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Survival and growth rates of mangroves planted in vertical and horizontal aquaponic systems in North Jakarta, Indonesia

ENDANG HILMI[1,♥], LILIK KARTIKA SARI[2], TRI NUR CAHYO[3], ARIF MAHDIANA[2], PETRUS HARY TJAHJA SOEDIBYA[4], EMING SUDIANA[5]

[1]Program of Aquatic Reources Management and Magister SDA, Faculty of Fisheries and Marine Science, Universitas Jenderal Soedirman. Jl. Dr. Suparno, Purwokerto Utara, Banyumas 53122, Central Java, Indonesia. Tel./fax.: +62-281-642360, ♥email: dr.endanghilmi@gmail.com

[2]Program of Aquatic Resources Management, Faculty of Fisheries and Marine Science, Universitas Jenderal Soedirman. Jl. Dr. Suparno, Purwokerto Utara, Banyumas 53122, Central Java, Indonesia

[3]Program of Marine Science, Faculty of Fisheries and Marine Science, Universitas Jenderal Soedirman. Jl. Dr. Suparno, Purwokerto Utara, Banyumas 53122, Central Java, Indonesia

[4]Program of Aquaculture, Faculty of Fisheries and Marine Science, Faculty of Fisheries and Marine Science, Universitas Jenderal Soedirman. Jl. Dr. Suparno, Purwokerto Utara, Banyumas 53122, Central Java, Indonesia

[5]Faculty of Biology, Universitas Jenderal Sudirman. Jl. Dr. Suparno No. 63, Purwokerto Utara, Banyumas 53122, Central Java, Indonesia

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Abstract. *Hilmi E, Sari LK, Cahyo TN, Mahdiana A, Soedibya PHT, Sudiana E. 2022. Survival and growth rates of mangroves planted in vertical and horizontal aquaponic systems in North Jakarta, Indonesia. Biodiversitas 23: 687-694.* Mangrove rehabilitation is aimed to reverse mangrove deforestation and degradation. Various efforts have been conducted to rehabilitate the degraded mangroves, yet problems arise when planting mangroves in the high and permanently water-logged areas in coastline. The aquaponic system is a mangrove planting method introduced to reduce the impact of permanent and high water inundation. This research aims to analyze the survival rate of mangroves planted using vertical and horizontal aquaponic systems in Jakarta's north coast and investigate the correlation between physico-chemical environmental parameters and the survival and growth rates of the planted mangroves. The results showed that the survival rate of mangroves planted in the vertical aquaponic system reached 55.4-96.9%. On the other hand, the highest survival rate in the horizontal aquaponic system was obtained in mangrove planting at 80-100 cm from the bottom with survived plants between 70-90%. The height growth rate of mangroves planted in the aquaponic system was between 0.95-2.33 cm/month. The correlation analysis showed that soil salinity, soil pH and water salinity had a high correlation to support living trees of mangrove seedlings. *Rhizophora apiculata, Rhizophora mucronata,* and *Rhizophora stylosa* had highest survival and adaptation in this planting system.

Keywords: Height growth rate, horizontal aquaponic, living trees, mangrove planting, vertical aquaponic

INTRODUCTION

The mangrove ecosystem in the north coast of Jakarta, Indonesia is an estuarine mangrove ecosystem type located on the northern coast of the Java Island facing toward Java Sea (Hilmi et al. 2017a; Onrizal et al. 2005), which is influenced by freshwater supply from the Citarum River, Bekasi River, and Ciliwung River (Hilmi et al. 2017a; Kusumahadi et al. 2020). This mangrove ecosystem has irreplaceable ecosystem services, for example, as the buffer to mitigate the risk of coastal disasters, including tsunamis (Giri et al. 2015; Hilmi 2018; Nur and Hilmi 2021; Suhendra et al. 2018), tidal flooding (Krauss and Allen 2003; Ysebaert et al. 2016) and land subsidence (Bomer et al. 2020; van Wesenbeeck et al. 2015), and serve as the habitat of aquatic organisms (Abubakar et al. 2018; Masni et al. 2016), as well as improving other ecosystem services (Duncan et al. 2016) by reducing wave energy and sediment stabilization (Ndirangu et al. 2017). In addition, the mangrove ecosystem in the northern coast of Jakarta has a specific affinity (Hilmi et al. 2021b), specific adaptation to reduce the impact of water inundation and flooding, pollution, salinity, and soil texture (Andriyani et al. 2020; Barreto et al. 2016; Hilmi et al. 2017a; Hilmi et al. 2019; Hilmi et al. 2021a; Tam et al. 2009).

