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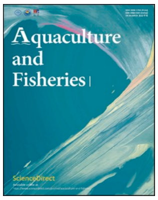

The age and quality of pond bottom soil affect water quality and production of *Pangasius hypophthalmus* in the tropical environment

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ABSTRACT

Pangasius hypophthalmus is the most cultured freshwater fish by smallholder farmers in Indonesia. One of the main challenges in the production is the highly weathered and infertile soils on the bottom of a pond that influences aquaculture productivity. This work investigated the effects of pond age on soil quality, water quality, benthic algae population, and P. *hypophthalmus* production. We carried out a field experiment in a randomized design with pond age of 4 levels: Ponds aged 0–5 years (P1), 6–10 years (P2), 11–15 years (P3), and 16–20 years (P4). The soil is a Typic Palaeudult (Ultisol), and fish were grown for three months. The results showed that the chemical soil quality parameters and soil organic matter content increased linearly with pond age, resulting in the enhancement of water quality parameters. The increase in nitrate and phosphate directly affected benthic algae richness. These, in turn, in the highest fish production in P3, 6.4 kg/m^2, specific growth rate was 3.76 %/d, survival rate of 66.7%, and feed conversion ratio of 1.8%. Linear correlation coefficients indicated that the contents of total N, total P, and organic carbon in the bottom soil of the pond were related to the increase in phosphate, nitrate, and organic matter content in pond water. Total N content, total P, carbon organic matter, C/N ratio, and CEC value in pond bottom soil significantly correlated to Pangus fish production. C/N ratio, CEC value in pond bottom soil, and CO_2 concentration in pond water significantly correlated to fish survival rate. Multiple linear regression indicated that fish production was significantly related to the pond age, water NH_3, total alkalinity, and soil total P and C/N ratio ($R^2 = 0.99$, $P < 0.001$). Increased soil C/N ratio caused a negative effect on fish production. The results suggested that old-aged ponds, with proper management, act as a nutrient sink, resulting in increased aquaculture production. The implementation of the best practices will benefit the Pangus culture in the tropical environment.

1. Introduction

The soil on the bottom of a pond acts as a source of nutrients and also buffers water in aquaculture. The soil also acts as a biological filter, adsorbing organic remains of feed, fish excrements, and algal products. The changes in pond soils over time are common, particularly in tropical countries, where highly weathered Ultisols, and Oxisols are dominant (Adiningsih & Sudjadi, 1993). These soils have low cation exchange capacity, acidic, and low in nutrient and organic matter content. In Indonesia, many areas are dominated by Ultisols, locally called red-yellow podzolic soil. For example, in Riau province, the soils are dominated by Ultisols, which are acid and poor in nutrients. The soils needed regular inputs of macronutrients and limed to improve its quality.

The important bottom soil fertility indicators in freshwater ponds are nitrogen concentration, C/N ratio, organic matter content, and dissolved phosphorus. Boyd (2008) found the condition of the pond bottom and the exchange of substances between soil and water can strongly

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influence the water quality of the fishponds. Thus, the soil directly affects water quality, nutrient availability, and fish productivity in aquaculture.

The age and depth of pond directly affect the physical and chemical quality of pond water (Boyd, 2010), which; in turn influences the growth of the phytoplankton, and benthic algae which are the base of the food chain in a fish pond. Low pH can inhibit the decomposition of organic matter and allow its accumulation in pond soil to cause high oxygen demand at the interface of bottom soil and pond water (Boyd, 1995; Boyd (2015). Low nitrogen concentrations also inhibit the decomposition of organic matter at the bottom of the pond by aerobic bacteria. In addition, anaerobic bacteria can use oxygen from dissolved oxygen to produce potentially toxic metabolites, e.g, nitrite, and sulfide, which can enter the water column. Impaired bottom soil quality is reflected in water quality detection in ponds and especially in old fishponds (Mondal, Rahman, Saha, Adhikary, & Hossain, 2013a, 2013b; Hossain & Rahman., 2017; Pravakar et al., 2013).

A good site for constructing fishponds is a deep layer of fertile soil with neutral pH, low water infiltration and mineralization of organic matter takes place rapidly (Siddique et al., 2012). Such ponds are ideal for the culture of iridescent shark (*Pangasius hypophthalmus*) a fast-growing edible fish that is in high demand in Southeast Asia, particularly in Indonesia, Vietnam, and Thailand (Bostock et al., 2010; Phuong & Oanh, 2010; & Jiwyam, 2015), and pangasius culture in Bangladesh (Ali et al., 2012). However, many ponds used for the culture of their fish do not have ideal bottom soil conditions either because of the original site soil quality or changes in soil quality with time.

In Indonesia, the iridescent shark is mostly cultivated by smallholder aquaculture farmers. This fish shows a positive response to fish pellets, and within 3 months of intensive cultivation, a fish can reach a weight of 150–200 g. The economy of the village relies on this freshwater fish, and thus a better understanding on the effect of pond age and pond management is needed to enhance the benefits of growing this fish in local villages.

A common problem in intensive fish cultivation has been a reduction in pond bottom soil quality due to sedimentation. Excess feed pellets settle to the bottom. As a result, the quality of the pond bottom deteriorates over time. Saraswathy et al. (2019), found that ammonia nitrogen and total alkalinity were higher at the soil-water interface as compared to the surface water. In contrast, pH, nitrate (NO_3^-), and inorganic phosphorus (PO_4^{3-}) showed the opposite trend. The two layers showed no significant difference in macronutrients: N, P, K, Ca, and Mg. The changes were mainly observed at the 1 cm top layer, which acted as a transition zone.

Pouila et al. (2019) found that nutrient sediment accumulation increased linearly with total nutrient input in a small-scale freshwater pond system. Makori et al. (2017) reported that reducing pond productivity could cause suboptimal water quality. Ojwala et al. (2018) demonstrated the uncontrolled addition of inputs (feed and inorganic fertilizer) can reduce water quality, increase the incidence of parasite infection, and reduce fish production.

From the literature cited above, it has been found that pond age contributes to the accumulation of organic feeding waste, phosphorus, and nitrogen in the bottom soil and influences water quality, fish growth, and production. However, the effect of pond age and soil quality on water quality and fish production in tropical soil has not been well researched. Therefore, the present investigation considered the effects of age on soil quantity, water quality, and fish production in an intensive culture pond a built-in Ultisol. Our hypothesis is that pond age in intensive pangasius cultivation systems could profoundly affect the physical, chemical, and biological quality of pond bottom soil, which in turn could affect pond water quality and fish productivity.

