment layer that needs to be eliminated is commonly greater than 1.0 m (46%); *(iii)* eliminating undesirable fish species naturally by using rotenone (derived from naturally local plants) known as a sensitive toxic to fish due to inhibiting oxygen transfer and

Table 2. Technical characteristics of the integrated mangrove-shrimp systems.

Variable	Unit	Value
Total mean area of interviewed farmers	ha household^{-1}	5.62 (1.30 – 12.15)
Mangroves forest area	ha household^{-1}	2.40 (0.40 – 5.50)
Shrimp pond area	ha household^{-1}	0.28 (0.89 – 6.60)
Forest:pond ratio	%	56.90:42.70
Households maintained the ratio at 70:30	%	10.00
Households maintained the ratio at 60:30	%	66.67
Households maintained the ratio at 50:50	%	23.33
Annual shrimp-pond regeneration schedule (lunar calendars)		
July	%	21.00
August	%	70.00
September	%	9.00
The height of sediment layer excavated		
≤0.5 m	%	10.00
0.5 – 1.0 m	%	44.00
≥ 1.0 m	%	46.00
Stocking density		
≤ 30,000 shrimp ha^{-1} yr^{-1}	%	20.18
30,000 - 50,000 shrimp ha^{-1} yr^{-1}	%	50.54
≥ 50,000 shrimp ha^{-1} yr^{-1}	%	29.28
Harvest frequency	time per month	2
Shrimp yield	kg ha^{-1} yr^{-1}	172.4 (120 - 260)
Net profit†	million VND ha^{-1} yr^{-1}	55.42 (35 - 70)

"†" indicates a direct response from interviewees regarding to shrimp productivity. The sub-income sources from the IMSF were omitted. Values presented in parentheses indicate fluctuation from minimum to maximum.

cellular respiration then applying multiple drainage to purify naturally; and *(iv)* holding clean water for 2–3 weeks before shrimp stocking.

The results showed that the shrimp stocking density was usually 30,000 to 50,000 shrimp ha^{-1} yr^{-1} in 50% of the households engaging in the IMSF. Approximately 30% of interviewed households stocked above 50,000 shrimp ha^{-1} yr^{-1}, although 20% of households used a lower stocking rate of 30,000 shrimp ha^{-1} yr^{-1} (Table 2). The stocking method could be revised multiple times in a year to obtain higher productivity. Shrimp harvest was carried out two times per month (4–6 days/time) based on water exchange combined with a net trap placed on a sluice gate at high tide (dates 15 and 30 based on the lunar calendar). The results showed that an average IMSF shrimp yield of 172.4 kg ha^{-1} yr^{-1} was achieved. As a result, the net profit from shrimp farming was 55.42 million VND ha^{-1} yr^{-1}.

Characteristics of water in shrimp ponds and water-distributed canals

The shrimp ponds exhibited significantly higher water quality levels (including temperature, pH, and DO) compared to the nearby rivers ($p < 0.05$) (Figure 3). However, there were no significant differences observed in TSS and phosphate levels ($p > 0.05$). N-NH4+ levels in the vicinity rivers were found to be lower in the shrimp ponds. Temperature, pH, and phosphate in the shrimp ponds and vicinity rivers were between or below maximum permissible levels of the national standard, whilst the concentration of TSS and $N\text{-}NH_4^+$ were slightly above the allowable levels: 1.12-fold compared to the national standard.

Some parameters, such as total Fe, F-, Mn, and coliforms (Table 3) in the shrimp ponds and water-distributed rivers, were found with higher detection limits, whereas the rest of the heavy metals, toxins, and persistent parameters were consistently lower than the detection limits. The level of total Fe in both shrimp ponds and surrounding rivers exceeded 2.72-fold and 1.64-fold of the permissible value regulated by a national standard. A higher concentration of total Fe in shrimp ponds was found compared to surrounding rivers ($p < 0.05$). Similarly, the attention of F^- and Mn in shrimp ponds were greater than that of nearby rivers ($p < 0.05$). Specifically, levels of F^- in the shrimp ponds and adjacent rivers were 0.90 mg L^{-1} and 0.8 mg L^{-1}, respectively. Mn levels in shrimp ponds and in-line rivers were 0.28 mg L^{-1} and 0.18 mg L^{-1}, respectively. In contrast, coliform values detected in shrimp ponds were permanently lower than in bordering rivers ($p < 0.05$). Unambiguously, coliforms reached a level of 9.00 MPN 100 mL^{-1} in shrimp ponds, while contiguous rivers exhibited a coliform value of 93 MPN 100 mL^{-1}.

Characteristics of sediment quality in shrimp ponds

The results showed that concentrations of heavy metals, toxins, and persistent parameters in sediment were reliably lower than the permissible levels prescribed in the national standards (Table 4). These parameters, including Hg, total Cr, Cu, and total PCB, were detected in the sediment of the shrimp ponds, while the remaining parameters (As, Cd, Pb, Chlordane, DDT, DDE, DDD, Dieldrin, Endrin, Heptachlor epoxide, Lindane, and total PCP) were consistently lower than detection limits. Although these parameters were detected, they were much lower than the tolerable values required by the national standards. In particular, Hg, total Cr, Cu, and total PCB were 17.50-, 8.90-, 10.37-, and 26.63-fold lower than the National Standard. Generally, heavy metals, toxins, and persistent parameters in the sediment deposits of surveyed shrimp ponds were tolerable.

