Deltares

Monitoring of mangrove restoration in aquaculture ponds

New method for restoring aquaculture farms in Indonesia

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Deltares
In association with **Blue Forest** and **Wetlands International Indonesia**

Project statement
This report was written in the context of the Building with Nature Indonesia programme by Ecoshape, Wetlands International, the Indonesian Ministry of Marine Affairs and Fisheries (MMAF), and the Indonesian Ministry of Public Works and Human Settlement (PU), in partnership with Witteveen+Bos, Deltares, Wageningen University & Research Centre, UNESCO-IHE, Blue Forests, and Von Lieberman, with support from the Diponegoro University, and local communities.

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Disclaimer
Project partners are committed to drive the current Building with Nature innovation trajectory, by demonstrating the approach in a case study site in Demak. Successful implementation requires in-depth system understanding, extensive stakeholder engagement, and adaptive management on the basis of monitoring and evaluation. We stimulate and support upscaling of the approach by disseminating knowledge, lessons learned and implementation guidance. Stakeholders interested to replicate our approach are strongly recommended to adhere to this guidance and bear full responsibility for the success and sustainability of the approach.

Monitoring of Mixed Mangrove Aquaculture
New method for restoring aquaculture farms

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Summary

Coastal erosion occurs in many areas of Northern Java, the Demak Regency being one of the most heavily impacted. Since 2009 the area has lost large swaths of mangrove habitat as a result of sea level rise and land use change. In an effort to prevent any further coastal degradation, coastal communities are starting to implement a new concept called Mix Mangrove Aquaculture (MMA). The MMA practice aims to restore the natural barrier of mangroves in the region, while at the same time providing a fisheries yield. Sections of aquaculture ponds that border rivers and the sea are reverted back to mangrove habitat by opening pond bunds and allowing sedimentation and natural mangrove settlement to take place. In comparison to other Silvo-fishery practices, MMA ponds have a clear delineation between where fisheries practice and restoration efforts occur. As a result, MMA ponds provide space for mangroves to settle and reduce the risk of water quality deterioration, and therefore do not disturb aquaculture production. Thus, implementing the MMA practice on a large scale can help reestablish a natural coastal and riverine barrier that is able to reduce the risk of erosion in an entire region.

This study monitored change in mangrove cover in 45 ponds spread over 7 coastal communities after implementation of MMA. Sediment accumulation and mangrove recruitment were monitored. The monitoring design was developed by Deltares, the monitoring infrastructure was installed by partners and monitoring was done by partners and local community members.

In each pond PVC poles were used to monitor the monthly vertical change in sediment (i.e. pond elevation) in the mangrove section of the pond. Once every three months mangrove numbers and mangrove size (seedling, sapling, tree) were monitored. At random a 5 m x 5 m grid was selected in the pond, and all mangroves were counted and measured. Other categorical variables of interest were *dyke condition*, *age pond*, *sluice gate regime*, *proximity pond dyke to the river* and *pond size*. A Paired sample T-test was used to analyze the difference in sedimentation and mangrove before and after project implementation. A Pearson chi square test was used to analyze the correlation between response variables and categorical variables.

The results indicate that the implementation of MMA led to an increase in SBL and mangrove cover. A paired sample T-test showed that there is a significant increase in sedimentation (significance value of **0.000**). The average SBL height ranged between -5 cm and 35cm and monthly average sedimentation rate ranged from 0.6-1.1 cm/month. Over the course of the monitoring period SBL showed a positive linear trend, with an average SBL of 2 cm in the first month and an average SLB of 16 cm by the end of the monitoring campaign. Statistical analysis shows that *proximity to the river* is the only categorical variable that correlates significantly with the level of sedimentation in our study (Pearson chi square test significance value of **0.016**). Paired sample T-test shows that mangrove recruitment was significantly higher at the end of the monitoring campaign (significance value of **0.010**). Meanwhile, none of the other categorical variables (Sluice gate regime, Dyke condition, Implementation time, Proximity to the river, Pond Size) correlated significantly with mangrove recruitment. The average monthly mangrove count ranges from 0.00-3.23 stems/m2, with the total mangrove recruitment 12.19 stems/m2 for whole ponds. The total mangrove recruitment rate is 1.20 stems/month or 14.63 stems/year. At the end of the monitoring campaign, the relative density of mangrove per stage were: 65% seedling, 34% sapling and 0.4% tree. No clear significant trend was found between mangrove recruitment rate, SBL rate, elevation, and water level.

Despite all the uncertainties and the limitations in data quality and quantity, this study shows that the practice of MMA can promote conditions that are suitable for mangrove recruitment. The implementation of the MMA program in Demak also shows the importance of community involvement and commitment when rehabilitating mangroves. By involving local stakeholders and local

communities, and transferring knowledge to them, new practices for aquaculture can continue to take place beyond the lifetime of the project.

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Many thanks to our partners at Blue Forest, Pak Yusran and Ka Regis for their efforts in collecting *in situ* measurements and organizing all the field activities. Your knowledge and experience were invaluable to the success of this study. Furthermore, much appreciation and thanks to the community that helped survey all the ponds: Ikhsan (Timbulsloko), Zaeni (Timbulsloko), Musyaatun (Surodadi), Mulyono (Surodadi), Maskan (Surodadi), Nur Aziz (Surodadi), Afi Khomarun (Surodadi), Nur Chomaidi (Surodadi), Suhadi (Tambak Bulusan), Ma'ruf (Tambak Bulusan), Abdul Ghofur (Tambak Bulusan), Mujairin (Tambak Bulusan), H. Sohibin (Tambak Bulusan), Ahmad Rosidin (Murodemak), Jaelani (Purworejo), Abdul Hadi K (Purworejo), Maftuhin, (Purworejo), Tasruchin (Purworejo), Abdul Karim (Onggojoyo), Nur Kamid (Onggojoyo), Masri (Onggojoyo), Saeful Mujab (Onggojoyo), Maskur (Onggojoyo), H.Asrofin (Onggojoyo), Abdul Jalal (Onggojoyo), Syafii (Onggojoyo), Fatoni (Onggojoyo), Mathohir (Onggojoyo), Muktaman (Onggojoyo), Abdul Gofar (Onggojoyo), Khoiriya (Seklenting), Saiful Arif (Seklenting), Muhajir (Seklenting), Ky.Mustofa (Seklenting), Ahmad Faridhi, (Seklenting), Fauzi (Seklenting), Mahdum Ibrohim (Seklenting), Abdul Wahab (Seklenting), Mashadi (Seklenting) and Sayudi (Seklenting). They proved that our new method on restoring mangroves without disturbing aquaculture production is possible. And would not have been possible without their cooperation, effort, and perseverance. Much appreciation also to our partners at UNDIP (especially Prof. Sri Rejeki), WUR (especially Roel van Bosma), and Wetlands International (Pak Eko) for their support. Finally, I would like to express my appreciation to my family, and especially to my husband, for supporting me during my pregnancy while authoring this report.

Jakarta, December 2020

Contents

1 Introduction

The Indonesian archipelago consists of 17,000 islands, with a coastline of about 81,000 km. Coupled with a warm tropical climate all year long, the potential for aquaculture is vast. By the end of the 20th century, communities along the north coast of Java, had converted around 50,000 ha of mangrove into aquaculture (Ilman et al, 2016). Even as the country only utilizes 7.38% of its total potential area for aquaculture, it already ranks among the most productive countries in aquaculture production worldwide. Indonesia's yield of aquaculture in 2014 trailed behind China and was slightly ahead of India. Aquaculture development in Indonesia has accelerated and is considered an important sector in supporting rural economic development. Aquaculture and inland water capture fisheries contribute to about 26 percent to the country's total fish production or about 16 million EUR income (MMAF, 2003), with over 2 million people working in aquaculture sector in Indonesia (FAO, 2006). The Indonesian Ministry of Marine Affairs and Fisheries (KKP) has set ambitious growth targets for most aquaculture species of around 8.5% growth per annum up to 2030 to satisfy national demand and increase exports (Henriksson, et al., 2019a). Given the current economic relevance of aquaculature, and considering the targeted growth, it becomes key to guarrantee a sustainable development and exploitation of aquaculture practices.