2. Materials and methods

2.1. Study area

The field experiment was carried out in the Village of Koto Masjid, Kampar, Riau (Lat N 0°19′ 30″ Long E 100° 51′ 40″), (Fig. 1), and samples were analyzed at the laboratory of Environmental Quality Laboratory Department of Aquaculture Fisheries and Marine Science Faculty, University of Riau, Indonesia. The location determination was selected because of its red-yellow podzolic soils (Typic Paleudult, USDA soil taxonomy), water source, and the variability of pond ages. This area was recognized as the pilot area for freshwater fish production in Riau Province and had a large number of pangasius ponds. The research supports the government policy in freshwater fish cultivation development.

2.2. Experimental design

The experiment was a single factor arranged in a randomized block design (Steel & Torrie, 1993), consisting of four levels of ponds age: P1 (0–5 years), P2 (6–10 years), P3 (11–15 years), and P4 (16–20 years) each with three replicates. Ponds similar in age were treated as blocks, and treatments were equally allocated to each block (Smart et al., 1997). Before the 12 pond units were used for research, ponds were drained, about 2–3 cm sediment and sludge were removed. The pond was left to dry for 5 days and limed using $CaCO_3$ at a rate of 168 g/m^2 (Hasibuan et al., 2012). The ponds are artesian wells and piped to the ponds. The inlets water of the pond is arranged diagonally of the drains outlets. Inorganic fertilizer was added with the following doses: urea 4.16 g/m^2, superphosphate 36 (SP 36) 1.36 g/m^2, and muriate of potash (KCl) 4.5 g/m^2, and quail manure 26.59 g/m^2 (Hasibuan et al., 2013). The sizes of ponds raried: P1: 1122.04–1749.30 m^2; P2: 1896.58–2668.87 m^2; P3: 2384.92–3183.57 m^2; and P4: 1466.81–1911.13 m^2. However, all ponds were 1.5 m in average depth. Slight differences in management had previously been applied to different ponds. Namely, in P1 ponds bottom drying had been after carried out were dried every three harvests, but in P2 ponds age productive pond draining of pond bottom were dried once every two harvests. The loose sediment had been discharged in drainage water in P3, and P4 ponds during every harvest. The 12 earthen ponds have been used for intensive pangasius cultivation. *Pangasius hypophthalmus* were collected from local fish suppliers in the Village of Koto Masjid. All fingerlings had the same age with an average length and weight of 7.56 ± 1.28 cm, and 3.85 ± 0.18 g, at a density of 50 fish/m^2. Feed pellets (30% protein, 6.5% fat, 10% moisture and 15% ash) were fed daily to satiation (feed given 5% of the bodyweight). Pangasius was fed three times a day at 07.00, 12.00, and 17.00.

2.3. Analysis of soil, water, algae, and fish production parameters

Soil samples from the pond bottom was taken at 0–10 cm depth using a soil sampler (a PVC tube of 1 cm diameter and length of 20 m) with 3 cores from each pond. They give a total of 36 individual samples at the beginning and end of the experiment. Soil composite samples were air-dried and sieved to 2 mm positive size. All samples were analyzed by the sieve–pipette method, (Gee & Or, 2002). Coarse particle distribution (50–200 μm and 200–2000 μm fractions) was determined by wet sieving, whereas clay (2 μm) and silt (2–50 μm fractions) were measured by pipette. The distribution of sand, clay, and silt was used with the textural triangle to obtain the descriptive texture soil name for the soil. The soil samples were analyzed for total N (Kjeldahl method), organic carbon (Walkley and Black method), C/N was calculated on the mass basis of organic C/N. Soil phosphorus was determined with the Bray-1 (HCl 0.025 N + NH_4F 0.03 N) (extraction method), and the Olsen ($NaHCO_3$ 0.50 N; pH 8.5) fraction technique. The cation exchange capacity (CEC) was measured by the 1 N NH_4OAC extraction and expressed in mmol charge per 100 g of soil mmolc.100 g^{-1}. For

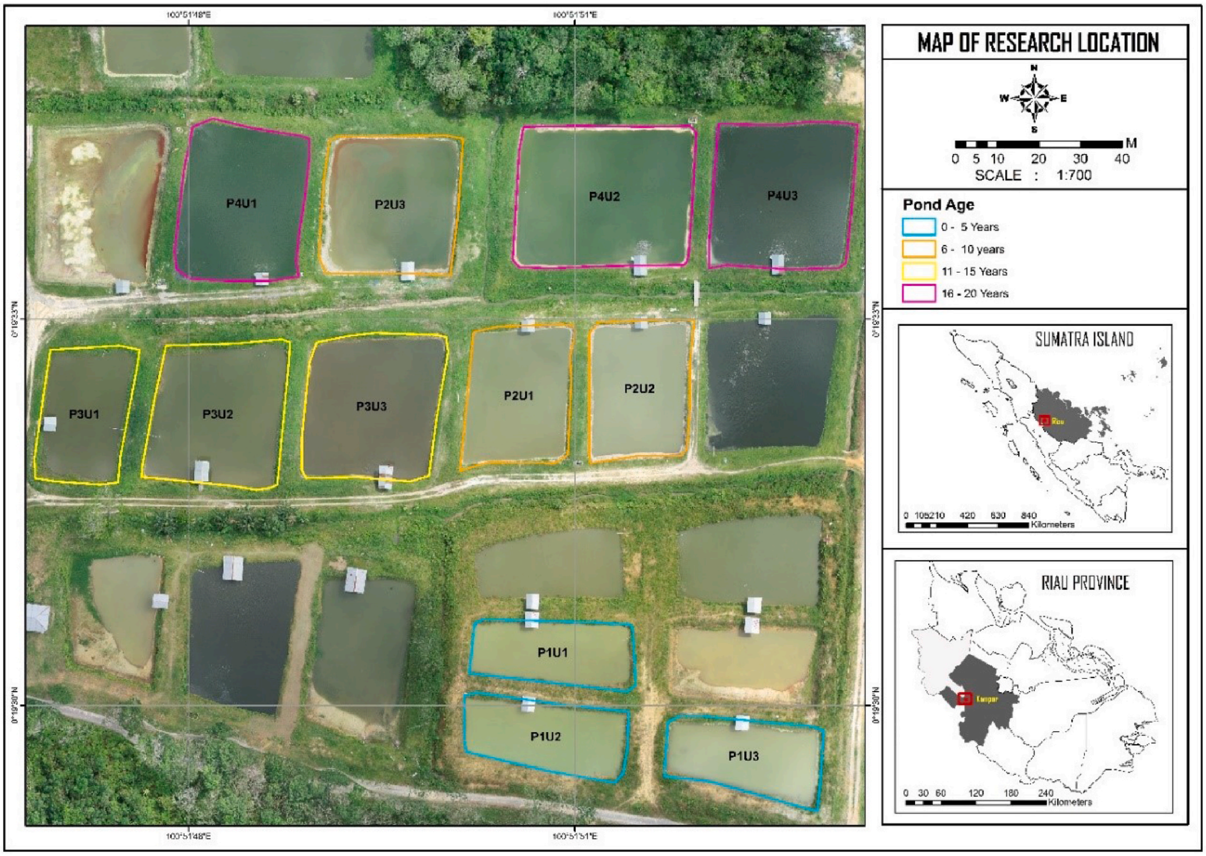

Fig. 1. Location of experimental ponds in the Koto Masjid, Kampar, Riau (Lat N 0° 19′30″ Long E 100° 51′ 40″).

