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Research article

Innovative silvofishery model in restored mangrove forests: A 10-year assessment

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ABSTRACT

The novelty of this study lies in the investigations of silvofishery in 10-year-old mangrove forest in former abrasive shrimp ponds. The sedimentation depths of this mangrove forest are different from the forest area in the core mangrove forest stand zone as a fishing area. This study aims to describe the relationship between mangrove conditions, the abundance of gastropods, and mud crabs (Scylla spp.) in Pandansari Hamlet, Kaliwlingi Village, Brebes District, Brebes Regency. The different sedimentation depths of the Mangrove tourist area resulted from the different locations, which were divided into 3 stations. Station I was a muddy substrate located within the mangrove tourism area. Station II was a sandy substrate located in the mangrove forest area bordering the sea, which was only 15 m away. Finally, Station III had a muddy sand substrate in the mangrove forest near the Pemali River, which was 8 m away. For sustainability management purpose, local communities needed to be involved. Utilizing mangrove forests in combination with fishery commodities, silvofishery could protect mangrove plants while providing more yields from the fisheries. Thus, the system could increase people's income while still maintaining the sustainability of mangrove forests. Based on these findings, it could be said that mangrove forest areas were feasible to be used as the best silvofishery area in Indonesia.

1. Introduction

The Kaliwlingi mangrove forest is geographically located at 109° 01′ 07″ East Longitude and 6° 48′ 18″ South Latitude or at Pandansari Hamlet, Kaliwlingi Village, Brebes District, Brebes Regency. Its soil has a sand-silt-clay texture consisting of 34.00 % sand, 44.89 % silt, and 21.11 % clay. Within the Kaliwlingi mangrove area, there is the Pemali Delta on the Pemali River. The soil is fertile for mangrove to grow, hence forming a mangrove forest. The mangrove vegetation in Pandansari, Kaliwlingi ranges from 10- to 25-years-old stand. This vegetation is the result of reforestation to reduce the risk of coastal abrasion that hit Kaliwlingi coast in the early 2000s, along with developments in the opening of mangrove areas for shrimp farming. Mangrove forests are typically found on muddy, sandy, or muddy sandy beach areas where the water is calm. Its vegetation can grow optimally in coastal areas, river estuaries, and deltas, where the flow contains much mud [1–3]. They are an ecosystem that has a reasonably high productivity value because they allow litter to decompose. They significantly contribute to organic detritus, which is very important as food for the biota that lives in them [4–7]. This is related to its ecological function as a place to live, find food, spawn, nurture, grow aquatic biota, and protect the coast from abrasion and pressure from the sea waves with primary and secondary data. Mangrove forests are complex ecosystems consisting

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of flora and fauna in coastal areas, both on land and at sea, and are usually affected by sea tides [8–11].

As a place to find food for biota, mangrove forests contribute to the complexity of the habitat and the diversity of macrofauna associated with the ecosystem, such as molluscs and crabs, which are the most dominant macrofauna in the ecosystem. The density, diversity, and distribution of biota life in an ecosystem are affected by environmental factors which have something to do with its community structure [9,12,13].

The mangrove vegetation in the area grow as a result of reforestation in Pandansari Hamlet, Kaliwlingi Village, Brebes District, Brebes Regency. Some other biota associated with mangrove forests are also present, including gastropods and mangrove crabs (Scylla spp.). Gastropods, the largest class of the mollusk phylum, are important biota in the mangrove forest ecosystems' ecological functions. They have reasonably high adaptability to various habitats and can accumulate heavy metals without dying. For this reason, they can be used as indicators of the coastal environment. Having the ability to respond to water conditions sustainably, gastropods survive a variety of habitats [14]. [3,15,16] state that around 75 % of mollusc species belong to the gastropod class. Gastropods, slugs, or snails come in highly varied body shapes and sizes. Most gastropods like to live in sandy mud substrates since organic matters are available in them [17,18]. Ecologically, gastropods are essential in the circulation of nutrients in waters. And economically, they have a selling point for their shells and meat [19]. In the water, they are generally found as detritivores and prey for other biota, including herbivores, carnivores, scavengers, deposit feeders, suspension feeders, and parasites. As vital organisms in the food chain in coastal ecosystems, gastropods can affect the existence and life of other biotas, including mangrove crabs [12].

Mud crab (Scylla spp.) is a coastal fishery commodity of high economic value. It has become a vital fishery commodity in Indonesia since the early 1990s. It is a macrobenthic fauna that belongs to the Crustaceae family and are commonly found in mangrove and estuarine waters. In addition to its high economic value, mud crabs play an essential role in mangrove ecosystems as their activities, such as making holes in the substrate in search of food, affect the decomposition process of organic matter content in mangrove ecosystems [20]. Naturally, mangrove crabs are cannibals and eat the carrion of fish and other biota, including gastropods. Thus, the presence of gastropods, which is influenced by the condition of the mangrove forest, will also determine the abundance of mangrove crabs in that location. In turn, this can increase people's income while still maintaining the sustainability of mangrove forests [10].

The needs for mud crabs can be met from catches, which can affect their abundance in the core zone of the mangrove forest. Therefore, to maintain the balance of the mangrove ecosystem a cultivation of mud crab is needed. One mud crab cultivation technique worth developing is mud crab cultivation with a silvofishery. Its worthiness for development comes from the fact that it utilizes mangrove forests sustainably in combination with fishery commodities. The basic principle of silvofishery is protecting mangrove

