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INCREASING RISK OF HEAVY METAL CONTAMINATION IN SILVOFISHERY PONDS

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Abstract

This research aims to observe the concentration of organic matter, Pb and Cd in a silvofishery pond, to study the toxicity level status, to analyze changes in their concentration within a year's period, and to analyze the correlation between the concentration and changes. The research was conducted through field observation and laboratory analysis from May 2016 to July 2017, which included five observation activities. Statistical analysis was conducted by using ANOVA and correlation tests. The results show that the concentration of organic matter, Pb and Cd, was increasing in all five observations. Throughout the research, the ranges of organic matter, Pb and Cd, were recorded at 1.60–3.30 mg/kg, 3.130–8.230 mg/kg, and 1.089–2.820 mg/kg, respectively. In all observations, toxicity level showed that Cd concentration in the sediment had exceeded the standards recommended by US EPA (≤1.0 mg/kg) and ANZECC & ARMCANZ (≤1.5 mg/kg), while Pb was within the safe range (≤21 mg/kg and ≤50 mg/kg). The correlation analysis showed that the concentration and accumulation of Pb and Cd were highly related, which indicated the possibility of the same pollutant sources. Recommendations for a better management plan to avoid heavy metal accumulation in silvofishery ponds would include the arrangement of mangrove plants in inlet canals and periodic pruning to hinder heavy metal from returning to the environment through litter fall.

Keywords: aquatic toxicology, bioremediation, cadmium, heavy metal, sediment chemistry, silvofishery

INTRODUCTION

Silvofishery has been applied to support aquaculture activities by emphasizing its environmental services (Suwarto et al. 2015). The Silvofishery system integrates mangrove plants into ponds to hinder environmental pollution caused by its effluent (Hastuti and Budihastuti 2016). The existence of mangrove plants is also expected to improve natural primary productivity because of nutrient cycling by mangrove vegetations (Budihastuti et al. 2013).

Mangrove plays an important role in controlling aquatic pollutants in the coastal ecosystem. Sediment which contains pollutants such as organic material and heavy metal can be trapped by mangrove rooting (Yunus et al. 2011). Thus, the concentration of pollutants in the aquatic system could be reduced. Mangrove plants are also capable of absorbing pollutants from the environment and accumulating them in certain organs, and this function is known as bioremediation (Pakzadtoochaei 2013). Thus, in addition to controlling pollutant distribution, mangrove also remediates its growing environment.

Mangrove roots may trap sediment which contains various types of pollutants. The trapped sediment is then suspended around the tree. Thus, as pollutants accumulate, their concentration below the mangrove stands increases (Kathiresan et al. 2014). However, the absorption of pollutants by mangrove stands would decrease their concentration (Selanno et al. 2015). Thus, the accumulation and shrink rates of pollutants are affected by the balance between the supply of pollutants and their absorption by mangrove plants.

Heavy metal is one of the most dangerous types of pollutants. It could be consumed and accumulated in plants' and animals' organs, which causes toxicity (Reis et al. 2010; Asati et al. 2016). Thus, food chain is the most important aspect in the distribution of heavy metal toxicity (Hajeb et al. 2014). Contamination of lower level organisms would lead to the accumulation of heavy metal in higher level organisms. Thus, the risk of heavy metal contamination may increase in a polluted environment.

Among the available heavy metal contaminants in the aquatic system, Pb and Cd are among the most common pollutants produced from daily activities. Sources of Pb include volcanic explosions, forest fires, lead emissions from industry and transportation, metal processing, and manufacturing (Zhang et al. 2015). Anthropogenic sources of Pb pollution include paints and glazed building materials (Walraven et al. 2016). The main source of Cd in the sediment is industrial and mining wastes (Yu et al. 2010; Donovan et al. 2016). The application of P fertilizer was also considered as an additional source of Cd in agricultural soil, although this is still debatable (Roberts 2014).

In order to control the environmental safety against pollutant contamination, some countries had developed environmental quality standards. Different countries might apply different standards. US EPA applies a maximum value of 1 mg/kg and 21 ppm respectively for cadmium (Cd) and lead (Pb), while ANZECC & ARMCANZ recommends the value of 1.5mg/kg and 50mg/kg for each element (Hubner et al. 2009).

The threat of heavy metal contamination is obvious due to the determined standards applicable from many environmental agencies. However, heavy metal would not available as single element in the environment. Heavy metal is mostly attached to organic matters. The accumulation of heavy metal is related to the accumulation of organic matters (Yang et al. 2010). Therefore, the importance of studying the trend of organic matter accumulation is as important as the heavy metal.

