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Adaptation of African and Striped Catfish in Peat Water with Low pH

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ABSTRACT The adaptation of African (*Clarias gariepinus*) and striped catfish (*Pangasianodon hypophthalmus*) on peat water with low pH was successfully done. The treated fish were reared on a mixture gradient of peat water and borehole water in the fiber tanks as an adaptation process, with a control treatment of 100% borehole water. After adapting to 100% peat water, catfish were then transferred into the enclosure nets (*hapa*) and placed on a man-made peat water pond. The mortality, length, weight of catfish, and water quality parameters were recorded and measured. Results showed that subject catfish can be adapted and adapt with peat water of low pH from the fingerling size to adult with small mortality. Fish were acclimatized and gradually adapted after 58 days in the fiber tanks with nearly 100% peat water, and let for the next 38 days. The growth rate of both catfish between the treatment and control tank did not significantly differ. Fish was then moved to the enclosure nets on the ponds after 96 days. This indicates that by adaptation mechanism, catfish can survive and grow in peat water of low pH and possibly be reared in dynamic peat waters (rivers, lakes, and ponds).

Keywords: Adaptation; african catfish; striped catfish; peat water of low pH

INTRODUCTION

The island of Kalimantan consists of six to nine million tonnes of peat which constitutes almost half of Indonesia's peatland area (Rieley *et al*., 1996). On the vastness of the peat swamp in Central Kalimantan hydrologically flows many rivers that are associated with and connected to lakes and swamps. Water is visually dark brown containing organic substances with high acidity. This includes a variety of peat swamp forest vegetation which is naturally associated with many organisms (Page *et al*., 2002). The characteristics of peat soils in the tropics are fully described by Rieley *et al*. (2008). According to Hooijer *et al*. (2010) unexposed peat deposits < 10% are plant residues and about 90% are water, and both are accumulated in the form of sponges which are always in high acidity for many years. This causes peat water to always have a low pH between 3 and 4 in Kalimantan and below 4.7 in Sumatra, with high dissolved organic carbon (DOC) due to containing organic acids causing a blackish brown color (Rieley & Page, 1996; Steinberg, 2003; Ishikawa *et al*., 2006; Bouma *et al*., 2007). DOC is in form of humic and fulvic acid (Perdue & Gjessing, 1990; Ishikawa *et al*., 2006). The pH of the water bodies supplied by peat water from the surrounding peatland in Central Kalimantan varies between 3.5 and 5.9 (Ardianor *et al*., 2012).

In peat waters, various aquatic biota has naturally adapted such as plankton, benthic organisms, and insects (Rieley & Page, 1996; Ohtaka *et al*., 2014; Gumiri *et al*., 2016; Husson *et al*., 2018), including fish (Husson *et al*., 2018; Thornton *et al*., 2018). Apart from being the living place for aquatic biota naturally, and so far fish are exploited for capture fishery aspects, peat waters may also prospectively be used for rearing cultured fish with certain technologies. In reality, the volume of peat water in Central Kalimantan is known very abundant, but underutilized.

Fish culture on the peatlands so far has been practiced by many people since the availability of land is quite large in Kalimantan and Sumatra. Even though practicing such an aquaculture system, they do not directly use peat water of low pH, rather than groundwater that is placed in fiber tanks, concrete ponds, and tarpaulin ponds on the peatland (Widodo *et al*., 2010; Huwoyon & Gustiano, 2013; Tahapari *et al*., 2015). The other way has applied the tarpaulin cage where the peat water has been put and treated with lime such as the work of Tantulo *et al*. (2020), and the floating net on the peat water bodies which unfortunately do not provide any information about pH value (Fitriadi *et al*., 2021).

Aquaculture in these ponds is generally commercially cultured species such as African catfish (*Clarias gariepinus*), striped catfish (*Pangasius hypophthalmus*), and tilapia (*Oreochromis niloticus*) which are still popular among fish farmers because of economical and technological reason, such as high growth rate, availability fish seed, stable prices, and practiced culture techniques. Unfortunately, those species have been difficult to survive and grow on peat water with low pH, except only on neutral water media with pH mostly between 6 and 8. Fish fingerlings, such as tilapia, 3-5 cm (*Oreochromis niloticus*) and striped catfish, 5-8 cm (*Pangasius hypophthalmus*) (Ardianor *et al*., 2012), and giant gourami, 3-5 cm (*Osphronemus gourami*) (Pusparani, 2020) can survive in peat water with low pH below 40%

in concentration by bioassay test. Likewise, African catfish (*Clarias gariepinus*) fingerling with the size of 10-15 cm can only survive on about 63% peat water of low pH (Ardianor *et al*., 2022). In line with Mustapha & Mohammed (2018) has tested the resistance of African catfish at a water pH of around 4 (but not peat water), getting mortality about 62%. Hence, it is difficult to apply aquaculture practice, e.g. cage and floating net culture on the dynamic peat water bodies such as lakes, rivers, natural ponds and swamps with low pH.

On the other hand, aquaculture aspects of the local fish naturally inhabits peat waters, for example, snakeheads (*Channa* spp.) are still constrained in breeding technology in peat waters of low pH, except for *C. striata* (Augusta & Pernando, 2019). Climbing perch (*Anabas testudineus*) have successfully been bred (Zalina *et al*., 2012; Perera *et al*., 2013; Bhuyan & Hussain, 2018), but unstable the fish seed supply in Indonesia and fingerling could not survive on peat water of low pH (Ardianor *et al*., 2013). One reason the weaknesses of climbing perch fingerlings to peat water of low pH might be because its breeding has been done in the neutral water media with a pH of around 7 (Singh *et al*., 2012). Even though several researchers have successfully bred the climbing perch on peat water with moderate pH ranging from 4.5 to 6.5 as reported by Yasin (2013); Agustinus & Minggawati (2018), but the fish fingerlings production was still low.

There are at least three works that possibly can be done in overcoming the challenge of fish culture on the peat waters of low pH, i.e. (1) developing peat water's local fish hatchery technology, (2) treating peat water to gain its pH for suitable fish culture, and (3) creating cultured fish species being adaptive to peat water. As for the studies related to increasing the pH of peat water chemically using kinds of limes have been done by Widaya & Said (2001) and Suherman & Sumawijaya (2013), as well as physically by mixing of peat water and borehole water (Augusta, 2012), and applying solar radiation (Ishikawa *et al*., 2005; Ardianor *et al*., 2012; Ardianor *et al*., 2013).