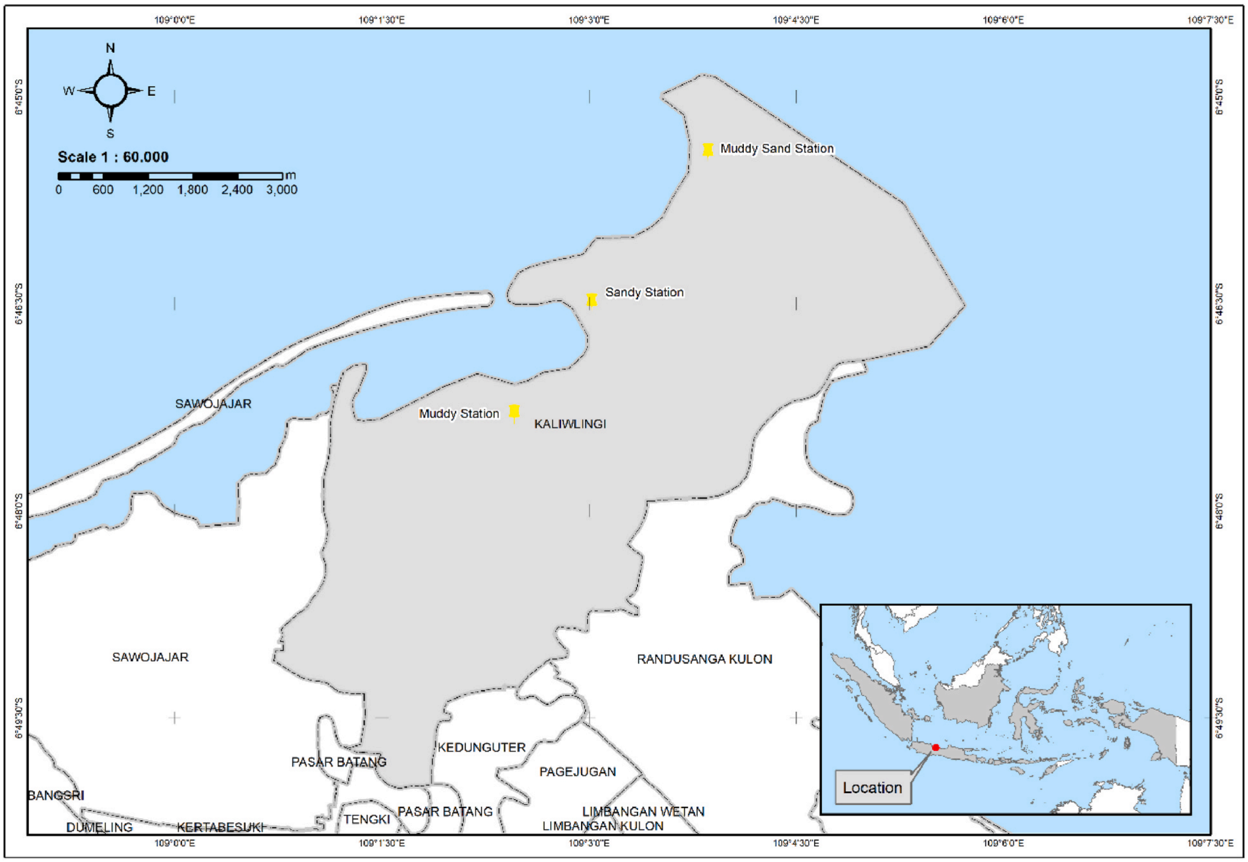

Fig. 1. Research locations in the core zone of the Pandansari mangrove forest.

plants while providing yields from the fisheries sector. The study's novelty lies in the investigation of silvofishery in 10-year-old standing mangrove forests in formerly abrasive shrimp ponds with different sedimentation depths from that of forest areas. The study aims to examine the density of the mangrove forest and the abundance of gastropods and mud crabs in the core zone of a 10-year-old mangrove forest in Pandansari Hamlet, Kaliwlingi Village, Brebes District, Brebes Regency, as well as the carrying capacity of the core zone of this mangrove forest as a salvofishery area for mangrove crabs (Scylla spp) in the district.

1.1. Research method

The research was conducted in April–July 2022 in the mangrove forest area, focusing on the relationship between the mangrove conditions, the abundance of gastropods and mud crabs, and mud crab cultivation locations in the core zone of a 10-year-old mangrove forest in Pandansari Hamlet, Kaliwlingi Village, Brebes District, and Brebes Regency. The locations of the stations were determined randomly at selected locations with specific considerations (purposive-random sampling) [21]. For sampling purpose, a 2 m × 2 m transect equipped with three mud crab traps at 0.5 m distance in each station was used when the research had just begun. The locations of each station are presented in Fig. 1.

1.2. Preparation

This stage began with preparing 2m × 2m transects and 60 cm × 20 cm x 22 cm traps for mud crabs. Each observation station had 3 pieces of these tools. The number of mangroves in the area over the last 10 years was used for sampling and only locations where mangroves grew were represented.

1.3. Identification of soil sediment and substrate

The organic matter sediments in the 10-year standing mangrove forest were measured for their depth. The soil substrate samples were taken from inside the observation transect by filtering and pipetting [6,22]. The obtained sediment grains were analyzed to determine the grain size and type of sediment. The grain size was analyzed further using dry sieving and wet sieving (piping), as was done by Refs. [6,23]. Identifying the sediment and soil substrate is a complex process and involves a variety of methods, depending on the type of sediment to be identified, the level of accuracy required, and the equipment available. The commonly used identification method was visual observation focusing on their color, texture and structure.

1.4. Mangrove vegetation Density Check

The mangrove vegetation was checked for its density by tracing and observing the density and condition of the mangrove vegetation that was ten years old. The mangrove vegetation density was measured using the 5m × 5 cm transects at each station (Sapling). The size of the 10-year-old mangrove tree trunks was measured using a length meter to ensure that the observation area became narrower to allowed the researchers to see their richness [24].

1.5. Identification of Gastropod samples

Gastropod samples were taken from 9 points, where 3 points were taken from each station. The gastropods were sampled at low tide. Gastropod samples were preserved as evidence of research results by immersing them in a 96 % alcohol solution [9,25]. The gastropod samples were then soaked and drained twice. The first step was soaking tjem in 0.5 L of 96 % alcohol mixed with distilled water in a 1: 1 ratio for 7–8 h. In the second stage, the samples were soaked in 96 % alcohol without water for a week and then drained and dried. The gastropods were identified and calculated based on the Gastropod Class Mollusc Identification Book, including the morphology and structure of the musty shell, spire, body whorl, suture, aperture, axial ribs, spiral cord, columella, posterior canal, anterior siphonal canal, and operculum [26], under an ethical clearance number 50/KEPMEN-KP/2017.

1.6. Calculation of Gastropod and mud crab abundance

The abundance of gastropods and mud crabs was calculated based on the samples found in three plots on each station's transect. The abundance of gastropods and mud crabs was calculated by dividing the number of individual gastropods or mud crabs caught in traps by the area of the sampling area [27,28]. Only a few non-cultivated samples of mud crabs were taken from the research location. The gastropods and mud crabs were caught on the second day of the 2-day study period for several catches. In addition to the data on the density of mangrove vegetation and the abundance of gastropods and mud crabs, the water quality was also measured for its temperature, pH, and salinity.

1.7. Data analysis

The obtained data on mangrove vegetation, gastropods, and mud crabs were analyzed using several formulas as stated by Refs. [22,29]. The analyses covered their absolute and relative density, their absolute and relative frequency, their absolute dominance and relative dominance, and their diversity and uniformity. Included in the analyses was a visual observation. When one part of the plant or animal experienced a problem and must be solved, adjustments would be made. The research also looks at the advantages resulting from the challenges of 10 years of developing mangrove vegetation and other animals which had important elements in life.

The diversity index (H′) was measured for the muddy Station I (A), the sandy Station II (B), and muddy and sandy Station III (C1). The diversity index for the three stations was classified as moderate since their values were 1–3 [27]. From a series of statistical tests and ANOVA test with SPSS, these diversity index values were normally distributed and homogeneous. Furthermore, the diversity between the observation stations was not significantly different from each other. Hence, it could be concluded that the gastropod diversity index between these stations was relatively the same and classified as medium.

