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Intensive culture of corydoras ornamental fish (*Corydoras aeneus*): evaluation of stocking density and water exchange

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Abstract. This research was conducted to find the best stocking density in combination with water exchange level in order to increase the productivity of corydoras (*Corydoras aeneus*). Corydoras at the initial body weight of 0.44-0.51 g and total body length of 2.20-2.31 cm were used in this research. The research was conducted in two-factor factorial design. The first factor was the stocking density level (3000, 4500, 6000 fish/m^2) and the second factor was the water exchange level (50 and 100 % day^{-1}). The result showed that specific growth rate of length and weight of fish were significantly different among treatments. There was interaction between stocking density and water exchange level in the specific growth rate. The highest value of specific length increase was 0.4±0.02 % day^{-1} and specific weight gain was 1.04±0.09 % day^{-1}, found at stocking density of 3000 fish/m^2 with 100 % $day^{-1}$of water exchange. There was no significant difference between survival rate of 3000 and 4500 fish/m^2 treatments at 94.81±0.64% and 98.33±1.44%, respectively. The range of water quality such as temperature, pH, dissolved oxygen, alkalinity, turbidity, ammonia, nitrate, and nitrite during rearing period were suitable for Corydoras fish culture. As a conclusion, the best stocking density for corydoras fish was 3000 fish/m^2 with 100 % $day^{-1}$of water exchange.
Key Words: *Corydoras aeneus*, specific growth rate, survival rate, wáter quality.

Introduction. Corydoras (*Corydoras aeneus*) is an ornamental freshwater fish that is usually exported and commonly cultured in Indonesia. The size of this fish is relatively small (5-8 cm), therefore it is suitable as aquarium-fish (Satyani 2005). Corydoras culture generally uses intensive technology at low stocking density (500-1000 fish/m^2), with 70-80% survival thus producing low productivity and in efficiency in space and water uses. One of the solutions to improve productivity is intensification by increasing the stocking density. Intensive culture system requires high stocking density (Avnimelech 2007), therefore production volume as a function of growth rate and stocking density determines the success of fish culture (Andrade et al 2015).

On one side, stocking density could be potentially affecting fish growth, survival, feed efficiency, reproduction performance, and productivity. On the other side, high stocking density could also be a critical factor as chronic stress inducer (Bonga 1997; Luo et al 2013) that will influence physiology, behavior, and growth of cultured fish.

High stocking density could lead to degradation of water quality and physiochemical factor, and also rise aggression among fish thus possibly causing stress. Long term or chronic stress will indeed influence fish physiology (Luo et al 2013). Magondu et al (2013) has reported that the increasing of stocking density could stimulate fish stress and affect fish digestibility, feed conversion, and growth rate. Feed competition is an important thing that becomes one of limiting factors in fish growth, while fish survival could indicate culture environment condition both physically and chemically (Niazie et al 2013).

High stocking density increases feed quantity given to culture media that could then leave more culture waste. Common toxic culture wastes are for instance ammonia and nitrite (Yusoff et al 2011). High level of ammonia in water decreases fish's ability to excrete ammonia from their bodies so that ammonia concentration in fish blood will increase, and oxygen transportation will be hampered (Yusoff et al 2011). Accumulation of ammonia in fish blood could decrease number of red blood cells and level of hemoglobin, and also damage the central nervous system (Randall & Tsui 2002), thus causing fish death (Kroupova et al 2005).

Water quality could be maintained by setting a water exchange system. In intensive fish culture, appropriate level of water exchange is required to keep water quality (Appleford et al 2012). Water exchange in high stocking density is beneficial to assure quality of fish living media due to its principal purpose for eliminating unusable chemical compounds and provides useful ones (Huisman 1987). In order to eliminate toxic nitrogen waste, water exchange should be conducted 40-60% daily (Lorenzen 1999). Daily water exchange in intensive fish culture is commonly conducted more than 30% (Weidner & Rosenberry 1992). Previous studies have evaluated several levels of water exchange application, best production of shrimp culture (*Penaeus setiferus*) is found at the level of 25% (Hopkins et al 1993), whereas in USA, shrimp culture is at the level of 100% (Hirono 1992), and in another shrimp culture 72% of water exchange can decrease significant nitrogen level (Teichert-Coddington et al 2000). Study of water exchange in intensive culture of ornamental fish has yet to be conducted. Therefore, this study was aimed to increase the productivity of corydoras ornamental fish by evaluation of stocking density and water exchange treatments.