Silvofishery has been considered as a "good system" in the management of conservative aquaculture (Jonell and Henriksson 2014). In spite of that, in most cases, the real application is different from the proposed model. For instance, plantations are set in the middle of ponds without any separating dikes which are supposed to prevent direct contact between the pool and the mangrove. Thus, the risk of pollutant contamination to the cultivars might increase.

Silvofishery is mostly applied in degraded ponds (Yunus et al. 2015). Thus, in addition to its poor environmental quality, the pollutant level may also be high. However, the accumulation of pollutants in silvofishery ponds such as organic matter and heavy metal has never aroused any serious concern. This research was conducted to study the concentration of organic matter, Pb and Cd in a silvofishery pond, to study the toxicity level status, to analyze changes in their concentration within a year's period, and to analyze the correlation between the concentrations and changes.

MATERIALS AND METHODS

The research was conducted in Mangunharjo Village, Tugu District, Semarang City, Central Java, Indonesia on a silvofishery pond from May 2016 to July 2017. There were 27 sampling points selected and distributed throughout the pond area. Data collection was performed in five sampling periods in May, July and September 2016 followed by May and July 2017. Generally, during the sampling the weather was bright with warm temperature. Since the sampling was carried out in dry season, the fresh water dominated the supply to the silvofishery pond. Samplings were carried out to observe the concentration of organic matter, lead (Pb) and cadmium (Cd) in the sediment over time. Samples were obtained from the sediment accumulated below mangrove stands and were then analyzed in the laboratory.

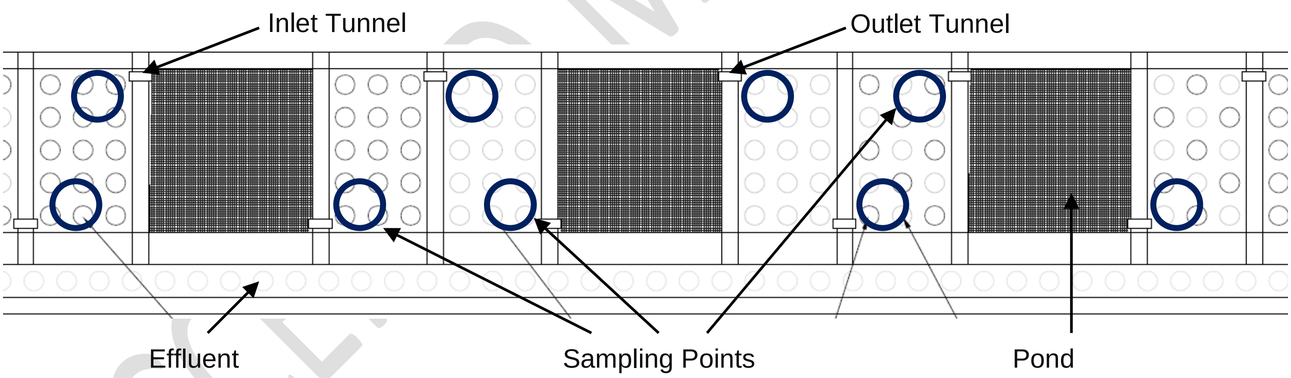

Figure 1. Schematic of sampling points

Samples of the sediment were taken from the surface to the depth of 30 cm using scoop and dipper as many as 500 gr. The sediment was easily washed, therefore ekman grab could not be used for sediment sampling. The water was tapped before the sediment was moved into the plastic bag. Laboratory analysis was carried out in Wahana Laboratorium, Semarang. The method used in organic matter analysis was ashing, while heavy metals were analyzed using Atomic Absorption Spectrophotometry (AAS) method. Analysis was carried out for total heavy metal content.

Data processing was conducted to calculate changes in organic matter and heavy metal concentration at each sampling point. Analysis of variance was performed to analyze the mean differences of values pertaining to organic matter and heavy metal taken from different sampling periods, as well as their changes over those periods. Correlation analysis was performed to analyze the relation between periodic average organic matter, Pb and Cd concentrations and their changes during the research using the Pearson correlation.

RESULTS AND DISCUSSION

Results show that there were variations in the concentration of organic matter, Pb and Cd in the silvofishery pond over five different periods. Data show that there were an increase in average concentration and a decrease in range, which indicated a trend towards stabilization. The concentration of organic matter, Pb and Cd decreased from the first to second observation. However, compared to that in the other periods, the concentration of Pb and Cd in the second period showed the most significant increase. The detailed range and average values of the parameters are shown in Table 1.