Just like the diversity index, the uniformity index (E) was also measured for the muddy Station I (A), the sandy Station II (B), and the muddy and sandy Station III (C). The uniformity index (E) values generally showed varying values, yet they were still classified as high to medium at a value of 0.61–1.49 [27]. Therefore, it could be concluded that the uniformity index between stations was relatively different within a high to medium range.

Finally, the dominance index (C) was measured for the muddy Station I (A), the sandy Station II (B), and the muddy and sandy Station III (C). The dominance index was classified as low where no species dominated other species. A low dominance index indicated low concentration (nothing dominated). The results of related statistical tests and the ANOVA test with SPSS revealed that the data were normally distributed and homogeneous and that the differences between stations were insignificant.

1.8. Water quality observation

The water quality parameters measured were the chemical and physical key parameters of water such as: temperature, salinity, pH, and dissolved oxygen (DO). These parameters supported the life of gastropods and mangrove crabs in the mangrove ecosystem. These parameters were measured in three repetitions at each station. The temperature was measured using a thermometer dipped in water for about 1 min. A drop of water sample was put on the hand refractometer lens to measure its salinity. Finally, the pH was measured by immersing the pH meter in the water at 3 cm depth for about 1 min.

2. Results and discussion

2.1. The sediment and soil substrate at research locations

The sediments in the research area were derived from the organic matter and silt at the mangrove forest deposited as a result of the hydrodynamics of the coastal area. The average thickness value of the sediment at the three observation stations ranged from 52.80 cm to 69.07 cm. Station I area had the highest sediment depth value at 69.07 cm. The sediment depth of Station II was 52.80 cm, and Station III was 65.20 cm deep. The stations where the observation was done used to be ponds affected by abrasion which was then turned into a mangrove reforestation area. Hence, the mud in the area was relatively deep. The results of observation of soil substrate at each research location are presented in Table 1 and Fig. 2.

2.2. Mangrove forest density

The research results on the density of mangrove forests in the 10-year-old core zone are presented in Table 2 and Fig. 3.

The average number of mangrove trees at each station is 5, at 5 individuals/m2 or 4.166 ind/ha density. The results of the statistical analysis showed that no significant difference was found in the density of mangrove forests at each station.

The size of mangrove trees at each observation station ranged from 5.00 to 13.50 cm, as presented in Table 3 and Fig. 4.

2.3. Gastropode composition

The research location had two sub-classes of gastropods, i.e., Pulmonata and Prosobranchia, and four families, i.e., Ellobidae and Littorinidae, Neritidae, and Potamididae. From the Ellobidae family, two species were found: *C. auriferous* and *C. nucleus*. From both the Littorinidae and Neritidae families, each only had one species, namely *L. articulate* and *N violacea,* respectively. Three species were

Table 1
Sediment and soil substrate at research location.

Station	Substrate	Plot	Sediment type	Information
I	Muddy	A1	Muddy silt	Soft and dense
I	Muddy	A1	Muddy silt	Soft and dense
I	Muddy	A1	Muddy silt	Soft and dense
II	Sandy	A2	Sandy silt	Soft Particle
II	Sandy	A2	Sandy silt	Soft Particle
II	Sandy	A2	Sandy silt	Soft Particle
III	Muddy and sandy	A3	Mix	Dull
III	Muddy and sandy	A3	Mix	Dull
III	Muddy and sandy	A3	Mix	Dull

Source: Result analysis (2022).

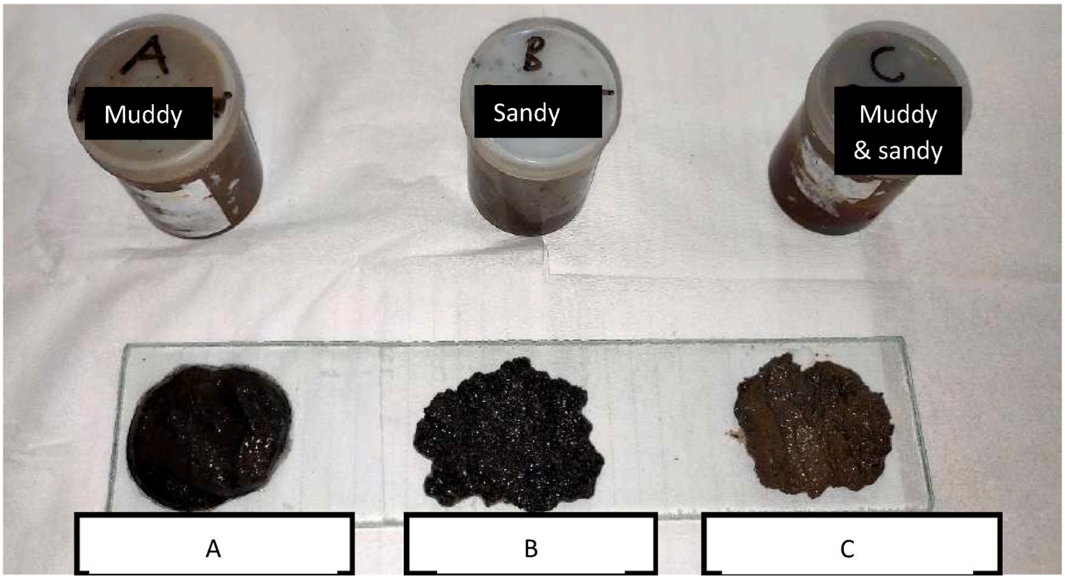

Fig. 2. The results of observation of soil substrate at each research location
(A. Muddy substrate station; B. Sandy substrate station; C. Muddy & sandy substrate station).

Table 2
Mangrove forest density data based on research results.

Mangrove type	Density (sampling/5 x 5)								
	Station I Muddy			Station II Sandy			Station III Muddy and Sandy		
	1st Transect 1	2nd Transect	3rd Transect	1st Transect	2nd Transect	3rd Transect	1st Transect	2nd Transect	3rd transect
Rhizophora mucronata	2	1	3	2	2	0	3	1	1
Avicennia marina	0	0	0	0	1	0	0	0	1

Source: Result analysis (2022)

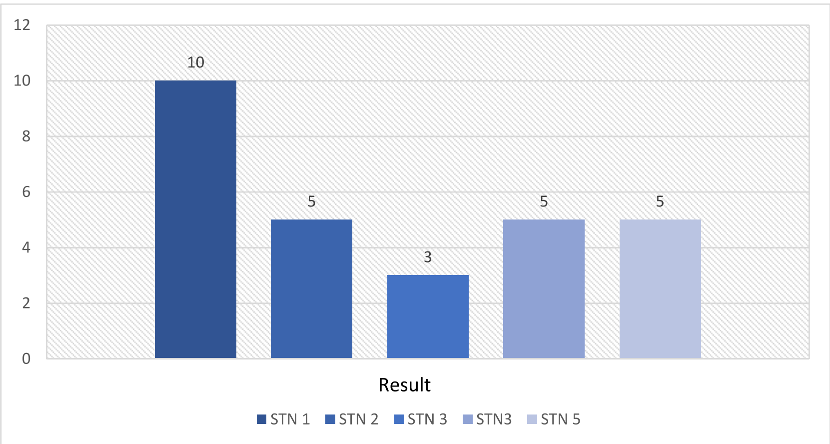

Fig. 3. Mangrove tree density chart at 5 stations.

found in the Potamidae family, namely *C. obtuse*, *T. Telescopium*, and *T. palustris*. These gastropods were found when the waters were receding. In general, the most commonly found species were from the Pulmonata sub-class of the Ellobidae family, namely *C. auriferous* and *C. nucleus*. The gastropods found at the research locatuon are presented in Table 4 and Fig. 5.