converting organic matter mass fraction to area basis, the calculation was based on soil bulk density (BD) and water content measured by the gravimetric method of Black et al. (1965) by the aquation:

$$N\ (kg/m^2) = N\ (kg/kg) \times BD\ (kg/m^3) \times \text{depth of soil (m)}$$

The following water quality parameters were measured: water clarity was by Secchi disk, temperature (°C), and pH with portable pH Meter Hanna HI 9124, dissolved oxygen with a YSI Pro20i Dissolved Oxygen Meter, carbon dioxide, NH_3, PO_4^{3-}, NO_3^{-}, total alkalinity (TA), and total organic matter (TOM) were analyzed in the laboratory using the methods described in Boyd and Tucker (1992). Water sampler was taken weekly using a sampler bottle and stored in a glass bottle for analysis. The samples were collected two times of the day.

Algae measurements also were made weekly. Compositions of benthic algae were identified using a microscope (Davis, 1955; Mizuno, 1970; Shirota, 1966), the abundance of benthic algae was calculated using the SRCC (Sedgwick Rafter Counting Chamber) method with formula modification LDMC (Lackey Drop Microtransect Counting Method) (APHA, 1995). Specific growths of length and weight were calculated every 2 weeks by methods given by Zonneveld et al. (1991), Hopkins (1992). The feed conversion ratio (FCR) was calculated from the amount of feed given during the cultivation period, compared divided by the amount of biomass during the cultivation period (Stickney (1979). The biomass of pangasius in each was pond measured at the end of the rearing period (90 days) by using a scale with a 1 g precision level were estimated from the numbers of fish correlated at actually and harvest, and survival rate (%), (Effendi, 2002).

2.4. Statistical analyses

One-way ANOVA was used to analyze for significant differences in the value of different parameters. A probability at the level of 0.05 or less was considered significant. Standard errors were also calculated. Duncan's multiple range test was used to determine differences at a significant level of $P < 0.05$. All statistical analyses were conducted using SPPS version 16. To investigate the relationship between pond age, soil parameters, water quality, and fish production. Pearson's linear correlation coefficients were calculated among these variables.

The Pearson's linear correlation coefficient was calculated to investigate the relationship between the age of pond, soil parameters and water quality and fish production parameters. Multiple linear regression was conducted to relate pond's age, water quality, and soil parameters to fish production. As there were 25 independent variables, significant parameters were first tested using the stepwise regression method. The stepwise method tested each independent variable's statistical significance ($P < 0.05$) in a linear regression model. The final multiple regression model included only potential significant independent variables and removed variables that were not statistically significant. All statistical analyses were conducted using SPPS version 16.

3. Results

3.1. Parameters of soil quality

Soil texture is named from sandy clay to sandy clay loam texture. The physical characteristics of this soil were highly suitable for aquaculture pond, according to the criteria of Ssegane et al. (2012) for the bottom to have clayed contents of 15%–30% clay. The soil was slightly acidic soil with a pH of 5.8–6.5 affected nutrient solubility and availability.

Table 1 shows the chemical properties of the treatment pond at the beginning and end of the experiment and their changes. The application of pelleted feed increased nutrient concentration in pond water. After three months, increases in soil organic carbon (SOC), N, C/N, P, and CEC were observable.

Table 1
Soil chemical characteristics as a function of pond age.

At the beginning of experiment (n)*	P1 (n = 3)	P2 (n = 3)	P3 (n = 3)	P4 (n = 3)
Soil Organic Content (SOC) (%)	1.25 ± 0.05^{a}	2.25 ± 0.04^{b}	6.77 ± 0.02^{c}	10.92 ± 0.01^{d}
N total (%)	0.07 ± 0.02^{a}	0.07 ± 0.02^{a}	0.20 ± 0,02^{b}	0.19 ± 0,03^{b}
C/N ratio	10.35 ± 0.03^{a}	18.64 ± 0.02^{b}	19.63 ± 0.02^{c}	33.34 ± 0.10^{d}
Total phosphorus (P_2O_5 (ppm))	23.31 ± 0.07^{a}	68.54 ± 0.01^{b}	89.72 ± 0.17^{c}	90.84 ± 0.08^{c}
CEC (mmol$_c$.100g^{-1})	4.53 ± 0.01^{a}	5.92 ± 0.10^{b}	6.32 ± 0.07^{c}	7.38 ± 0.11^{d}
At the end of the experiment (n)*	**P1 (n=3)**	**P2 (n=3)**	**P3 (n=3)**	**P4 (n=3)**
Soil Organic Content (SOC) (%)	3.83 ± 0.03^{a}	6.77 ± 0.02^{b}	8.2 ± 0.04^{c}	13.09 ± 0.02^{d}
N total (%)	0.20 ± 0.03^{a}	0.20 ± 0,02^{a}	0.29 ± 0,07^{b}	0.21 ± 0,05^{a}
C/N ratio	11.11 ± 0.02^{a}	19.63 ± 0.02^{c}	16.40 ± 0.07^{b}	36.15 ± 0.07^{d}
Total phosphorus (P_2O_5 (ppm))	39.42 ± 0.11^{a}	124.53 ± 0.15^{b}	279.62 ± 0.10^{c}	385.71 ± 0.15^{d}
CEC (mmol$_c$.100 g^{-1})	8.15 ± 0.07^{a}	10.87 ± 0.05^{b}	9.17 ± 0.03^{b}	15.15 ± 0.03^{c}
Change (end - beginning)	**P1**	**P2**	**P3**	**P4**
Soil Organic Content (SOC) (%)	2.58 ± 0.02^{c}	4.53 ± 0.05^{d}	1.45 ± 0.03^{a}	2.17 ± 0.02^{b}
Soil organic matter (kg/m^2)	8.30 ± 0.06^{c}	14.50 ± 0.15^{d}	4.60 ± 0.09^{a}	6.90 ± 0.06^{b}
N total (%)	0.13 ± 0.01^{b}	0.13 ± 0.01^{b}	0.09 ± 0.06^{b}	0.02 ± 0.02^{a}
N (kg/m^2)	0.21 ± 0.02^{b}	0.21 ± 0.02^{b}	0.14 ± 0.12^{b}	0.03 ± 0.06^{a}
C/N ratio	0.72 ± 0.03^{a}	0.99 ± 0.01^{b}	−3.23 ± 0.07^{d}	2.81 ± 0.04^{c}
Total phosphorus (P_2O_5 (ppm))	16.11 ± 0.16^{a}	55.99 ± 0.15^{b}	189.90 ± 0.14^{c}	294.87 ± 0.08^{d}
CEC (mmol$_c$.100 g^{-1})	3.62 ± 0.08^{b}	5.29 ± 0.45^{c}	1.45 ± 0.03^{a}	7.77 ± 0.08^{d}