The expansion of aquaculture has led to the removal of vast swaths of mangrove forests. The northern coast of the Central Java Province has been severely impacted by coastal erosion over the last few decades (Rejeki, 2019). The removal of mangrove habitat has taken place along the entire coastline from Semarang to Demak (Figure 1.1). In the beginning of the 20th century mangrove habitat was being converted to rice paddy fields. As it became financially less attractive to invest in rice fields, people started to convert their fields to aquaculture ponds over the last 2 decades. Moreover, due to economic development, ground water extraction rates continue to increase as populations grow in urban deltaic areas (Yeung 2001, Small and Nicholls 2003, Nicholls 2004, Hanson, Nicholls et al. 2011). This in turn causes subsidence and is a major driver of erosion and mangrove loss. Under natural conditions mangroves attenuate waves and trap sediment.

Figure 1.1. (a) Green and blue colors represent areas where surface water changes occurred during the last 30 years. Green pixels show where surface water has been turned into land (accretion, land reclamation, droughts). Blue pixels show where land has been changed into surface water (erosion, reservoir construction). (b) The bars represent the erosion/accretion along coasts, every 500m, over the period 1984-2016. Green bars indicate where shoreline accretion has occurred (natural accretion, land reclamation, nourishments). Red bars indicate erosive shorelines, based on a linear fit through shoreline ***Source:*** http://aqua-monitor.appspot.com/

However, in the absence of mangroves wave attenuation decreases and the chances of large erosive events increase significantly (van Wesenbeeck, et al, 2015). Furthermore, in most aquaculture systems, natural floodplains are disconnected from the rivers and therefore hamper the sediment supply. Riverine sediment flux is essential to maintain coastal stability (Naohiro, 2012).

The total extent of erosion along the coastal regions of Demak Regency has reached 495.80 ha (Ervita and Marfai, 2017). By 2100 sea level rise is projected to inundate14,700 hectares in Demak, affecting over 70,000 people and is likely to result in the loss of 6000 hectares of aquaculture ponds (van Wessenbeck, 2015). The implementation of mixed mangrove aquaculture in Demak is aimed to rehabilitate the eroded areas while maintaining a fisheries yield.

Many studies have encouraged an integrated concept that is able to preserve mangrove and maintain/ increase aquaculture production. Silvo-fishery (known as Wana Mina in Indonesian) is a common concept that has been introduced as an eco-friendly method of aquaculture. The method combines aquaculture and mangrove restoration practices (Fitzergerald, 2000). However, recent studies have shown that silvo-fishery practices have negative effects on fish and shrimp biology (Rejeki, 2019). The decomposition of organic matter derived from the leaves, releases tannins that are harmful for aquaculture's yield. Tannins are anti-nutritional elements which affect protein utilization and nutritional digestibility of various herbivorous and detritivorous crustaceans and fish species (Rejeki, et al, 2019). Thus, although the method benefits mangrove restoration, it is a less attractive option for farmers because their yields are less compared to conventional methods.

In this project, a new concept is introduced, called mix mangrove aquaculture (MMA). The concept of MMA is similar to that of silvo-fisheries, as it aims to restore mangrove habitat while also providing a fisheries yield. However, instead of having mangroves inside the aquaculture ponds, the mangroves act as a green belt and surround the ponds (Figure 1.2), hereby reducing the risk of water quality deterioration and do not disturb the production of aquaculture. Farmers that implemented MMA construct one or more dykes and separate the mangrove area from the aquaculture area of ponds.

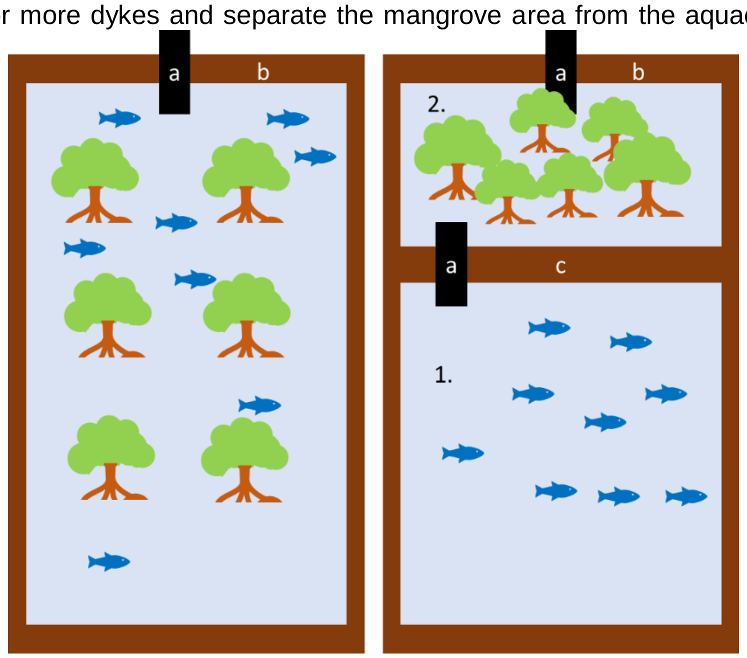

*Figure 1.2. A schematic representation of the Silvo-fishery concept (left) and the Mixed-mangrove aquaculture (MMA) concept (right). The trees shown in the figure represent mangroves, the fish represent crop (usually fish or shrimp), the brown box represents (b) the outer barrier of the ponds, and the black rectangles represent in/outlets (a). For the Silvo-fishery ponds, mangroves are restored in the same pond as where aquaculture takes place. For the MMA ponds, a new dyke is constructed (c) to separate the restoration area and aquaculture area. Mangroves are restored in area **2**, and aquaculture activities occurs in area **1**.*

Water is allowed into the mangrove area of the pond, which eventually leads to sedimentation and the sediment bed level to rise. Once sedimentation occurs, the chances of successful mangrove settlement start to increase. The water management in silvo-fisheries often only has one sluice gate, while MMA ponds have more than one sluice gate. As such, MMA ponds have the benefit of being able to manage the drainage of their yield and mangroves seperalty. This is important, since the mangrove area needs to be flushed more frequently in order to deal with the accumulation of leaf litter (Bosma et al., 2016).

The objective of this study is to quantify the changes in sedimentation and mangrove recruitment after the implementation of MMA ponds. Monitoring of the MMA ponds is a collaborative effort between Blue Forest, Wetlands International and Deltares. All partners contributed to the project, Blue forest and Wetlands International assisted with data collection, and Deltares designed the experimental setup and conducted the data analysis. For the data analysis, sediment bed level height and mangrove recruitment are the dependent variables which were of interest during the monitoring. Potential explanatory variables are water level, elevation, dike condition, dike height, sluice gate regime and MMA implementation.

2 Methods

2.1 Pilot location

Demak Regency is in the northern part of Central Java Province. The area of Demak regency is 89.743 ha and directly borders Semarang City which is the center of government and economy in Central Java. The regency is subdivided into 14 *kecamatan* (subdistrict), 243 *desa* (village) and 6 *kelurahan* (sub-village).

The pilot implementation of mixed mangrove aquaculture took place in 6 villages within Demak. In the beginning of the project 48 ponds have implemented MMA, but only 45 ponds have been monitored until the end of the project due to other 3 ponds implemented additional interventions which were not suited for the MMA concept. The distribution of the MMA ponds can be seen in Figure 2.1, next to an indication of the villages hosting the pilot.

Figure 2.1. Satellite image from google earth showing the different locations of the MMA ponds. The count of MMA pond per village in the Demak Regency: (1) 4 ponds (red) in Timbulsloko (2) 6 ponds (blue) in Surodadi (3) 6 ponds (orange) in Tambakbulusan (4) 3 ponds (purple) in Morodemak (5) 4 ponds (yellow) in Purworejo (6) 12 ponds (green) in Wedung, (7) 10 ponds (pink) in Seklenting, sub village of Wedung.