Material and Method

Experimental fish. Fish used in this study were *C. aeneus* at initial weight of 0.44-0.51 g and at standard length of 2.20-2.31 cm. Fish were taken from a hatchery in Bogor Indonesia. The research took place at the Laboratory of Aquaculture Production Technology and Management, Faculty of Fisheries and Marine Science, Bogor Agricultural University, Indonesia, from April to June 2015.

Experimental design. The research used factorial randomized design with stocking density factor (3 levels) and water exchange volume factor (2 levels) in triplicates. Treatments applied consisted of:
3000A: stocking density at 3000 fish/m^2 and water exchange level at 50% day^{-1};
3000B: stocking density at 3000 fish/m^2 and water exchange level at 100% day^{-1};
4500A: stocking density at 4500 fish/m^2 and water exchange level at 50% day^{-1};
4500B: stocking density at 4500 fish/m^2 and water exchange level at 100% day^{-1};
6000A: stocking density at 6000 fish/m^2 and water exchange level at 50% day^{-1};
6000B: stocking density at 6000 fish/m^2 and water exchange level at 100% day^{-1}.

Fish rearing. Fish were adapted to the laboratory condition for 10 days, reared in an aquarium sized 100 cm x 50 cm x 40 cm at stocking density of 1500 fish/m^2. During adaptation period, fish were fed Tubifex *ad libitum*. One day prior to the treatments, fish were fasting and samples were taken for body chemical analysis. Afterward, fish were reared for 40 days in an aerated-aquarium sized 20 x 20 x 20 cm, with 15 cm of water depth (at total water volume of 6 L). During rearing period, fish were fed alive Tubifex with 8.12% of protein content, 4.26% of lipid, 0% of crude fiber, 82.29% of water, and 4.26% of extract materials without nitrogen. Feed was given twice a day at 07.00 and 18.00 at the feeding rate of 5% from total biomass. Water exchange and siphoning were conducted twice a day (in the morning and afternoon), one hour before feed was given. Growth sampling was conducted every 10 days with 30 fish for each treatment, to measure fish standard length and body weight. Sampling for survival was also conducted by counting number of fish alive.

During rearing period, daily water quality such as dissolved oxygen (DO), pH, and temperature was evaluated in the morning (at 07.00), at noon (at 12.00), in the

afternoon (at 17.00), and in the evening (at 22.00). Ammonia, nitrite, nitrate, alkalinity, and turbidity were weekly evaluated. In the end of study, final fish growth and survival were measured, and fish body samples were taken for chemical analysis (phosphor, calcium, RNA, and DNA). Cortisol and blood glucose level were analyzed in the initial, middle, and end of study.

Measuring method. Fish body weight was measured using electronic balance (with 200g x 0.01 g of capacity by Sonic China), and fish body length was measured using Vernier calliper. Analyses of phosphor and calcium contents were conducted using Takeuchi method (1988). Blood glucose level was calculated in the same method as Eames et al (2010), and cortisol level measurement used [^{125}I] RIA KIT (Ref: RK-240CT) - Institut of Isotopes Ltd Budapest, based on manual book procedure. RNA analysis was conducted regarding to Sambrook et al (1989), while DNA analysis used Puregene®Core Kit A for molecular biology applications based on manual book procedure. Water temperature was measured using thermometer, dissolved oxygen by DO-meter, and pH by pH-meter. Water quality in the forms of alkalinity, turbidity, ammonia, nitrite, and nitrate were measured using spectrophotometer regarding to method established by APHA (1989).

Parameters evaluated in this study consisted of:

- growth performance: daily length increase rate, daily weight gain rate, and survival rate;
- chemical analysis: calcium (Ca), phosphorus (P), Ca/P ratio, DNA/RNA ratio, body cortisol level, and blood glucose level;
- water quality: temperature and turbidity.