Remarks: Cation Exchange Capacity (CEC), P1: 0–5 years, P2: 6–10 years, P3:11–15 years, P4:16–20 years.

The same letter within a row indicated the treatments are not significantly different ($P < 0.05$).

[*] n = Total samples analyzed.

3.1.1. *Soil organic content (SOC)*

The SOC increased linearly with time, from 1.25% (P1: 0–5 years) to 10.92% (P4: 16–20 years). SOC increased in each pond age category with the highest SOC content of 13.04% in P4. The ANOVA showed that pond age affected SOC and post-hoc analysis showed P4 different from P1, P2, and P3. Comparing the beginning and the end of the experiment, all pond age categories were different, P2 showed the largest increase (4.35%), followed by P1, P4, and P3. This implied that P1 and P2 with the lower SOC had a larger capacity to increase in SOC compared to older pond P3 and P4 which already had a high OC content.

3.1.2. *Total N, C/N ratio, total phosphorus, and cation exchange capacity (CEC)*

An increase of soil N was observed in all pond age categories, with the highest increase of 0.29% for P3. P1, P2, and P3 which were significantly larger in P4 (0.02%). The P4 pond with a higher organic C, and N content but showed the least amount of increase (Table 1).

Pond age also had a significant effect on the C/N ratio. The C/N ratio increased linearly with age, from 10 in P1 to 33 in P4 (Table 1). Fish cultivation also increased the soil's C/N. The ANOVA showed that the age of earthen ponds for intensive pangasius cultivation caused significant differences on C/N with P4 significantly different to P1, P2, and P3. The best C/N (~15) was achieved in P1, and P3. The P4 had a very wide C/N ratio of 36.15, which cannot be explained from available data.

The initial total P concentration increased from 23.31 to 90.84 ppm among the pond age categories (Table 1). After fish cultivation, total phosphorus increased proportionally with the pond age with the highest value and rate of increase in P4 (385.71 ppm).

Greater pond soil age led to increased CEC. For example, the initial soil condition revealed a CEC of 4.53 mmcol$_c$.100 g^{-1} for P1 and 7.38 mmcol$_c$.100 g^{-1} for P4. (Table 1). After the 3 months of cultivation, CEC increased with the highest value 15.15 mmol$_c$.100 g^{-1} in P4 soil. The decomposing remains of organic matter have a high CEC, and low CEC in soils income in CEC with more organic matter (Boyd, 1977).

3.2. *Water quality parameters*

The increase of soil organic matter in the cultivation period of water watch: concentration changed clarity, dissolved oxygen, NH_3, PO_4^{-3}, NO_3^-, total alkalinity, CO_2, and total organic matter, but water temperature, and pH were not affected. The changes in soil organic matter and other aspects of soil quality were reflected in changes in pond water quality (Table 2).

3.2.1. *Temperature, water clarity, and pH*

The water temperature did not differ among the pond age categories (Table 2), and its range was 27.6–27.9 °C, which is optimal for fish production. Water temperature was, fortunately, because the water temperature is among the important physical properties affecting chemical and biological reactions roles in the water pond ecosystem. Water clarity differed among the pond age categories. The water clarity averages were: P1 23.98 cm; P4 24.03 cm; P3 24.98 cm; P2 25.28 cm. Water pH was as follows: P1 6.77 ± 0.40; P2 6.50 ± 0.40; P3 6.80 ± 0.60; P4 6.87 ± 0.45. Pond age had no effect on water pH, and pH was suitable for fish in all ponds.

3.2.2. *Dissolved oxygen*

The average of measured dissolved oxygen concentrations for the four age groups of ponds was highest in P3 (4.05 mg/L) followed by P2 (3.99 mg/L), P1 (3.75 mg/L), and P4 (3.74 mg/L). There are averages at below 4 mg/L (3.88) and, in theory, be higher by midday. However, the concentrations are low and suggest that greater fish production might not be possible without aeration. Group P3 was significantly different from other pond groups.

3.2.3. *Ammonia (NH_3), nitrate, and orthophosphate*

Table 2 shows NH_3 levels depended on the pond age with the highest value of P4, 0.21 mg/L, followed by P2, 0.20 mg/L, P3, 0.19 mg/L, and P1, 0.16 mg/L.

The average measured nitrate concentration (Table 2), increased with pond age. The lowest was in P1, 0.94 mg/L, followed by P2, 0.98 mg/L, P4, 1.03 mg/L, and P3, 1.07 mg/L. Their concentrations are relatively high when compared with those typically found in fertilized ponds (Boyd and Tucker, 1998).

The average of orthophosphate values (Table 2), are highest for the oldest pond and decreased linearly with pond age: P4, 1.05 mg/L, followed by P3, 0.90 mg/L, P2, 0.86 mg/L, and P1, 0.62 mg/L.

3.2.4. *Total alkalinity and free carbon dioxide*

The average total alkalinity for ponds decreased in older ponds. This was related to longer periods of liming in P4 and P3 ponds. The average of free carbon dioxide (Table 2) were unrelated to pond age. The average of free carbon dioxide (Table 2) were unrelated to pond age.

3.2.5. *Total organic matter*

The average values of total organic matter (Table 2) were highest (7.48 mg/L) for P3, but unrelated to pond age groups.

Table 2
The average values of water quality parameters at each pond age.