2.2 Pond description

MMA ponds are aquaculture ponds with a dyke, which separates and confines an area of the pond so that mangroves can settle and grow. For clarity, the area where mangroves can grow, the restoration area, is no longer used for aquaculture practices. The elements of an MMA pond are shown in Figure 2.2. Aquaculture ponds where the MMA approach was implemented were selected by using an ecosystem mapping assessment (Priyanto, 2019). This method assesses the potential to restore an aquaculture farm. The following criteria were used to select a pond:

1. The pond is connected to the river system. In this way, the needs of sediment flux and seed supply are fulfilled.
2. The pond has a clear status of ownership. This is to prevent potential conflicts.
3. The owner of the pond agrees to continue maintenance after the project ends.
4. The pond has an inlet and an outlet sluice gate.
5. The pond is no longer utilized for aquaculture yield.

If all the above criteria received a positive outcome, the pond is suitable for the implementation of the MMA approach.

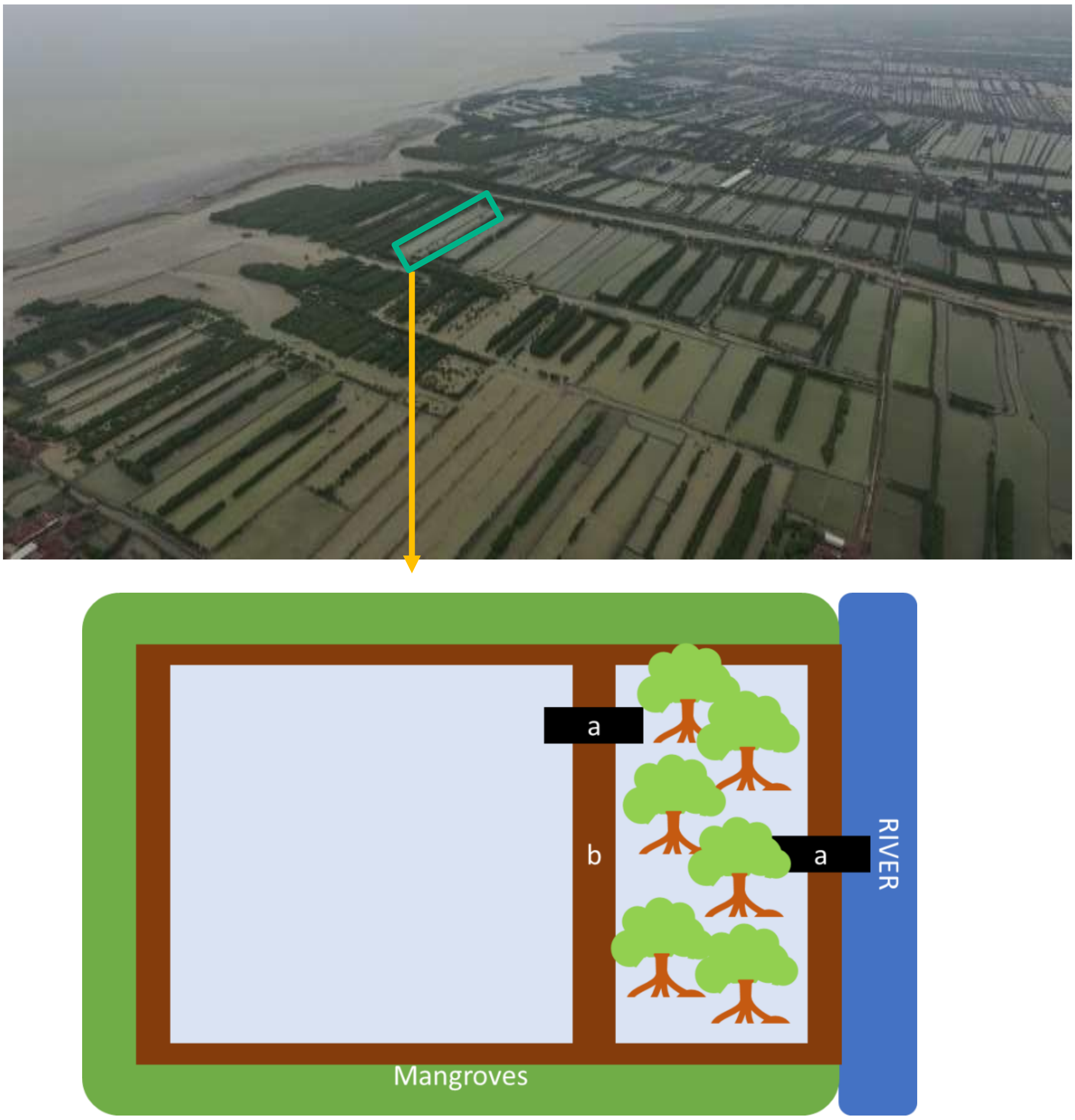

Figure 2.2. Top panel: A areal picture taken by drown of the study area. The picture shows the coastline, rivers and aquaculture ponds. Bottom panel: A schematic representation of a mixed mangrove aquaculture pond, showing how a pond can be situated in relation to the mangroves (outer green area) and a river. The pond can regulate the water at the sluice gates (a). The creation of a new dyke (b) separates the pond into two areas, one where aquacultures can still take place (left), and another area where mangrove restoration can take place (right). It is in the later area where sediment accumulates, mangroves grow, and all monitoring activities occurred.

2.2.1 Pond variables

During the monitoring campaign a series of variables were noted for each pond (Table 2.1).

Table 2.1. Variables of the pond that were noted for each pond.

Variables	Description
Sluice gate regime of the dyke connected to the river	Always open. Farmers leave the pond always open.
	Open and close. Farmers open and close the pond.
Dyke condition	Good. The dyke is in a good condition.
	Broken. The dyke is in a bad condition, letting water in or out.
Implementation time	Years (y)
Proximity to the river	Meters (m)
Pond Size	Square meters $(m)^2$

2.3 Measurements and data

To obtain our objectives, the mangrove recruitment and the change of sediment bed level was monitored. Drone pictures were taken every three months to monitor change in mangrove and sediment over time (see appendix). The change of mangrove recruitment is measured every two months in the first six months of monitoring period and every three months after six months monitoring period. Meanwhile, the change of sediment bed level height is measured once a month using poles placed in platform and ditch of the pond. In addition, water level and pond elevation also have been measured once in the beginning of the program (Figure 2.3).

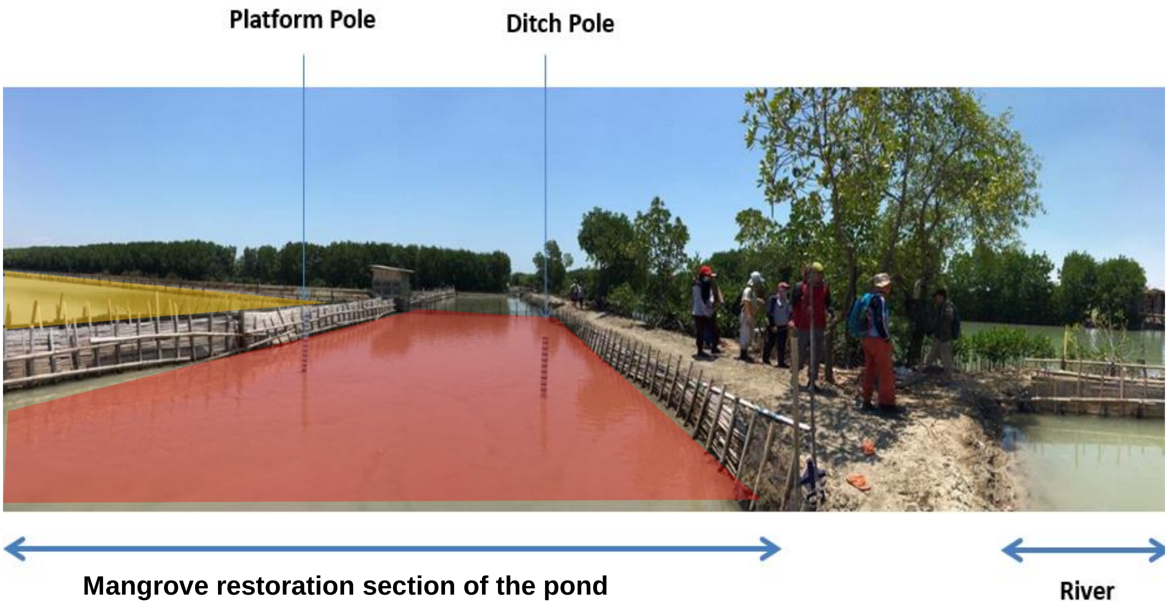

Figure 2.3. Picture of one the aquaculture ponds, depicting the monitoring poles used for the measurements of sediment bed level. One pole is placed in the ditch and one pole on the platform. Mangrove count, water level elevation with respect to MSL were also monitored in this section of the pond. The red section of the pond is where mangroves can come back. The orange section of the pond on the far left, is where aquaculture activities continue to take place. The wood structure is the new dyke that separates the two areas.

