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Impacts of Aquaculture at Different Depths and Distances from Cage Culture Sites in Batang Ai Hydroelectric Dam Reservoir, Sarawak, Malaysia

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Abstract: Aquaculture is increasingly important world-wide as landings from natural captured fisheries is unable to meet the demand for fish. The Batang Ai Hydroelectric Dam Reservoir, located in Sarawak, Malaysia, has been an aquaculture site for the last 18 years. However, little information is available on the impact of aquaculture on the water quality of the Batang Ai reservoir. Therefore, the objective of this study was to evaluate the impact of cage culture activities on the water quality at different distances and depths from the culture site. Four sampling stations were selected where three were at cage culture sites and one control site. Samplings were conducted at 0 m, 20 m and 100 m distance from the culture site and at three depths; subsurface, 10 m and 20 m. Results show that temperature ranged from 25.2-32.2°C and were in decreasing trend as depth increased. DO ranged from 0.26-8.45 mg/l and at 20 m depth it was significantly lower than other depths. Water clarity decreased as it gets nearer the cage culture sites. TSS ranged from 1.5-9.1 mg/l and were significantly higher at 20 m depth than at subsurface. Conductivity ranged from 33 µS/cm - 89 µS/cm and was significantly higher at 20 m depth. At that depth, conductivity values at all cage culture stations were higher than the control station. Furthermore, BOD_5 ranged from 6.80-13.86 mg/l. BOD_5, nitrate-nitrogen, nitrite-nitrogen and ammoniacal-nitrogen were also higher at cage culture stations when compared with the control. Chlorophyll-*a* concentrations at 0 m from cage culture stations were higher than the control station. Therefore, proper management of aquaculture activities is required in order to ensure long term sustainability of cage culture at Batang Ai Reservoir.

Key words: Cage culture · Dam · Batang Ai · Reservoir water quality · Inland aquaculture

INTRODUCTION

Worldwide, fish provides more than 1.5 billion people with almost 20 percent and 3.0 billion people with at least 15 percent of their average per capita intake of animal protein [1]. In 2008, capture fisheries production was about 90 million tonnes and landings have not shown any increase in the past decade. Aquaculture, on the other hand is a fast growing industry worldwide and accounted for 46 percent of total food fish supply. Production of food fish from this industry increased at an average rate of 8.3 percent per annum and reached 52.5 million tonnes valued at US$98.4 billion in 2008 [1].

In Malaysia, the aquaculture production in 2010 was 581,048 metric tonnes (mt) with a wholesale value of RM2.798 billion. Freshwater aquaculture contributed 155,398 mt or equivalent to 26.7% of total aquaculture production with a wholesale value of RM760.34 million [2]. In Sarawak, aquaculture production in 2009 was 8,045 mt with a wholesale value of RM105.26 million. Freshwater aquaculture contributed 2,560 mt or equivalent to 31.9% of total aquaculture production with a wholesale value of RM23.24 million [3].

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Freshwater cage culture is an important industry in Sarawak as it provides a source of protein and fulfills the high market demand for freshwater fishes. Currently, the main freshwater cage culture activity is concentrated at the 9,000 ha Batang Ai Hydroelectric Dam Reservoir in Lubok Antu, Sarawak. Cage culture was initiated by the Department of Agriculture in 1993. Currently, there are about 2,696 cages and each cage is stocked with 500 fish fry. Tilapia is the main fish species cultured in the reservoir. Production has increased significantly in the last few years. In 1993, production was only 22.9 mt and this has increased to 298.9 mt in 2009, 488.8 mt in 2010 and 744.1 mt in 2011.