Table 1. Concentration of organic matter, Pb and Cd in the sediment from a silvofishery pond, its level status, and its mean differences in five different observation periods.

No.	Parameters	Observation Period				
		I	II	III	IV	V
1.	Organic Matter (%)					
a	Range	1.89-3.30	1.71-3.12	1.60-2.70	1.65-2.62	1.90-2.83
b	Average	2.23 ± 0.28^{p}	2.21 ± 0.31^{p}	2.27 ± 0.27^{p}	2.29 ± 0.25^{p}	2.38 ± 0.20^{p}
c	Average Change		-0.04^{x}	0.05^{x}	0.02^{x}	0.09^{x}
2.	Pb (mg/kg)					
a	Range	3.130-8.230	4.120-7.230	4.353-8.090	4.501-7.930	5.130-7.449
b	Average	5.178 ± 1.258^{p}	5.234 ± 0.747^{p}	6.028 ± 0.868^{q}	6.041 ± 0.759^{q}	6.138 ± 0.627^{q}
c	Average Change		-0.044^{x}	0.795^{y}	0.012^{x}	0.098^{x}
3.	Cd (mg/kg)					
a	Range	1.089^{ε}-2.409^{ϕ}	1.118^{ε}-2.440^{ϕ}	1.460^{ε}-2.820^{ϕ}	1.510^{ϕ}-2.710^{ϕ}	1.583^{ϕ}-2.772^{ϕ}
b	Average	$1.887^{\phi} \pm 0.353^{p}$	$1.851^{\phi} \pm 0.344^{p}$	$2.110^{\phi} \pm 0.339^{q}$	$2.120^{\phi} \pm 0.336^{q}$	$2.171^{\phi} \pm 0.258^{q}$
c	Average Change		-0.026^{x}	0.259^{y}	0.010^{x}	0.052^{x}

Annotation: ε = exceeded the standard value of US EPA
ϕ = exceeded the standard value of US EPA and ANZECC & ARMCAZ
^{p,q,x,y}Different letter in the same line indicates a significant difference.

Concentration of heavy metals as shown in Table 1 indicated that Pb was still within the safe range. The observations of Pb concentration generated the maximum value of 8.090 mg/kg, which was far below the critical value proposed by US EPA and ANZECC & ARMCAZ. Thus, the silvofishery pond in Mangunharjo Village was safe from Pb contamination. However, the observations of Cd concentration showed that it exceeded the recommended limit. The minimum concentration of Cd in the first to third observations only exceeded the US EPA limit with the expected concentration of ≤ 1 mg/kg. Unfortunately, the fourth and fifth observations showed that the minimum concentration of Cd even exceeded the limit set by ANZECC & ARMCAZ with the expected concentration of ≤ 1.5 mg/kg.

The analysis of variance of organic matter showed that there was no significant difference in mean values and concentration changes from one observation to another. This indicated that the management of organic matter concentrations and changes in the silvofishery pond was effective. However, the analysis of variance of Pb and Cd concentrations and changes showed that there was a significant difference among different treatments. There were two groups of mean concentration: the first group which consisted of the first and second observations, and the second group which consisted of the third to fifth observations. This indicated that there was significant accumulation of Pb and Cd which took place in the second period. Analysis of concentration changes showed that there was a significant change which occurred between the second period and another period. The significant increase in Pb and Cd concentration in the second period indicated the domination of heavy metal accumulation in certain sampling points.

Another important concern raised by these findings is the increasing accumulation of Pb and Cd. In the first period, the concentration of both heavy metal elements tended to decrease, but in the second to fourth periods it tended to increase. This indicated the increasing risk of heavy metal pollution in the silvofishery pond, which might trigger the contamination of the cultivars. The concentration of Cd alone was sufficient proof that the pond was contaminated. Thus, a more effective pond management plan should be formulated in order to avoid the danger of heavy metal pollution and contamination.

The accumulation of heavy metal in the sediment is related to the sedimentation process. The sediment usually carries various substances including organic matter and heavy metal. Thus, the accumulation of heavy metal might be interrelated with that of any other substances. This research evaluated the correlation between heavy metal and organic matter, as shown in Table 2.

Table 2. Correlation among OM, Pb, and Cd concentration and changes in a silvofishery pond.

