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Abstract

Information concerning the functionality of mangrove within silvofishery ponds is needed, especially relating to the accumulation rate of organic materials and nutrients. This research studied the effect of mangrove structure on the accumulation rate of nutrients within silvifishery ponds. The research, conducted in May 2016, used canals of width 1, 2, and 3 m, with mangrove species *Avicennia marina* and *Rhizophora mucronata*, alone or in combination. Nutrients measured were nitrogen, phosphorus and organic matter, in the sediment of the treatment ponds, through soil sampling followed by laboratory analysis. The respective analysis methods used were Kjehdahl, spectrophotometry, and ashing. Data analysis was conducted using factorial ANOVA. The highest nitrogen concentration was detected in the treatment with 15 stands of mixed mangrove species (0.63 ± 0.04 %), the treatment with 10 stands of mixed mangroves showed the highest phosphorus concentration (62.86 ± 12.31 mg/kg), and the highest organic matter concentration (2.55 ± 0.67 %) was seen with 10 stands of *R. mucronata*. The highest average value based on partial group showed that *R. mucronata* had the highest nitrogen accumulation at 0.56 ± 0.07 %; for phosphorus, the mixed species pond (62.02 ± 7.84 mg/kg); and for organic matter, *R. mucronata* (2.41 ± 0.39 %).

Abstrak

Akumulasi Nutrien dalam Sedimen Tambak Wanamina di Kota Semarang. Informasi mengenai fungsi mangrove dalam tambak wanamina dibutuhkan, khususnya terkait dengan laju akumulasi bahan organik dan nutrien. Penelitian ini mempelajari pengaruh struktur mangrove terhadap laju akumulasi nutrien dalam tambak wanamina. Penelitian ini dilakukan pada bulan Mei 2016, dengan menggunakan lebar saluran 1, 2, dan 3 m, dengan spesies mangrove *Avicennia marina* dan *Rhizophora mucronata*, baik secara tunggal maupun kombinasi. Nutrien yang diukur meliputi nitrogen, fosfat dan bahan organik, dalam sedimen tambak perlakuan melalui pengambilan sampel yang dilanjutkan dengan analisis laboratorium. Metode analisis yang digunakan masing-masing yaitu Kjehdahl, spektrofotometri, dan pengabuan. Analisis data dilakukan dengan ANOVA faktorial. Konsentrasi nitrogen paling tinggi terdeteksi pada perlakuan dengan 15 tegakan mangrove campuran ($0{,}63 \pm 0{,}04$%), sedangkan perlakuan dengan 10 tegakan mangrove campuran menunjukkan konsentrasi fosfat paling tinggi ($62{,}86 \pm 12{,}31$ mg/kg), dan konsentrasi bahan organik tertinggi ($2{,}55 \pm 0{,}67$%) teramati pada perlakuan dengan 10 tegakan *R. mucronata*. Nilai rerata paling tinggi dari masing-masing kelompok nutrien menunjukkan bahwa pada perlakuan *R. mucronata* terdapat akumulasi nitrogen paling tinggi sebesar $0{,}56 \pm 0{,}07$%; fosfat pada perlakuan campuran sebesar $62{,}02 \pm 7{,}84$ mg/kg, dan bahan organik pada *R. mucronata* sebesar $2{,}41 \pm 0{,}39$%.

Keywords: abundance, mangrove species, nitrogen, organic matter, phosphorus

Introduction

The integration of mangroves within fish ponds, known as silvofishery, is intended to exploit the benefits of the ecosystem they create to achieve a balance of aquaculture activities and environment sustainability [1]. Coastal environments have been degraded through the conversion of land to fish ponds [2], and this will lead to a decrease in the carrying capacity of coastal ecosystems, especially for fisheries [3]. Various long-term negative impacts have been seen following unsustainable management of coastal areas, such as soil erosion and coastal flooding [4], limiting the scope for sustainable aquaculture activities.