Table 3
Differences in size of Rhizophora mangrove vegetation stems (cm).

Sta	Sediment Texture	Mangrove tree size (cm)					Average	SD
		1	2	3	4	5		
1	Muddy substrate	8.30	8.50	10.40	9.50	8.00	8.94	0.99
2	Sandy substrate	8.50	10.00	10.00	5.00	8.00	8.30	2.05
3	Muddy & sandy substrate	7.00	8.00	11.00	11.00	13.50	9.50	2.60

Source: Result analysis (2022)

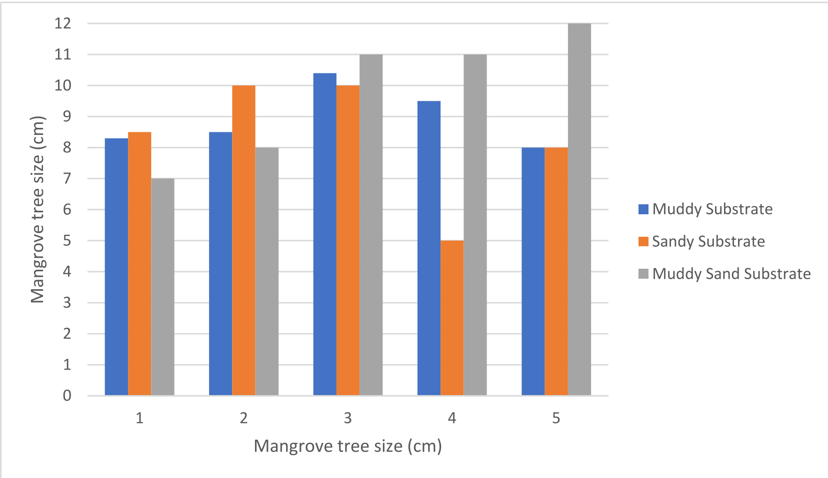

Fig. 4. Mangrove tree size chart at 3 observation stations.

2.4. Gastropod density

The gastropod density values at each station are presented, different in Table 4(7 species), in Table 5 and Fig. 6 all of species in station research.

2.5. Gastropod diversity, uniformity, and dominance indices

The analysis results of the gastropod diversity, uniformity, and dominance indices at the research location are presented in Table 6 and Fig. 7.

The diversity index (H′) of muddy Station I (A) was (A1) = 1.61, (A2) = 1.58, (A3) = 1.58 at an average value of 1.59. The diversity index of sandy Station II (B) was (B1) = 1.44, (B2) = 1.57, (B3) = 1.44 at an average value of 1.48. Finally, the diversity index of muddy & sandy Station III (C) was (C1) = 1.69, (C2) = 1.58, (C3) = 1.51 at an average value of 1.59. These diversity index values were

Table 4
Composition of gastropods found in the research location at each observation station(7 species).

No	Species	Composition/type of substrate									Amount
		Muddy			Sandy			Muddy & sandy			
		1	2	3	1	2	3	1	2	3	
1	*C. aurisfelis*	50	53	46	15	8	9	30	33	29	273
2	*C. nucleus*	55	45	59	25	17	8	28	27	23	287
3	*L. articulata*	8	4	6	0	1	0	5	3	0	27
4	*N. violacea*	26	30	33	14	16	10	20	18	25	192
5	*C. obtusa*	2	0	0	0	0	1	3	2	0	8
6	*T. telescopium*	7	12	9	2	5	0	5	3	6	49
7	*T. palustris*	30	26	39	15	17	14	25	33	29	238
Amount		178	171	192	72	64	42	116	119	112	
Amount (ind)			541			178			347		
Amount (%)			51			17			32		
Average/station (ind)		25.5	25.7	27.4	10	9.1	5.6	23.7	17	16	

Source: Result analysis (2022)

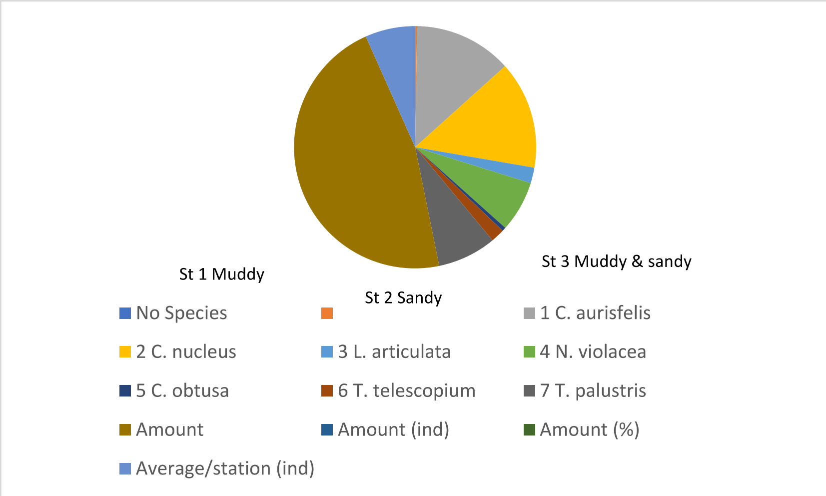

Fig. 5. Composition chart of gastropods found per station.

Table 5
Results from Density for Gastropods found at the research location.