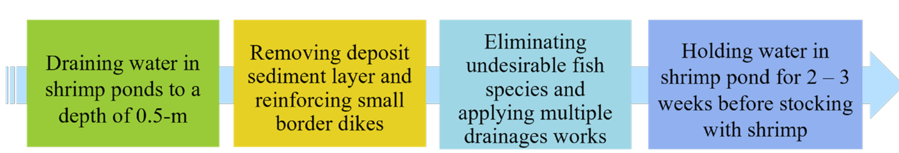

Figure 2. Common procedures for regenerating shrimp ponds in the IMSF at Thua Duc commune, Binh Dai district, Ben Tre province.

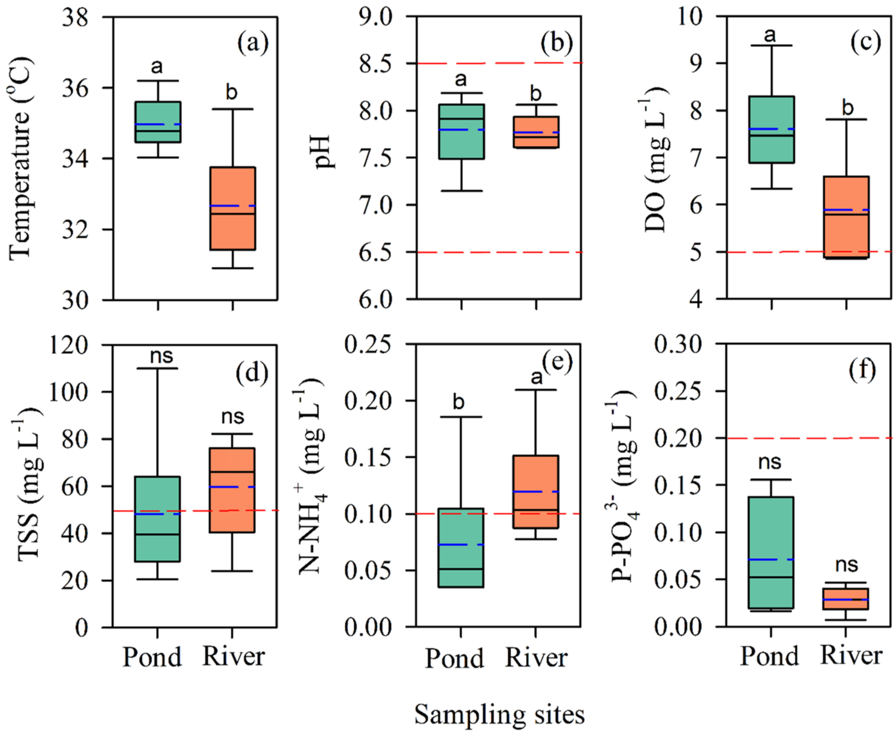

Figure 3. Environmental parameters in shrimp ponds (blue color), and vicinity rivers (orange color). Blue medium-dash lines indicate mean values of measured environmental parameters; red short-dash lines denote the restriction of environmental parameters regulated by the National Standards for Marine Water Quality (QCVN 10-MT:2015/BTNMT). Values below or between red lines indicate acceptability. The absence of red lines for temperature is due to the standard not regulating it.

DISCUSSION

The results showed that most local households incorporated a high ratio of forest:pond coverage at over 60:40. Only a handful of farmers embraced a lower ratio. Notably, the holding ratio was kept higher than 50:50. The Natural Standard for Organic Aquaculture (Naturland) requires IMSF to hold a 5-year period with mangrove coverage of at least 50% (Naturland, 2010). Primarily, the mangrove ratio in the targeted area obviously met the Naturland Standard. In practice, the proportion of mangrove coverage and shrimp ponds significantly impacts shrimp yield. Several studies have recently discussed the relationship between the forest to pond ratio and shrimp yields (Johnston et al., 2000; Trang et al., 2022). Specifically, Binh (1997) and Bosama et al. (2014) proposed 30–50% coverage of mangrove forests as being best for shrimp yield, while 60% coverage has been proposed for optimal shrimp yield by Truong and Do (2018) and Trang et al. (2022), even though surveyed local farmers expected to reduce the mangrove coverage. The contrasting information could be due to the lack of control variables, natural shrimp production, and other vital inputs (Truong and Do, 2018). Thus, to eliminate biased estimations, future research should focus on the association with several factors, such as mangrove coverage ratios, ages, environmental limits, and IMSF configuration.