In relation to the work of creating cultured fish species being adaptive to peat water, the present study is the adaptation of common cultured fish species to peat water of low pH. This is aimed to know whether both African and striped catfish can survive and grow on media of peat water with low pH or not. This research is important to support and gain our knowledge in rearing cultured fish species, especially in dynamic peat waters, such as lakes, rivers and swamps with low pH.

Based on our trial treatment previously in rearing the African catfish (*C. gariepinus*), this species could be adapted to peat water of low pH by a progressive increase of peat water concentration in the mix of peat water and borehole water. The concentration of peat water was gradually increased to about 100% in line with the rising size of catfish from fingerling to adult size in a certain time. Hence by the time the catfish have been able to adapt to about 100% of peat water of low pH in line with their increasing size.

MATERIALS AND METHODS

Materials

The equipment used in this study were fiber tanks, hapa nets, plastic basins, buckets, scoop nets, pH meter Horiba LaquaAct D74 (Japan), DO meter Horiba OM-12 (Japan), Handheld Colorimeter Ammonia LR, HI700 (USA), electric aerator, aerator hose, Beaker glass, Erlenmeyer and micropipettes. The research materials consisted of peat water of low pH, borehole water, and fish fingerlings (African catfish, 500 inds. and striped catfish, 500 inds.) with the length size of 8-10 cm.

Methods

The research was conducted in Yos Sudarso V Street No. 107 and Peat Techno Park-University of Palangka Raya (PTP-UPR), B. Koetin Street of Palangka Raya City from August to October 2021, which include preparation of materials and equipment, construction of treatment site, mobilization of peat water, acclimatization and fish release, adaptation process, and initial measurement and monitoring of water quality parameters.

This study was designed experimentally to test whether African catfish and striped catfish can adapt or not to peat water with low pH of around 4. The four circular fiberglass tanks (dimensions: 125 cm in diameter and 80 cm in height) with a capacity of about 980 liters were set up in such a way according to the statistical experimental design as the main treatment. African and striped catfish were reared separately in each two fiber tanks. Each of the test fish was reared in both peat water (PW) and borehole water (BW). To compare the main treatment, each control was made in a similar way with only different water media. Water for the control treatment used borehole water which pH value at the beginning was adjusted to around 7 with a slaked lime amount of 185 mg per liter. The total fish input into each tank was 500 inds., with sizes ranging from 8 to 10 cm for each species. The condition factor and survival of the fish during the experimental period were observed. After both catfish species adapted in the fiberglass tank, they were then moved to the *hapa* nets that were placed in open water ponds of peat swamp waters with relatively the same pH.

The first step of the treatment was preparing water media. The peat water of low pH was transported from the primary canal of the ex-peatland mega rice project in Kalampangan village, Palangkaraya City of Central Kalimantan to the laboratory. The borehole water was locally pumped from groundwater at a depth of about 20 meters. Afterward was filling up borehole water into each fiberglass tank either for African catfish (PW African catfish and BW African catfish) or striped catfish (PW striped catfish and BW striped catfish).

The technique of mixing peat water of low pH and borehole water for the present work was carried out in a way based on our previous treatment. About 613 liters of borehole water were filled into each fiberglass tank. This volume was equivalent to the 50 cm height of water level from the bottom of the tank. Every one cm increase in water level in the tank was equal to the additional water of about 12.2 liters. For this conversion, we set up metered tape inside the tank. Instead of the volume for ease practically, we divided the water height (50 cm) into five parts. As to the tank of the peat water (marked as PW) for both African and striped catfish, each initial mixing of peat water to borehole water was started from the 1/5 parts of the total height of the water, then periodically done for the next 2/5, 3/5, 4/5, and 5/5 parts. In this manner, the water of each tank was reduced by such portion (amount), then replaced with pure peat water of low pH in an equivalent portion. Thus, the volume or height of water in the treatment tank was constant for either main and control treatment, but the concentration of peat water in the main treatment changed every time addition of peat water. The initial concentration of peat water in the tank of 1/5 part was about 20%, i.e. borehole water was reduced by 10 cm, then 10 cm of peat water was added. The next increase of peat water concentration was the addition of 2/5 part, where the existing water in the tank was reduced by 20 cm, then replaced again with peat water equivalent to 20 cm. A similar was the process of adding and replacing peat water for the next 3/5, 4/5, and 5/5 parts. The renewal with 100% of peat water was done afterward for the 4 times for PW tanks of both catfish species. The same process was done also for the control treatment, BW tanks where the peat water was changed with borehole water. The reason for the periodical renewal of water media was to keep constant pH of water because pH tends to increase by the effect of artificial feed.

The second step was the initial measurement of water quality i.e. water temperature (WT), electrical conductivity (EC), pH, dissolved oxygen (DO), ammonia (NH_3), and the length and the weight of catfish. The third was the acclimatization of fish which was done before stocking them in the tanks.

To maintain water quality, especially the increase of suspended material during treatment, we used floating macrophytes, a combination of Salvinia (*Salvinia molesta*) and water lettuce (*Pistia stratoites*) as information from Raissa & Tangahu (2017) and Novita *et al*. (2019). These macrophytes were put in the floating wire screen enclosure (length ×width×depth, 120×40×15cm), covering around 2/3 part of the fiberglass tank surface area. The floating enclosure was constructed of screen wire (0.5 cm mesh-size) that is framed with a PVC pipe of 1.25 inches in diameter.

Provision of factory-made feed was carried out every day, morning and afternoon in such a way. The amount of feed given was about 5% of the total weight of fish that is estimated from the previous sampling. The artificial feed used was the product of PT. Matahari Sakti, the floating feed type of different sizes, PF-800, PF-1000, and LP-1 to LP-5 (https://www.mataharisakti.com).

After being adapted to 100% peat water of low pH in the laboratory, fish were then transferred to 4 hapa-nets with length×width×height, 2×2×1.2 meters that were placed on the open peat waters of low pH, the man-made ponds (20×10×3 meters) at the Peat Techno Park, University of Palangka Raya. The hapa-net is the enclosure net that is made from a polyethylene net of 5 mm mesh size. The man-made ponds were expected to be relatively stable naturally in terms of peat water of low pH. Over time the development of the fish continued to be monitored and fed ad libitum while observing their feeding response, adaptation, and mortality.