Fish in cages are feed with pellets two to three times a day. Excess feed and waste are directly released into the water body. It is estimated that for every ton of fish produced in cage culture, 132.5 kg of nitrogen and 25.0 kg of phosphorus are released into the environment [4]. Furthermore, for tilapia cage culture, it has been reported that 81 - 90% of carbon is lost from the cages to the surrounding environment [5]. For a reservoir where there is not much exchange of water, accumulation of these waste potentially result in water quality deterioration such as eutrophication and anoxic water as reported in Lake Cirata in Indonesia [6]. This could threaten the cultured fish as what has happened in Lake Cirata where mass mortality of fish in cages occurred [7]. However, in Batang Ai Reservor, little information is available on the impact of cage culture on the water quality of the reservoir. The objective of this study is to determine the extent of cage culture impact on water quality in terms of depth and distance from the culture site.

MATERIALS AND METHODS

Sampling was conducted at four stations in Batang Ai Reservoir in September of 2009 (Fig. 1). Three of the stations (Culture 1, Culture 2 and Culture 3) were located at the cage culture site. One station (Control) was located away from the cage culture. At each station, sampling was carried out at three distances away from the edge of the culture sites at 0 m, 20 m and 100 m. At each site, sampling were also carried out at three depths; 0.2 m, 10 m and 20 m.

In situ parameters such as temperature, pH, electrical conductivity, turbidity, dissolved oxygen were measured using YSI multiparameter probe. Water samples were collected in triplicates using a Van Dorn sampler at distance and depth. Water samples collected were kept in 2-L polyethylene bottles and cooled in the cooler box with ice blocks to prevent oxidation of the samples and were

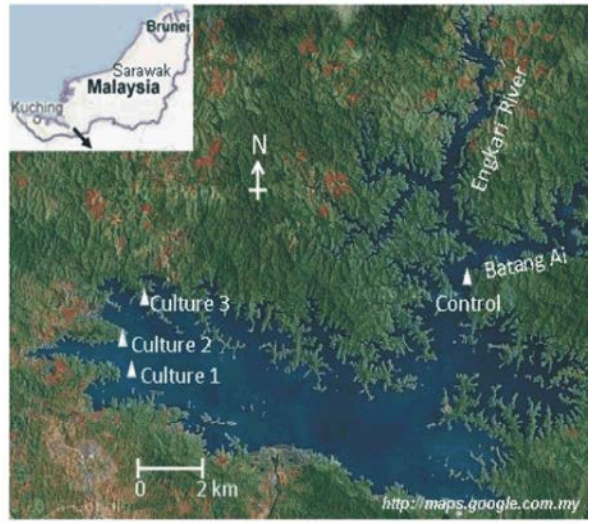

Fig. 1: The four sampling stations in the Batang Ai Reservoir

brought back to the laboratory for analysis. Water samples were filtered before nutrient analysis. Filtered water samples were stored in refrigerator at 4ºC and the samples were brought to room temperature before analyses were conducted.

Triplicates water samples were analyzed for total suspended solids (TSS), biochemical oxygen demand (BOD_5) and chlorophyll-*a* (chl-*a*) according to Standard methods [8]. Nitrite-nitrogen (nitrite-N), nitrate-nitrogen (nitrate-N) and ammoniacal-nitrogen (ammoniacal-N) were analyzed using methods of Hach [9]. Nitrate was analyzed using Cadmium Reduction Method and the value of nitrate was measured using Hach spectrophotometer DR2010 at the wavelength of 507nm [9]. Diazotization Method was used to analyze nitrite [9]. In analyzing NH_3-N, Nessler Method was used with 425 nm wavelength [9]. Data analysis was conducted using Univariate ANOVA and Tukey's test was used to compare among the stations. Dunnett's test was used to compare all cage culture stations with the control station. All analyses were performed using SPSS Ver. 17.

RESULTS

Comparing among Depths: Fig. 2 shows the different water quality variables as a function of depth. Mean temperatures ranged from 25.2 - 32.2°C and were in decreasing trend as depth increases (Fig. 2a). pH values show that the water was mostly acidic with means ranging from 6.42 at 20 m to 6.97 at 0.2 m depth. pH values also decreased with increasing depth at all stations.