According to Domínguez-domínguez et al. (2019; Duncan et al. (2016) and Ysebaert et al. (2016), mangrove rehabilitation is promoted to improve the vegetation cover of deforested and degraded mangroves with the objectives to mitigate the impacts of conversion activities (Brander et al. 2012; Taillardat et al. 2018), to improve the ecosystem services (Cochard 2017; Hilmi et al. 2021b; Jakovac et al. 2020), and to develop economic activities, recreation, ecotourism, and others (Giri et al. 2015; Miettinen et al. 2016; Taher et al. 2012). In practice, mangrove rehabilitation activities require community participation, good government policies (Ruzol et al. 2020), and suitability and feasibility in terms of ecology, economic and social aspects (Yanuartanti et al. 2015; Zhang et al. 2021)

Mangrove rehabilitation efforts have been conducted on the north coast of Jakarta. These efforts are aimed to restore the functions of the mangrove ecosystem as a greenbelt to reduce the risk of seawater intrusion, land subsidence, tidal flooding (Bomer et al. 2020; Hilmi et al. 2017a; Marois and Mitsch 2017), as well as to sequester carbon for mitigating greenhouse gas emissions (Cameron et al. 2019) and economic benefits (Hilmi et al. 2019; Rachmawati et al. 2014). However, the major problem of mangrove planting in this area is the high mortality of the planted mangrove, especially in permanently water-inundated areas. Mangrove rehabilitation in areas with permanent water inundation needs specific methods other than the conventional techniques (Abdullah et al. 2014) to reduce the impact of inundated water (Yanuartanti et al. 2015; Ysebaert et al. 2016). As a consequence, mangrove rehabilitation in such areas requires significant effort and cost to increase the adaptation of planted mangrove to enhance the survival and growth rates in terms of height and diameter (Hilmi et al. 2017b; Hilmi 2018; Munji et al. 2013; Nur and Hilmi 2021).

The aquaponic system is a unique mangrove rehabilitation method by planting mangroves in permanently water-inundated areas using integrated approaches of restoration ecology, silviculture and environment, which aims to recover resilience and adaptive capacity of mangrove ecosystems to reduce the impact of water inundation and support coastal buffering from seawater flooding. The aquaponic system is an alternative technique of mangrove rehabilitation to reduce the impact of water inundation besides the gulud technique (Yanuartanti et al. 2015). The gulud technique is constructed to support mangrove planting of *Avicennia marina* and *Rhizophora apiculata* as main species with the spacing of 0.25 m x 0.25 m, 0.5 m x 0.5 m, and 1 m x 1 m. However, this system is costly. On the other hand, the the aquaponic system uses bamboo as planting media to support mangrove growth in areas with water inundation. There are two planting methods in the aquaponic system, i.e. a vertical and horizontal plantings. Vertical planting is a technique following vertical inundation of depth water, while horizontal planting is a technique following a horizontal layer of water inundation (0 cm, 20 cm, 40 cm, until 100 cm from bottom).

While it is promising as a mangrove rehabilitation approach, not much information is available regarding the effectiveness of aquaponic system of mangrove planting. Therefore, this research aims to analyze the survival rate (measured as living trees compared to the planted ones) of mangroves planted using vertical and horizontal aquaponic system in the north coast of Jakarta, and to investigate the correlation between physico-chemical environmental parameters and the survival and growth rates of the planted mangroves.

MATERIALS AND METHODS

Study area and period

This research was conducted on the north coast of Jakarta at four sites (high and permanently water inundation), namely mangrove preservation area, ecotourism area, arboretum area and Galatama rea (Figure 1 and Table 1) (Yulianti and Ariastita 2012) between 2020-2021. There were six observation stations across the studied sites, i.e.: mangrove ecotourism (station 1), Angke preservation 1 (station 2), Angke preservation 2 (station 3), Angke preservation 3 (station 4), Arboretum area (station 5) and Galatama Area (Tol Sediatmo) (Station 6).