The main response variable measured was the survival rate and relative growth of catfish, and the supporting variable was water quality such as water temperature, pH, DO, and ammonia. The survival rate was calculated according to Effendi (1979) and the relative growth according to Effendi (2002). The relative conditions factor (Kr) was calculated to know the physical condition of the fish which is useful for survival and reproduction (Effendie, 2002).

This study was designed statistically with a Randomized Block Design (RBD), with one-factor treatment, 2 levels i.e. peat water and borehole water, for each catfish species, African and striped catfish. The group (block) was the sampling time. To calculate the effect of the treatment variable on the response variable statistically, we used the two-way Anova according to RBD. As an alternative to Anova, we also analyzed using nonparametric statistics, the Friedman test. The standard significance level was 95% ($\alpha \leq 0.05$). The reference for statistical analysis has been Sokal & Rohlf (1995) and Quinn & Keough (2002), and the calculation using Microsoft Excel 2010 and the Statistical and Computing program of R ver.4.1.1 (R Core Team, 2021) as well as drawing graph with R package of ggplot2 (Wickham, 2016) and Rmisc (Hope, 2022).

RESULTS AND DISCUSSION

The necessity for simple technology in utilizing peat water sources for the cultivation of promising cultured fish species in Central Kalimantan considering that the huge peatlands with abundant sources of peat water are the urgency of this research. It would not be an exaggeration if this hope could, directly and indirectly, contribute to the needs and income of the community for the future. The description of the results includes an overview of water quality during the experiment, conditions, and adaptation processes, as well as an analysis of the survival rate, growth, and condition factors of African and striped catfish.

Water quality

Water quality is an external factor outside the body of fish that has a direct or indirect effect on fish life, such as their survival level and growth. Among water quality parameters that strongly affect fish survival and growth are water temperature, pH, DO, and ammonia (Boyd, 1979 & 1990; Diana *et al*., 1997; Bhatnagar & Devi, 2013; Ut *et al*., 2016; Tumwesigye *et al*., 2022). This study was related to the water quality of both surface water and groundwater (borewell water) that were used as media in rearing catfish.

The quality of borehole water, WT, EC, pH, and DO was respectively 28.6°C, 3.08 mS/m, 4.10, and 3.25 mg/l. By keeping such borehole water in the tanks and aerated for 24 hours, the value of WT, EC, pH, and DO were respectively 30.4 °C, 2.13 mS/m, 4.76, and 4.81 mg/l. After being treated with the amount of slaked lime, the pH of borehole water increased to above seven ($\bar{x}$±sd, 7.58 ±0.06).

The peat water of low pH as surface water taken from the Kalampangan canal, the range for WT, EC, pH, and DO were respectively 27.1 - 27.5°C, 5.41-5.64 mS/m, 3.13 -3.85, and 3.43 - 4.25 mg/l. According to Thornton *et al*.

(2018) pH of peat water in the Sebangau River ranges from 3.2 to 4.8 with an average of 3.9, but it can even drop to an average of 3.2 in the dry season. The pH of the Kalampangan canal was slightly the same as the pH of the Sebangau River. The water quality parameters, such as WT, EC, pH, DO and NH_3 of PW and BW of both catfish species during the 4 sampling times are shown in Table 1.

Description of water quality parameters of peat water media at african catfish tank (PW), in the Table 1, WT minimum - maximum values, ranged from 27.10 - 29.30°C ($\bar{x}$=28.02°C), EC, 36.50-78.60 mS/m ($\bar{x}$=49.98 mS/m), pH, 4.83-7.61 ($\bar{x}$=5.60), DO, 1.00-3.01 mg/l ($\bar{x}$=2.41 mg/l), and NH_3-N, 18.6-46.4 mg/l ($\bar{x}$=31.52 mg/l). The same thing for peat water at striped catfish tank, the temperature ranged from 26.80 - 29.40°C ($\bar{x}$=28.32°C), EC, 36.40-77.10 mS/m ($\bar{x}$=44.90 mS/m), pH, 4.93-7.10 ($\bar{x}$=5.78), DO, 1.84-4.82 mg/l ($\bar{x}$=2.90 mg/l), and NH_3-N, 17.20-50.10 mg/ l ($\bar{x}$=29.13 mg/l). As for borehole water quality African catfish tank (BW), WT ranged from 26.70 - 29.10°C ($\bar{x}$= 27.73°C), EC, 42.70-108.60 mS/m ($\bar{x}$=81.20 mS/m), pH, 4.18 -7.58 ($\bar{x}$=5.30), DO, 1.75-3.96 mg/l ($\bar{x}$=2.49 mg/l), and NH_3, 15.61-51.60 mg/l ($\bar{x}$=36.90 mg/l). Furthermore, in borehole water striped catfish, WT ranged from 26.70-29.20°C ($\bar{x}$=27.73°C), EC, 32.50-120.50 mS/m ($\bar{x}$=75.00 mS/m), pH, 4,42-7.49 ($\bar{x}$=5.25), DO, 1.30-3.61 mg/l ($\bar{x}$= 2.44 mg/l), and NH_3-N, 35.40-62.40 mg/l ($\bar{x}$=49.58 mg/l).

According to Bhatnagar & Devi (2013), the water temperature during the experiment was within the acceptable value, but dissolved oxygen was slightly low, despite being supplied with aerators. In turn, ammonia was higher than the acceptable concentration of 0-0.05 mg/l as suggested by Bhatnagar & Devi (2013). Even though ammonia in the form of NH_3-N was detected very high during the experiment, it did not strongly affect on mortality of both catfish. It was presumably because of the low pH of the water media. According to Boyd (1990), ammonia is toxic to fish when the pH is higher. And the equilibrium between ammonia and ammonium depends on pH. The ratio of NH_4^+ to NH_3 tends to increase as pH decreases and vice versa. Rump & Krist (1992) stated that in the equilibrium between ammonia and ammonium when pH is less than 7, free ammonia tends to zero, and ammonium ions increase to about 100%. Boyd (1990) stated that in aquaculture systems aquatic animals, such as fish, are rarely killed by elevated ammonia concentration. However ammonia was identified as an important factor controlling the health and growth of aquatic animals, especially in semi-intensive and intensive culture systems.