No	Station	Gastropod Density (ind/m^2)
1	Muddy	7.20
2	Sandy	2.36
3	Muddy & sandy	4.62
	Summary	14.18
	Average	4.72

Source: Result analysis (2022)

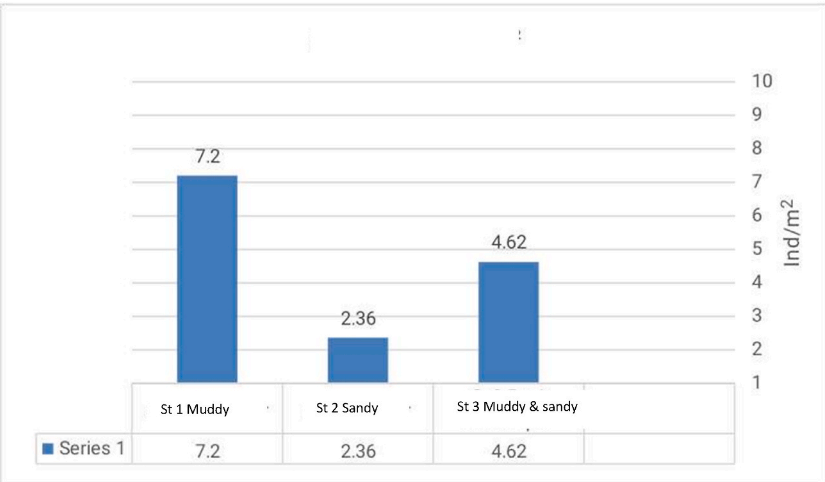

Fig. 6. Density Chart for Gastropods found at the Research Location The statistical test results showed that the density of gastropods between stations was typically distributed, homogeneous, and significantly different from each other (Sig 0.002 < 0.01 with F hit = 82,965 > F tab 2.6; 0.01 = 2.305).

classified as moderate since the values ranged from 1 to 3 (Wilhm, 1975). From a series of statistical tests and ANOVA test, the Diversity Index values were found to be normally distributed and homogeneous, and the diversity between observation stations was not significantly different from each other (Sig = 0.163 > 0.05 or F hit = 2.491 F Tables 2 and 6; 0.05 = 5.143). Thus, it could be concluded that the gastropod diversity index between stations was relatively the same as the Medium category.

The uniformity index (E) for the muddy Station I (A) was (A1) = 0.83, (A2) = 0.81, and (A3) = 0.81 at an average value of 0.81. The uniformity index for the sandy Station II (B) was (B1) = 0.74, (B2) = 0.80, and (B3) = 0.74 at an average value of 0.76. Finally, the

Table 6
The average diversity (H′), uniformity (E), and dominance (C) indices.

No	Station	Indicator					
		Diversity		Uniformity		Dominance	
		H'	Category H′	E	Category E	C	Category C
1	Muddy	1.59	Medium	0.81	High to medium	0.227	ND
2	Sandy	1.49	Medium	0.76	High to medium	0.243	ND
3	Muddy & sandy	1.59	Medium	0.81	High to medium	0.221	ND

Source: Result analysis (2022) Information: H' = Wilhm (1975), E = Krebs (1985), C = Odum (1993), ND = No Density

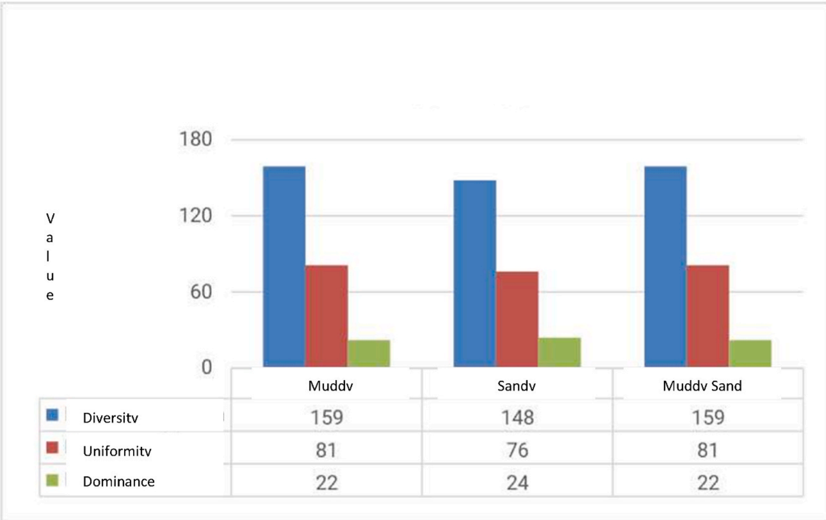

Fig. 7. Chart of Diversity (H′), Uniformity (E), and Dominance (C) Indices, with value 1.0 just high value.

uniformity index for the muddy and sandy Station III (C) was (C1) = 0.86, (C2) = 0.81, and (C3) = 0.77 at an average value of 0.81. The uniformity index (E) values generally showed varying values. However, they were still within the high-to-medium range at a value of 0.61–1.49 (Wilhm, 1975). The results of related statistical tests and the ANOVA test showed that the data are normally distributed and homogeneous, yet the uniformity between observation stations was relatively different (sig value = 0.153 > 0.05 or F hit = 2.604 F tab 2.6; 0.05 = 5.143). Therefore, it could be concluded that the uniformity index between stations was relatively different in the high-to-medium range.

The dominance index (C) for the muddy Station I (A) was (A1) = 0.228, (A2) = 0.227, and (A3) = 0.226 at an average value of 0.227. For the sandy Station II (B), it was (B1) = 0.253, (B2) = 0.226, (B3) = 0.251 at an average value of 0.243. And for the muddy and sandy Station III (C), it was (C1) = 0.206, (C2) = 0.230, (C) = 0.229 at an average value of 0.221. The dominance index value is classified as low where no species dominated. A low dominance index indicated low concentration (nothing dominates). The results of relevant statistical tests and ANOVA test revealed that the data were normally distributed and homogeneous and that the differences between stations were insignificant (sig value = 0.164 > 0.05 with F hit = 2.478 F tab = 2.6; 0.05 = 5.143). As a result, the dominance index between stations was relatively equal, implying that no one station had one dominant species [30,31].

Table 7
The abundance of mud crabs at observation stations.

No	Passive gear	The abundance of mud crabs (individuals/passive gear)		
		Station I	Station II	Station III
1	1	2	1	0
2	2	1	1	0
3	3	0	0	2
	Average	1.00	0.66	0.66

Source: Analysis result (2022)

2.6. The abundance of mud crabs

The number of mangrove crabs found at each observation station was the same, i.e., 2 for each observation station. The abundance of mud crabs at the research location is presented in Table 7 and Fig. 8.

The gender of mangrove crabs caught during the study is presented in Table 8 and Fig. 9.

The mud crabs found at the research locations consisted of 5 male crabs and only two female crabs [32]. It was possible that this was because female crabs spent part of their life cycle in the sea, rather than in the mangrove forest [33–35]. After spawning with the male crabs in the mangrove forest area, they migrated to deep sea waters to lay their eggs. On the other hand, male crabs remained in the mangrove forest area, thus there were more of them in the mangrove forest area than their female counterparts [33,36].

2.7. Carapace growth and individual weight of mangrove crab

The carapace length and individual weight of mud crabs (Scylla spp.) found at the study site ranged from 6.5 to 8.5 cm, with individual weight sizes ranging from 48.2 g to 117.9 g as presented in Table 9.

2.8. Waters quality parameters

The water quality, which was also an essential part of the research, was measured based on the parameters used in Table 10.

In general, the water quality parameters at the research location supported the existence of a mangrove ecosystem with associated biota, especially gastropods and mangrove crabs (Scylla spp.).