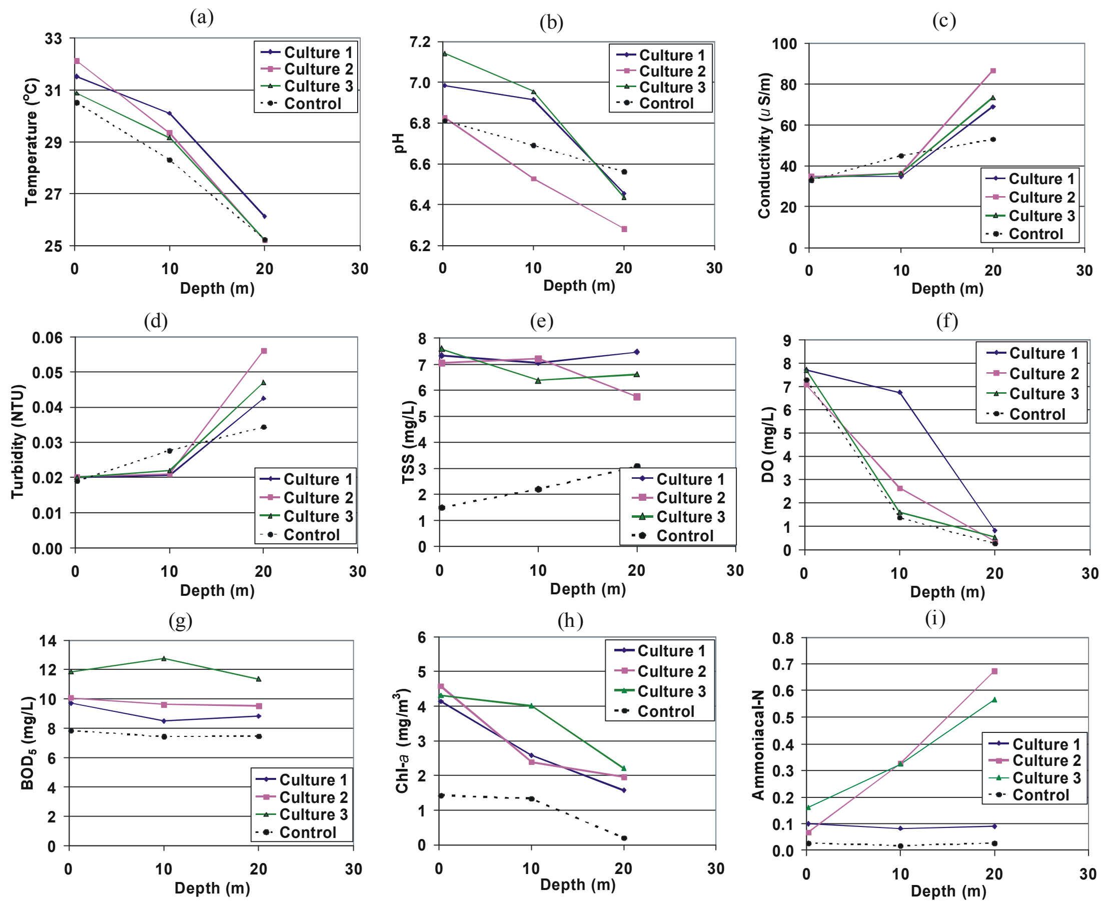

Fig. 2: Water quality variables as a function of depth: (a) Temperature, (b) pH, (c) Conductivity, (d) Turbidity, (e) TSS, (f) DO, (g) BOD_5, (h) Chl-*a* and (i) Ammoniacal-N

At 20 m depth pH values were lower at the culture stations than the control station (Fig. 2b). Electrical conductivity ranged from 33 µS/cm - 89 µS/cm and showed an increasing trend with depth and was significantly higher at 20 m depth than the two shallower levels (P<0.0005) (Fig. 2c). Turbidity measurements ranged from 0.019 to 0.057 NTU. Mean value at 20 m depth was significantly higher than at 0.2 m and 10 m depths as shown in Fig 2d (P<0.0005). TSS ranged from 1.50 - 9.10 mg/l and the mean values were not significantly different among the depths (P=0.411) (Fig. 2e).