Process and conditions of adaptation

The way of adaptation of African and striped catfish to the peat water of low pH generally ran well. For the initial mixing, adding peat water amount of 1/5 parts of the volume of borehole water to the tank of African catfish and striped catfish decreased the pH of water from 7.63 to 7.39 in the African catfish tank and 7.61 to 7.41 in the striped catfish tank. After 6-day rearing, the second, the addition of 2/5 parts of pure peat water to initial, the pH decreased from 7.10 to 5.36 in the African catfish tank and 7.25 to 6.25 in the striped catfish tank. After 10 days, the third, the addition of 3/5 parts of pure peat water to the second, decreased pH from 5.19 to 4.64 in the African catfish tank and 6.64 to 5.16 in the striped catfish tank. After 10 days, the fourth, the addition of 4/5 parts of pure peat water to the third, decreased pH from 5.40 to 4.93 in the African catfish tank and 5.60 to 4.89 in the striped catfish tank. After 14 days, the fifth, the addition of 5/5 parts of pure peat water to the fourth, decreased pH from 4.86 to 4.40 in the African catfish tank and 5.54 to 5.12 in the striped catfish tank. In these 5/5 parts was the concentration of peat water close to 100%, and the fish was let for 18 days. Until about 100% of peat water concentration, it was spent 58 days and continued for the next 38 days. During these 38 days, 100% peat water renewal was done 3 times. The day in total for the fiber tank treatment was 96.

After the addition of peat water to tanks, the pH value usually decreased. However, after 1 to 2 days, it gradually increased again as a result of feeding to fish, considering that the ash content in the artificial feed is quite large. According to Gracia Lovez *et al*. (2002), the ash content in artificial fish feed reaches 16%, and calcium is around

Table 1. Water quality parameters consist of water temperature (WT, °C), electrical conductivity (EC, mS/m), pH, dissolved oxygen (DO, mg/l) and ammonia (NH_3-N, mg/l), and mortality (inds.) of African catfish (*Clarias gariepinus*) and striped catfish (*Pangasius hypophthalmus*) tanks during the experiment.

Sampling Time	Peat Water (PW)						Borehole Water (BW)					
	African catfish						African catfish					
	WT	DO	pH	EC	NH_3-N	Mortality	WT	DO	pH	EC	NH_3-N	Mortality
06/08/2021	27.1	3.01	7.61	36.2	46.4	1	26.7	3.96	7.58	42.7	42.2	24
01/09/2021	27.6	3.01	4.83	52.6	24.0	0	27.3	1.9	5.21	72	15.6	0
01/10/2021	29.3	2.61	4.88	78.6	37.1	4	29.1	2.34	4.18	109	38.2	1
10/11/2021	28.1	1.00	5.08	32.5	18.6	1	27.8	1.75	4.22	102	51.6	2
Sampling Time	Striped catfish						Striped catfish					
	WT	DO	pH	EC	NH_3-N	Mortality	WT	DO	pH	EC	NH_3-N	Mortality
06/08/2021	26.8	4.82	7.63	36.5	50.1	6	26.7	3.61	7.49	32.5	35.4	5
01/09/2021	27.5	2.77	5.27	39.6	21.8	5	27.1	2.63	4.42	35.8	50.1	0
01/10/2021	29.4	2.17	5.29	77.1	27.4	2	29.2	2.24	4.68	121	50.4	0
10/11/2021	28.2	1.84	4.93	26.4	17.2	1	27.9	1.3	4.42	111	62.4	1

3.5%. Ardianor *et al*. (2012) reported that the feed ash content ranges from 12-16%.

In line with the increase of peat water concentration from 1/5 to 5/5 parts in the tanks, catfish have been adaptive to peat water's low pH in line with increasing their size. There were 3 times the renewal of 100% low pH peat water after the fifth (5/5 parts) of PW tanks during the observation as well as borehole water for BW tanks.

The changes in pH from sampling 1 to 4 indicated a sharp decrease from sampling 1 to 2 for all experimental units. Moreover, from sampling 2 to 4, it was almost flat, except for African catfish BW seemed to decrease from sampling 2 to 3 (Figure 1).

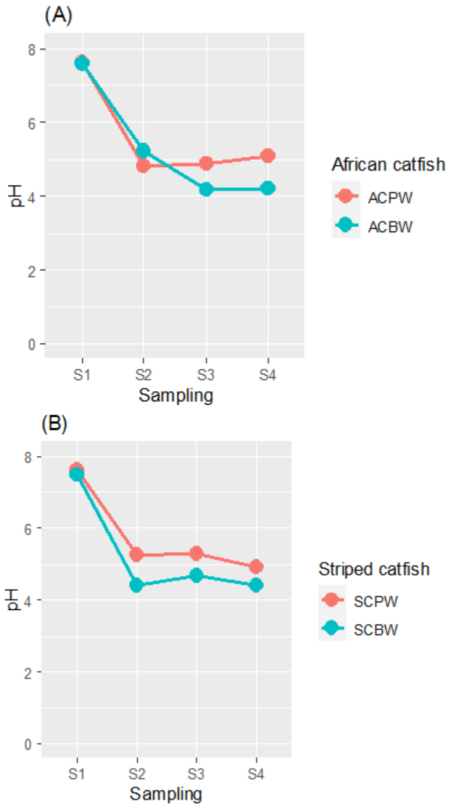

Figure 1. Trends in pH in each treatment (experimental unit), (A) African catfish, AC (peat water, PW, borehole water, BW), and (B) striped catfish, SC, on peat and borehole water, from sampling 1 to 4. It seems the decrease in pH value as the peat water concentration increased.

Response of African and striped catfish after decreasing pH was observed. Some individuals were rising to the water's surface just like taking oxygen from the atmosphere. Their response to a decrease in pH after an increase in the concentration of peat water in the tank was short, only after 1-3 hours the fish have returned to normal behavior. It was indicated by normal swimming and good adaptation. According to Mustapha & Mohammed (2018), the catfish mortality response exposed to low pH of water is possible due to decreased oxygen uptake, stress, and circulatory collapse. All of these results in behavioral responses and morphological abnormalities such as erratic swimming, panting and dark bodies, and coloring and lethargy. The morphological responses of the subject fish present study are similar to the African catfish of a previous study which is more discussed by Ardianor *et al*. (2022).

The subject fish that had started to adapt after sampling 3 was about 58 days and the peat water concentration was above 90% (Figure 2B). After catfish were seen to be highly adaptive, on day 96th, fish were transferred to the hapa-nets at the man-made pond at PTP UPR (Figure 3). Description of the water quality at peat pond, water temperature ranges, min-max value: 27.8 – 30.8°C ($\bar{x}$= 29.9°C), so on EC: 2.60 – 7.31 mS/ m ($\bar{x}$= 5.16 mS/m), pH: 3.71 – 4.73 ($\bar{x}$= 4.14) and DO: 0.21 – 1.89 mg/l ($\bar{x}$= 1.11 mg/l). No big difference was found in the pH of water between tanks and ponds except for DO concentration which was lower in the pond than in the tank. This was because no specific treatment was made to increase DO concentration.