Data analysis. Data were presented in average number and standard deviation. Data were processed and analyzed using Ms. Excel 2007 and SPSS 20.0. Several parameters were analyzed with ANOVA at 95% confidence level, and if significant difference was identified, data were then confirmed using Duncan's test.

Results and Discussion

Growth performance. Daily length increase rate, daily weight gain rate, also survival rate (SR) of corydoras fish in each treatment were shown in Table 1.

Table 1

Specific growth rate (SGR) of weight and length, and survival of corydoras fish in stocking density and water exchange (WE) treatments

Density (fish/m²)	*WE (%)*	*SGR length (%/day)*	*SGR weight (%/day)*	*SR (%)*
3000	50 (A)	0.22 ± 0.02^{bab}	0.82 ± 0.08^{baa}	98.33 ± 1.44^{baa}
	100 (B)	0.40 ± 0.02^{bd}	1.04 ± 0.09^{bb}	96.67 ± 0.83^{aa}
4500	50 (A)	0.19 ± 0.01^{a}	0.76 ± 0.04^{a}	97.78 ± 0.96^{ba}
	100 (B)	0.24 ± 0.02^{c}	0.77 ± 0.08^{a}	94.81 ± 0.64^{a}
6000	50 (A)	0.18 ± 0.01^{a}	0.84 ± 0.01^{ba}	89.31 ± 2.55^{a}
	100 (B)	0.23 ± 0.01^{bc}	0.87 ± 0.06^{a}	89.58 ± 3.00^{a}
Two-way ANOVA (P value)				
Density		0.000	0.050	0.000
WE		0.000	0.018	0.114
Density x WE		0.000	0.037	0.329

* Same letter in the same column showed no significant difference in 5% range test (Duncan's test);
** P-value < 0.05 showed significant difference.

Statistical analysis showed that stocking density and water exchange, and interaction between both treatments have shown significant effects on daily length increase rate and daily weight gain rate. The highest value of daily length increase rate was found at the stocking density of 3000 fish/m^2 and at water exchange of 100 %/day (3000B) of

0.40±0.02 % day^{-1} (Table 1), approximately two times higher than the lowest value of 0.18±0.01 % day^{-1}. This is in line with the value of daily weight gain rate, in which the highest value was at treatment 3000B at 1.04±0.09 % day^{-1}, approximately 1.4 times higher than the lowest value of 0.76±0.04 % day^{-1}. The high growth in the low stocking density is due to sufficient feeding of fish. Fish reared in high stocking density tend to compete in the feed. Feed competition is a limiting factor in the growth (Luo et al 2013), due to high competition in obtaining feed causes less feed consumption, resulting in lower fish growth. In this study, the higher stocking densities showed lower growth of fish, and the results are consistent with several previous studies such as the goldfish - *Carassius auratus* and black widow tetra fish - *Gymnocorymbus ternetzi* (Priestley et al 2006), piabanha - *Brycon insignis* (Tolussi et al 2010), *Scortum barcoo* (Luo et al 2013), goldfish (Niazie et al 2013), bronze ornamental corydoras - *Corydoras aeneus* (Diatin et al 2014) and *Solea senegalensis* (Andrade et al 2015).

Chemical analysis. Data of calcium (Ca), phosphorus (P) content, and Ca/P ratio were shown in Table 2.

Table 2

Ca, P, and Ca/P ratio of corydoras fish in stocking density and water exchange (WE) treatments