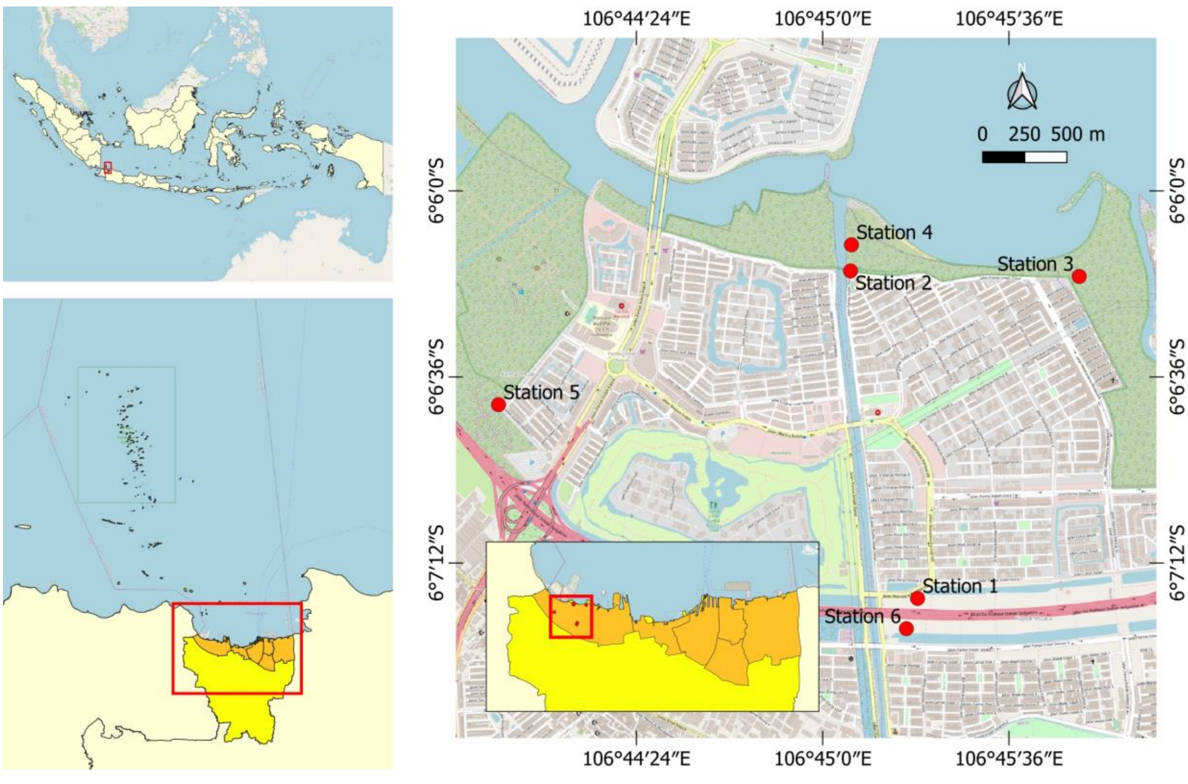

Figure 1. Map of the study area on the north coast of Jakarta, Indonesia (Hilmi et al. 2021a)

Table 1. Description of six observation stations across four study areas on the north coast of Jakarta, Indonesia

Stations	Site	Utilization of mangrove ecosystem	Coordinates	
			Latitude (S)	Longitude (E)
1	Mangrove ecotourism	Ecotourism area	06˚07’18.88”	106˚45’18.37”
2	Angke perservation 1	River preservation and greenbelt	06˚06'15.50"	106˚45' 05.41"
3	Angke preservation 2	River preservation and greenbelt	06˚06’16.556”	106˚45’49.608”
4	Angke perservation 3	River preservation and greenbelt	06˚06’16.614”	106˚45’49.619”
5	Mangrove arboretum	Tidal fooding	06˚06’41.386”	106˚43’57.374”
6	Galatama area	Greenbelt	06˚07’24.733”	106˚45’16.124”

Description of mangrove planting method

Vertical aquaponic system

The vertical aquaponic planting is developed to provide a vertical planting system to support mangrove growth in high water inundation areas using bamboo as planting media (Figure 2). This method can tolerate water inundation between 60 and 200 cm. Mangrove seedlings are planted vertically on the bamboo to support root growth and reduce the impact of water inundation. The number of bamboo sticks in this system is between 1100-5000 sticks/ha, while the number of mangrove seedlings is between 1650 and 7500 mangrove seedlings/ha. In this study, three species, *Rhizophora apiculata*, *Rhizophora mucronata*, and *Rhizophora stylosa*, were planted in the vertical aquaponic system.