Cultivation period	Water quality parameters									
	Temp.	WC	pH	DO	NH_3	PO_4^{3-}	NO_3^-	TA	CO_2	TOM
(n)*	(^{0}C)	(cm)		(mg/ L)	(mg/ L)	(mg/ L)	(mg/ L)	(mg/ L)	(mg/ L)	(mg/ L)
P1 (46)	27.9 ±0.25	23.98 ±0.01 ^{a}	6.77 ±0.40	3.75 ±0.02 ^{a}	0.16 ±0.03 ^{a}	0.62 ±0.06 ^{a}	0.94 ±0.03 ^{a}	81.2 ±0.25 ^{b}	9.49 ±0.01 ^{b}	6.94 ±0.03 ^{a}
P2 (46)	27.7 ±0.06	25.58 ±0.03 ^{d}	6.50 ±0.40	3.99 ±0.03 ^{b}	0.20 ±0.02 ^{ab}	0.86 ±0.03 ^{b}	0.98 ±0.02 ^{a}	69.1 ±0.15 ^{a}	10.05 ±0.04 ^{c}	7.13 ±0.04 ^{b}
P3 (46)	27.6 ±0.25	24.98 ±0.02 ^{c}	6.80 ±0.60	4.05 ±0.01 ^{c}	0.19 ±0.02 ^{ab}	0.90 ±0.04 ^{b}	1.07 ±0.02 ^{b}	83.4 ±0.45 ^{c}	9.04 ±0.06 ^{a}	7.48 ±0.04 ^{d}
P4 (46)	27.6 ±0.15	24.03 ±0.01 ^{b}	6.87 ±0.45	3.74 ±0.02 ^{a}	0.21 ±0.02 ^{b}	1.05 ±0.02 ^{c}	1.03 ±0.03 ^{b}	100.5 ±0.35 ^{d}	9.49 ±0.01 ^{b}	7.23 ±0.05 ^{c}

Remarks: Temp (temperature), WC (water clarity), DO (dissolved oxygen), TA (total alkalinity), CO_2 (free carbon dioxyde), TOM (total organic matter).
Numbers with the same letter in a column indicated that they were not significantly different ($P = 0.05$).

[*] n = Total samples analyzed.

3.3. *Effects of the earthen pond soil quality on water quality*

Although the concentration of water quality variables were not always clearly a function of pond age, the relationship to bottom soil quality ware more obvious. The Pearson's linear correlation coefficient between soil nutrient parameters (N, P, and OC content) and water quality were calculated for all the ponds (Table 3). Most of the concentrations of water quality variables were positively correlated with soil N, P, and OC content. This is other except than for CO_2, dissolved oxygen, and ammonia.

The quantity is compelling evidence that soil quantity is a major nutrient content factor influencing water quality in fertilized fish ponds. The higher nutrient concentrations in ponds will more organic matter could be expected to stimulate phytoplankton growth (Boyd and Tucker, 1998).

3.4. *Biological quality parameters (benthic algae)*

Greater pond age led to increased soil organic matter and nutrient contents, which affected nutrient contents of water (nitrate and phosphate), but did not import richness of benthic algae (Table 4). This resulted in greater phytoplankton growth in response to greater nutrient concentrations. Water clarity was similar among ponds of different ages, but in ponds within benthic feeding fish, considerable turbidity (reduction in water clarity) can result from fish feeding activity. Thus, the water clarity was not a good climate of phytoplankton abundance in this study.

Benthic algae richness (Table 4), peaked between 8th (P2 and P3) and 9th week (P1 and P4). The highest value was 4.742 ind. /cm^2 for P2. The ANOVA showed ponds age had a significant effect on benthic algae richness ($P < 0.05$). Post-hoc analysis showed P3 with the highest richness of benthic algae compared to other pond groups. This observation coincided with the highest total-N, total organic matter, and nitrate concertation (Table 2). Visually, the color of the water was greener in P2.

3.5. *Production of P. hypophthalmus*

Fish production variables included total yield, survival rate, and feed conversion ratio (FCR) (Table 5). Harvesting was carried out at the end

Table 4
The average abundance of benthic algae (ind./cm^2) at each ponds age.

Week	Total abundance of benthic algae (ind./cm^2)			
	P_1 (n* = 3)	P_2 (n* = 3)	P_3 (n* = 3)	P_4 (n* = 3)
1	3.220	1.631	3.548	2.161
2	2.372	2.362	3.633	3.972
3	3.686	4.491	2.987	2.245
4	3.114	3.633	3.622	3.029
5	2.976	4.533	4.109	3.421
6	3.707	3.209	3.612	3.283
7	3.389	3.209	3.929	3.569
8	2.637	4.724*	3.993*	2.891
9	3.728*	1.928	3.940	3.590*
10	2.235	3.029	1.991	2.521
11	1.525	1.546	2.150	3.326
12	1.928	1.642	3.982	1.769
Total	34.516	35.935	41.495	35.776
Average	2.876 ± 184,3^{a}	2.995 ± 171,6^{a}	3.458 ± 165,3^{b}	2.981 ± 100^{a}

Note:Data shown with different letters are statistically different at $P < 0.05$ level.
*the peak of benthic algae richness.
*n = Total samples analyzed.

Table 5
Average of fish productivity by pond age group.

Cultivation period (n****)	SGR (%/d)*	Yield (kg/ m^2)	SR (%)**	FCR***
P1 (n = 3)	3.44 ± 0.04^{a}	4.2 ± 0.15^{a}	59.4 ± 0.06^{b}	1.9 ± 0.06^{ab}
P2 (n = 3)	3.58 ± 0.02^{b}	5.2 ± 0.10^{b}	64.5 ± 0.20^{c}	2.0 ± 0.04^{b}
P3 (n = 3)	3.76 ± 0.02^{d}	6.4 ± 0.15^{c}	66.7 ± 0.25^{d}	1.8 ± 0.15^{a}
P4 (n = 3)	3.68 ± 0.02^{c}	5.0 ± 0.06^{b}	56.7 ± 0.10^{a}	1.9 ± 0.08^{ab}

Note: Numbers with the same letter on a column indicated that they are not significantly different ($P = 0.05$).

[*] Specific Growth Rate.

[**] Survival Rate.

[***] Feed Conversion Rate.

[****] n = Total samples analyzed.

Table 3
Linear Correlation coefficient between soil quality and water quality.