2.3.1 Sediment bed level measurements

The sediment bed level is monitored using sediment poles (Figure 2.4). These are PVC tubes, with a diameter of 7.5 cm and a length of 1.5 m. Every 10 cm's tape is placed on the tube. The pole is placed 50 cm into the soil and is fortified with bamboo and mud. Monitoring poles are placed into the restoration section of MMA ponds, located further from the inlet. There are 2 poles in each pond, one is in ditch and one is in platform. During the high tide, the strips are measured from the top-most strip to the water surface, for both ditch and platform pole. The changes in sedimentation level is measured once a month. The output of this measurement is the sediment bed level height (cm) and sedimentation rate (cm/month). For clarity, this information is illustrated in the following sketch:

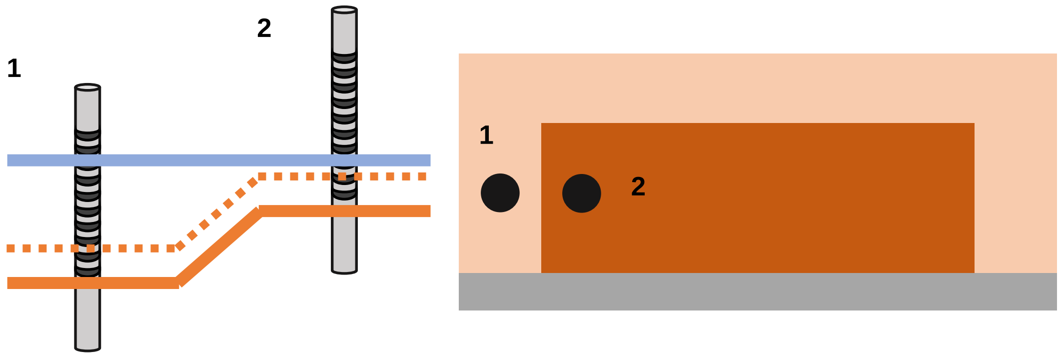

*Figure 2.4. A schematic representation of placement of the poles in the ditch and in the platform of the pond. The right figure represents a side view. Poles are placed in the sediment at T_0. The dotted line represents the sediment that accumulates over time and is measured at T_{0+n}. The blue line represents the water level. Pole number **1** is placed in the ditch, and pole number **2** is placed on the platform. The figure on the right represents an aerial view of the pond. Where the light brown represents the ditch, and the dark brown represents the platform. The black circles represent the poles, and the numbers corresponding to the ditch (**1**) and platform (**2**).*

2.3.2 Elevation data and water level

The water level of MMA ponds is monitored once a month. The measurement is done by using the same set-up as sediment changes measurement (by using stripped PVC). Water level is measuring the height of the water with respect to the bottom of the PVC pole. The elevation of a specific pole is measures by calibrating the poles to the mean sea level (MSL). The time and location were documented using a GPS. This information is used as input for calculating mangrove count relative to MSL using a tidal model based on Semarang tidal gauge measurements.

2.3.3 Mangrove measurements

For each pond monitored, mangrove settlement is counted in the rehabilitated area of a pond (see Figure 2.2 and Figure 2.3) for the following species: *Rhizopora*, *Avicennia* and *Sonneratia*. Because ponds vary in size, monitoring occurs in a 5 m x 5 m quadrant, which is selected at random each month. The output of these measurement is the potential monthly and yearly mangrove recruitment of MMA ponds (in # stems/m^2). Mangrove count is estimated per pond by calculating the product of the measured # stems per m^2 with the surface area of a specific pond (in m^2). Pictures were also taken of ponds to keep track of mangrove cover (see Appendix A). Mangrove sizes are categorized as:

- Tree (height > 1.3 m; trunk Diameter at breast height ≥ 2.5cm).
- Sapling (height > 1m < 4m; Diameter at breast height < 2.5 cm).
- Seedling (height < 1m; Diameter at breast height N/A).

2.4 Data analysis

Statistical analysis is done using the statistical software package: SPSS 21.0. Descriptive statistics is used to analyze the distribution of pond variables in relation to SBL and mangrove recruitment. Pearson chi square analysis is used to explore the relationship between the dependent variable (SBL and mangrove recruitment) and independent variables: proximity to the river, sluice gate regime, dike condition, elevation and water level. Paired sample T-test is conducted to analyze the significant difference of the SBL height and mangrove recruitment at the beginning and at the end of the program. Furthermore, the crosstabs analysis by Pearson chi-square test also has been done to see the correlation between the main variable (SBL and mangrove recruitment) and explanatory variables.

2.5 Tasks and responsibilities

Developing and implementing a monitoring strategy for this project was a multi-party effort that faced numerous budget and operational challenges. The experimental setup and design were developed by Deltares. Local partners, i.e. Blue Forest and Wetlands International Indonesia, were then trained by Deltares on how to monitor changes in mangrove cover and SBL. Blue Forest and Wetlands International Indonesia led the installation of the monitoring polls. Aqua culture farmers were trained by Wetlands International Indonesia and Blue forest to assist with the monthly monitoring activities. The local farmers did the monitoring and handed in their monthly reports to Blue Forest. Blue Forest transcribed the handwritten measurements, and Deltares used this as input for all data analysis.

3 Results

3.1 Quantitative Analysis of Sedimentation

3.1.1 Descriptive statistics of categorical variables

Table 3.1 Descriptive statistics of categorical variables

Variables	Category/Unit	Count	Percentage
Sluice gate regime	Always open	17	39.5
	Open and close	26	60.5
Dyke condition	Well condition	35	81.4
	Broken	8	18.6
Implementation time	< 1 year	2	4.7
	1-2 years	6	14
	> 2 years	35	81.4
Proximity to the river	<1 meter	10	23.3
	1-5 meter	21	48.8
	6-10 meter	7	16.3
	>10 meter	5	11.6
Pond Size	0-500 m^2	7	16.3
	500-1000 m^2	15	34.9
	1000-2000 m^2	12	27.9
	>2000 m^2	9	20.9

Table 3.1 depicts the descriptive statistics of several categorical variables, which are sluice gate regime, dyke condition, implementation time of MMA pond, proximity of MMA pond to the river, and pond size. As for sluice gate regime, 60.5 % is using open and close system and the rest (39.5%) is using always open sluice gate. Dyke condition is distinguished into well condition and broken, which covered 81.4% and 18.6% of samples respectively. Less than 5% of MMA ponds are younger than 1 year, as many as 14% have been active as MMA ponds for 1-2 years, and most of them (81.4%) have been active as MMA ponds for more than 2 years. Proximity to the river variable is divided into 4 categories: less than 1 meter to the river, between 1-5 meter to the river, between 6-10 meters to the river and more than 10 meters to the river. Most of the MMA ponds (48.8%) have a distance between 1-5 meter to the river and only 5 of them (11.6%) have a distance more than 10 meters to the river. Pond sizes distributed quite fairly between 0-500 m^2 (16.3%), 500-1000 m^2 (34.9%), 1000-2000 m^2 (27.9%) and >2000 m^2 (20.9%), with overall average pond size being 1740 m^2.