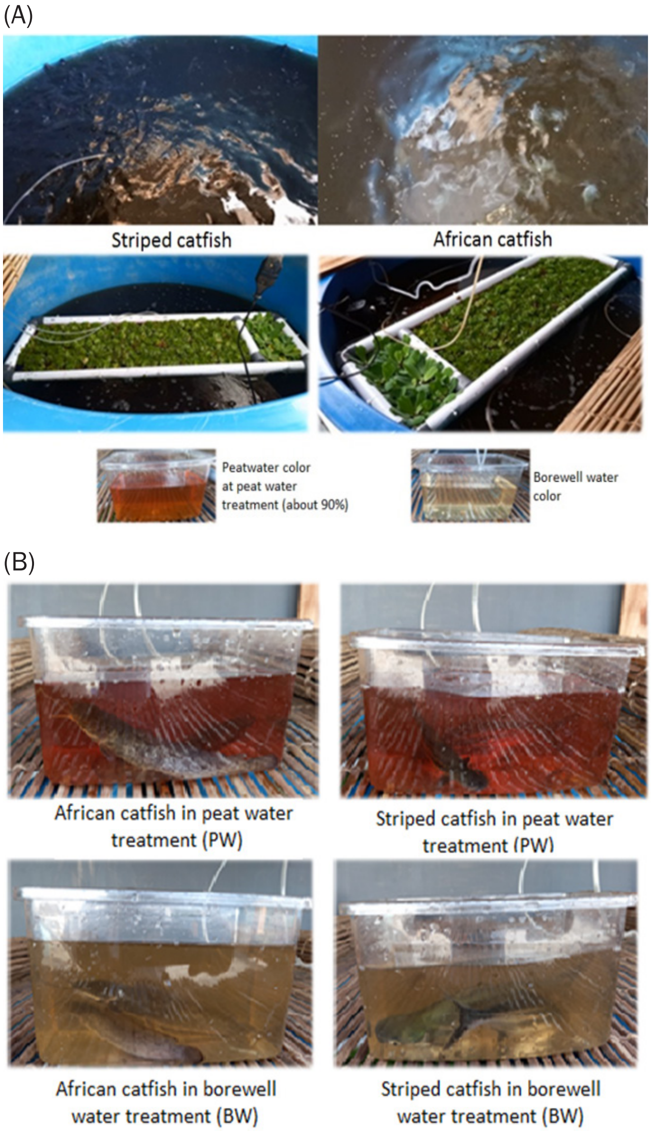

Figure 2. (A) Condition of African and striped catfish in sampling 1, and the application of floating aquatic plants, Salvinia (*Salvinia molesta*) and Water lettuce (*Pistia stratiotes*) covered about 1/3 of the surface of tanks to reduce the large increase in suspended materials. (B) The African and striped catfish have already adapted to the peat water concentration of about 90% (dark brown color, on the top) in sampling 3.

To minimize the increase of suspended material on the tanks, floating macrophytes, the combination of Salvinia (*Salvinia molesta*) and water lotus (*Pistia stratoites*) were used. Their roots capable to catch and take up suspended feed residues and metabolic wastes of reared fish. The root of the floating macrophyte was washed weekly to remove suspended material. The number of individuals of both floating macrophytes was kept constant on the frame during observation (Figure 2A).

Figure 3. The hapa(enclosure)-net set up on a peat water pond which has dynamic water quality to rear catfish (left: striped, right: African) after mostly adaptive of 96 days to peat water of low pH in the fiber tank. Image of striped catfish (top-left) and African catfish (top-wright) taken after 20 days rearing in hapa-net.

Survival rate, growth, and condition factor

The survival ability of the two fish species in the hapa-net placed in the pond after being adapted to low-pH peat water in a fiberglass tank was quite good. Mortality of African and striped catfish after 20 days transferred to the hapa-net from the tank was respectively 1 and 5 individuals, and considered very low that was respectively only 0.4% and 2.1% of total fish. It means that the adaptation process of the two catfish from the controlled situation on the tank to the hapa-net on the pond was successful since the ponds have been under natural and dynamic conditions with low pH.

There was no big difference in survival rate, SR between African catfish and striped catfish, and was all above 85%. The SR of African catfish on PW was higher than on BW, and of striped catfish was vice versa (Figure 4A). From sampling 1 to sampling 4, the SR of African and striped catfish varied narrowly between 85 and 100%, as shown in Figure 4B. It seemed a good survival rate for both the test catfish. According to Khairuman *et al*. (2008) in neutral water, African catfish survival is considered high when SR is more than 80% as well as striped catfish (Wangni *et al*., 2019). Although, Tantulo *et al*. (2020), found that the survival rate of African catfish (93.5%) in peat water was higher than striped catfish (66.3%). In their study, the pH of peat water was increased to about 7 with lime. The treated catfish were reared in the peat water which was put into the tarpaulin enclosure inside the wooden cages that are placed on the peat water bodies. In the present