The present study identified four steps in the annual shrimp pond regeneration process between July and September. Removing the deposit sediment layer has a positive impact on eliminating limiting factors. Accumulation of mangrove leaf litter negatively affects shrimp survival and growth (Johnston et al., 2000). Decomposition of leaf litter or debris requires a high demand for DO, resulting in decreased environmental quality, increased toxicity, disease, and diminished shrimp growth (Alam et al., 2021, 2022).

Table 3. Characteristics of heavy metals, toxic, persistent parameters, oil and grease and coliform in surface water in shrimp ponds and water-distributed rivers.

Parameter	Unit	Pond	River	Standard†
Total Fe	mg L^{-1}	1.36±0.63[a]	0.82±1.82[b]	0.5
Cu	mg L^{-1}	<DL	<DL	0.2
Zn	mg L^{-1}	<DL	<DL	0.5
F^-	mg L^{-1}	0.90±0.08[a]	0.80±0.79[b]	1.5
CN	mg L^{-1}	<DL	<DL	0.01
As	mg L^{-1}	<DL	<DL	0.02
Cd	mg L^{-1}	<DL	<DL	0.005
Pb	mg L^{-1}	<DL	<DL	0.05
Hg	mg L^{-1}	<DL	<DL	0.001
Cr_6^+	mg L^{-1}	<DL	<DL	0.02
Total Cr	mg L^{-1}	<DL	<DL	0.1
Mn	mg L^{-1}	0.28±0.05[a]	0.18±0.21[b]	0.5
Aldrin	µg L^{-1}	<DL	<DL	0.1
Benzene hexachloride (BHC)	µg L^{-1}	<DL	<DL	0.02
Dieldrin	µg L^{-1}	<DL	<DL	0.1
Total DDTs	µg L^{-1}	<DL	<DL	1
Heptachlor and heptachlor epoxide	µg L^{-1}	<DL	<DL	0.2
Total phenol	mg L^{-1}	<DL	<DL	0.03
Oil and grease	mg L^{-1}	<DL	<DL	0.5
Total coliform	MPN 100mL $^{-1}$	9.00±5.61[b]	93±29.75[a]	1000

Note: "<DL" indicates below detection limits of all collected samples. Limits of detection of parameters were as follows: Cu=0.04 mg L^{-1}, Zn = 0.05 mg L^{-1}, CN- = 0.001 mg L^{-1}, As = 0.006 mg L^{-1}, Cd = 0.005 mg L^{-1}, Pb = 0.05 mg L^{-1}, Hg = 0.001 mg L^{-1}, Cr6+ = 0.006 mg L^{-1}, total Cr = 0.06 mg L^{-1}, Aldrin = 0.025 µg L^{-1}, BHC = 0.02 µg L^{-1}, Dieldrin = 0.029 µg L^{-1}, Total DDTs = 1 µg L^{-1}, heptachlor and heptachlor epoxide = 0.014 µg L^{-1}, Total Phenol = 0.2 mg L^{-1}, oil and grease = 0.04 mg L^{-1}. "†" National technical regulation on marine water quality (QCVN 10-MT:2015/BTNMT). The letters "a" and "b" show significant differences of parameters between shrimp ponds and adjacent rivers according to assuming equal variances (Student's t-test).

Sediment is currently used for shrimp pond small-dike reinforcement and levelling, implying a potential impact on surrounding environment characteristics, such as increasing turbidity and releasing poisonous pollutants to the water environment. In the present study, the relationship between the sediment-eliminated stages and the environmental limits for aquaculture remain unclear. Although shrimp pond regeneration activities are neglected in the Naturland Standard, it is suggested that the probable effects of shrimp pond regeneration activities on environmental quality should be scrutinized and investigated in future research.

The current study revealed that all surveyed farmers used rotenone at low levels to kill undesirable fish species that could predate shrimp larvae at stocking. Rotenone naturally derived from plant roots is used by farmers in the study areas as a practical measure to kill undesirable fish species (Rayner and Creese, 2006). No external rotenone chemicals were used on their farms. The Naturland Standard permits rotenone derived from naturally occurring vegetable substances such as *Derris spp., Lonchocarpus* spp. *or Terphrosia spp* (Naturland, 2010). Thus, the farmers' practices are suitable in terms of the standards. It is noticeable that although the utilisation of rotenone could be effective for killing undesirable fish species and is accepted by the Naturland Standard, misapplication could cause adverse efficacy. EU organic certification for aquaculture (EC 85/337/EEC) is currently not allowed. Thus, the guidelines for using rotenone in IMSF technical management should be clarified.

Table 4. Characteristics of heavy metals, toxic, and persistent parameters in deposit sediment shrimp in ponds.