3.1.2 Trend of sediment bed level (SBL) height

Figure 3.1 shows sediment bed level height over the entire monitoring period, from November of 2018 till march of 2020. The graph shows an almost steadily increasing trend of average sediment bed level height, with the exceptions of March, May, and November of 2019, where SBL drops are registered. Starting with an average of 1.13 cm in the first month of monitoring, the sediment bed level height reaches its peak in the last monitoring period (March 2020), with a final increase of 16.51 cm. During the period of December 2018 till February 2019 the increase in SBL is the largest.

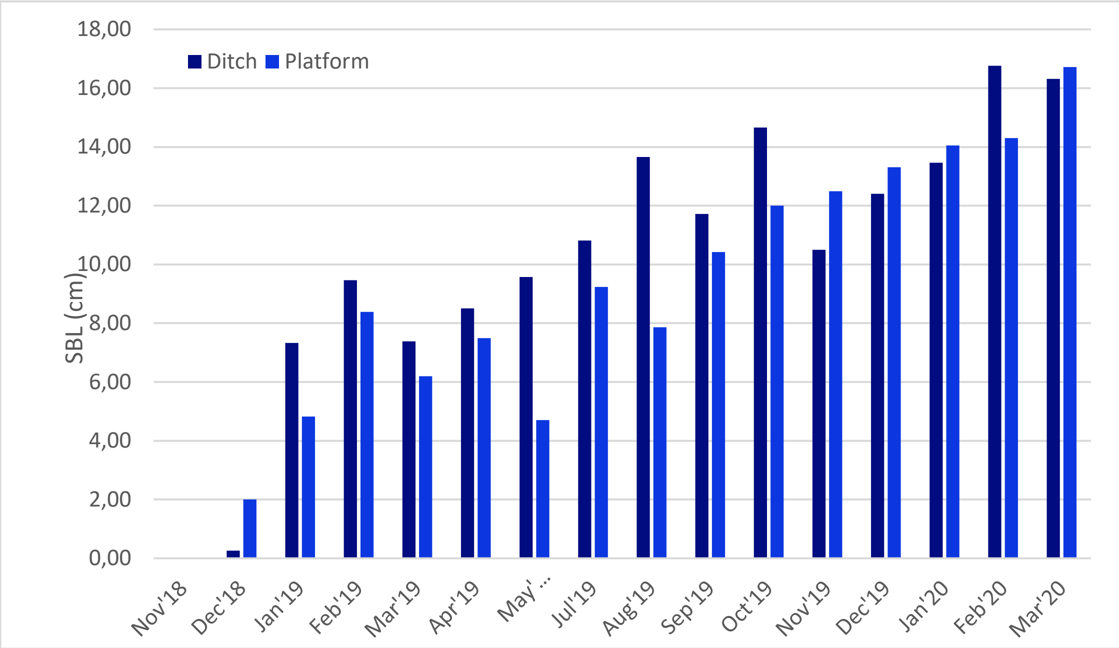

Figure 3.1. Monthly average of all ditch (light blue) and platform (dark blue) poles.

Figure 3.2 depicts the overview of average sediment bed level height among different monitoring locations. It must be noted that there is a difference in amount of ponds per village, some locations have 2 while others have 12. The highest average of sedimentation can be seen in Morodemak, though it is based in only two measurements.

The lowest average of sedimentation is in Gojoyo. The difference of SBL height between ditch and platform poles can be seen clearly in Morodemak and Purworejo. However, in Morodemak SBL height in platform is higher; while in Purworejo SBL height in ditch is higher.

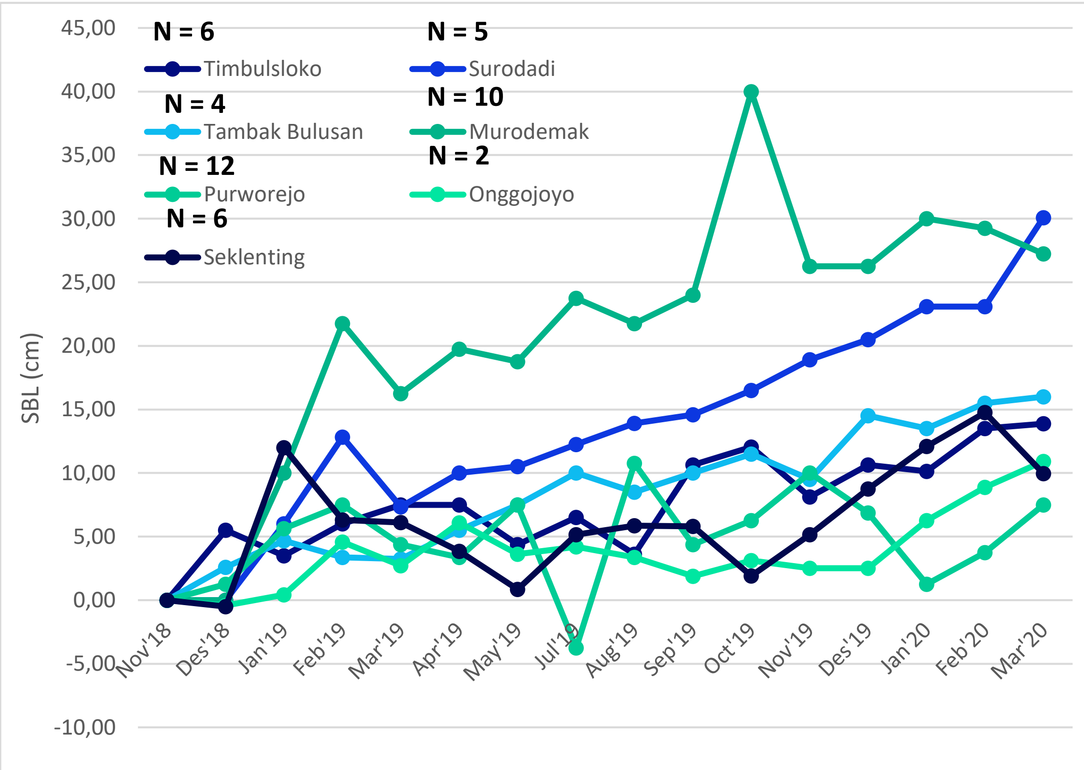

Figure 3.2. Average (ditch and platform) sediment bed level height per location.

3.1.3 Sediment bed level (SBL) and SBL-Water Level

The trend of average water level and sediment bed level accumulation rate over monitoring period can be seen in Figure 3.3 . The figure shows no clear trend between water level and sediment bed level.

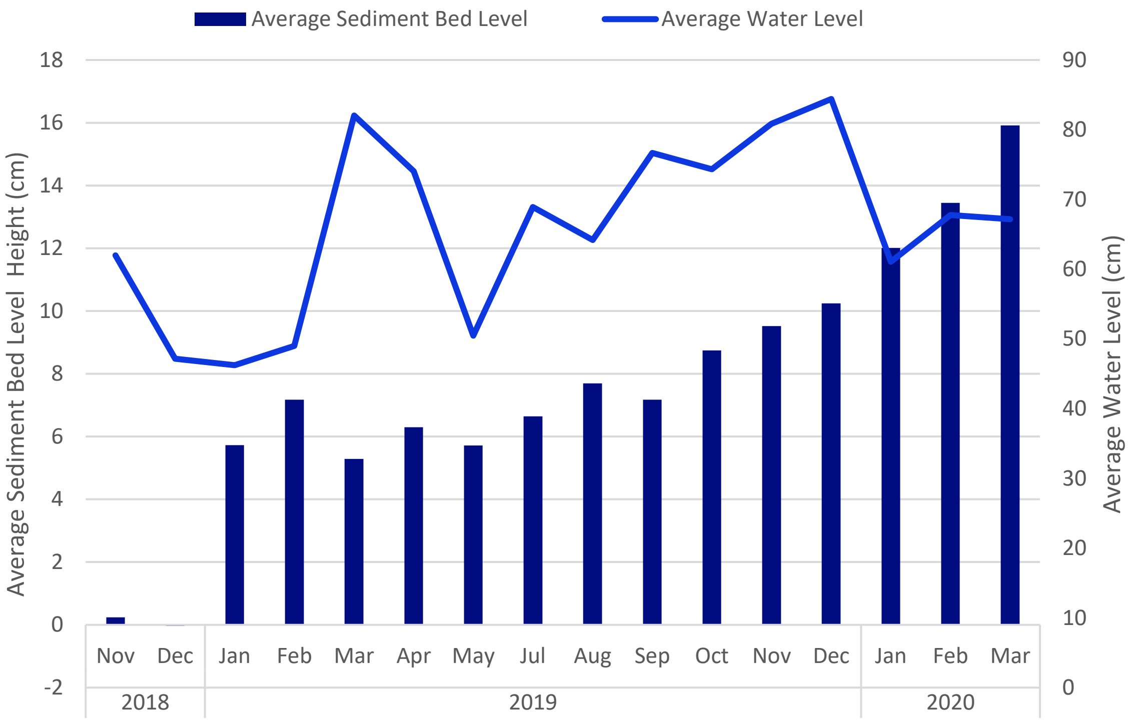

Figure 3.3 The trend of SBL rate and water level during monitoring period. The graph show the average among all ponds.