2.9. Substrate conditions

The condition of substrate in Pandansari mangrove forest constituted one of the important ecological factors that affected the community structure and life for mollusks. This substrate also played an essential role as a habitat for foraging, reproducing, and shelter [37]. The substrate texture was a place for gastropods to stick to, crawl and walk on. The substrate contained oxygen and increased the availability of nutrients in the sediment [38,39].

As one of the main ecological factors, the primary substrate affected macrobenthos' community structure and distribution. Macrobenthos, which had the nature of being deposit-feeding diggers, tended to exist around where they lived, either on sandy, muddy, or a mixture of the two substrates [38]. Good substrate conditions affected the development of the gastropod community because a substrate composed of sand and silt with a small quantity of clay could serve as a very suitable place for gastropods to live. Its distribution and abundance were directly related to the size of the sediment grains under or above the gastropods [40]. Muddy sand substrate had a high oxygen supply due to the pores in the sand texture, which allowed oxygen to enter the substrate. This allowed gastropods to survive in muddy sand. Apart from being a place to live, the substrate was also a food source for some macrobenthos animals, including several types of gastropod species such as *C. aurisfelis*, *C. nucleus*, *L. articulata*, *N. violacea*, *C. obtusa*, *T. telescopium*, and *T. palustris*. Thanks to these conditions and the role that the muddy sand sediments and organic matter played, the land was conducive for mangrove forests to grow.

2.10. Mangrove forest density

According to Ref. [41], the area of mangrove forest in Kaliwlingi Village, Brebes District, and Brebes Regency in 2003 was 48.42 ha wide, then it increased in 2013 to 149.9 ha wide, and increased further in 2018 to 333.9 ha wide. This increase was the result of the mangrove reforestation. Considering its importance for mud crab habitat, this research also investigated the mangrove forest density.

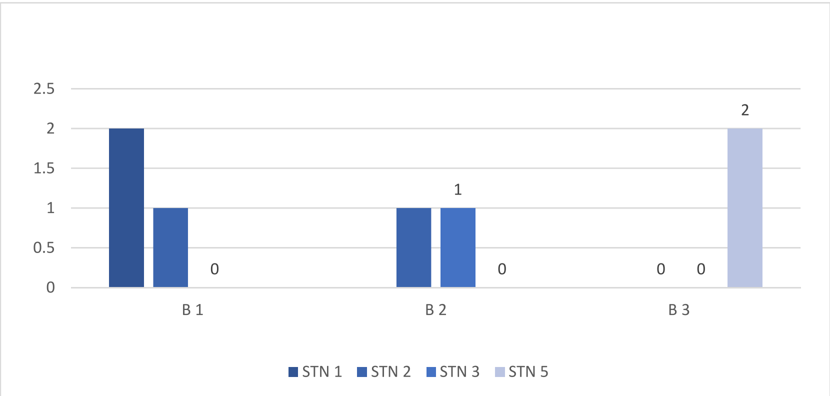

Fig. 8. Mud Crab (Scylla spp.) Abundance Chart at 5 Stations.

Table 8
Data of Male and Female Mud Crabs (Scylla spp.).

	Station	Gender		Amount
		Male	Female	
1	I	2	1	3
	II	2	0	2
2				
	III	1	1	2
3				
	Amount	5	2	7

Source: Analysis result (2022)

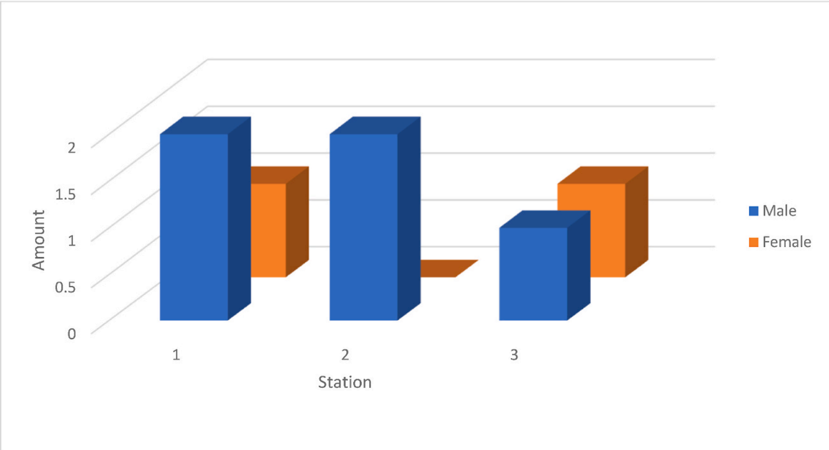

Fig. 9. Mud Crab (Scylla spp.) gender found at 5 Stations.

Table 9
Data on Carapace Length and Weight of Mud Crab (Scylla spp.).

No	Station	Carapace length, cm (Individual weight, grams)		
		Passive Gear 1	Passive Gear 2	Passive Gear 3
1	1	0	0	6.4 and 7.5 (48.2 and 73.5)
2	2	8.5 and 7.3 (117.9 and 63.0)	0	0
3	3	0	6.5 and 7.5 (76.8 and 50.5)	0

Source: Analysis result (2022)

Table 10
Results of water quality measurements during the study.

No	Variable	Observation Station									Optimum value (Reference)
		1 Muddy			2 Sandy			3 Muddy sand			
		1	2	3	1	2	3	1	2	3	
1	Temperature (°C0	28–29	28–29	27–29	28–29	27–29	27–29	28–29	28–29	28–29	26-32 (Hewitt et al., 2022)
2	Salinity (ppt)	26–27	25–27	25–27	27–28	27–28	27–28	29–30	29–31	29–31	15-32 (Hewitt et al., 2022)
3	pH	8.0–8.2	7.8–8.0	7.9–8.1	7.8–7.9	7.6–7.8	7.6–7.7	7.6–7.7	7.7–7.8	7.7–7.8	7.5–8.7 (Hewitt et al., 2022)
4	DO (ppm)	2.3–2.5	2.2–2.5	2.3–2.4	2.4–2.5	2.4–2.6	2.6–2.7	2.5–2.7	2.5–2.7	2.4–2.7	1.0–6.0 (Kurkute et al., 2019)
5	NO_2 (ppm)	0.08	0.08	0.07	0.07	0.07	0.08	0.09	0.08	0.08	<0.1 (Kurkute et al., 2019)
6	NH_3 (ppm)	0.16	0.14	0.13	0.14	0.14	0.16	0.16	0.15	0.16	0.06-0.2 (Kurkute et al., 2019)
7	H_2S (ppm)	0.001	0.001	0.002	0.001	0.002	0.002	0.001	0.002	0.001	<0.002 (Kurkute et al., 2019)

Source: Analysis result (2022)

The results showed that the highest tree density was found at Station I, with a muddy texture of 10 trees at less than 0.5 m distance. Meanwhile, the lowest density was found at Station III, with a sandy, muddy soil texture and three trees at more than 0.5 m distance. This was possibly because the salinity at Station I was lower and optimal for mangrove vegetation to exist. Furthermore, the direct influence of waves on mangrove vegetation at Station III could erode its mangrove vegetation. However, the statistical test results showed that the density of mangrove vegetation between stations was relatively the same. This was possible since the texture of sand, mud, and a mixture of both at each observation station provided adequate and relatively the same carrying capacity for the existence and growth of mangrove vegetation [40].