Parameter	Unit	Shrimp pond	Standard†
As	mg kg^{-1}	<DL	41.6
Cd	mg kg^{-1}	<DL	4.2
Pb	mg kg^{-1}	<DL	112.0
Hg	mg kg^{-1}	0.04±0.01	0.7
Total Cr	mg kg^{-1}	17.97±0.76	160.0
Cu	mg kg^{-1}	10.41±0.93	108.0
Chlordane	µg kg^{-1}	<DL	4.8
DDT	µg kg^{-1}	<DL	4.8
DDE	µg kg^{-1}	<DL	374.0
DDD	µg kg^{-1}	<DL	7.8
Dieldrin	µg kg^{-1}	<DL	4.3
Endrin	µg kg^{-1}	<DL	62.4
Heptachlor epoxide	µg kg^{-1}	<DL	2.7
Lindane	µg kg^{-1}	<DL	1.0
Total PCB	µg kg^{-1}	8.00±0.00	189.0

Note: "<DL" indicates below detection limits of all collected samples. Limits of detection of parameters were as follows: As = 10 mg kg^{-1}, Cd = 1 mg kg^{-1}, Pb = 15 mg kg^{-1}, Chlordane = 4 µg kg^{-1}, DDT = 5 µg kg^{-1}, DDE = 5 µg kg^{-1}, DDD = 5 µg kg^{-1}, Dieldrin = 4 µg kg^{-1}, Endrin = 5 µg kg^{-1}, Heptachlor epoxide = 2 µg kg^{-1}, Lindane = 0.8 µg kg^{-1}. "†" National technical regulation on marine water quality (QCVN 10-MT:2015/BTNMT).

The current study examined the environmental quality of ponds in IMSF and surrounding rivers. As surveyed, the feed sources for shrimps in the IMSF were totally natural, and no supplementary outside feeds were applied. Thus, environmental quality reflects the natural processes taking place in the IMSF. The present work demonstrated that environmental parameters (temperature, pH, DO, TSS, N-NH_4^+, and P-PO_4^{3-}) in shrimp ponds met the National Standard, reflecting the environmental safety in the IMSF. Furthermore, these measured values are in line with previous reports in the IMSF (Binh, 1997; Cong and Khanh, 2022).

Higher concentrations of TSS and N-NH_4^+ in the vicinity rivers show pollution, and need actions for intake. TSS in water depends considerably on tidal flows (Oliveira et al., 2018) and could be used as an indicator of nutrient pollution (Park, 2007) and ecological conditions of water because they create a high risk to aquatic life (Nurgiantoro and Jaelani, 2017; Sa'ad et al., 2021). Conversely, P-PO_4^{3-} is recognised as a limiting factor for eutrophication due to the predominant uptake of aquatic algae (Clarke et al., 2006).

It is noticeable that the total Fe concentration in all water environment samples surpassed the permissible levels of the National Standard, which indicates the presence of Fe contamination in the targeted area. Several studies elucidated that total Fe could pose a potential risk for shrimp in the IMSF, as when Fe^{2+} oxidises into Fe^{3+}, it precipitates to $Fe(OH)_3$ at the surface of shrimp gills (Wepener et al., 2004; Teien et al., 2008; Schmidt et al., 2009; Lemonnier et al., 2021). Thus, technical measures should be implemented to mitigate ecological and human consumption risks in future organic shrimp production plans.

Iron is recognised as a critical element in the biogeochemistry of estuarine soil (Nóbrega et al., 2013) and plays a vital role in the decomposition of organic matter below ground (Kristensen et al., 2008; Alongi et al., 2001). Iron generally exists in the roots and leaves of mangrove forest plants and translocates to the water environment through leaf litter decomposition in poor oxygen (Thanh-Nho et al., 2019). The presence of total Fe in the environment is more relevant to the existence and oxidisation of several Fe compounds, for example, Fe (III) oxide (crystalline Fe and hydroxide) and Fe sulphides (FeS and FeS_2), controlled principally by oxidation–reduction reactions of sulphates in mangrove forests (Burton et al., 2006; Hinokidani and Nakanishi, 2019). Fe mostly has low bioavailability in seawater, but it is highly reactive in the presence of oxidants (Saulnier and Mucci, 2000; Morgan et al., 2012; Hinokidani and Nakanishi, 2019). Furthermore, natural and anthropogenic disturbances, such as high-flow drains, shallow estuaries, and sediment excavation, increase the presence of Fe in the water, posing a significant risk to ecological sustainability (Morgan et al., 2012). Deposited sediment in the IMSF was removed annually by excavators and mud-suction pumps between July and September, which imposes the possibility of increasing total Fe concentration in water. Thus, total Fe monitoring strategies during shrimp pond regeneration should be incorporated.

The concentration of heavy metals, toxins, persistent parameters, and coliforms in water and sediment ranged from the lower detection limits to lower national regulation limits. The results strongly indicate clear evidence of environmental safety and suitability for developing organic shrimp production systems in accordance with mangrove forest preservation strategies. Several studies on heavy metal concentration in mangrove-forest sediment and mangrove plants have been reported (Costa et al., 2013; Thanh-Nho et al., 2019; Costa-Böddeker et al., 2020). Although toxic and persistent compounds were not found in the water and sediment samples in the present study, further investigation over tidal cycles, time of shrimp harvesting schedules, and season are needed. Thus, the current work showed a general view of the IMSF's toxic and persistent parameters. Generally, toxic and persistent compounds are more significant than natural factors, or the accumulation derived from fertilizers, agrochemicals, and bioproducts. The surveyed results showed that no fertilizers and chemicals (except for rotenone originating from natural plants) were used in the IMSF. Thus, the low recorded toxicity concentrations are reliable and positive indicators for developing organic shrimp farms in line with the Naturland Standard.