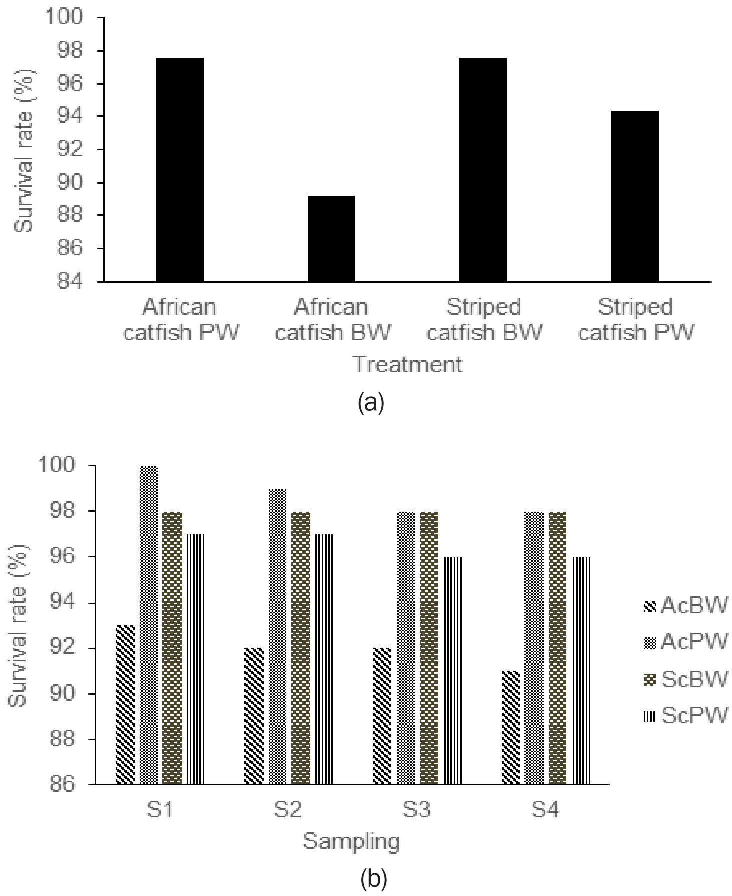

Figure 4. (A) survival rate (SR) of African and striped catfish in both peat water (PW) and borehole water (BW) by treatments. (B) the survival rate of African and striped catfish in both peat water (PW) and borehole water (BW) based on sampling time.

study, the survival ability of African catfish was slightly greater than that of striped catfish, especially after passing through juvenile size.

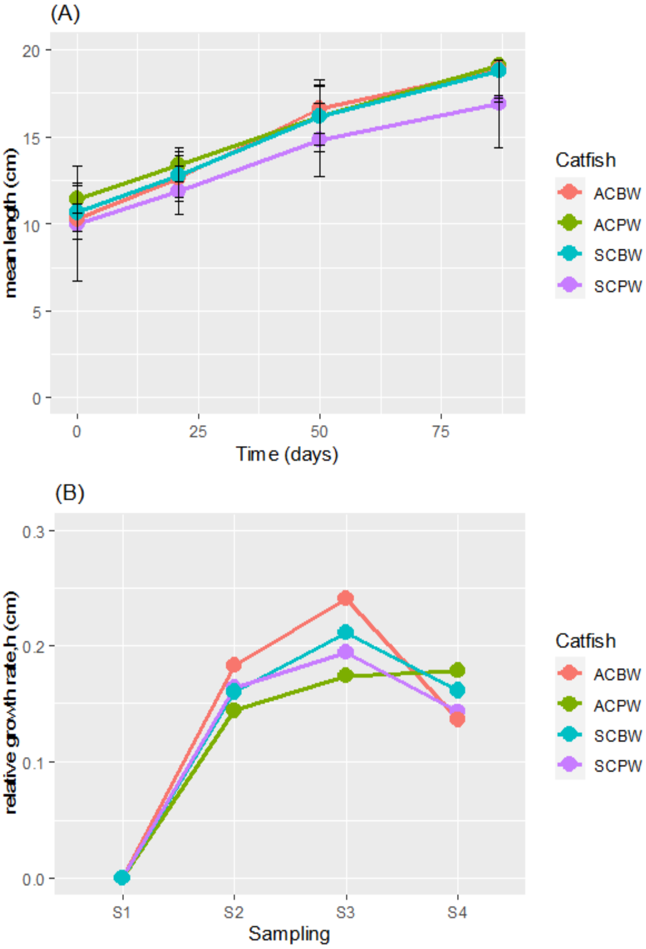

Figure 5. (A) The trend of fish length, and (B) the trend of relative length growth (h) of the African and striped catfish in both peat water (PW) and borehole water (BW) according to sampling time (day).

The length of African and striped catfish on both peat water (PW) and borehole water (BW) treatment tended to increase from the beginning until the last sampling as shown in Figure 5A. The relative length growth (h) of the catfish increased significantly as indicated by the effect of time of two ways Anova on both the African catfish (F: 14.15, Pr(>F): 0.028), and striped catfish (F: 230.8, Pr(>F): 0.000). The trend of relative length growth up to the 3rd sampling all seemed to increase except at the 4th sampling which slightly decreased for striped catfish PW, African catfish BW, and striped catfish BW, except African catfish PW, there a small increased of the relative growth from 3rd to 4th sampling (Figure 5B). The decrease in the relative growth of the striped catfish PW, African catfish BW, and striped catfish BW, as well as a slowdown in the relative growth in the African catfish PW, might be because after the 3rd sampling, the peat water concentration was high, above 90%. It meant that the high concentration of peat water whose pH was low tended to impede fish growth. According to Ndubuisi *et al*. (2015) pH of less than 5 decreases African catfish fry growth, as well as a pH of more than 9.

Although the relative growth appears to have decreased, the length of the test fish, both African and striped catfish continued to increase as shown in Figure 5A. Likewise, there was a slight decrease in the relative length growth of striped catfish PW from the 2nd to 3rd sampling, on the other hand, the condition factor (Kr) of striped catfish PW was more stable than the others which tended to increase (Figure 6). The relative condition factor of fish in all experimental units showed a fairly good condition where the Kr value was above 1. It was no significant difference between PW and BW treatment (Table 2 and Table 3), except visually in particular striped catfish was PW higher than BW (control). Wilaksana & Arfiati (2021) showed Kr for African catfish with a mean was 1.02, while Khalil *et al*. (2018) reported higher Kr for striped catfish with a mean of 1.44. The Kr value ranging from 3-4 indicates that the fish is plump, rather fat or rounded, while for Kr ranging from 1-2 is thin (Sutriana *et al*., 2020). According to Effendie (2002), some factors affecting Kr value are food, fish size, age, sex, and gonad maturity, as well as fatness and suitability of environment (Le Cren, 1951). In this study, slightly low Kr was presumably affected by peat water.