Density	*WE*	*Ca (%)*		*P (%)*		*Ca/P*	
(fish/m²)	*(%)*	*Initial*	*Final*	*Initial*	*Final*	*Initial*	*Final*
3000	50 (A)	0.94±0.00	1.53±0.23^{aba}	0.66±0.00	0.75±0.01^{aaa}	1.43±0.00	2.04±0.34^{aba}
	100(B)	0.94±0.00	0.59±0.20^{aa}	0.66±0.00	0.69±0.26^{aa}	1.43±0.00	0.85±0.03^{aa}
4500	50 (A)	0.94±0.00	1.56±0.40$^{b\ a}$	0.66±0.00	0.79±0.01^{aa}	1.43±0.00	1.98±0.49^{a}
	100(B)	0.94±0.00	1.51±0.07^{a}	0.66±0.00	0.99±0.06^{a}	1.43±0.00	1.53±0.16^{a}
6000	50 (A)	0.94±0.00	1.93±0.05^{ba}	0.66±0.00	0.87±0.06^{a}	1.43±0.00	2.23±0.10^{a}
	100(B)	0.94±0.00	1.33±0.09^{a}	0.66±0.00	0.78±0.01^{a}	1.43±0.00	1.70±0.10^{a}
Two-way ANOVA (P value)							
Density			0.018		0.193		0.077
WE			0.005		0.732		0.003
Density x WE			0.062		0.220		0.164

* Same letter in the same column showed no significant difference in 5% range test (Duncan's test);
** P-value < 0.05 showed significant difference.

Calcium contents in corydoras fish were significantly influenced by stocking density, water exchange, and interaction between both treatments ($p < 0.05$). Nevertheless, different result has been shown in phosphorous content whereas no significant difference was found among treatments and their interactions. The lowest calcium content were found at the stocking density of 3000 fish/m^2 and at water exchange of 100% day^{-1} (3000B).

Minerals that play a role in the growth of fish are calcium and phosphorus. Calcium along with phosphorus serves for the formation and maintenance of bone tissue, in addition to the calcium itself also serves for muscle contraction, blood clotting, nerve transmission, maintenance of cell membrane integrity, activation of several enzymes and hormone secretion (Lall 2002; Sugiura et al 2004). The phosphorus is indispensable for energy storage in the form of ATP that is needed to support metabolic activity and bone tissue (Lall 2002; Lall & Lewis-McCrea 2007). High or low retentions of calcium and phosphorus in the body as well as the ratio of calcium to phosphorus (Ca/P) determine the fish growth (Lall & Lewis-McCrea 2007). At the treatment 3000B that has the highest length increase rate and weight gain rate, showed the lowest calcium and phosphorus levels (Table 2) at 0.59±0.20% and 0.69±0.26%, respectively. According to Stanek et al (2013), there is a negative correlation between calcium and phosphorus levels in the fish body with length increase rate and weight gain rate of fish. The low levels of calcium and phosphorus at the treatment 3000B indicate that these minerals have been used for metabolic processes and the formation of bone tissue that increase fish growth.

Comparison of Ca/P content is very important because it illustrates the good bone health, in terms of bone development and maintenance of the skeletal system (Lall & Lewis-

McCrea 2007; Stanek et al 2013). If the ratio of Ca/P is too high, it can interfere with the phosphorus absorption and contrarily can limit the calcium absorption (Chavez-Sanchez et al 2000; Lall 2002; Lall & Lewis-McCrea 2007), eventually causing irregularities in bone mineralization, homeostasis and metabolism (Kumar et al 2012). The optimum ratio of Ca/P depends on the type of fish species, in which the ratio Ca/P of some species of fish ranging from 0.7 to 1.6 (Lall 2002). The juvenile of vundu catfish (*Heterobranchus longifilis*) shows the highest value of specific growth rate at Ca/P ratio of 0.92-1.1 (Toko et al 2008). The most optimal ratio in generating the highest growth in corydoras aquaculture is 0.85±0.03, which is expressed at 3000B treatment; while other treatments have Ca/P ratio of more than 1.53. If Ca/P ratio is greater than 3:2, it can cause growth disorders (Stanek et al 2013) and cause disability at a ratio of more than 2 (Sugiura et al 2004).

Based on the data of ribonucleic acid (RNA) and deoxyribonucleic acid (DNA), ratio between RNA and DNA could be calculated (Table 3).