Bordering intensive shrimp farms under the control of the Thua Duc Forest Management Board could pose a high risk of increased pollution (Figure 4). This could be explained by high shrimp stocking and highly daily multiple water-exchange frequencies. It means that a considerable amount of wastewater would be discharged into the exterior environment. Indeed, if wastewater sources are not well-managed, then potential risks for organic shrimp production areas will occur. Thus, a strict monitoring programme with a suitable separate plan for intensive shrimp farms is recommended. Moreover, eliminating accumulated sediment releases heavy metals, organic matter, and toxicity in the water environment and adjacent rivers/canals through water exchange. This could possibly affect bordering households.

Therefore, it is suggested that a proper excavating-time distribution is essential to avoid pollution-excessive concentration. Simultaneously, disturbed water should be kept for several days, combined with the application of lime to reduce turbidity and sediment before releasing it into the external environment.

Figure 4. The existence of intensive shrimp farms (left) and neighbouring the IMSF system (right).

Furthermore, using rotenone to kill undesirable fish species in the shrimp farm increases risks because the toxin is not allowed by EU organic certification for aquaculture, as mentioned above. Therefore, to reduce the associated risks, it is recommended that saponin is used rather than rotenone. Obstacles can be overcome if farmers take part in practical training courses according to organic shrimp production standards. Farmers should be trained to use fish-killing toxins safely to comply with organic aquaculture practices. Lastly, high Fe in the water potentially influences shrimp and human consumption. It is proposed that technical interventions to reduce Fe concentration in water are inevitable for developing organic shrimp production in the IMSF.

CONCLUSION

The results provide evidence that the control of environmental characteristics (water and sediment), an optimal ratio of mangrove forest to shrimp ponds, and technical practices are completely feasible for organic shrimp production criteria complying with the Naturland Standard. Higher total Fe levels found in water is a concern, as well as the use of rotenone to kill undesirable fish, but technical measures could be applied to obtain a permissible level. Obstacles can be overcome if farmers take part in practical training courses according to organic shrimp production standards. This study would be helpful for the Ben Tre local government in making decisions regarding the establishment of ecological shrimp production combined with better mangrove forest management strategies. Our study recommends technical interventions should be applied to reduce total Fe in the surface water of the IMSF in order to comply with environmental quality and organic food standards. Moreover, we also suggest that an environmental quality monitoring programme in the target area should be considered as part of the organic shrimp production system.

ACKNOWLEDGMENTS

This study was funded by IUCN project No. P01222. The authors would like to thank to the College of Environment and Natural Resources, Can Tho University, Vietnam, for the supply of equipment for onsite measurements. We also thank Thua Duc Forest Management Board for their collaboration. We thank anonymous reviewers for taking the time and effort necessary to review the manuscript. We sincerely appreciate all valuable comments and suggestions which helped us improve the manuscript's quality.

AUTHOR CONTRIBUTIONS

H.V.T.: Methodology; Software; Formal Analysis; Investigation; Writing – original draft;

N.V.C.: Conceptualization; Methodology, Investigation; Resources; Project Administration; Funding Acquisition; Writing – review & editing;

REFERENCES

AHMED, N., THOMPSON, S. & GLASER, M. 2017. Integrated mangrove-shrimp cultivation: potential for blue carbon sequestration. *Ambio*, 47(4), 441-452.

ALAM, M. D. I., AHMED, M. U., YEASMIN, S., DEBROT, A. O., AHSAN, M. D. N. & VERDEGEM, M. C. J. 2022. Effect of mixed leaf litter of four mangrove species on shrimp post larvae (Penaeus monodon, Fabricius, 1798) performance in tank and mesocosm conditions in Bangladesh. *Aquaculture*, 551, 737968.

ALAM, M. D. I., DEBROT, A. O., AHMED, M. U., AHSAN, M. D. N. & VERDEGEM, M. C. J. 2021. Synergistic effects of mangrove leaf litter and supplemental feed on water quality, growth and survival of shrimp (Penaeus monodon, Fabricius, 1798) post larvae. *Aquaculture*, 545, 737237.

ALONGI, D. M. 2012. Carbon sequestration in mangrove forests. *Carbon Management*, 3(3), 313-322.

ALONGI, D. M., WATTAYAKORN, G., PFITZNER, J., TIRENDI, F., ZAGORSKIS, I., BRUNSKILL, G. J., DAVIDSON, A. & CLOUGH, B. F. 2001. Organic carbon accumulation and metabolic pathways in sediments of mangrove forests in southern Thailand. *Marine Geology,* 179(1-2), 85-103.

APHA (American Public Health Association). 2012. *Standard methods of for the examination of water and wastewater.* 22nd ed. Washington, DC: American Public Health Association.