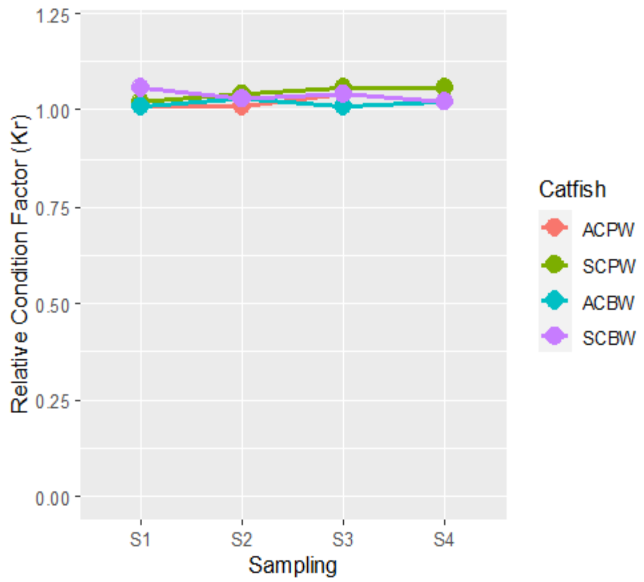

Figure 6. The changes of relative condition factor (Kr) of African catfish (AC) and striped catfish (SC) treated in peat water (PW) and borehole water (BW) during treatment. The Kr value varied narrowly between 1.0 and 1.07.

As to the African catfish PW, there was also an increase in the Kr value, from the 2nd to the 3rd sampling, but then decreased to the 4th sampling. Meanwhile, for the African catfish BW and striped catfish BW, the Kr seemed to have fluctuated from the 1st to 4th sampling (Figure 6).

The response variables such as mortality, condition factor, and relative growth of African and striped catfish were not significantly different between the peat (PW) and borehole (BW) water (Table 2 and Table 3). Even though statistically there were no significant differences in mortality, condition factor, and relative growth of the test catfish between PW and BW treatment, its mean showed slightly different.

Visually the boxplot in Figure 7B shows that striped catfish in the peat water (SCPW) had higher mortality than in

Table 2. Anova and non-parametric Friedman test of the African catfish (*C. gariepinus*) response to peat water and borehole water (control) during treatment time (4 sampling times as block). The main response variables are mortality, condition factors, and relative growth, and the supporting variables were the water quality parameters, e.i. temperature, conductivity, pH, dissolved oxygen, and ammonia.

Response variable	F		Pr(>F)		Friedman χ^2 (factor)	p
	Factor	Block	Factor	Block		
Mortality	0.771	0.902	0.444	0.533	0.333	0.564
Condition Factor (Kr)	0.059	0.373	0.824	0.781	0	1
Relative Growth (h)	0.535	14.149	0.517	0.028*	0.333	0.564
Water Temperature (WT)	33.0	618.5	0.010*	0.000**	4	0.045*
Electrical Conductivity (EC)	14.80	22.32	0.031*	0.015*	4	0.045*
pH	0.973	30.481	0.396	0.009**	1	0.317
Dissolved Oxygen (DO)	0.170	1.437	0.708	0.386	1	0.317
Ammonia (NH_3)	1.276	20.883	0.341	0.016*	0	1

Table 3. Anova and non-parametric Friedman test of the striped catfish (*P. hypothalamus*) response to the peat water and borehole water (control) during treatment time (4 sampling time is as a block). The main response variables are mortality, condition factors, and relative growth, and the supporting variables were the water quality parameters, e.i. temperature, conductivity, pH, dissolved oxygen, and ammonia.

Response variable	F		Pr(>F)		Friedman χ^2 (factor)	p
	Factor	Block	Factor	Block		
Mortality	3.429	3.857	0.161	0.148	3	0.083
Condition Factor (Kr)	0.194	0.137	0.689	0.932	1	0.317
Relative Growth (h)	3.0	230.8	0.182	0.000**	2	0.157
Water Temperature (WT)	12.79	448.58	0.037*	0.000**	4	0.045*
Electrical Conductivity (EC)	2.092	7.038	0.072	0.244	0	1
pH	13.81	77.92	0.034*	0.002**	4	0.045*
Dissolved Oxygen (DO)	0.974	9.637	0.396	0.047*	0	1
Ammonia (NH_3)	2.244	0.078	0.231	0.967	1	0.317

borehole water (SCBW) as well as the condition factor (K). Even though their mortality was slightly high in the peat water, the condition of striped catfish was still good in peat water. The pH and ammonia seemed inversely proportional. The pH in peat water was higher than in borehole water, and ammonia was vice-versa. The high striped catfish mortality in the peat water might be due to ammonia which was relatively more toxic under the high pH conditions. On the other hand, the lethal effect of ammonia in borehole water did not so strong because of the low pH conditions. As African catfish mortality Figure 7A shows lower in peat water (ACPW) than in borehole water (ACBW). The greater mortality of African catfish in borehole water (ACBW) may be due to relatively high levels of ammonia in the situation where pH was low. Meanwhile, the same situation in ammonia concentration also occurred for African catfish in peat water (ACPW), but it was slightly low mortality. This might be because the lethal effect of ammonia was not strong at a lower pH in peat water as mentioned earlier according to Boyd (1990) and Rump & Krist (1992). According to Eddy (2005); Levit (2010) who have reviewed some journals said that the effect of ammonia on fish in freshwater is influenced by water temperature and pH, as well as in marine waters, plus the presence of salinity. An increase in pH will cause a lot of ammonia (NH_3) to be converted into ammonium (NH_4+) in the fish's body. High levels of ammonium in the body of fish will cause toxicity to fish.

Over the observation time, the effect of decreasing the pH of peat water was statistically significant (F: 30.48, Pr(>F): 0.009), and ammonia levels also increased significantly (F: 20.88, Pr(>F): 0.016). The significant increase in ammonia levels was a result of the metabolism of the test catfish, and the reshuffling of unabsorbed feed residues. However, some of the NH_3-N levels might have been minimized by placing the floating aquatic plants as phytoremediators during treatment.

This result showed that by the adaptation process of two test fish, they were able gradually to acclimate and adapt to the peat water during the experiment. The lethal effect of low-pH peat water was minimized to occur on the African and striped catfish might be because of the slow physiological adjustment of fish during the adaptation.