DO values ranged from 0.26 to 8.45 mg/l and the mean values decreased with increasing depths (Fig. 2f). Mean DO at 20 m depth was significantly lower than that at 10 m and at 10 m depth was significantly less than at 0.2 m depth (P<0.0005). There was no significant difference in mean BOD_5 among the depths (Fig. 2g). Chl-*a* values ranged from 0.10 mg/m^3 at 10 m to 4.58 mg/m^3 at 0.2 m depth (Fig. 2h). At 0 m distance from cage culture stations, mean chl-*a* values were significantly different at all the three depths with the mean values in decreasing order at 0.2 m (3.6 mg/m^3) > 10 m (2.6 mg/m^3) > 20 m (1.5 mg/m^3) (P<0.001). Mean BOD_5 at the three depths (8.69 - 9.14 mg/L) were not significantly different (P=0.327). The ammoniacal-N values were significantly different at the three depths (P<0.021). The values ranged from 0.01 to 1.15 mg/L and the mean increased significantly from 0.2 m to 10 m depth and subsequently to 20 m depth at culture sites 2 and 3 (Fig. 2i).

Comparing among Stations: Water temperature at the control station (28.01°C) was significantly lower than the three culture stations (28.44 - 29.25°C) (P<0.0005). pH at 20 m depth at the control station was significantly higher than all the other stations (P=0.014) whereas pH at the culture station 2 was significantly lower than all the other stations (P<0.05). At 20 m depth, turbidity values at all culture stations were significantly higher than the control station (P=0.002). DO at culture station 1 was significantly higher than all other stations (P<0.0005).