BAUMGARTNER, U., KELL, S. & NGUYEN, T. H. 2016. Arbitrary mangrove-to-water ratios imposed on shrimp farmers in Vietnam contradict with the aims of sustainable forest management. *SpringerPlus*, 5, 438.

BINH, C. T., PHILLIPS, M. J. & DEMAINE, H. 1997. Integrated shrimp-mangrove farming systems in the Mekong delta of Vietnam. *Aquaculture Research*, 28(8), 599-610.

BOSMA, R. H., NGUYEN, T. H., SIAHAINENIA, A. J., TRAN, H. T. P. & TRAN, H. N. 2016. Shrimpbased livelihoods in mangrove silvo-aquaculture farming systems. *Review In Aquaculture*, 8(1), 43-60.

BURTON, E. D., BUSH, R. T. & SULLIVAN, L. A. 2006. Fractionation and extractability of sulfur, iron and trace elements in sulfidic sediments. *Chemosphere*, 64(8), 1421-1428.

BRANDER, M. L., WAGTENDONK, A. J., HUSSAIN, S. S., MCVITTIE, A., VERBURG, P. H., GROOT, R. S. & VAN DER PLOEG, S. 2012. Ecosystem service values for mangroves in Southeast Asia: a meta-analysis and value transfer application. *Ecosystem Services*, 1(1), 62-69.

CAN, N. D. 2015. Adaptation to salinity intrusion: an economic assessment of diversified farming systems in saline affected area of coastal ben tre province of the Mekong delta, Vietnam. *In: International Symposium on Current Agricultural Environmental Issues in Pacific Rim Nations and their Countermeasures - II*, 2015 Mar 16-18, Saga University, Saga, Japan. Japan: Saga University.

CHATTING, M., AL-MASLAMANI, I., WALTON, M., SKOV, M. W., KENNEDY, H., HUSREVOGLU, Y. S. & LE VAY, L. 2022. Future mangrove carbon storage under climate change and deforestation. *Frontiers in Marine Science*, 9, 781876.

CLARKE A. L., WECKSTRÖM, K., CONLEY, D. J., ANDERSON, N. J., ADSER, F., ANDRÉN, E., DE JONGE, V. N., ELLEGAARD, M., JUGGINS, S., KAUPPILA, P., KORHOLA, A., REUSS, N., TELFORD, R. J. & VAALGAMAA, S. 2006. Long-term trends in eutrophication and nutrients in the coastal zone. *Limnology Journal of Oceanography*, 51(1 Pt 2), 385-397.

CLOUGH, B., JOHNSTON, D., XUAN, T. T., PHILLIPS, M. J., PEDNEKAR, S. S., THIEN, N. H., DAN, T. H. & THONG, P. L. 2002. *Silvofishery Farming Systems in Ca Mau Province, Vietnam. (1) A Description of Systems and Management Practices. (2) A Socio-Economic Study. N. Report prepared under the World Bank, WWF and FAO Consortium Program on Shrimp Farming and the Environment. Work in Progress for Public Discussion*. Gland: World Bank/WWF/FAO.

CONG, N. V. & KHANH, H. C. 2022. Comparison environmental conditions and economic efficiency between organic and non-organic integrated mangrove-shrimp farming systems in Ca Mau Province, Vietnam. *Journal of Ecological Engineering*, 23(5), 130-136.

COSTA, B. G. B., SOARES, T. M., TORRES, R. F. & LACERDA, L. D. 2013. Mercury distribution in a mangrove tidal creek affected by intensive shrimp farming. *Bulletin Environmental Contamination and Toxicology*, 90(5), 537-541.

COSTA-BÖDDEKER, S., THUYÊNTHUYEN, L. X., HOELZMANN, P., DE STIGTER, H. C., VAN GAEVER, P., HUY, H. ĐD., SMOL, J. P. & SCHWALB, A. 2020. Heavy metal pollution in a reforested mangrove ecosystem (Can Gio Biosphere Reserve, Southern Vietnam): Effects of natural and anthropogenic stressors over a thirty-year history. *Science of Total Environment*, 716, 137035.

EDDY, S., MILANTARA, N., SASMITO, S. D., KAJITA, T. & BASYUNI, M. 2021. Anthropogenic drivers of mangrove loss and associated carbon emissions in South Sumatra, Indonesia. *Forests*, 12(2), 187.

EPA (Environmental Protection Agency). 1998. *Semivolatile organic compounds by gas chromatography/mass spectrometry (GC/MS), Method 8270D (SW-846): Revision 4*. Washington: EPA (Environmental Protection Agency).

GOLDBERG, L., LAGOMASINO, D., THOMAS, N. & FATOYINBO, T. 2020, Global declines in human-driven mangrove loss. *Global Change Biology*, 26(10), 5844-5855.

HA, T. T. P., VAN DIJK, H. & VISSER, L. 2014. Impacts of changes in mangrove forest management practices on forest accessibility and livelihood: a case study in mangrove-shrimp farming system in Ca Mau Province, Mekong Delta, Vietnam. *Land Use Policy*, 36, 89-101.