Attempts have been made to use silvofishery to reclaim the lost and damaged land, not just for aquaculture [5], but this has not proved easy. Land reclamation through mangrove planting has faced difficulties, a major prob-

lem being the low survival rate of planted mangrove [6], a problem also seen in the application of the silvofishery pond system to fish culture.

Mangrove ecosystems provide various benefits in aquatic systems, the main being acting as the source and controlling agent of nutrient distribution and pollutant assimilation [7]. Complex mangrove root systems slow water flow, improving sedimentation rates [8]. Generally, sediment particles consist of a wide variety of components, including nutrients, but also chemical pollutants both organic and inorganic (such as heavy metals) [9]. The reduction in the rate of water flow caused by mangrove root systems can limit the nutrient and pollutant flow into the aquatic system [10].

Mangroves have a role as producers of organic nutrients [11], mainly in the form of leaf litter, the main source of organic matter in the ecosystem [12]. The decomposition of mangrove litter produces huge amounts of nutrients which support the various fauna associated with mangroves, such as crab, fish, shrimp, etc. [13]. Although the production of nutrients is large, the distribution of those nutrients to the surrounding aquatic system remains controlled, most being reabsorbed by the mangroves for growth requirements [14].

The integration of mangroves in silvofishery ponds is based on utilizing their environmental control capabilities [15]. Mangrove stands are expected to be able to manage pollutants through their root systems, hence water quality should be improved, reducing any negative impact on fish cultivation. The nutrients produced by mangrove stands are expected to support the livelihood of the fish as well. However, the development of stable ecosystems takes a significant amount of time. Past experience shows that seedling mortality is frequently high, leaving few well grown stands. The expectation that mangroves could fulfill their role as environmental service and nutrient provider within a short period is optimistic. Even so, the presence of mangrove stands in the pond canals should confer some advantages (in maintenance of water circulation and control of nutrient and pollutant distribution), although the competition between the mangroves and cultivated stock for nutrients is undeniable.

Planting mangroves in silvofishery ponds means changing the pond structure itself. The presence of mangroves affects the effective size of the embankment, and changes the pattern of water circulation, nutrient distribution, etc. An important factor to consider is the change in the nutrient cycle due to water fertility. Accumulation of nutrients in the surrounding mangrove stand is an indicator of mangrove function in controlling nutrient availability in the water. This needs to be considered in pond management, since the input water generally contains a high concentration of nutrients, whether from the land or from the sea. High nutrient concentrations are liable to harm the biota through eutrophication, yet the role of mangroves in accumulating nutrients is often ignored, especially during the early development of the pond when the mangrove seedlings are still vulnerable to ecological disturbances.

Semarang City is a region where the application of silvofishery in aquaculture is increasing. The coastal regions of Semarang City are experiencing intense disturbance from industrial and anthropogenic activities dramatically increasing nutrient supplies, leaving the local aquaculture activity vulnerable to the effects of "hypernutrition." As yet, the accumulation of nutrients in ponds is not well understood in relation to silvofishery development, and research is necessary to study nutrient accumulation, especially under mangrove stands developed in the coastal area of Semarang City. This research aimed to study nutrient accumulation and to analyze the effect of plantation structure on variations in nutrient accumulation under mangrove stands in silvofishery ponds.

Materials and Methods

Our research was conducted in May 2016 at a one-year-old silvofishery pond located in the coastal area of Semarang City. The mangrove stands in the silvofishery pond were in the seedling stage and, owing to a low mangrove survival rate, replantation was conducted repeatedly to maintain the pond development. The ponds contained two structures; embankments and canals. Each pond block had one embankment and two canals, one (inlet) canal located before and one (outlet) canal after the embankment. Mangrove seedlings were planted in the canals. The generalized design of a pond is shown in Figure 1.

Nine variations of silvofishery structure were applied, involving combinations of different mangrove species and variations in mangrove abundance (population). The mangrove species used were *Avicennia marina* and *Rhizophora mucronata,* alone or in combination. Mangrove plantation abundance was 5, 10, and 15 stands with a plantation density of 1 stand/m^2, grown in 5 m-long canals of width 1, 2, and 3 m. Embankment size was 5 x 5 m. The detailed design of the treatment ponds is shown in Figure 2.