Horizontal aquaponic system

The horizontal aquaponic system also used bamboos to reduce the impact of tidal inundation and provide planting media for mangrove seedlings (Figure 3). The bamboos are arranged horizontally with a height of 0 cm, 20 cm, 40 cm, 60 cm, 80 cm, and 100 cm from the bottom of the water inundation. One layer of bamboo has a length between 1 and 3 meters, and the mangrove seedlings can be planted every 25 cm in the bamboo layer. In this study, five mangrove species were planted in this system, namely *R. apiculata*, *R. mucronata* and *R. stylosa*, *Sonneratia alba* and *A. marina*.

Figure 2. Vertical aquaponic system in mangrove planting

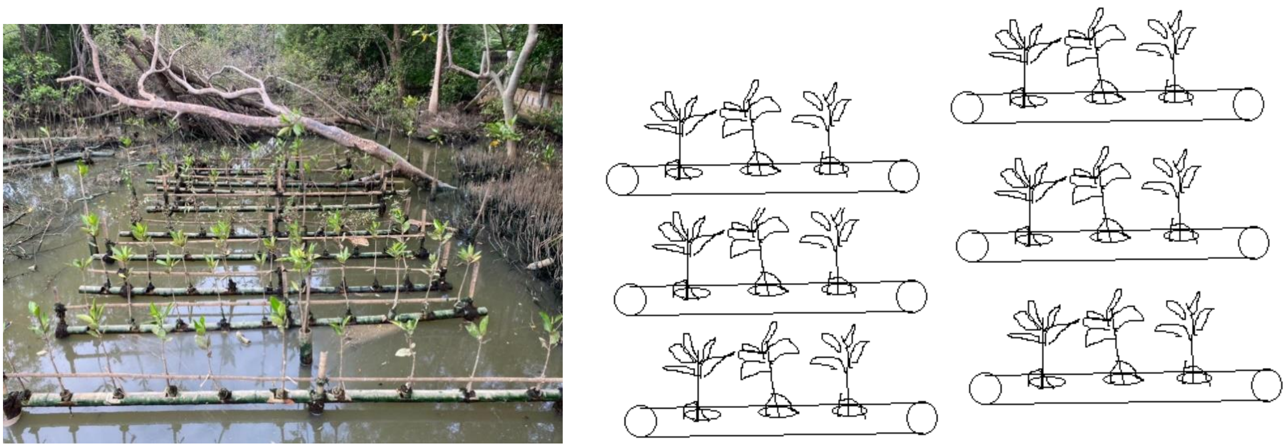

Figure 3. Horizontal aquaponic system in mangrove planting

Data collection procedure

Physical and chemical parameters

The physical and chemical parameters of the water and soil in the studied sites were measured as presented in Table 2 (De Valck and Rolfe 2018; Hilmi et al. 2020; Lunstrum and Chen 2014). The physical and chemical parameters data were collected from six stations, each station with three samples plots and each plot consisted three replicates. In total, there were 54 samples analyzed.

The survival rate of planted mangrove

The survival rate (living trees) was calculated using the formula below (Hilmi et al. 2015; Kusmana and Maulina 2015).

$$\text{Survival rate (living trees) (\%)} = \frac{\textit{living trees}}{\textit{tree planting}}\ x\ 100\%$$

Besides the survival rate, the root growth rate of the planted mangrove was also measured.

Growth rate of planted mangrove (height, in cm/month)

The growth rate of planted mangroves was calculated by the equation below:

$$\text{The rate growth of height} = h_t - h_{t-1}$$

Where:
h_t = (mangrove height t year)
h_{t-1} = (mangrove height t-1 year)

Data analysis

Data analysis was carried out using (a) correlation analysis between environmental factors and survival rates of the planted mangrove (%); and (b) tabulation data and graphics (Njana 2020; Willard 2020). This data analysis was used to describe the growth and survival rates of mangrove plants in each planting system.