	NH_3	PO_4^{3-}	NO_3^-	TA	DO	CO_2	TOM
Soil N	0.436	**0.728***	**0.861***	**0.700***	0.148	**−0.692***	**0.813***
Soil P	**0.653***	**0.915***	**0.819***	0.374	0.409	−0.232	**0.815***
Soil OC	0.474	**0.864***	**0.741***	**0.860***	−0.149	−0.430	**0.606***

Note: *Correlation coefficient is significant ($P < 0.05$).

of the 3 month cultivation period, and an average weight of individual fish was 167.17. The highest yield and SGR was P3, and the lowest was P1. The highest survival rate was also observed in P3 66.7% and the lowest at P4 56.7%. The lowest FCR was also observed in P3 1.8. The ANOVA showed pond age had a significant effect on SGR, yield, survival rate, and FCR richness ($P < 0.05$). Post-hoc analysis showed P3 with the highest SGR, yield and survival rate compared to ponds in other age groups but P3 had the lowest FCR.

The best result of P3 is thought to be the result of good efficiency feed use efficiency (low FCR). The efficient use of feed as in economically beneficial, followed by P1 and P4 because the feed was the main expenditure accounting for more than 60% of production cost.

3.6. *Soil and water factors affecting the production of P. hypophthalmus*

The Pearson's linear correlation coefficient was calculated to determine which of the soil and water quality factors were related to the fish production parameters. The linear correlation coefficients in Table 6 several that soil CEC, and N, P, and OC contents and NH_3, PO_4^{3-}, and TA concentrations in the pond water were correlated with positively related with fish production with correlation coefficients of 0.579–0.983.

Fish Survival Rate was positively related to PO_4^{3-}, NH_3, and CO_2, and C/N ratio and CEC of soil but negatively related to benthic algae. The FCR (Table 6) did not exhibit a significant correlation other than related to water parameters: negatively related to AT, TOM, benthic algae, soil N but a positive relationship with FCR. This suggests that as FCR increased (became less efficient) there was more carbon dioxide in the water.

The correlation coefficient also were calculated for each pond age group separately (Table 7). The findings are similar to the correlations drawn in Table 6, and confirm that soil quality affects water quality in ponds, and both, in turn, influence the fish production parameters.

In 11−15 year-old ponds (P3), fish production was by 6.4 ± 0.15 kg/m^2, SR by 66.7 ± 0.25, and FCR by1.8 ± 0.15, was thought to be due to the linear correlation coefficient value of the pond soil quality parameter, which was significantly positive ($P < 0.05$) to yield. In contrast to the old pond (16–20 years), there was a decrease in production (5.0 ± 0.06 kg/m^2), SR (56.7 ± 0.10), and FCR (1.9 ± 0.08), presumably due to the linear correlation coefficient, which has a negative value on soil quality parameters.

To further investigate pond age effect on fish production, a multiple linear regression was conducted to relate fish production to pond age, soil, and water quality parameters. A stepwise linear regression was first conducted to remove insignificant variables. The results (Table 7) indicated a significant relationship between pond age, water quality, soil parameters, and fish production ($R^2 = 0.999$, $P < 0.05$). The regression coefficients indicated the age of the pond has a significant relationship ($P < 0.05$). In terms of water quality, NH_3 and TA presented a significant relationship ($P < 0.05$) with negative coefficients on both parameters indicating a negative effect of NH_3 on fish production. In terms of soil quality, total P had a significant positive relationship and C/N had a significant negative relationship.

Table 6
Linear correlation coefficient between water and soil quality parameters on fish production parameters.

	Yield	SR	FCR
DO	−0.135	−0.424	−0.025
NH_3	**0.579***	0.527	0.213
PO_4^{3-}	**0.917***	0.520	0.029
NO_3^-	0.523	−0.126	−0.370
AT	**0.626***	0.280	−0.413
CO_2	0.066	**0.666***	**0.758***
TOM	0.403	−0.267	−0.382
Benthic Algae	**0.939***	**0.729***	−0.484
Soil N	**0.588***	−0.056	−0.520
Soil P	**0.769***	0.245	−0.039
Soil OC	**0.862***	0.347	−0.306
Soil C/N	**0.983***	**0.658***	−0.005
Soil CEC	**0.907***	**0.447***	−0.187

Note: *indicates the correlation coefficient was significant at $P < 0.05$.

Table 7
Multiple linear regression coefficients on the effect of pond age, water and soil parameters on fish production.

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	45.441337	5.119605	8.88	0.0714
Age[P1]	−8.494495	0.327948	−25.90	0.0246*
Age[P2]	−2.410991	0.137646	−17.52	0.0363*
Age[P3]	−0.572696	0.059845	−9.57	0.0663
WC (Water clarity)	−0.596308	0.19024	−3.13	0.1966
NH_3	−5.364797	0.082668	−64.90	0.0098*
NO_3	−0.839589	0.083894	−10.01	0.0634
TA (Total Alkalinity)	−0.123091	0.005914	−20.81	0.0306*
P	0.3160959	0.014054	22.49	0.0283*
C/N	−0.66502	0.028174	−23.60	0.0270*
CEC	0.0028621	0.007088	0.40	0.7557

Note: *indicates the correlation coefficient was significant at $P < 0.05$.

4. Discussion

4.1. *Characteristics of the pond bottom soil*

The pond age had significant effects on bottom soil quality (Table 1) for example, organic matter accumulated during the grow-out period, and older ponds had higher organic matter content than younger ponds. Soil organic matter originated from solid wastes (uneaten feed and fecal droppings of fish), dissolved wastes from fish metabolism, and remains of algae. This increase in organic matter affected other soil chemical properties. Relatively old ponds (P3 and P4) had a higher organic carbon content at the beginning of the experiment than did the younger pond (Table 1). The soil organic matter concentrations reported in Table 1 are comparable to those obtained for aquaculture ponds in Honduras (1%–6%), Alabama (1%–6%), and Egypt (5%–15%) by Boyd (1977), Munsiri, Boyd, Green, and Hajek (1996), Munsiri et al. (1995), Munsiri, Boyd, Teichert-Coddington, and Hajek (1996), and Simpson et al. (1983), but higher than those found by Ritvo et al. (1999).

The total N concentration was highest at P3, and phosphorus is highest at P4. The high concentrations of N and P were also derived from unused feed. These nutrients can eventually be released into the water as nitrate, and phosphate.