Data collection was conducted through field sampling on May 21st, 2016, followed by laboratory analysis to determine the concentration of nutrients in the water surrounding the mangrove stands. Organic matter, nitrogen and phosphorus were measured by ashing, Kjehdahl, and spectrophotometry, respectively. Samples were taken in triplicate for each parameter. Factorial ANOVA was used to analyze the significance of nutrient accumulation rate difference for each treatment, partially or simultaneously.
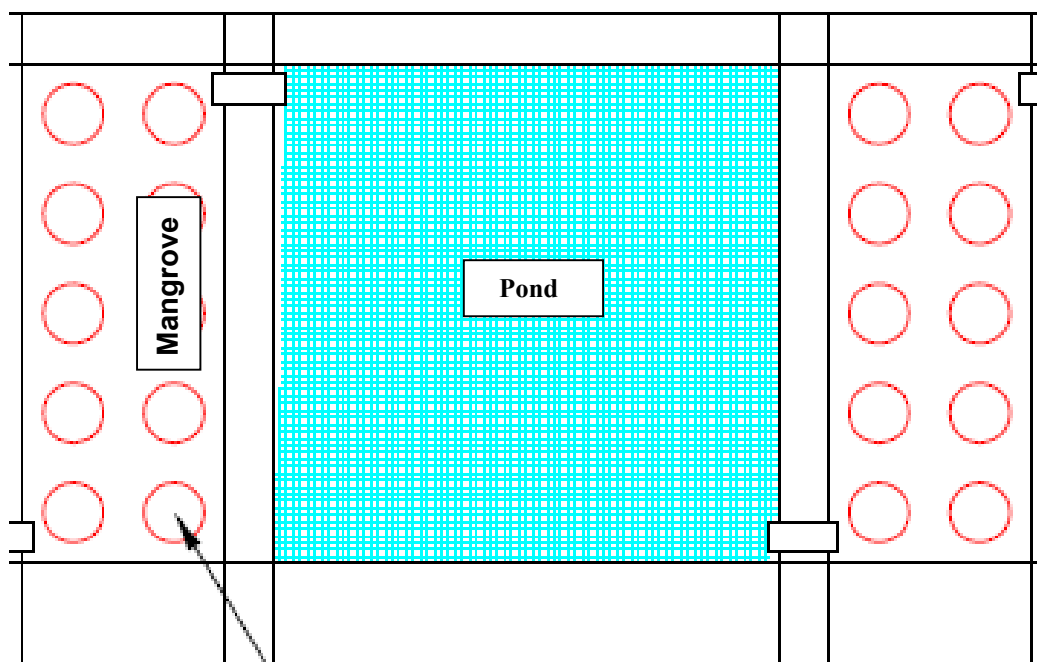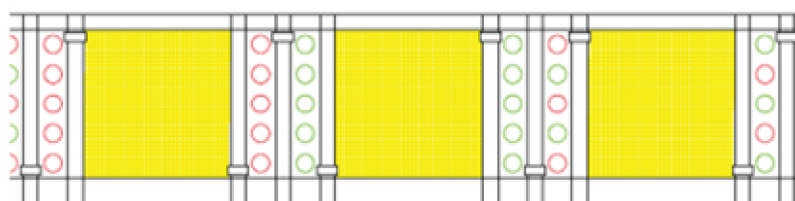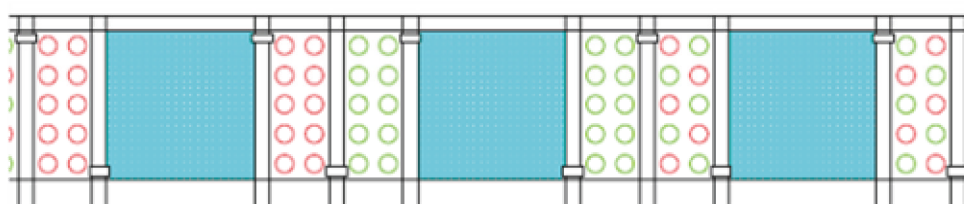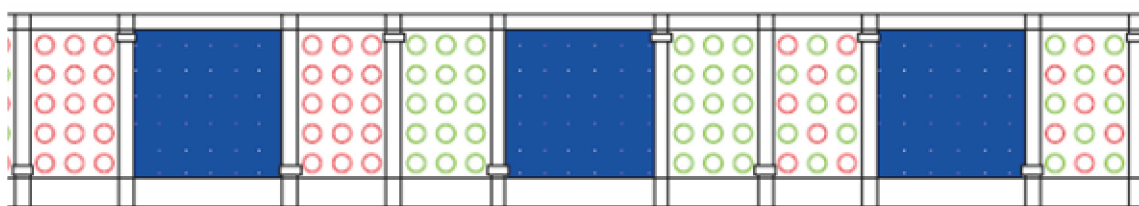
Figure 1. Design of Silvofishery Pond