RESULTS AND DISCUSSION

Physical and chemical parameters

The physical and chemical parameters of the mangrove ecosystem in the studied area on the north coast of Jakarta are shown Table 3. The area had water temperature between 25.0-30.5ºC, water salinity between 6.0-7.5 ppt, water pH of 5.0-6.4, soil pH between 6.0-7.0 with a muddy clay texture, soil nitrate of 11.5-14.5 mg/l, soil phosphate between 8.2-16.0 mg/l and soil pyrite of 1.0-3.0%. This data is not different from Hilmi et al. (2021a) which reported that the mangrove ecosystem in Segara Anakan had physical and chemical properties of soil nitrate between 10.0-22.0 mg/l, soil pH between 5.7-6.92, soil texture of clay, loam, loamy clay, mud and mud clay, soil phosphate between 6.85-17.65 mg/l, soil pyrite between 1.03-3.10%, water pH between 5.6-7.07, and water salinity between 0-40 ppt. These conditions show that both studied sites on the north coast of Jakarta and Segara Anakan had a similarity of environmental factors to support mangrove growth.

According to Shiau et al. (2017) and Yang et al. (2008), basically, the potential soil fertility in North Jakarta had phosphate and nitrate at a moderate level and pH was neutral. Therefore, the environmental data (salinity, pH, nitrate, phosphate, and soil texture) suggest that the studied area in north Jakarta had good suitability for supporting mangrove growth (Abdelhakeem et al. 2016; Barreto et al. 2016; Hilmi et al. 2020; Hilmi et al. 2017a; Hilmi et al. 2021b; Tam et al. 2009). Based on the salinity level, the water studied on the north coast of Jakarta could be defined as brackish water (Djohan 2012; Hilmi et al. 2021a; Kusmana and Maulina 2015; Wang et al. 2019). Furthermore, the data of nitrate and phosphate also indicated that the mangrove ecosystem had good fertility to support mangrove growth (Sharafatmandrad and Mashizi 2020).

Table 2. Physical and chemical parameters measured and method of analysis used in this study

Physical and chemical parameters	Unit	Tool/method	Sources
Temperature	°C	Thermometer	APHA (2005)
Salinity	Ppt	Hand refractometer	APHA (2005)
pH	Unit	pH meter	APHA (2005)
Soil texture	%	Gravimetric	APHA (2005)
Pyrite (FeS_2)	mg/L	Spectrofotometric	Spectrofotometric method
Nitrate (NO_3)	mg/L	Brussin Spectofotometric	Spectrofotometric method
Phosphate (PO_4)	mg/L	Absorbic acid	ACS publication

Table 3. Physical and chemical parameters of mangrove ecosystem in the north coast of Jakarta

Sta tion	Temp. (ºC)	Water salinity (ppt)	Water pH	Soil pH	Soil texture	Nitrate (mg/l)	Phos phate (mg/L)	Pyrite (%)	Inundation (cm)
1	26.5-28.5	6.0-6.5	5.0-5.8	6.0-6.7	Clay -muddy clay	13.0-13.7	8.2-9.0	1.0-1.3	20-50
2	25.5-29.5	7.1-7.5	6.0-6.1	6.1-6.9	Clay -Muddy clay	14.2-14.5	11.5-12.0	2.5-3.0	50-200
3	25.5-29.5	6.0-6.8	5.8-6.4	6.1-6.8	Clay -Muddy clay	11.7-12.0	13.1-13.5	2.5-3.0	50-200
4	25.0-28.5	7.3-7.5	5.5-6.4	6.5-7.0	Clay -Muddy clay	14.7-15.0	12.9-13.3	1.7-2.0	50-200
5	25.0-28.7	6.7-7.0	5.0-6.4	6.1-6.8	Clay -Muddy clay	12.2-13.0	15.0-16.0	1.4-2.0	50-200
6	26.0-30.5	7.1-7.5	5.0-6.4	6.1-7.0	Clay -Muddy clay	11.5-12.0	11.5-12.0	2.0-2.5	30-60