Table 3

Ratio between RNA/DNA of Corydoras fish in stocking density and water exchange (WE) treatments

Density (fish/m^2)	*WE (%)*	*RNA/DNA*
3000	50 (A)	0.55±0.05^{baa}
	100 (B)	0.59±0.07^{aa}
4500	50 (A)	0.51±0.09^{ba}
	100 (B)	0.58±0.06^{a}
6000	50 (A)	0.31±0.03^{aa}
	100 (B)	0.45±0.14^{a}
Two-way ANOVA (P value)		
Density		0.026
WE		0.563
Density x WE		0.326

* Same letter in the same column showed no significant difference in 5% range test (Duncan's test);
** P-value < 0.05 showed significant difference.

Table 3 showed that stocking density has given significant difference on RNA/DNA ratio, but not in water exchange treatment and their interactions. The highest RNA/DNA ratio was obtained in the lowest stocking density treatment (3000 fish/m^2). In contrary, the highest stocking density (6000 fish/m^2) has shown the lowest RNA/DNA ratio. There is a strong linear relationship between somatic growth rate with RNA/DNA ratio (Vrede et al 2002). This ratio has to do with the potential of protein synthesis that is used as a growth indicator (Mukherjee & Jana 2007). RNA/DNA value of treatment 3000B has the highest value, indicating the best growth. Based on several indicators above, it is evident that the length increase rate and weight gain rate of corydoras fish at stocking density of 3000 fish/m^2 and at water exchange of 100%/day are the highest.

In this research the survival of corydoras fish has made significant difference in stocking density treatment, but not in water exchange treatment nor in their interactions. The survival rate of density 3000 fish/m^2 and 4500 fish/m^2 was not significantly different, but it was significantly different compare with survival rate of density 6000 fish/m^2. The highest survival rate of 98.33±1.44% and 97.78±0.96% were recorded for density 3000 fish/m^2 and 4500 fish/m^2 respectively. The lowest survival rate of 89.31±2.55% was recorded for density 6000 fish/m^2 of water exchange 50% day^{-1} (Table 1). According to Manley at al (2014), high stocking density causes fish swimming space to be limited, resulting in the space competition and the increasing aggression between fish and cannibalism resulting in death. The fish aggressiveness generates dominant fish within the group and the inferior fish lost in the competition will be isolated and becomes stress that can lead to death (Huntingford & Damsgard 2012). Therefore, higher density produces a low survival rate. These results are consistent with study conducted by Kupren et al (2008) in Buenos Aires tetra fish (*Hemigrammus caudovittatus*) low density 50 fishL^{-1} with survival rate 94.5% and high density 200 fishL^{-1} with survival rate 90.7%. It is also consistent with research conducted by Jamroz et al (2008) in European catfish

(*Silurus glanis* L.) which low density 7.5 fish L^{-1} and high density 15.0 fish L^{-1} with 90% and 84% survival rate respectively.

High stocking density was a critical factor because it was potential to become a stress inducer, shown by the level of cortisol and blood glucose (Tables 4 and 5). Body cortisol level in corydoras fish at day-20 has shown significant difference among treatments. Cortisol level in treatment 4500A has increased at day-20 and decreased afterward, while other treatments have constantly reduced since the beginning. Blood glucose level in the end of study had no significant difference among treatments and was relatively lower than in the beginning.

Table 4

Cortisol level (ng mL^{-1}) of corydoras fish in stocking density and water exchange (WE) treatments

Density	*WE*	*Time (day)*		
(fish/m²)	*(%)*	*0*	*20*	*40*
3000	50 (A)	10.22±0.25	7.94±0.12^{aba}	7.50±1.62^{aba}
	100 (B)	10.22±0.25	4.53±0.72^{aa}	4.47±1.89^{aa}
4500	50 (A)	10.22±0.25	12.04±0.93^{ba}	6.68±0.15^{aa}
	100 (B)	10.22±0.25	7.45±0.46^{a}	5.84±0.22^{a}
6000	50 (A)	10.22±0.25	9.10±0.18^{aa}	7.84±1.45^{aa}
	100 (B)	10.22±0.25	4.21±1.31^{a}	2.67±0.10^{a}
Two-way ANOVA (P value)				
	Density		0.000	0.503
	WE		0.002	0.004
	Density x WE		0.385	0.104

* Same letter in the same column showed no significant difference in 5% range test (Duncan's test);
** P-value < 0.05 showed significant difference.