Ponds with 1 m canal width
(5 stands of mangrove)

Ponds with 2 m canal width
(10 stands of mangrove)

Ponds with 3 m canal width
(15 stands of mangrove)

Figure 2. Treatment Design

Results and Discussion

The result showed variations in nutrient concentration between treatments. Data filtering based on mangrove species or stand abundance showed there were partial differences in nutrient concentration in the sediment. Results of the detailed analysis of the average concentration of nutrients, including nitrogen, phosphorus, and organic matter in the sediment within silvofishery pond canals, is presented in Tables 1–3.

Results showed that the lowest average value for nitrogen concentration (0.46 ± 0.07%) was in the treatment with 10 seedling stands of *A. marina*, while the highest value was achieved in the treatment with 15 seedling stands of mixed mangrove species (0.63 ± 0.04%). Data filtering based on stand abundance showed that the greater the seedling abundance the higher the level of accumulated nitrogen; 5 stands: 0.52 ± 0.06%, 10 stands: 0.53 ± 0.08%, 15 stands 0.56 ± 0.07%. Results for species composition showed that canals with *R. mucronata*

had the highest nitrogen concentration (0.56 ± 0.07%), and *A. marina* stands the lowest (0.50 ± 0.06%).

Data analysis with ANOVA showed that there were no significant effects individually for either stand abundance or mangrove composition on the concentration of nitrogen in the sediment. Statistical analysis showed F value of 1.064 with $p = 0.366$ ($p > 0.05$) for the treatment of stand abundance, and F value of 2.092 with $p = 0.152$ ($p > 0.05$) for treatment of species composition. Factorial ANOVA analysis showed there was significant effect of combined treatments on the nitrogen concentration within the sediment, with F value of 3.439 with $p = 0.030$ ($p < 0.05$). The significance of nitrogen concentration difference among treatments is shown in Table 1.

Results for concentration of phosphorus showed that, generally, pond canals with mixed mangrove species accumulated phosphorus better than treatments with *A. marina* and *R. mucronata* alone. Based on the composition of mangrove species, the accumulation of phosphorus

Table 1. Variations in Nitrogen Concentration (%)

		Mangrove Species			Average by Stand Abundance
		A. marina	*R. mucronata*	Mixture	
Stand Abundance	5 stands	0.54 ± 0.06	0.53 ± 0.09[a]	0.49 ± 0.06[b]	0.52 ± 0.06
	10 stands	0.46 ± 0.07[c]	0.61 ± 0.05[bc]	0.53 ± 0.04	0.53 ± 0.08
	15 stands	0.51 ± 0.06[d]	0.53 ± 0.06	0.63 ± 0.04[abcd]	0.56 ± 0.07
Average by Mangrove Species		0.50 ± 0.06	0.56 ± 0.07	0.55 ± 0.08	