3.1.4 Paired Sample T-test for sediment

Table 3.2 Paired Sample T-test of sedimentation

	Mean	Standard deviation	Standard error	95% CI lower	95% CI upper	t	df	Sig. (2 tailed)
Sedimentation T0+3	5.03	4.71	0.78	-11.75	-4.6	-4.685	35	0.000
Sedimentation T0+15	13.21	9.54	1.59					

In this analysis, the comparison between sedimentation at the third month of monitoring (when the sedimentation clearly can be seen in early stage) and sedimentation at the fifteenth month of monitoring (the last monitoring period for sedimentation) has been carried out. Paired sample T-test analysis shows that there is significant difference (significant value 0.000) between sedimentation at the third month and at the end of monitoring. Therefore, we can conclude that the sedimentation as reported in the previous section was statistically significant. Table 3.2 depicts that average of sedimentation at the third month of monitoring is 5.03 cm, while at the end of monitoring the average of sedimentation is 13.21 cm.

3.1.5 Pearson chi square analysis for sediment

Table 3.3 Significant value of Pearson chi square analysis for Sedimentation

	Sluice gate regime	Dyke condition	Proximity to the river	Pond Size	Implementation time
Level of SBL	0.299	0.857	**0.016 ***	0.451	0.475

Crosstabs analysis has been done between the level of sediment bed level height and other independent variables (Table 3.3). Pearson chi square analysis shows that from five independent variables, proximity to the river is the only variable that correlate significantly with the level of SBL (significant value > 0.05).

Table 3.4 Distribution of SBL level and proximity to the river

Level of SBL	Proximity to the river				Total
	< 1 meter	1-5 meter	6-10 meter	>10 meter	
Low (0-10 cm)	31.6%	21.1%	21.1%	26.3%	100.0%
Medium (10-20 cm)	0.0%	100.0%	0.0%	0.0%	100.0%
High (>20 cm)	18.2%	72.7%	9.1%	0.0%	100.0%
Total (within level of SBL)	22.2%	50.0%	13.9%	13.9%	100.0%

The distribution of SBL level with respect to proximity to the river can be seen in Table 3.4. The table above depicts that proximity to the river of less than one meter and up to five meters contributes to a higher level of SBL height (18.2 % and 72.7%). Meanwhile, further than ten meters, SBL does not increase beyond 10cm.

3.2 Quantitative analysis of mangrove

3.2.1 Mangrove count

Figure 3.4 depicts the number of mangroves per location over the entire monitoring period. At its peak, mangrove count was just over 18,000 in February of 2019, with most of the mangroves located in the village of Tambak Bulusan. After 8 months, the total mangrove count in the field was estimated at around 13,000. Which is still a substantial increase compared to initial conditions. The location with the highest number was in Gojoyo in April of 2019. In the months of January, February, and April, the bulk (more than 45%) of all mangroves counted were found in two specific ponds. The two ponds are below the average pond size of 1740 m^2 (max pond size being 7100 m^2), having a surface area of 900 m^2 and 1500 m^2. Thus, the peak in mangrove count for these two ponds is not attributable to their size.

Our findings show that the majority of mangrove species in our mixed mangrove aquaculture are *Rhizopora mucronata* and *Avicennia marina*. More than 80% of all the mangroves found were of *Avicennia sp*. Based on the stages of growth the overall distribution was 65% seedling, 34% sapling and 0.4% tree.

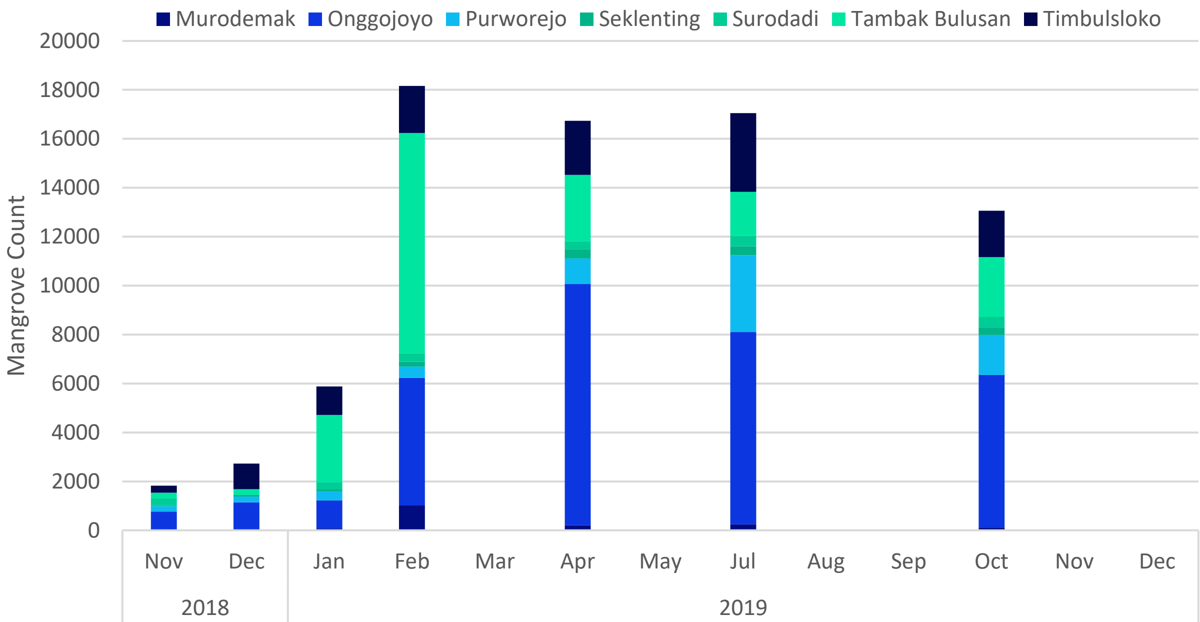

Figure 3.4. Mangrove density for monitoring period per village. The vertical axis denotes the average density per village, as multiple ponds were monitored at each village.

3.2.2 Mangrove count and Sediment Bed Level

Figure 3.5 shows the relation between mangrove count and sediment bed level height. The figure shows a peak of mangrove occurrence between 0 and 10 cm. In fact, just over 50 % of all measurements were found between this range (Figure 3.6). With these data, it is difficult to say if this is an inherent feature of the system, or a chance occurrence. Data shows that mangroves recruitment continues to take place even if SBL height decreases.