The survival rate of mangroves planted in the vertical aquaponic system

Planting in the vertical aquaponics system is developed to reduce the impact of highly tidal inundation which provides different survival and growth rates than the direct planting system. The root growth and survival rate (% of living trees) of mangroves planted in vertical aquaponic systems versus direct systems can be seen in Table 4. The survival rate of mangroves planted in a vertical aquaponic system one year after planting ranged from 66.0-84.7%, while the direct planting system without vertical bamboo media had a survival rate of 13.5-48.5%. The root growth rate of mangroves planted in the vertical aquaponic system was between 15 - 80 %. The majority of mangroves planted in the vertically aquaponic system had excellent survival rate and root growth because the vertical aquaponic system protects the planted mangroves from permanent water inundation (Bullock et al. 2017; Domínguez-domínguez et al. 2019; Hilmi et al. 2021b).

High and permanent water inundation negatively impacted on the survival rate of mangroves planting which can be inferred from the average of survived trees of direct planting in permanent water inundation compared to those of vertical aquaponic system. High and permanent water inundation in direct planting systems caused high mortality, stunting growth, lower biodiversity and trigger of species domination. Nur and Hilmi (2021) and Hilmi et al. (2021a) explained that tidal waves and water inundation primarily affect mangrove growth. Water inundation is caused by water dynamics occurring due to river discharge and tidal waves (Hilmi et al. 2017a; Suhendra et al. 2018). Basically, water inundation requires a unique adaptation of mangrove vegetation to its environment (Leng and Cao 2020). Tidal inundation patterns influence mangrove zoning patterns, affinity and clustering (Hilmi et al. 2021b; Leng and Cao 2020; Owuor et al. 2019), degradation and potential of biodiversity (Owuor et al. 2019), the structure of the mangrove ecosystem (Leng and Cao 2020; Njana 2020), growth and productivity (Njana 2020).

The survival rate of mangroves planted in the horizontal aquaponic system

The survival rate of mangroves planted in the horizontal aquaponic system is presented in Table 5. Horizontal aquaponic is an alternative for mangrove rehabilitation in inundated areas other than gulud system (Yanuartanti et al. 2015) and vertical aquaponic method. This method is much cheaper than the two rehabilitation techniques. The horizontal aquaponic system only costs around 50-85 Indonesian Rupiahs (IDR) per ha compared to the vertical aquaponic system with 85-150 million IDR/ha and gulud system with 1-2 billion IDR/ha.

In this study, the horizontal aquaponic system was developed to reduce the impact of permanent inundation on the planted *R. mucronata*, *R. apiculata*, *R. stylosa*, *A. marina* and *Sonneratia caseolaris*. The data showed that the planting system of 80 and 100 cm from the bottom had the highest survival rate between 62-89% compared to the planting system with a depth of 0 to 60 cm with only survived plants between 0-35 %. Mangroves planted directly in the bottom of flooded areas had the lowest survival rates than a horizontal and vertical aquaponic system. The data also showed that *Rhizophora* spp. and *A. marina* had the best survival rate when planted in the horizontal aquaponic system due to its unique and good adaptation ability in reducing the impact of high and permanent water inundation (Hilmi et al. 2021a; Yanuartanti et al. 2015).

Table 4. Survival rate (percent of survived trees and mortality) and root growth of mangroves planted in the vertical aquaponic system versus direct planting.

Station	Vertical aquaponic system			Direct planting system	
	Survived plants (%)	Mortality (%)	Root growth (%)	Survived plants (%)	Mortality (%)
1	75.0-93.8	6.2-25	15-25	15.0-67.8	33.2-85.0
2	66.7-96.9	3.1-33.3	30-40	15.4-61.2	38.8-84.6
3	69.5-86.4	13.6-30.5	50-60	10.2-51.7	48.3-89.8
4	57.8-69.9	30.1-42.2	70-80	13.2-52.5	47.5-86.8
5	71.5-89.7	10.3-28.5	60-75	-	-
6	55.4-71.5	28.5-44.6	75-80	-	-
Average	66.0-84.7	15.3-34.0	50.0-60.0	13.5-48.5	39.8-86.5

Table 5. Survival rate (percent of survived trees) of mangroves planted in the vertical aquaponic system versus direct planting