The density of mangrove vegetation at the research location was still fairly good, as shown by the results of absolute density of *Rhizophora* and *Avicennia* mangrove vegetation, which made up a total of around 7000. This was consistent [42,43] who argued that the density of mangrove vegetation in Pandansari Hamlet, Kaliwlingi Village, Brebes District, and Brebes Regency was classified as good at 1 m and 0.5-m distance. The density of mangrove vegetation affected the abundance of mangrove crabs. The size of the mangrove vegetation ranged from 5.0 to 13.7 cm. Considering such condition of the mangrove vegetation, the mangrove forest in the research location could be considered "good" (as explained by the good condition ecosystem). This allowed the biota in the research location to live well in the mangrove forest, including gastropods and mangrove crabs [44].

2.11. Gastropod composition

At the research location, there lived a class of gastropods with two sub-classes, namely Pulmonata and Prosobranchia, consisting of 4 families, namely Ellobidae, Littorinidae, Neritidae, and Potamididae. From the Ellobidae family, two species were found, namely *C. auriferous* and *C. nucleus*. One species from both the Littorinidae and Neritidae family were found, namely *L. articulata* and *N. violacea*, respectively. Three species were found in the Potamidae family,i.e., *C. obtusa, T. telescopium, and T. palustris*. These gastropods were found when the waters were receding.

The most commonly found gastropods were C. *aurifelis* and C. *nucleus*, both from the subclass Pulmonata family *Ellobidae*. This had something to do with the mangrove vegetation in Pandansari mangrove forest. The gastropods were evenly distributed in a clustered pattern in the Pandansari mangrove forest. Species likes Rhizophora and Avicennia mangrove vegetation with their family often lived on or attached to mangrove vegetation's stems, roots, and branches. These species had the tendency to be able to win the competition to get the desired food and living space compared to other gastropod species [45].

The fewest gastropods found were the *Cerebralia obtuse* and *Telescopium Telescopium* species. The difference in the density of mangroves and organic matter at each station, be it muddy, sandy, or muddy and sandy, was thought to influence the presence of these *C. obtuse* and *T. Telescopium*. As a result, they could only be found in a few plots where the density of mangrove vegetation was sparse. The rarer the density of mangrove vegetation, the less organic matter was produced to support the lives of existing gastropods. *Terebralia palustris*, a member of the Potamididae family, was found more frequently in stations with brackish, muddy, or mangrove waters.

2.12. Gastropod density index

Gastropods had the tendency of favoring coastal areas with mangroves and a relatively high density of mangrove vegetation for their habitat and place to live, just like the Pandasari mangrove forest area, which was a Mangrove rehabilitation and reforestation area. The gastropod density index values varied significantly (Sig 0.001) between stations, with gastropod density index values at the muddy subtrate of Station I averaging 7.20 ind/m2, the sandy substrate of Station II averaging 2.36 ind/m2, and the muddy and sandy substrate of Station III averaging 4.62 ind/m2. It was a possibility that the highest density index value of 7.20 individuals/m2 at Station I (muddy substrate) was because it had mangrove vegetation with better density, which was one of the producers of organic matter derived from mangrove leaf litter before being used as a food source for gastropods [21,46,47]. In addition, the minimum human activity in the area due to the tight rules for entering it as a protected forest zone also helped maintain the presence of gastropods on Station I. Likewise, at Station III (muddy-sandy substrate), several species of gastropods were found at an average individual density index value of 4.62 individuals/m2, which was greater than that in Station II (sandy substrate), at an average density index of 2.36 individuals/m2. It was possible that this was because the mud substrate had a fine texture and a higher nutrient content than a coarse-textured or sandy substrate since organic matter settled more easily on fine particles and was very good for the survival of gastropods [48].

2.13. Gastropod Diversity Index

The value of the Gastropod Diversity Index (H) at the research location ranged from 1.49 to 1.59, which according to Refs. [46,47,49] was classified as medium. The gastropod diversity index was not significantly different between the three stations ($Sig = 0.163 > 0.05$ or F hit $= 2.491$ F Tables 2 and 6; $0.05 = 5.143$). In other words, the gastropod diversity index was relatively the same. The diversity index was influenced by the number and average density of each species of gastropod at each observation station. A community with a moderate diversity value had competitive biota-life interactions, adequate productivity, fairly balanced ecosystem conditions, and moderate ecological pressure [47]. Likewise, the species of gastropods found at each station were relatively related to the ability of gastropods to adapt to their environment, especially the muddy and sandy substrates at each observation station.

2.14. Uniformity index

The uniformity index values between stations varied, yet they still fell into the high-to-medium range. The gastropod diversity index between stations was not significantly different (Sig = 0.153 > 0.05 or F hit = 2.604 F Tables 2 and 6; 0.05 = 5.143), thus it could be said that the gastropod uniformity index between stations was relatively the same. The high-to-medium uniformity index values was likely because of the relatively small number of gastropods at each observation station. Furthermore, this might be because the gastropods had limited adaptability to their environment [17].

2.15. Gastropod dominance index

Each observation station's average dominance index value ranged from 0.221 to 0.243. Based on the Simpson's dominance index, any value close to 0 meant that almost no gastropod species dominated the area. This was possibly because the food availability was sufficient and the environmental condition was favorable to support the lives of existing gastropod species. This non-dominance of any species in the area would result in moderate to high species diversity. The gatropod dominance index was not significantly different (Sig = 0.164 > 0.05 or F hit = 2.478 F Tables 2 and 6; 0.05 = 5.143), meaning the dominance index between stations was relatively the same. A possible cause was that the each gastropod species had relatively similar adaptability to its environmental conditions.

2.16. Abundance and body size of mud crab (Scylla spp)

The mud crabs caught in the study were five male and two female mud crabs possibly because the male ones spent more of their lives in the waters of the mangrove forest, which had more abundant food for them than the open sea. In addition, mangrove vegetation was a haven from various environmental factors, such as sea waves [50,51]. The less significant number of female mangrove crabs in mangrove forests was because they did not spend their entire life in the mangrove forest. They migrated to deep sea waters to lay their eggs after mating with the male crabs in the mangrove forest area. Furthermore, the female mud crabs returned to the forest area again to take shelter after laying their eggs until their egg-laying time [18,52].

The mud crab was a marine biota whose life depended on the presence of mangroves. The research was conducted at the core zone of 10-year-old stands. Mangrove forests had at least two zones: the core and outer zones. The former was generally located close to the sea and river mouths and had relatively dense mangrove vegetation compared to the outer one, around ponds. This zone division was quite influential in the survival of mangrove crabs. According to Refs. [44,49], the division of mangrove zones dramatically affected the survival of the mangrove association biota, including mangrove crabs in each zone.