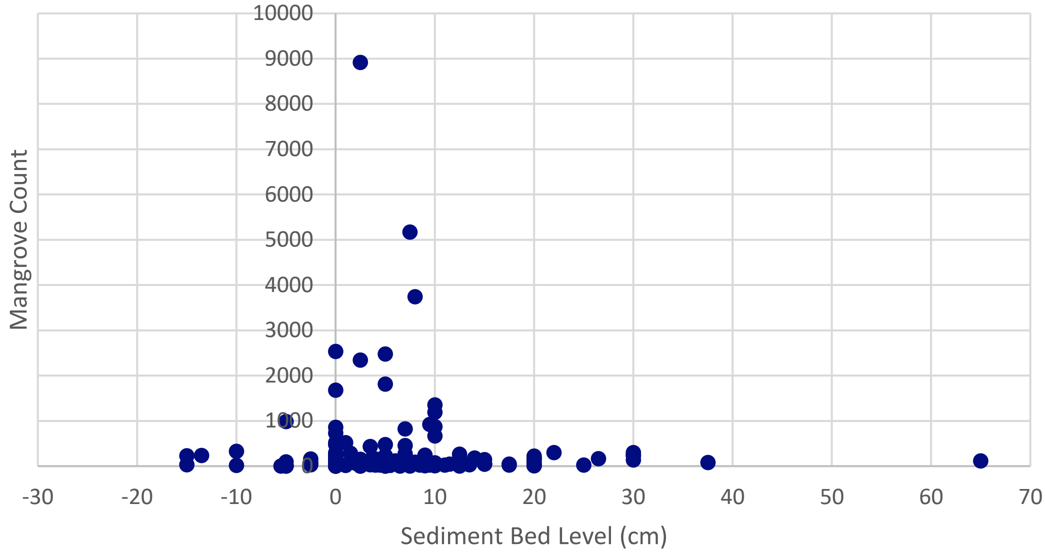

Figure 3.6 Distribution of mangrove rate and average sediment bed level height (left) and average SBL height (right)

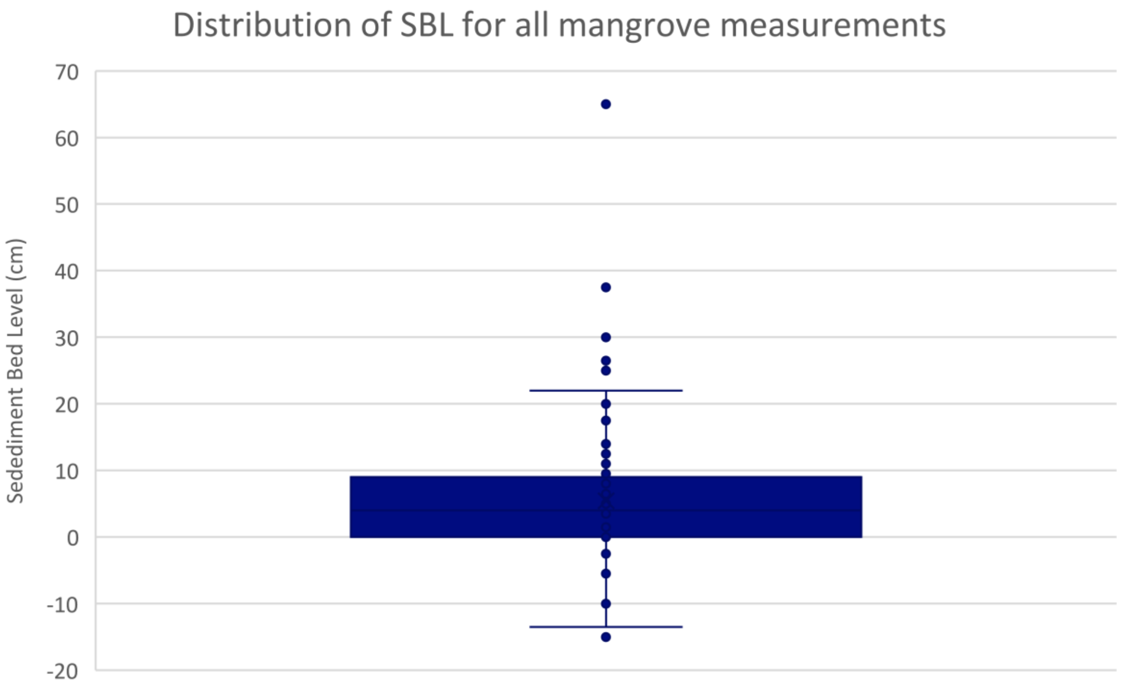

Figure 3.5. Box plot showing the distribution of the SBL measurements for all mangrove measurements

3.2.3 Mangrove count and water level

The trend of water level and mangrove count over monitoring period can be seen in Figure 3.7. Here we examine if there is a relationship between height of water level and total mangrove count. However, the measurements indicate that no such trend exists. It could be argued that the peak in water level seen in March of 2019 was preceded by a peak in mangrove count. However, variation in water level in the later months, is not mirrored by mangrove count, which stays fairly stable for February, April and July. The last month of mangrove measurement, i.e. October, decreases compared to previous months, whereas water level increases from May till December. To get a better understanding how changes in mangrove cover look like *in situ*, see appendix A.

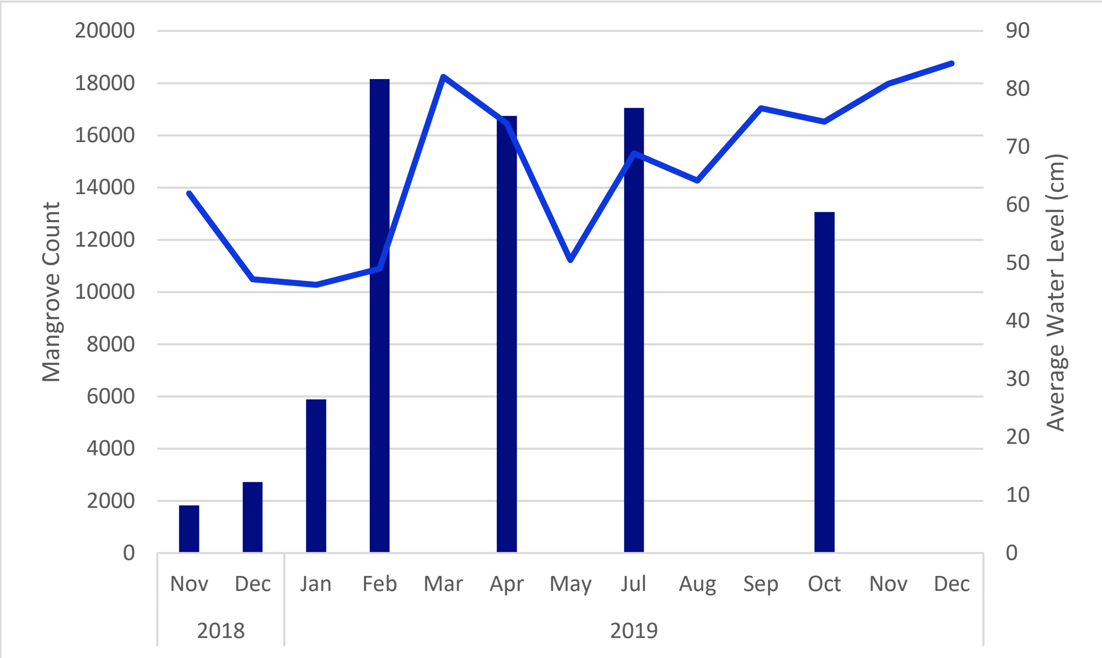

Figure 3.7. Mangrove rate (#/m2) and average water level (cm) over time (months after first measurement). Figures show average of all measurements per month for the ditch (a) and the platform (b).

3.2.4 Paired Sample T-test of mangrove recruitment

Table 3.6 Paired Sample T-test of mangrove recruitment

	Mean	Standard deviation	Standard error	95% CI lower	95% CI upper	t	df	Sig. (2 tailed)
Mangrove T0+0	0.09	0.16	0.03	-0.99	-0.14	-2.740	35	0.010
Mangrove T0+10	0.67	0.36	0.22					

For mangrove count, a comparison is made between the beginning of monitoring (as initial condition) and mangrove recruitment at the tenth month of monitoring (the last monitoring period for mangrove recruitment). Paired sample T-test analysis shows that there is significant difference (significant value 0.010) between mangrove recruitment at the beginning and at the end of monitoring (Table 3.6). Table 3.6 depicts that average mangrove at the beginning of monitoring is 0.09 #stems/m^2, while at the end of monitoring the average mangrove recruitment is 0.67 #stems/m^2. Changes in mangrove cover within a pond can be quite substantial, see pictures in Appendix A for further inspection.