HA, T. T. T., BUSH, S. R., MOL, A. P. J. & VAN DIJK, H. 2012. Organic coasts? Regulatory challenges of certifying integrated shrimp–mangrove production systems in Vietnam. *Journal of Rural Study*, 28(4), 631-639.

HAI, T. N. & YAKUPITIYAGE, A. 2005. The effects of the decomposition of mangrove leaf litter on water quality, growth and survival of black tiger shrimp (Penaeus monodon Fabricius, 1798). *Aquaculture,* 250(3-4), 700-712.

HAYASHI, S. N., SOUZA-FILHO, P. W. M., NASCIMENTO, W. R. & FERNANDES, M. E. B. 2019. The effect of anthropogenic drivers on spatial patterns of mangrove land use on the Amazon coast. *PLoS One*, 14(6), e0217754.

HINOKIDANI, K. & NAKANISHI, Y. 2019. Dissolved iron elution from mangrove ecosystem associated with polyphenols and a herbivorous snail. *Ecology and Evolution*, 9(12), 6772-6784.

ISO (International Organization for Standardization). 1990. *ISO 6439:1990. Water quality — Determination of phenol index — 4-Aminoantipyrine spectrometric methods after distillation*.

ISO (International Organization for Standardization). 1998. *ISO 11047:1998. Soil quality — Determination of cadmium, chromium, cobalt, copper, lead, manganese, nickel and zinc — Flame and electrothermal atomic absorption spectrometric methods*. Genebra: ISO.

ISO (International Organization for Standardization). 2002. *ISO 10382:2002. Soil quality — Determination of organochlorine pesticides and polychlorinated biphenyls — Gas-chromatographic method with electron capture detection*. Genebra: ISO.

ISO (International Organization for Standardization). 2004. *ISO 16772:2004. Soil quality — Determination of mercury in aqua regia soil extracts with cold-vapour atomic spectrometry or cold-vapour atomic fluorescence spectrometry*. Genebra: ISO.

ISO (International Organization for Standardization). 2007. *ISO 20280:2007. Soil quality — Determination of arsenic, antimony and selenium in aqua regia soil extracts with electrothermal or hydride-generation atomic absorption spectrometry*. Genebra: ISO.

IUCN (International Union for Conservation of Nature). 2015. *Towards sustainable coastal management and development in three coastal Districts of Ben Tre Province (Binh Dai, Ba Tri and Thanh Phu)*. Gland: IUCN (International Union for Conservation of Nature).

JOHNSTON, D., LOUREY, M., TIEN, D. V., LUU, T. T. & XUAN, T. T. 2002. Water quality and plankton densities in mixed shrimp-mangrove forestry farming systems in Vietnam. *Aquaculture Research,* 33(10), 785-798.

JOHNSTON, D., TRONG, N. V., TIEN, D. V. & XUAN, T. T. 2000. Shrimp yields and harvest characteristics of mixed shrimp-mangrove forestry farms in southern Vietnam: factors affecting production. *Aquaculture*, 188, 263-284.

KRISTENSEN, E., BOUILLON, S., DITTMAR, T. & MARCHAND, C. 2008. Organic carbon dynamics in mangrove ecosystems: a review. *Aquatic Botany*, 89(2), 201-219.

LEMONNIER, H., WABETE, N., PHAM, D., LIGNOT, J. H., BARRI, K., MERMOUD, I., ROYER, F., BOULO, V. & LAUGIER, T. 2021. Iron deposits turn blue shrimp gills to orange. *Aquaculture*, 540, 736697.

MINH, T. H., YAKUPITIYAGE, A. & MACINTOSH, D. J. 2001. Management of the Integrated Mangrove-Aquaculture Farming Systems in the Mekong Delta of Vietnam. *ITCZM Monograph*, 1, 24.

MORGAN, B., RATE, A. W. & BURTON, E. D. 2012. Trace element reactivity in FeS-rich estuarine sediments: Influence of formation environment and acid sulfate soil drainage. *Science of the Total Environment,* 438, 463-476.

NAGELKERKEN, I., BLABER, S. J. M., BOUILLON, S., GREEN, P., HAYWOOD, M., KIRTON, L. G., MEYNECKE, J. O., PAWLIK, J., PENROSE, H. M., SASEKUMAR, A. & SOMERFIELD, P. J. 2008. The habitat function of mangroves for terrestrial and marine fauna: a review. *Aquatic Botany*, 89(2), 155-185.

NANJO, K., KOHNO, H., NAKAMURA, Y., HORINOUCHI, M. & SANO, M. 2014. Effects of mangrove structure on fish distribution patterns and predation risks. *Journal of Experimental Marine Biology and Ecology*, 461, 216-225.

NATURLAND. 2010. *Naturland standards for organic aquaculture*. Germany: Naturland – Association for organic Agriculture.