The research was conducted in a 10-years old mangrove forest area resulting from a reforestation activity. This reforestation allowed a dense mangrove vegetation, supported by sedimentation and organic matter from the sea and the Pemali River at its estuary. Organic matters became a food supply for mud crabs and existing gastropods. The river mouth was also one of the doors for the entry of young crabs from the sea to reach the mangrove forest to continue their lives. This allowed the mangrove crabs to live in it and fulfil their needs. Only seven individual mud crabs were obtained from the three observation stations with a 2m × 2m transect area per station. It was possibly because the environmental conditions at the research location were disrupted by high tides that entered the research location area. This made the mangrove crabs move to another safer location. Thus, some mangrove crabs also partly found in the outer zone, around the pond area, which had also grown quite a lot of mangrove vegetation due to the reforestation, especially in the pond bunds. According to Ref. [5] mud crabs preferred to be in the outer zone of ponds, where they could continuously be exposed to water and lots of food and which served as places of refuge for crabs from all threats, such as environmental hazards. Due to the relatively small number of mud crabs, the statistical test results showed that the abundance of mud crabs is relatively the same.

The carapace length of the mud crabs ranged from 6.4 cm to 8.5 cm, with an individual weight of 48.2–117 g. The mud crab carapace length and individual weights were not significantly different between stations, possibly because the condition of the mangroves at each station was also relatively the same. Hence, the growth of the mangrove crab carapace was also relatively the same. When matured, mangrove crabs had a relatively large body size with a carapace length of up to 8.5 cm [46].

2.17. Water quality parameters

In general, the value of each water quality parameter for all stations showed promising results in supporting gastropod life. The water temperature at all research stations ranged from 26 °C to 29 °C. Differences in the intensity of sunlight penetration, tides, and the presence or absence of mangrove plants were caused by temperature difference. The tolerable temperature for the development and reproduction of gastropods was 0°–480 °C [24,37,53], while mud crabs could tolerate a temperature range of 12–35 °C.

The water salinity at all observation stations ranged from 25 to 31 ppt. Low salinity was found at Station I on a muddy substrate, and higher salinity was found at Station III on a muddy and sandy substrate. This was because Station I was located in the ecotourism area closer to the upstream area. Hence, its salinity level was slightly lower than other stations. Station III was located closer to the sea, thus its salinity level was high [24]. Mud crabs could survive at a 10–30 ppt salinity, but they could grow and develop well in the 15–35 ppt range.

The pH value of the water at all observation stations ranged from 7.6 to 8.0. This pH range of the water was classified as optimum, namely 7–8 for gastropod to live [54]. Gastropods did not like too acidic areas because it would damage their shell structure.

Meanwhile, the dissolved oxygen in Pandansari mangrove forest area ranged from 2.4 to 2.7 mg/l. According to Ref. [53], a dissolved oxygen content of 2.4–4 ml/l was sufficient to support macrobenthos life, such as gastropods. NO2, NH3, and H2S at the research location were still within the permissible limits for aquaculture activities. The maximum tolerance limits for N2, NH3, and H2S concentrations for aquaculture activities were 0.1 ppm, 0.06–0.2 ppm, and 0.002 ppm, respectively [53].

2.18. Feasibility of silvofishery system for mangrove crab cultivation activities

The communities around the mangrove forest played an important role to make the ecosystem sustainable. It was, therefore, necessary to involve local communities to manage mangroves sustainably. And one attempt to do this was using the silvofishery system for mud crab cultivation [32]. Silvofishery was the utilization of mangrove forests combined with fishery commodities. The basic principle of silvofishery was to protect mangrove plants while providing yields for the community from the fishery commodity. This system could increase people's income while still taking care of the sustainability of mangrove forests [52,55,56].

The primary substrate in Pandansari mangrove forest area (Kaliwlingi Village. Brebes District, Brebes Regency), with 10-years old mangrove stand, was sand and clay sediments. In addition, the sediment was also enriched by the presence of organic matter from the mangrove forest and precipitated mud due to the hydrodynamics of the coastal area. The thickness of the sediment was relatively large at 52.80–69.07 cm. This was because it was in what used to a pond location affected by abrasion. The former pond was then used as a mangrove reforestation area. The substrate condition allowed gastropods to live and provided natural foods for mud crabs. Other than that, the sand sediment, muddy clay, and the presence of organic matter in the soil made the land conducive for the mangrove forest to grow and develop. The mangrove vegetation at the research location resulted from the reforestation at 0.5–1 m distance between trees. Meanwhile, the size of the mangrove vegetation was 5.0–13.7 cm. Considering this condition of mangrove vegetation, the mangrove forest in the research location could be considered good to allow the biota in the research location to live well, including gastropods and mangrove crabs.

In general, the value of each water quality parameter for all observation stations showed good results to support the life of mangrove vegetation, gastropods, and mangrove crabs. The water temperature ranged from 260 °C to 290 °C. This range of temperature was still within the optimal range for the life of gastropods, namely 0 °C–480 °C, and for the life of mud crabs, namely 12 °C–35 °C [24]. The water salinity ranged from 25 to 31 ppt. The pH value of the water ranged from 7.6 to 8.0, which was still within the optimum range for gastropod life, namely 7–8, and mangrove crabs, namely 7 to 9. The dissolved oxygen ranged from 2.4 to 2.7 mg/l.Again, this was still within the range that could support gastropod, namely 2.4–4 ml/l and crabs. The values of NO_2, NH_3, and H_2S at the research location were still all within the allowable limits for aquaculture activities. The maximum concentration limits of N_2, NH_3, and H_2S that could still be tolerated for aquaculture activities were 0.1 ppm, 0.06–0.2 ppm, and 0.002 ppm, respectively [36].

3. Conclusion

This study investigated the silvofishery potential of a 10-year-old restored mangrove forest in Brebes, Indonesia. The research focused on the relationship between mangrove conditions, gastropod abundance, and mud crab populations in different sedimentation zones. The results demonstrated that the mangrove forest could support diverse marine life and provide significant ecological and economic benefits. By integrating silvofishery practices, local communities could sustainably utilize mangrove resources while preserving the ecosystem. The study highlighted the feasibility of restoring degraded mangrove ecosystems for both ecological and socio-economic purposes.

CRediT authorship contribution statement

Suyono: Writing – original draft, Validation, Software, Project administration, Investigation, Formal analysis, Conceptualization, Writing – original draft, Validation, Software, Project administration, Investigation, Formal analysis, Conceptualization. **Alin Fithor:** Writing – review & editing, Visualization, Supervision, Resources, Methodology, Funding acquisition, Data curation.

Data availability statement

[Standardized datatype] data have been deposited at [datatype-specific repository (http://repository.upstegal.ac.id/id/eprint/10037)] with accession numbers [10037]

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:Suyono reports administrative support, article publishing charges, and travel were provided by Pancasakti University Tegal. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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