3.2.5 Pearson chi square analysis of mangrove recruitment

Table 3.7 Significant value of Pearson chi square analysis for Mangrove Recruitment

	Sluice gate regime	Dyke condition	Proximity to the river	Pond Size	Implementation time
Level of mangrove recruitment	0.473	0.690	0.874	0.285	0.769

The level of mangrove recruitment has been distinguished into low (0-0.4 #stems/m2), medium (0.41-0.80 #stems/m2) and >0.80 #stems/m2. Table 3.7 depicts the crosstabs analysis between mangrove recruitment and other independent variables. Pearson chi square analysis shows that there is no variable that has significant correlation to mangrove recruitment (significant value >0.05).

4 Discussion

Mixed Mangrove Aquaculture practice aims to restore mangrove habitat in aquaculture ponds that are actively producing fish. MMA ponds consist of two areas, the restoration and the aquaculture sections. This study assesses the effectiveness of the mixed mangrove aquaculture method at elevating the SBL and restoring mangrove cover in the restoration section of such ponds. The results indicate that this method of fish aquaculture can be used to increase the sediment bed level and facilitate mangrove recruitment.

Sedimentation

An increase in Sediment Bed Level height in the aquaculture ponds was clearly visible throughout the entire monitoring campaign. Results of the SBL rate show an initial peak in the first months which eventually levels off. The measurements indicate no seasonal or temporal effect. Statistical analyses show a significant difference between SBL in the first months compared to SBL at the end of the campaign. Thus, confirming a significant accumulation of sediment during the monitoring period. The analyses revealed that the categorical parameter *proximity to the river* positively influences SBL height. Likely this is related to the fact that ponds next to the river receive more sediment input than ponds further away. Hereby, underscoring the importance of hydrological connectivity as is a key criterion for successful mangrove restoration. However, there was no significant relation between SBL and sluice gate regime nor with state of the pond-bunds. SBL was expected to correlate with water level in the pond since larger levels of accommodation space would result in more deposition, especially in areas with little hydrological forcing. However, the data does not corroborate this.

Mangrove recruitment

Statistical analysis showed that there is no significant relationship between the SBL and mangrove settlement. Factors that might influence mangrove occurance, such as *dike condition*, *sluice gate regime* and *proximity to the river* showed no significant effect. Nor is there a correlation between mangrove count and water level. According to McIvor (2013), mangrove forests occur in intertidal areas, at heights between mean sea level (MSL) and high tide, which vary between different species and locations. The bulk of the measurements (more than 50%) indicated that mangrove occurred at locations with SBL ranging between 0 and 10 cm. However, this is likely an artifact of the conditions in the field, since most ponds have SBL at ranges between 0 – 10 cm. Seedling growth potential is reduced with increased flood durations (Krauss et al., 2008). For most species, ideal conditions for settlement and growth are at or above MSL (Bijsterveld, et al. 2020). Nonetheless, the field observations show that successful settlement is possible at depths of -40 cm MSL, probably because of the sheltered conditions in the ponds. However, it is expected that at such depths, seedling settlement and growth is likely to be hindered for *Avicennia* and *Rhizophora* species. Overall, the measurements show that mangrove recruitment was substantial, with peak occurance of 18,000 mangroves settled throughout the entire study area (see Appendix A for pictures on changes in mangrove cover for some ponds).

Methods

During the monitoring period, there were two important deviations from the original design of the experimental setup. First, it was not possible to implement a control pond. A scientific control would help minimize the effects of variables other than the independent variables. In this case, a control pond is one where “normal” aquaculture practice takes place instead of MMA. By having a control pond, it becomes possible to test the null-hypothesis: *Changes in SBL and mangrove cover in MMA-ponds occur at similar rates compared to standard aquaculture ponds*. However, all aqua culture farmers that participated in the monitoring program had already changed their ponds to Mixed Mangrove practice. This meant that no comparison could be done between the different type of aquaculture techniques. Even though it is not possible to distinguish if mangroves cover changes are similar, the data still showcases that MMA ponds are a viable option for mangrove restoration. Secondly, SBL was to be monitored at five locations within each pond, instead of just at two locations (i.e. the ditch and platform). Monitoring poles would be placed at each corner and at the center of a pond. However, due to restrictions in resources and time, the consortium was confronted to choose between monitoring more ponds but have fewer sample points within each pond or monitor less ponds but sample at more location within each pond. The consortium eventually opted for the latter. Thus, although less variation is captured at the pond-scale, variation at the landscape scale is captured.

Conclusion

The implementation of mixed mangrove aquaculture has been introduced in Demak where the aquaculture is facing coastal erosion issues. This study shows that MMA can facilitate an increase of sediment bed level height and mangrove recruitment. The implementation of program in Demak shows that the commitment of community determine success in the rehabilitation of the MMA. The community played a crucial role for collecting the data needed. Without their involvement, support and approval of such a pilot study would not be possible.

In addition, now having been involved in the restoration of mangrove habitat, the management of the community acknowledge that growth of mangroves restored naturally is much faster and more successful than restoring mangroves by planting. This underscores the importance of conducting an analysis to understand and clearly communicate the environmental (physical, biological and chemical factors) parameters limiting mangrove growth to communities.

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A Appendix: Mangrove cover change

In this Appendix the mangrove cover change for three MMA ponds are shown. The pictures showcase the ponds at the beginning and towards the end of the monitoring period (10 months). These pictures were taken by Blue Forest and the local aquaculture farmers. Photos were taken of all ponds, however below only a selection of the pictures are shown where differences in mangrove cover change are most obvious.

Pond ID: MMA-01

Figure A.1 shows the mangrove of pond MMA-01 during two different moments. At the end of the program implementation, mangrove cover in the pond had increased and was about 1.53 stems/m^2. This pond has a proximity of less than 1 meter to the river. Most mangroves in this pond were *Avicennia sp.* and emerged close to the pond dike.

Figure A.1 The overview picture of MMA-01 pond from front view (above) Aerial view (bottom) before monitoring period (left side) and after 10 months of monitoring (right side). The green box in the bottom two pictures, marks the location of pond MMA-01. Aerial view pictures were taken by drone.

Pond ID: MMA-25

After ten months, the mangrove cover in pond MMA-25 is about 3.23 stems/m^2. At the start of the monitoring period, some mangroves were already present, and increased drastically (Figure A.2). The proximity of the ponds to the river is about 9.5 meter and the sedimentation in platform is high and does not get inundated during low tide. The amount of sediment is sufficient for mangrove to growth since the beginning of the program. In the ditch area, a natural channel has formed.

Figure A.2 The overview picture of MMA-25 pond from front view (above) Aerial view (bottom) before monitoring period (left side) and after 10 months of monitoring (right side). The green box in the bottom two pictures, marks the location of pond MMA-25. The Aerial view pictures were taken by drone.

Pond ID: MMA-24

Towards the end of the monitoring period, the mangrove cover was about 2.07 stems/m^2 in pond MMA-24. Figure A.3 shows that mangrove cover increased over a period of ten months. The proximity of the pond to the river is about 9.6 meter, the sedimentation in platform is high and is not inundated during low tide. In the ditch area, a natural channel has formed. Sedimentation rate is low and sluice gate has not been functioning well.

Figure A.3 The overview picture of MMA-24 pond from front view (above) aerial view (bottom) before monitoring period (left side) and after 10 months of monitoring (right side). The green box in the bottom two pictures, marks the location of pond MMA-24. The Aerial view pictures were taken by drone.

POND ID: MMA-12

At the start of the monitoring period, many *Avicennia* saplings were already present in the pond, they were all situated in the most elevated part of the pond (Figure A.4). Both mangrove density and size increased. The natural channel in the pond provides access for seedings to enter but are less suitable for establishment and growth.

Figure A.4. The overview picture of MMA-12 pond from front view (above) aerial view (bottom) before monitoring period (left side) and after 10 months of monitoring (right side). The green box in the bottom two pictures, marks the location of pond MMA-24. The Aerial view pictures were taken by drone.

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