NÓBREGA, G. N., FERREIRA, T. O., ROMERO, R. E., MARQUES, A. G. B. & OTERO, X. L. 2013. Iron and sulfur geochemistry in semi-arid mangrove soils (Ceará, Brazil) in relation to seasonal changes and shrimp farming effluents. *Environmental Monitoring and Assessment*, 185(9), 7393-7407.

NURGIANTORO, N. & JAELANI, L. M. 2017. Monitoring of total suspended solid in coastal waters due to conventional gold mining using multi temporal satellite data, case study: Bombana, Southeast Sulawesi. The 2nd International Seminar on Science and Technology August 2 nd 2016, Postgraduate Program Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia. IPTEK Journal of Proceedings Series, 84-89.

OLIVEIRA, A. R. M. D. E., BORGES, A. C., MATOS, A. T. & NASCIMENTO, M. 2018. Estimation on the concentration of suspended solids from turbidity in the water of two sub-basins in the doce river basin. *Engenharia Agrícola,* 38(5), 751-759.

PARK, G. S. 2007. The role and distribution of total suspended solids in the macrotidal coastal waters of Korea. *Environmental Mornitoring and Assessment*, 135, 153-162.

RASYID, A. B. D., AKBAR, A. S., NURDIN, N., JAYA, I. & IBRAHIM. 2016. Impact of human interventions on mangrove ecosystem in spatial perspective. *IOP Conference Series: Earth and Environmental Science,* 47, 012041.

RAYNER, T. S. & CREESE, R. G. 2006. A review of rotenone use for the control of non-indigenous fish in Australian fresh waters, and an attempted eradication of the noxious fish, *Phalloceros caudimaculatus*. *New Zealand Journal of Marine and Freshwater Research*, 40(3), 477-486.

SA'AD, F. N. A., TAHIR, M. S., JEMILY, N. H. B., AHMAD, A. & AMIN, A. R. M. 2021. Monitoring total suspended sediment concentration in spatiotemporal domain over Teluk lipat utilizing landsat 8 (OLI). *Applied Science*, 11(15), 7082.

SARATHCHANDRA, C., KAMBACH, S., ARIYARATHNA, S., XU, J., HARRISON, R. & WICKRAMASINGHE, S. 2018. Significance of mangrove biodiversity conservation in fishery production and living conditions of coastal communities in Sri Lanka. *Diversity*, 10(2), 20.

SAULNIER, I. & MUCCI, A. 2000. Trace metal remobilization following the resuspension of estuarine sediments: Saguenay Fjord, Canada. *Applied Geochemistry*, 15(2), 191-210.

SCHMIDT, C., CORBARI, L., GAILL, F. & LE B. N. 2009. Biotic and abiotic controls on iron oxyhydroxide formation in the gill chamber of the hydrothermal vent shrimp *Rimicaris exoculata*. *Geobiology*, 7(4), 454-464.

STRAUCH, A. M., COHEN, S. & ELLMORE, G. S. 2012. Environmental Influences on the Distribution of Mangroves on Bahamas Island. *Journal of Wetlands Ecology*, 6, 16-24.

TEIEN, H. C., GARMO, Ø. A., ÅTLAND, Å. & SALBU, B. 2008. Transformation of Iron Species in Mixing Zones and Accumulation on Fish Gills. *Environmental Science and Technology*, 42(5), 1780-1786.

THANH-NHO, N., MARCHAND, C., STRADY, E., HUU-PHAT, N. & NHU-TRANG, T. T. 2019. Bioaccumulation of some trace elements in tropical mangrove plants and snails (Can Gio, Vietnam). *Environmental Pollution*, 248, 635-645.

TRANG, N. T. D., ASHTON, E. C., TUNG, N. C. T., THANH, N. H., CONG, N. V., NAM, T. S., THUAN, N. C., KHANH, H. C., DUY, N. P. & TRUONG, N. N. 2022. Shrimp farmers perceptions on factors affecting shrimp productivity in integrated mangrove-shrimp systems in Ca Mau, Vietnam. *Ocean and Coastal Management*, 219, 106048.

TRUONG, T. D. & DO, L. H. 2018. Mangrove forests and aquaculture in the Mekong river delta. *Land Use Policy*, 73, 20-28.

VEETTIL, B. K., QUANG, N. X. & THU-TRANG, N. T. 2019. Changes in mangrove vegetation, aquaculture and paddy cultivation in the Mekong Delta: a study from Ben Tre Province, southern Vietnam. *Estuarine, Coastal, and Shelf and Science*, 226, 106273.

VIET, L. Q. & HAI, T. N. 2016. Technical aspects and costs benefits of the model mangroves shrimp in Nam Can district, Ca Mau province. *Vietnam Journal of Marine Science and Technology*, 16(1), 99-105.

QCVN (Vietnam Environmental Protection Agency). 2015. *National Technical Regulation on Surface Water Quality (QCVN 10-2015/BTNMT)*. Hanoi: Vietnam Environmental Protection Agency.

QCVN (Vietnam Environmental Protection Agency). 2017. *National Technical Regulation on Surface Water Quality (QCVN 43-2017/BTNMT).* Hanoi: Vietnam Environmental Protection Agency.