		Correlation (Sig.)		
		OM	Pb	Cd
Average concentration	OM	----	0.770 (0.128)	0.810 (0.097)
	Pb		----	0.998 (0.000)**
	Cd			----
Average concentration change	OM	----	0.394 (0.606)	0.484 (0.516)
	Pb		----	0.995 (0.005)**
	Cd			----

Annotation: * = correlation is significant at the 0.05 level
** = correlation is significant at the 0.01 level
Some cells are left blank intentionally due to similar correlation items

Table 2 shows that even though the correlation coefficients were high, organic matter concentration did not correlate with Pb and Cd concentration, as well as with concentration changes. Surprisingly, the concentrations and changes of Pb and Cd correlated with each other. This indicated that the source of organic matter was not only sediment accumulation. Low correlation level between concentration changes indicated the difference in the accumulation rate between the organic matter of Pb and Cd. Fortunately, the high and significant correlation between Pb and Cd concentrations and changes showed that both heavy metal elements came from the same source, i.e. the contaminated sediment.

The silvofishery pond in Mangunharjo Village tended to accumulate organic matter and heavy metal elements, which was indicated by the increasing concentration of those substances in the sediment. Mangrove vegetations in the pond provide fine sediment trapping by slowing down the current; thus, the sedimentation rate might increase (Adame et al. 2010). An increase in heavy metal concentration in ponds is highly related to the water sources. Coastal ponds are supplied by both sea and river water. However, river streams are considered as the main source of pollutants in the coastal area since they have become channels for anthropogenic and industrial waste disposal (Kumar et al. 2015).

Various inland activities produce heavy metal contaminated wastes which then enter the aquatic system (Zhang et al. 2010). When the freshwater flows to the estuaries, the heavy metal might be dispersed throughout the surrounding ecosystem (Ruzhong et al. 2010), such as the ocean and ponds. Most heavy metal pollutants are bound to fine sediments (Zhang et al. 2014). When the water enters vegetated ecosystem, the flow would slow down, increasing the chance of sedimentation (Turgut et al. 2015). Thus, the accumulation of heavy metal occurs along with sediment deposition.

The increasing heavy metal concentration in the silvofishery pond indicated that the water sources were polluted. The source could be from the freshwater river stream or the seawater. Semarang rivers, as well as the city's coastal area, have been known to be polluted due to high industrial activities (Hastuti 2015). Thus, there is a severe risk of pollutant contamination in silvofishery ponds. The pollutant might increase due to sediment trapping by mangrove roots in the ponds. Thus, there is a probability that heavy metal concentration would keep increasing.

Mangrove has been known as a bioremediator of heavy metal pollutants (Kannan et al. 2016). However, its capacity is limited. Mangrove would accumulate heavy metal elements in its various parts, but the elements would be returned to the environment through litter fall and decomposition processes (Martuti et al. 2017). Thus, the accumulation rate of heavy metal pollutants would depend on the supply rate from the sources and the uptake rate by mangrove. The trend of increasing accumulation of pollutants showed that the mangrove uptake rates could not match the pollutant supply rates. This requires the development of more effective management plans to prevent the risk of heavy metal contamination and to reduce the toxicity of the cultivars.

The extreme increase of organic matter and heavy metal concentration in the second period (from the 2^{nd} to 3^{rd} observations) showed the high input rate of sediment during that period. This might occur due to frequent rain occurrences which cause pond flooding (Gharbi et al. 2016). Thus, high amount of sediment might be carried from the river stream to ponds. Ponds which generally occupy a single canal as water inlet and outlet would trap incoming water, thus increasing the chance of sediment deposition.

The concentration of Cd in the silvofishery pond indicated an insecure environment. Although heavy metal concentration in the sediment is not directly related to water quality, this may affect the availability of dissolved heavy metal in the water (Hassaan et al. 2016). US EPA recommends a maximum concentration of 1 mg/kg of Cd in the sediment, while ANZECC & ARMCANZ’s standard is higher at 1.5 mg/kg (Hubner et al. 2009). However, the average concentration of heavy metal exceeded both standards in all observations, which showed the possibility of a polluted environment since the beginning. Therefore, such increase in concentration values should be taken into consideration in the management of silvofishery ponds.

This research shows that Pb and Cd were accumulating in the silvofishery pond sediment. However, only Cd exceeded the recommended value, while Pb was still within the safe range. Such condition increases the possibility of heavy metal contamination of cultivated fish (Kumar et al. 2011). Any toxic elements in the aquatic system can be easily transported from one organism to another through food chain. Heavy metal pollutants would be absorbed by a low trophic level organism such as phytoplanktons, which are then consumed by zooplanktons and finally by fish (Hassaan et al. 2016). Thus, the risk of contaminated fish consumption by humans increases as well.