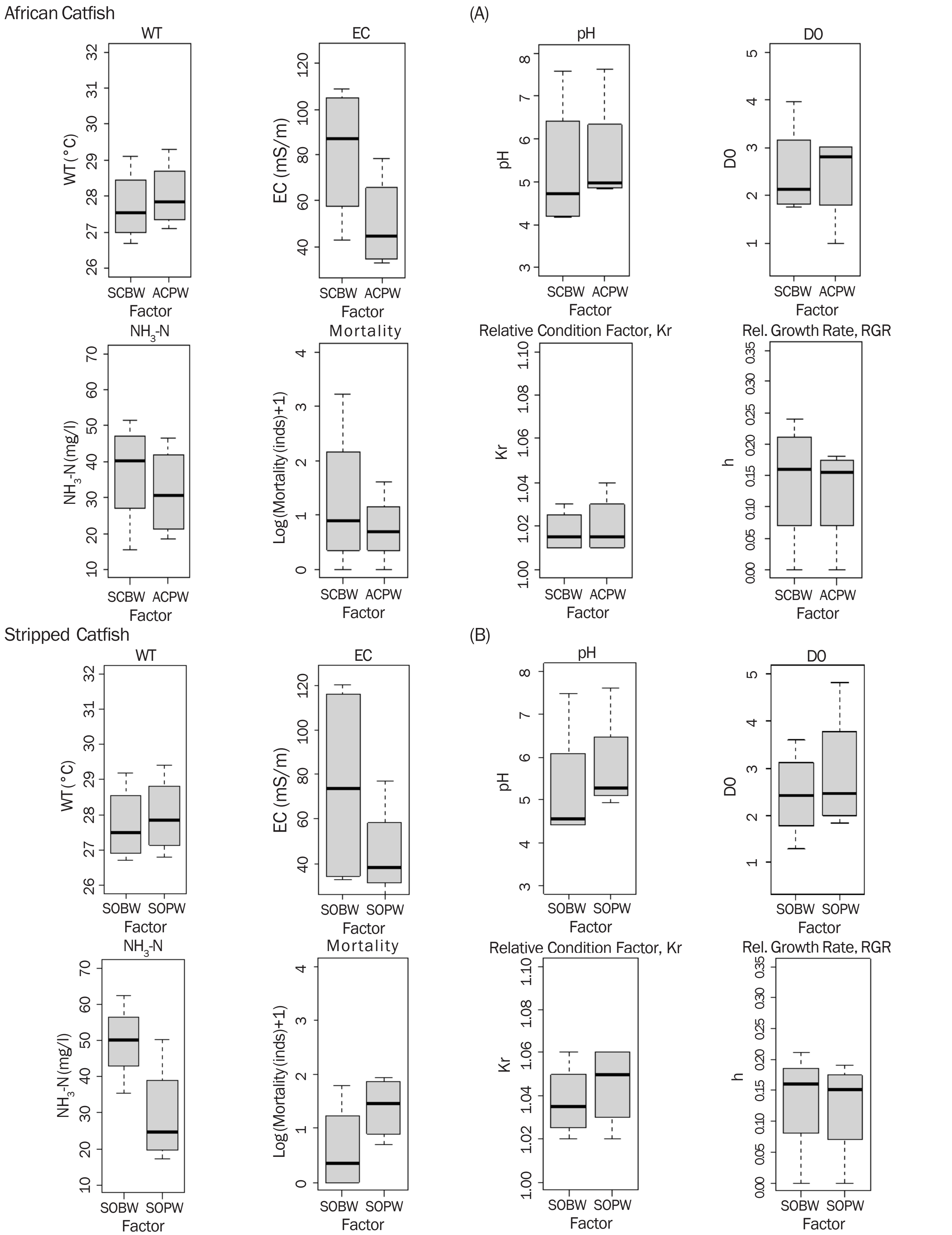

Figure 7. The boxplots show the visual comparison of the median of each of the main response variables, e.i. mortality, relative condition factor, Kr, and relative growth rate, RGR, as well as supporting water quality (water temperature, WT, electrical conductivity, EC, pH, dissolved oxygen, DO, and ammonia, NH_3-N) between the factor level, (A) African catfish in peat water (ACPW) and borehole water (ACBW), and (B) striped catfish in peat water (SCPW) and borehole water (SCBW).

It meant that the mortal effect of low pH of peat water on mortality of cultured fish, African and striped catfish can be minimized through the adaptation process. Once cultured fish have already been adaptive to the peat water, their growth seemed not to be disturbed. Even cultured fish can grow normally in humic water with some advantages to their survival. Prokešová *et al*. (2015) found that humic acid can improve the health of catfish (*C. gariepinus*) and has the potential as an anti-oxidant. This statement is in line with what was found by Thoriq Al Islam *et al*. (2021) that humic acid supplementation in catfish feed can increase the growth and number of good bacteria in the catfish digestive tract.

In general, both African and striped catfish as previously predicted were able to adapt to the pH of low-pH peat water ranging from 3.0 to 4.5, with low mortality through the adaptation process. By mixing the low-pH peat water with borehole water, while gradually increasing the concentration of peat water in the mixture at a fixed volume inside the tank, the ongoing adaptation of the catfish from the beginning of release was successfully achieved. This method succeeded in making African and striped catfish adaptive for about 58 days. The advanced treatment has been done by placing or rearing both catfish species in the hapa-net placed inside the man-made ponds which are more dynamic peat water quality and condition until about 96 days. This treatment was to test and justify that the cultured catfish could survive and thrive in the cages, *hapa*-net, or floating nets placed in the rivers, lakes, and swamps of low pH peat water.

CONCLUSION AND RECOMMENDATION

Conclusion

The cultured fish, African catfish (*C. gariepinus*), and striped catfish (*P. hypothalamus*) have adapted and survived to peat water with a low pH between 3.0 and 4.5 with the simple adaptation process. The adaptation was by rearing catfish from the fingerling size on the peat water in a tank gradually increasing its concentration to about 100% until the time fish reached adult size for about 58 days. The advanced treatment has been done by placing or rearing the test catfish species in the *hapa*-net placed on the man-made pond which was more dynamic peat water quality and condition after 96 days in the fiber tank. This treatment was to test and justify that the cultured catfish could survive and thrive in the cages, hapa-net, or floating nets that are placed in the rivers, lakes, and swamps with low pH peat water, or the peat water pond without liming. The growth length, survival rate, and condition factor of the treated catfish in the peat (acidic) water statistically did not significantly differ from borehole (neutral) water.

Recommendation

The present study did not explore or study the physiological aspects of both catfish species that are exposed to the peat water of low pH. We merely recorded and revealed visually the morphological aspect, and focus on the survival and mortality of the subject fish. Hence, for the next study is suggested to study deeply the physiological aspect of such species. The other study will be important to apply the same treatment but different cultured fish species, such as scaly fish, carp, tilapia, and giant gourami.

AUTHOR'S CONTRIBUTIONS

The contributions of each author, AA was the main idea, doing research, data analysis and principal writing manuscript. NSY was doing research, co-writing and verifying manuscript. TH was doing research, data recording and co-writing manuscript. HH is co-writing, editing and verifying English manuscript.

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