Planting position (cm)	Survived plants (%)				
	Rhizophora mucronata	*Rhizophora apiculata*	*Rhizophora stylosa*	*Avicennia marina*	*Sonneratia caseolaris*
0 (direct planting)	0-2	0-3	0-2	0-2	0-1
20	5-10	6-11	4-10	4-8	4-8
40	5-15	5-15	5-15	5-10	5-9
60	11-40	11-39	10-35	10-25	10-24
80	70-83	72-85	72-85	60-75	60-74
100	74-89	76-90	75-89	63-78	62-77

Table 7. Correlation between environmental factors and mangrove growth in the aquaponic rehabilitation system

	Temperature	Water salinity	Soil salinity	Water pH	Soil pH	Nitrate	Phosphate	Pyrite
Temperature	1							
Water salinity	-0.02337	1						
Soil salinity	0.03286	0.880229	1					
Water pH	-0.15457	0.37467	0.687271	1				
Soil pH	-0.30391	0.795494	0.864736	0.452754	1			
Nitrate	-0.56592	0.410441	0.313013	0.164777	0.478449	1		
Phosphate	-0.49393	0.298327	0.318708	0.491381	0.3323	-0.15758	1	
Pyrite	0.317254	0.324329	0.602198	0.867862	0.17818	-0.16565	0.311892	1
Survival rate	-0.14724	-0.66361	-0.74117	-0.18515	-0.82787	0.006529	-0.19086	-0.12717

Note: The shaded text shows a high correlation

Table 6. Distribution of mangrove height and height growth rate of planted mangrove in the the aquaponic system

Height class (cm)	Composition (%)	Height growth rate (cm/month)
40-60	3.5	1.60
60-80	26.7	0.95
80-100	39.1	1.11
100-120	9.4	1.43
120-140	7.9	2.33
140-160	13.4	2.17

Height class and height growth rate of mangroves planted in aquaponic system

The mangroves planted in the aquaponic system were grouped based on height classes as presented in Table 6. Table 6 showed that the average height growth of mangrove planting reached 1.6 cm/month (range between 0.95-2.33 cm/month). This result suggests the potential of mangrove growth in the aquaponic rehabilitation system in which mangroves must have sufficient height growth as an adaptation in permanent water inundation (Hilmi et al. 2021c; Lu et al. 2013).

Basically, the permanent and high water inundation are important factors of mangrove species to develop adaptation ability to reduce the impact of water inundation. The height growth correlates with the ability of mangroves to support root growth which affects the ability of mangroves in getting oxygen supply to support root respiration and metabolism. Mangroves need oxygen supply in anaerobic conditions as a major growth inhibitor (Asaeda and Barnuevo 2019; Dai et al. 2018).

Correlation between environment factors and mangrove growth

Correlation analysis of environmental factors showed that temperature, pH and salinity had a high impact on supporting mangrove growth (Table 7).

Soil salinity, soil temperature, soil water pH, soil pH, and soil texture strongly influenced mangrove growth (Hilmi et al. 2020). Similarly, nitrate and phosphate also greatly influence to support mangrove growth in West and East Segara Anakan (Ariani et al. 2016; Hilmi et al. 2019a; Neal et al. 2018). In contrast, pyrite is an inhibitor of mangrove growth (Barreto et al. 2016). However, in this study, only salinity, pH and temperature were essential in supporting mangrove growth. Mangrove vegetation needs specific adaptation to reduce the impact of water salinity and water inundation with the activity of excreting, accumulating and reducing the salinity. Mangrove also develops pneumatophore root to reduce the impact of the anaerobic condition, because of the high and permanent water inundation.

In conclusion, the mangrove rehabilitation area on the north coast of Jakarta had high water inundation, which reached 200 cm. The vertical and horizontal aquaponic systems developed to reduce the impact of water inundation provided a higher growth rate and survival rate than the direct planting system. Planting mangroves using the horizontal aquaponic system at 80 and 100 cm from the bottom had the highest survival rate compared to planting at 0 to 60 cm. *Rhizophora* spp. and *Avicennia marina* had high adaptability to support vertical and horizontal aquaponic systems. Water salinity, soil salinity and water pH correlated in supporting mangrove growth and survival in the aquaponic system.

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