Notation: cells with similar letter showed significant difference

Table 2. Variations in Phosphorus Concentration (mg/kg)

		Mangrove Species			Average by Stand Abundance
		A. marina	*R. mucronata*	Mixture	
Stand Abundance	5 stands	52.01 ± 10.53	44.21 ± 4.31	62.09 ± 5.56	52.77 ± 10.02
	10 stands	50.57 ± 9.14	62.34 ± 5.30	62.86 ± 12.31	58.59 ± 10.10
	15 stands	53.49 ± 14.07	54.41 ± 5.45	61.10 ± 7.80	56.33 ± 9.22
Average by Mangrove Species		52.02 ± 9.99	53.65 ± 9.00	62.02 ± 7.84	

Notation: cells with similar letter showed significant difference

Table 3. Variations in Organic Matter Concentration (%)

		Mangrove Species			Average by Stand Abundance
		A. marina	*R. mucronata*	Mixture	
Stand Abundance	5 stands	2.34 ± 0.13	2.47 ± 0.23	2.18 ± 0.10	2.33 ± 0.19
	10 stands	2.04 ± 0.19	2.55 ± 0.67	2.28 ± 0.06	2.29 ± 0.41
	15 stands	2.25 ± 0.19	2.20 ± 0.03	1.93 ± 0.04	2.13 ± 0.18
Average by Mangrove Species		2.21 ± 0.20	2.41 ± 0.39	2.13 ± 0.17	

Notation: cells with similar letter showed significant difference

in the mixed treatment was 62.02 ± 7.84 mg/kg, while the accumulation of phosphorus in the treatments with *A. marina* and *R. mucronata* alone was lower at 52.02 ± 9.99 mg/kg and 53.65 ± 9.00 mg/kg, respectively. Based on stand abundance, the treatment with 10 stands accumulated phosphorus most effectively (58.59 ± 10.10 mg/kg), while the treatment with 5 stands showed the lowest accumulation (52.77 ± 10.02 mg/kg). Considered in combination, the lowest accumulation level (44.21 ± 4.31 mg/kg) was seen for 5 stands of *R. mucronata*, while the highest accumulation was achieved with 10 stands of mixed mangrove species (62.86 ± 12.31 mg/kg).

Statistical analysis showed that there were no significant effects individually for mangrove composition or stand abundance on the accumulation of phosphorus in sediment, and no significant effects using factorial ANOVA. Analysis showed F value of 0.980 with p = 0.395 (p > 0.05) for seedling abundance treatment, F value of 3.270 with p = 0.061 (p > 0.05) for species composition treatment, and 1.132 with p = 0.373 (p > 0.05) for the combined treatments.

Results for organic matter concentration showed that pond canals bordered by 10 stands of *R. mucronata* demonstrated the highest accumulation level compared to any other treatment (2.55 ± 0.67 %), while the treatment with 15 stands of mixed composition had the lowest level (1.93 ± 0.04%). Pond canals bordered by *R. mucronata* also had the highest average accumulation rate (2.20 ± 0.03%), while the mixed composition provide the lowest average value (2.13 ± 0.17%). For stand abundance, results showed that the higher the abundance the lower the accumulation level of organic matter. Pond canals bordered by 15 stands of mangrove accumulated organic matter with an average value of 2.13 ± 0.18%, while the value in canals bordered by 5 stands of mangrove was 2.33 ± 0.19%.

Statistical analysis with factorial ANOVA showed there were no significant effects of the treatments individually or combined. The analysis showed F value of 1.566 with p = 0.236 (p > 0.05) for seedling abundance, F value of 2.776 with p = 0.089 (p > 0.05) for species composition, and F value of 1.257 with p = 0.323 (p > 0.05) for combined treatments.