There was more feeding at a higher FCR than at a lower FCR. The average feed not converted to fish biomass, calculated based on FCR was 13 kg/m^2 for the rearing period of 90 days. The amount that ended up in soil can be calculated based on the increase of organic matter in the soil, which was calculated based on the difference in soil organic content before and after the experiment (Table 1). Using the conversion of organic C to organic matter (OM) of 2 (Pribyl, 2010), there was an average increase of 8.58 kg OM/m^2 across all ponds. Thus 66% of the unconsumed feed ended up in the soil. For nitrogen, the calculated average N content in the unconsumed feed was 585 g N/m^2 over the 90 day period. The average increase of N content in soil was 148 g N/m^2. And thus, 26% of the N from uneaten feed ended up in bottom soil.

Pond of groups P3 and P4 had C/N ratio of 16.40 and 36.15, respectively. According to Boyd (2008), the optimal value of C/N for ponds ranges between 8 and 12, and ponds with fresh inputs of organic matter have a greater tendency towards anaerobic conditions of the soil-water interface. A high C/N ratio in sediment is usually the result of the organic matter which decomposed slowly (Munsiri et al., 1995) and can reduce pond productivity. We suspect that the high organic carbon value in the tropical system is still optimal for fish production as the case in P3 and P4 ponds of the present study. Liang et al. (2017) showed C/N ratio of organic residue inputs also altered soil microbial community composition and structure (Xue et al., 2018). Decomposition rates can be increased if pond bottoms are dried between cultivation and liming materials are applied to acidic soil to increase pH during the dry-out period (Ayub et al., 1993; Boyd & Teichert-Coddington, 1994).

4.2. *The effect of soil quality on water quality*

The age and quality of earthen ponds significantly affected the quality of the pond water nutrient concentrations. In addition, nutrient concentrations were directly correlated with soil N, P, and OC.

Nitrogen is released into pond water in the form of ammonia through fish metabolism and microbial degradation of organic matter. The increase of NH_3 is affected by the availability of dissolved oxygen to support aerobic respiration. The elevated concentration of NH_3 (0.16–0.21 mg/L) resulted from the combined high organic matter metabolism of the fish and other pond biota. However, a high concentration of un-ionized ammonia (NH_3) can be toxic, but in warm water, adult fish are quite tolerant to ammonia. Its safe concentration is considered to be below 1 mg L^{-1}. Yang et al. (2017) showed that a high level of NH_3 of 0.6–2.0 mg/L could produce chronic toxicity.

Nutrients also enter the water from pond bottom soil in the form of nitrate and phosphate. The ranges of nitrate and phosphate in the study were 0.94–1.03 mg/L and 0.61–1.05 mg/L, respectively. Both of these nutrients and ammonia are used by benthic algae and phytoplankton for their growth. Ammonia and nitrate are the major forms of nitrogen in watershed runoff into and ponds nutrients for phytoplankton and other aquatic plants. The nitrate concentration in the study was still optimal, lower than the threshold of 5 mg/L, which indicates pollution. According to Boyd and Tucker, 1998, the availability of orthophosphate in water was influenced by organic matter decomposition, fertilization, and phosphorus in the water. The increase of orthophosphate was also influenced by the types of dead plants and animals in the water. Phosphorus is available to phytoplankton or aquatic plants after being converted to orthophosphate ions. The concentration in this study was way below the of pollution protection threshold of 10 mg/L for freshwater fish cultivation in Indonesian refer to Governmental Decree no. 82, 2001, class II. It is important to note that soil N, P, and OC content affected total organic matter in water (TOM) as revealed by a correlation coefficient ($0.6 < r < 0.8$).

Alkalinity is the buffering capacity of water, i. b., the capacity to neutralize additional acid without reducing the pH of the solution (Boyd, 2015). Alkalinity was positively related to soil N and OC content. In aquaculture, alkalinity also provides the buffering capacity to protect fish from abrupt pH changes caused by changes in CO_2 concentrations related to the relative rates of photosynthesis and respiration which change between day and night. Alkalinity in fish poorly should exceed 40 mg/L and 80–100 mg/L is even better (Boyd & Tucker, 1998).

An excess of CO_2 could inhibit fish growth, and ponds with high organic matter input (pelleted feed) showed higher CO_2 availability which would be beneficial in dissolving liming material applied to ponds. Of course, CO_2 also enters ponds by diffusion from the atmosphere and from organic matter decomposition by anaerobic bacteria. The maximum acceptable concentration of CO_2 by fish is around 15–30 ppm. Low concentration of dissolved oxygen and decomposition bacteria was considered responsible for organic matter accumulation in ponds (Budiardi et al., 2007).

4.3. *Effects of soil quality on fish production*

All soil parameters had a significant correlation with fish yield. In particular, soil C/N and CEC were highly correlated with yield ($r =$ 0.983 and 0.907), respectively. Benthic algae were not correlated with yield. In feed-base aquaculture systems, natural food production (benthic algae and plankton) is not the main food leading to fish production, but it still contributes to fish production (Boyd & Tucker, 1998). Moreover, the presence of benthic alga regulates the availability of dissolved oxygen during the day. In concentrations of NH_3, NO_3^-, and PO_4^{3-} were highly correlated with yield. As previously discussed, these nutrients were derived from feed waste from feeding and sediments.

Pond of the P3 group produced the highest SGR, fish yield, and survival rate (Table 4). The older ponds (P3 and P4) also had the highest soil organic matter content. Tour the standpoint of water quality, sediment which accumulates excess organic matter from feeding west and feces in intensive cultivation systems can cause oxygen depletion and release toxic metabolites in the water column (Boyd & Tucker, 1998). However, in this study, the organic matter was not excessive and was content positively correlated with yield. It is hypothesized that became Ultisols typically have a high iron content that had the capacity to stabilize organic matter in the soil (Minasny et al., 2020; Zhang & Horn, 2001). Thus, the high organic matter in these soils remained at a concentration that supported fish production and continues to function as sinks for added nutrients.

Fish survival in ponds often is dependent upon was dissolved oxygen concentration. Low dissolved oxygen causes fish stress or even mortality in high-density cultures (Boyd & Tucker, 1998). Dissolved oxygen cause levels (>5 mg L^{-1}) can negatively affect fish respiration, and high concentrations of ammonia and nitrite can lead to toxicity. The survival rate (56.7%–66.7%) had a negative correlation with DO concentration and benthic algae. Nevertheless, as (Misra & Chaturvedi, 2016) pointed out, fish survive under a lower concentration of dissolved oxygen and excessive nutrient loading. Other environmental conditions also affect fish survival but becoming of these productive and survival may be a negative impact. For example, oxygen concentration decreased with water depth and in the sediment. In line with the study of Sanz-Lázaro and Arnaldo (2011), further research is needed to have a more accurate forecasting ability of these patterns. There is an interaction between organic matter deposition rates, local sediment characteristics, and macrofauna diversity patterns. Advances in these directions could help environmental protection agencies to improve their management strategies to guarantee a good status of the diversity and ecosystem functioning of sediments influenced by fish farming.