Heavy metal elements are bioaccumulative in living organisms which include plants, animals, and humans. The toxicity in a plant is usually shown by several symptoms, such as changes in leaf color or abnormal plant growth (Nagajyoti et al. 2010). Unfortunately, mangrove has a high level of tolerance due to its bioaccumulation capability (Kannan et al. 2016). Thus, the heavy metal toxicity in mangrove is usually unnoticeable. The effect of toxicity may expand to other aquatic animals including crabs, shells, and cultured fish. Some animals are known to be tolerant to heavy metal toxicity, such as shells (Shirneshan and Bakhtiari 2012). However, the animals with low tolerance level may show toxicity symptoms, such as decreasing the growth rate and the damage of liver and kidney tissues (Jayakumar et al. 2016).

The bioaccumulative capability of aquatic organisms increases the chance of heavy metal to be consumed by humans and accumulated in the body. Consuming a small amount of contaminated fish would not affect the human body in a short period of time. However, the effects of heavy metal toxicity would be noticeable when the concentration is high enough. Various symptoms caused by Cd toxicity include kidney damage, osteoporosis, cardiovascular diseases, hypertension, diabetes, modification of several organs, infertility, and many others (Bernhoft 2013). To avoid Cd toxicity, humans can only take a maximum of 1 µg/kg per day (USEPA 1998).

The analysis shows that the concentration and accumulation of Pb and Cd correlated with each other. This indicated that there was a common factor which had caused the accumulation of both elements. Sediment input from contaminated sources was considered as one possible factor. Thus, both heavy metal elements were deposited along with the sedimentation (Zhang et al. 2014). Insignificant correlation between heavy metal and organic matter concentration and accumulation indicated that organic matter might experience further decomposition to nutrient.

This research shows that even though silvofishery provides various beneficial services to the environment, some negative impacts might arise after a considerable period of time. Various heavy metal elements might accumulate over time, which contributes to their increasing concentration. After certain periods of time, the accumulation of heavy metal may exceed the safe limit and cause environment toxicity. This leads to environmental hazards, especially for aquaculture activities which are related to human livelihood.

In order to maintain the environmental quality and to avoid heavy metal toxicity in silvofishery ponds, more effective management plans and actions should be devised and carried out. Decreasing heavy metal concentration in the pond sediment must be the main objective, especially in Mangunharjo Village. However, the process may take quite a long time, and controlling heavy metal concentration in sediment cannot be done instantly because it is a gradual process. An important thing to do in order to decrease the sediment input into the pond is by separating the mangrove plantation. Mangroves should be planted in the inlet as a canal formation, while dikes need to be constructed around it. Thus, water input could be filtered, and sediment would be deposited before it enters the pond. By doing this, the risk of heavy metal accumulation in the pond would decrease.

Another strategy to decrease heavy metal concentration in the ecosystem is by pruning the mangrove leaves and branches. Thus, heavy metal elements which have been absorbed and accumulated in the plant organs, especially its leaves and branches, could be totally removed from the ecosystem by preventing the elements from reentering the ecosystem through litter falls. The pruning also stimulates the development of fresh branches and leaves. Thus, more heavy metal could be absorbed from the ecosystem. In this way, the concentration of heavy metal in the silvofishery pond would gradually decrease. The combination of both techniques may improve the effectiveness of heavy metal removal from the silvofishery pond ecosystem. Thus, the risk of heavy metal toxicity could be prevented.

CONCLUSION

A silvofishery pond has been found to accumulate organic matter and heavy metal elements of Pb and Cd, which indicated an increasing risk of environmental toxicity. The pond was contaminated with Cd pollutant, which was found to have exceeded the recommended level. This excessive concentration might affect the aquatic organisms in the ecosystem. The increasing accumulation rate during the last periods of observation indicated an imbalance between pollutant supply and mangrove uptake rates. The concentration and accumulation of Pb and Cd show a high degree of correlation, indicating a possibility that both elements come from the same sources. The recommendations for better management plans and actions include changing the pond setting by planting mangroves in the inlet canals, developing dikes to avoid direct rapid water flow from the mangroves to the pond, and pruning the mangrove leaves and branches to decrease heavy metal recycling. Such pruning would also promote the development of fresh leaves and branches which can increase heavy metal absorption.

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