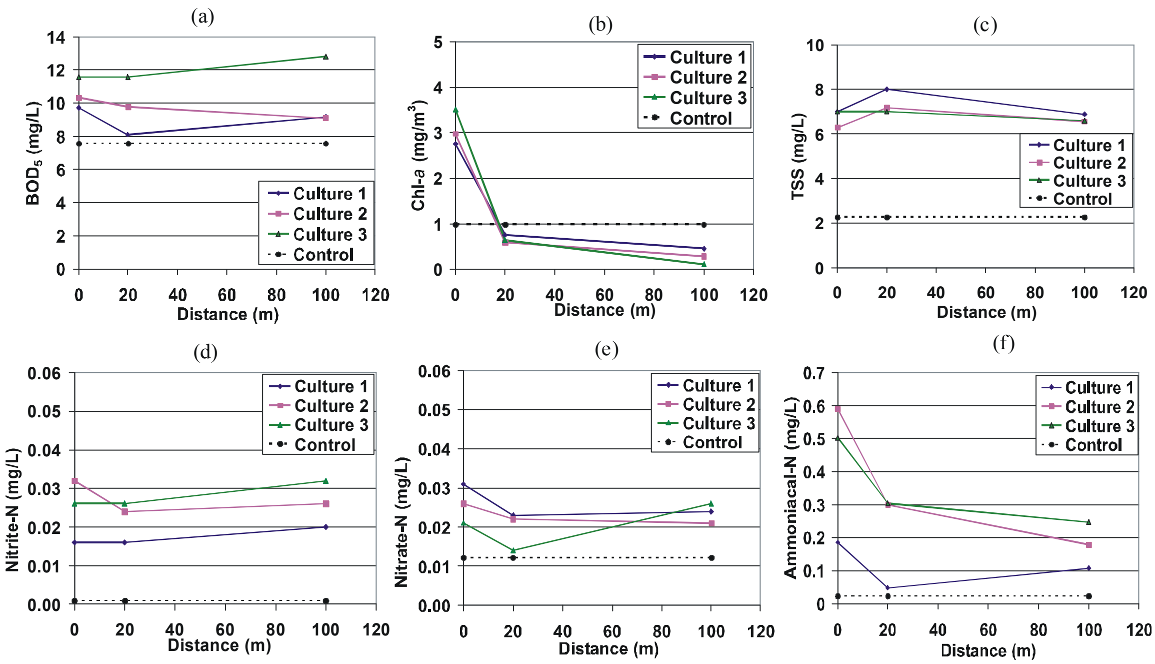

Fig. 3: Water quality variables as a function of distance: (a) BOD_5, (b) Chl-*a*, (c) TSS, (d) Nitrite-N, (e) Nitrate-N and (f) Ammoniacal-N

At 20 m depth, turbidity and conductivity were significantly higher at the three culture stations than the control station indicating the presence of higher dissolved solids. TSS at all culture stations at all depths were significantly higher than the control station ($P<0.0005$) (Fig. 2 g).

Mean BOD_5 at the culture stations ranged from 8.3 mg/L at culture station 1 to 11.3 mg/L at culture 3 and the values at all culture stations were higher than the control station of 6.7 mg/L ($P<0.0005$). For chl-*a*, at 0 m distance from culture stations, the mean values were significantly higher at culture stations than the control station ($P<0.0005$). Among the culture stations, culture 3 showed the highest values of pH, BOD_5 and chl-*a*. Ammoniacal-N at different distances of three culture stations were significantly higher than control station except 20 m distance of culture 1 and 100 m distance of culture 2 ($P<0.05$).

Comparing among Distances: At 20 m depth, turbidity and conductivity were significantly higher at 20 m than 0 m distance away from the culture station ($P<0.05$). BOD_5 ranged from 6.80 to 13.86 mg/l (Fig. 3a) and the means were not significantly different among the different distances from culture station ($P=0.081$). Chl-*a* at 0 m from culture stations were significantly higher than 20 m and 100 m away (Fig. 3b) ($P<0.0005$). TSS at 20 m distance from cage culture site was significantly higher compared with 0 m and 100 m from the site (Fig. 3c) ($P=0.008$ and $P=0.003$ respectively). Nitrite-N ranged from 0.001 to 0.053 mg/L. Nitrite-N at different distances for the three culture stations were significantly higher than control station except 100 m from culture 3 ($P<0.05$) (Fig. 3d). Nitrate-N values ranged from 0.01 to 0.06 mg/L. Dunnett's test showed that at 0 m distance nitrate-N was significantly higher than that at the control station ($P=0.007$) (Fig. 3e). At all culture stations, ammoniacal-N were significantly higher at 0 m distance when compared with 20 m and 100 m away (Fig. 3f) ($P<0.0005$).

DISCUSSION

Water temperature at the cultured stations was higher than the control station as the control station is situated nearer to the inflow of the reservoir where it receives water from Batang Ai and Engkari River. These two rivers are the main tributaries that contribute water to the reservoir. The culture stations were situated in the main reservoir where there is less exchange of water. Temperature decreased with depth at all stations as the surface water is heated up by solar radiation but not the bottom layer. Since there was little exchange among the surface, middle and bottom waters, the temperature gradient indicates the existence of stratification.

Electrical conductivity increased with depth showing an increase in dissolved solids concentrations likely to be contributed by fish waste such as urine and feces as well as uneaten feed and their products of decomposition especially at the deeper part of the reservoir [10]. Gassama *et al*. [11] also reported an increase in conductivity values as depth increased in the Bicaz reservoir, Romania when there was no mixing in summer. Electrical conductivity measured in this study were lower than the values (151 - 338 µS/cm) reported by Gassama *et al*. [11] likely because of lower organic load at Batang Ai reservoir. The electrical conductivity values measured were lower than the standard of Interim National Water Quality Standard of Malaysia (INWQS) of 1000 µS/cm [12].