Nutrients play a key role in mangrove ecosystems. Although mangrove stands don't grow optimally in the coastal area, their existence contributes to the control of nutrients in the aquatic system [8]. The results of our research indicate that mangrove stands could be utilized in controlling the distribution of nutrients, especially nitrogen, within silvofishery ponds. The establishment of a mangrove seedling is controlled to a large extent by the development of its root system; if root growth proceeds normally, then satisfactory growth of the trunk follows, and a stand is established. The complex physi-

cal structure of the mangrove root system also plays an important role in controlling the distribution of nutrients [8], as well as reducing the flow rate of surrounding water, enhancing sedimentation rates.

Although mangrove root systems vary among species, most exhibit a common specific feature, the aerial roots known as pneumatophores [16]. *A. marina* and *R. mucronata* have different root formation and size but both root types possess similar functions. The advantages of planting mangroves in silvofishery ponds are seen even at low density, and the root system will provide a physical structure creating favorable rate of water flow.

Reports have shown that variations in nutrient levels within silvofishery pond canals is affected by differences in mangrove species composition and in stand abundance [17,18]. The species composition defines the barrier characteristics developed by the mangrove root systems, with bigger, taller, and denser systems inhibiting water flow more; stand abundance also affects water flow [19]. Higher accumulation rate should be achieved from a wider canal due to its slower current. Our results for nitrogen concentration show that an increase in seedling abundance results in a higher nitrogen concentration in the sediment. However, the inverse was found for organic matter analysis; a higher seedling abundance resulted in a lower level of organic matter accumulation in the sediment, and although the difference was not significant, it is a factor that could be considered in the management of silvofishery ponds.

Results for the accumulation of nutrient based on mangrove species composition showed that *R. mucronata* exhibited the highest values for nitrogen and organic matter, while a combination of *A. marina* and *R. mucronata* exhibited the highest values for phosphorus. The physical complexity of the root system and the total basal area covered by the stands influence sedimentation within mangrove ecosystems [20]. A higher basal area and greater root system complexity provide more of an obstacle to water flow, thus increasing the sedimentation rate. In *R. mucronata* stands, both trunk size and roots are larger than *A. marina*, as we considered these to be the factors producing the high accumulation level of nutrients within pond canals occupied by *R. mucronata*.

The accumulation of nutrients in the sediment is influenced not only by the physical attributes of the mangrove stands but also by the rate of uptake of nutrients by the mangrove plants; the actual accumulation level of nutrients is therefore the difference between the gross accumulation rate and uptake rate by the mangroves [17]. This leads to the fluctuation of nutrient concentration under mangrove stands [18]. In this study, the concentration of nitrogen was affected significantly by some

of the permutations of species and stand abundance, but not the concentration of phosphorus or organic matter.

Our research showed that a one-year-old silvofishery pond exhibited useful functionality in controlling nutrient concentrations, to a significant level for nitrogen accumulation in the sediment but also, to a lesser extent, for phosphorus concentration and organic matter. Some trends were noted, such as the increasing accumulation rate of nitrogen with an increase in abundance of *R. mucronata*, and the decreasing accumulation rate of organic matter with an increase in abundance of *R. mucronata*. Pond canals occupied by *R. mucronata* were observed to have the highest accumulation level for nitrogen and organic matter compared to any other mangrove compositions. Further research is required on how the nutrient release rates and levels are influenced by the pond embankments to better understand the impact on pond fertility. That research should also take into account biotic factors (such as plankton as an aquatic fertility indicator, and as the natural food source for the cultivated species) in order to understand the impact of silvofishery design on pond productivity.

Conclusion

This research proved that the structure of silvofishery pond, especially the application of species composition and stand abundance could be utilized to control the distribution of nutrient in the pond. Variation of mangrove species and abundance affects the accumulation rate of nutrients, especially nitrogen, within silvofishery ponds. The accumulation of nitrogen and organic matter was highest in canals with *R. mucronata* stands (with an average concentration of $0.56 \pm 0.07\%$ and $2.41 \pm 0.39\%$, respectively) while the accumulation of phosphorus was highest in the treatment with mixed mangrove composition (average concentration 62.02 ± 7.84 mg/kg).

Acknowledgments

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