Inter present studies, FCR ranged from 1.80 to 2.00, but the oldest pond (P4) showed no significant difference in FCR P1, P2 & P3. But P3 is different in FCR from P2, indicating that in ponds more than 10 years old and having good maintenance can still be productive (Table 4). The sediment draining at the end of harvest according to different schedules among the groups of study ponds did not have a great influence on FCR. The FCR values in all four pond age groups are similar to those that were found by other studies on Thai Pangus. For example, Azimuddin, et al. (1999) found the FCR value within 1.73–2.04 in three months of production. Chaikaew et al. (2019) stated that FCR determined the level of feed nutrient efficiency. The rather high FCR of 2.0 indicated that the farm needs a better feed management strategy.

The FCR showed a negative correlation with TOM and a positive correlation with CO_2, due to the C/N ratio steadily increasing from 10.35 to 36.15 in younger to older ponds. The FCR value increases with the age of the pond as well as TOM, but the concentration of free CO_2 (9.05–10.05 mg/L) was still within the safe limit for fish. This is in contrast with the findings of Fivelstad (2013) who studied a flow-through system, where CO_2 concentrations up to 15–20 mg/L reduce Atlantic salmon growth rates. Of course, this comparison is between a coldwater apeciet which has more stringent water quality sequiturs than tropical species.

This experiment demonstrated significant effects of ponds age on the quality of pond soil, water quality, and abundance of benthic algae, in increasing the pond productivity. Greater pond age had a direct relationship with the increasing concentration of soil chemical parameters (SOC, C/N, CEC, N total, and P total). Although prolonged use of ponds increased organic matter in pond bottoms. The ponds were able to sustain fish production.

Nevertheless, a high C/N value can decrease fish production. The soil's cation exchange capacity at the beginning of the experiment P4 (7.38 $\text{mmol}_c.100\ g^{-1}$) was increased at the end of the experiment (15.15

$mmol_c$.100 g^{-1}). However, this CEC value was still considered low. For example, Sonnenholzner and Boyd (2000) found the value CEC of shrimp pond soils in Ecuador averaged 31 $mmol_c$.100 g^{-1} and a few soils had CEC <20 $mmol_c$.100 g^{-1} (lower CEC). The limits of organic matter accumulation on the pond bottom Ultisol need further investigation. Regular sediment removal can maintain the original quality of bottom soil (Shafi et al., 2021).

The linear correlation coefficients and multiple linear regression indicated that pond's age, soil nutrients (P, C/N), and water quality (NH_3 and TA) parameters significantly correlated with fish production (Yield). Increasing pond's age increased soil nutrients (OC, N, P, CEC) which have positive effects on yield. However, the yield can be negatively affected by increased NH3 and total alkalinity which were caused by too much feed. In addition, high C/N had a significant negative relationship with yield, indicating that undecomposed feed (high C) can decrease yield. Soil nutrients directly affected the availability of nutrients in the pond water and in turn, controlled fish production: total yield. However, this CEC value was still rather low, compared to that reported in other studies. For example, Sonnenholzner & Boyd. (2000) found the value CEC of shrimp pond soils in Ecuador averaged 31 mmolc.100 g^{-1} and a few soils had CEC <20 mmolc.100 g^{-1}. More studies of the extent to which CEC may be influenced in pond bottoms consisting of Ultisol are needed, just as with organic matter and nutrient accumulation. Soil nutrients directly affected the availability of nutrients in the pond water and in turn, controlled fish production. Thus, bottom soil quality and its influence on water quality are desiring much more attention than has been given (Boyd & Tucker, 1998; Cole et al., 2019).

Sediment accumulates in the pond bottom over time. In actually of over 150 ponds write ages ranger from 1 to 52 yr, Boyd et al. (2010) found rate sediment accumulation varied from 0.5 to 3.7 cm/yr. Sediment had been removed on one or more occasions from some of the ponds in Thailand, nevertheless, reported on sediment depth was correlated with pond age ($r = 0.78$; $P < 0.01$). Shafi et al. (2021) found an interactive effect of pond age and soil depth on soil clay content and electrical conductivity which increased with the pond age. Some of these also found that regular removal of sediment can maintain the original quality of bottom soil. Boyd (2015) reported an excess of feed and fecal particles with high organic carbon content and nitrogen content could lead to anoxic conditions at the bottom soil-water interface, which negatively impacted water quality in ponds.

5. Conclusions

The age of earthen ponds in intensive pangasius cultivation had significant effects on the quality of the pond soil, nutrient concentrations in pond water, and benthic alga richness. Pond age had a direct relationship with the soil chemical parameters. SOC, C/N ratio, Total P, and CEC increased proportionally over time, indicating that Ultisol pond bottom was a significant sink for added nutrients with about 66% of the feed nutrient content not converted to fish biomass accumulating in the soil.

The pond bottom soil directly affected the concentrations NH_3, and PO_4^{-3}, NO_3^-, and total alkalinity in pond water. Pond age also directly affected fish yield, survival rate, and FCR. The highest SGR of 3.76 %/d, the yield of 6.4 kg/m^2 was achieved in P3 (ponds' age of 11–15 years) which also had the highest survival rate of 66.7%, and best FCR of 1.8. Good production in ponds 11–15 years of age could still be maintained of liming and fertilizing and mud sediment removal after each harvest.

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Institutional review board statement

The study was conducted according to the guidelines of the Declaration of Helsinki and Indonesian national legislation (Governmental Decree no.82 of year 2001, class II) for water quality in aquaculture and according to SNI 01-6483.5-2002 for Patin fish *Pangasius hypophthalmus* for healthy aquaculture. The protocol was approved by the Committee on the Ethics of Animal Experiments at Universitas Riau, February 10, 2019.

Data availability statement

The data supporting the results reported here can be requested from the authors.

CRediT authorship contribution statement

Saberina Hasibuan: Conceptualization, Methodology, Formal analysis, Validation, writing draft, Writing – review & editing. **Syafriadiman Syafriadiman:** Conceptualization, Methodology, Formal analysis, Validation, writing-review and editing. **Netti Aryani:** Methodology, Formal analysis, writing draft, review and editing. **Muhammad Fadhli:** Conceptualization, Methodology, Resources, review. **Monalisa Hasibuan:** Conceptualization, Methodology, Resources, review, All authors contributed equally to this manuscript, sAll authors have read and agreed to the published version of the manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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