Furthermore, there is an obvious decrease in pH as depth increases due to decaying organic matter especially from the vegetation which were not removed prior to impoundment and contributions from feed and waste from the cage culture especially at Culture 2. DO decrease with depth as there was little aeration as depth increases. Additionally, oxygen is also used up in the decomposition process as solid waste sink to the bottom. DO values at 10 m and deeper than 10 m were not suitable for fish survival as it is below 5 mg/L that was required for healthy fish growth [13]. Only DO at 0.2 m depth satisfy the Class II range of the INWQS (5-7 mg/L). Even though fish cages do not extend to such depths as the cages normally range from 3 m to 7 m deep [7], the upwelling of the anoxic water that may occur during heavy rain could result in fish kills. At all culture stations, TSS values at different distances and different depths were higher than the control due to fish excretion and excess fish feed [10]. There was not much difference in TSS among the depths due to the downward movement of the solid excess feed and waste. The TSS values measured fall under Class I of the INWQS of less than 25 mg/L.

Most of the inorganic nitrogen such as nitrite-N, nitrate-N and ammoniacal-N at culture stations were higher than the control due to the contribution from fish waste and excess feed. Ammoniacal-N from the waste is oxidized to nitrite-N and nitrate-N in the presence of oxygen. Ammoniacal-N was higher at the center of the fish culture site mostly due to the feces released by the fish. This observation is similar to those reported by Guo and Li [14] where total nitrogen values inside the cage, at the side of the cage and 20 m away from the cage were the highest. The observed levels of ammoniacal-N fall under Class II (0.1-0.3 mg/L) and III (0.3-0.9 mg/L) of INWQS. The range of nitrite-N, nitrite-N and ammoniacal-N (0 - 0.171 mg/L, 0 - 0.502 mg/L and 0 - 1.120 mg/L respectively) fall in the range reported by Effendie *et al*. [7] at 0 m, 5 m and 10 m depth below the floating cages in Lake Cirata.

Fish excretion and excess fish feed were also responsible for the higher chl-*a* at all cage culture stations and at all depths as the nutrients from the excess feed and fish waste provided the necessary nutrients of nitrogen and phosphorus for algal bloom. However, chl-*a* values measured in the reservoir did not exceed the 40 mg/m^3 level of moderate algal bloom [15]. In the process of decay of fish feed and waste, oxygen is consumed as indicated by higher BOD_5 at all culture stations as compared with the control station.

The movement of excess feed and waste downward also cause the BOD_5 to be not significantly different among the depths. Comparisons with INWQS shows that BOD_5 at the culture stations fall under Class IV (6-12 mg/L) and V (> 12 mg/L). Fish feed are high protein diets with nitrogen and phosphorus contents of 6.86-7.81% and 1.00 - 2.14% respectively [16]. Gondwe *et al*. [5] reported that carbon and nutrients loss from tilapia fish cages in Lake Malawi ranged from 81-91% for carbon, 59-80% for nitrogen and 85-92% for phosphorus. Therefore, excess feed and waste derived from feeding have resulted in the differences in water quality between stations with and without cage culture.

CONCLUSIONS

Aquaculture has impacted the water quality as indicated by the lower pH, higher turbidity, conductivity, TSS, BOD_5 and chl-*a*. The impact of chl-*a* was mainly at the subsurface (0 m) of the culture stations whereas the impact of turbidity and conductivity were mostly at 20 m depth. However, the impact of TSS and BOD_5 could be observed up to 100 m from the culture stations. The impact of ammoniacal-N was mostly close to the culture station (0 m distance) and at deeper depth (20 m deep). DO values at 10 m depth and below at two of the three cage culture stations were below 3 mg/L and this could pose a threat to fish culture during mixing when the bottom anoxic water moves upwards to the culture zone.

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