Table 5

Blood glucose level (mg dL^{-1}) of corydoras fish in stocking density and water exchange treatments

Density	*WE*	*Time (day)*		
(fish/m²)	*(%)*	*0*	*20*	*40*
3000	50 (A)	55.00±1.41	52.00±5.66^{aba}	43.00±2.83^{aaa}
	100 (B)	55.00±1.41	40.50±3.54^{aa}	44.00±4.24^{aa}
4500	50 (A)	55.00±1.41	45.00±4.24^{aa}	49.00±0.00^{aa}
	100 (B)	55.00±1.41	40.50±6.36^{a}	39.50±4.95^{a}
6000	50 (A)	55.00±1.41	46.50±2.12^{aa}	42.50±2.12^{aa}
	100 (B)	55.00±1.41	41.00±2.83^{a}	41.00±5.66^{a}
Two-way ANOVA (P value)				
	Density		0.064	0.655
	WE		0.006	0.180
	Density x WE		0.060	0.207

* Same letter in the same column showed no significant difference in 5% range test (Duncan's test);
** P-value < 0.05 showed significant difference.

Fish density is a critical factor because due to its potential as a source of stress, which can affect the physiology and behavior of fish, affecting the growth and survival of fish (Luo et al 2013; Niazie et al 2013). Stress is a condition that disrupts the dynamic balance of organisms (homeostasis) as a result of environmental factors. Response to stress is regarded as an adaptive mechanism of fish to maintain its homeostasis (Bonga 1997; Barton 2002). Fish physiological responses in facing stress are divided into primary, secondary and tertiary (Barton 2002). Primary response is characterized by increased catecholamines and corticosteroids hormones, secondary response causes metabolic changes that increase the levels of glucose and lactate, decrease glycogen, disrupt osmoregulation and changes in immune function, while tertiary response causing changes in the whole performance of the animal such as growth, immune response, resistance to disease and changes in behavior (Barton 2002; Nardocci et al 2014).

The indicators commonly used to view the stress response are cortisol and blood glucose levels, in which during the state of acute stress, cortisol concentration can be increased by 10-100 times (Bonga 1997). Cortisol and glucose levels in this study tended to increase along with density increase and low water exchange at 50%. Nevertheless, it was seen that corydoras fish was able to adapt to the time in which during all treatments, cortisol levels increased until day-20 and then decreased at day-40 (Tables 4 and 5). Several results of previous studies generate cortisol levels before the stress and after stress in carp (*Cyprinus carpio*) at 7.4 ng mL^{-1} and 79 ng mL^{-1}, in rainbow trout (*Onchorhynchus mykiss*) at 1.7 ng mL^{-1} and 43 ng mL^{-1}, and in salmon (*Salmo trutta*) at 1 ng mL^{-1} and 94 ng mL^{-1} (Barton 2002). The highest cortisol level in this study showed at treatment 4500A at 12.04±0.92 ng mL^{-1}, which is relatively low compared to the results above, indicating that corydoras fish has the ability to tolerate changes in the environment and has a wide range of stress response.

Water quality of corydoras fish culture. Daily water quality parameters such as DO, temperature, and pH were shown in Table 6, 7, and 8. Other parameters like alkalinity, turbidity, ammonia, nitrite, and nitrate could be seen in Figures 1-5.

Table 6

DO range (mg L^{-1}) in the morning, noon, and afternoon during rearing period of corydoras fish in stocking density and water exchange (WE) treatments

Density	*WE*	*DO (mg L^{-1})*			
(fish/m²)	*(%)*	*Morning*	*Noon*	*Afternoon*	*Night*
3000	50 (A)	5.3-7.6	5.4-7.4	4.7-6.2	4.5-6.6
	100 (B)	5.8-7.9	5.6-7.5	4.9-6.0	4.2-6.4
4500	50 (A)	5.1-7.4	5.2-7.5	4.6-7.0	4,1-6,3
	100 (B)	5.5-7.8	5.5-7.3	4.5-6.6	4.0-6,3
6000	50 (A)	5.4-7.8	5.3-7.1	4.7-6.9	4.0-6.7
	100 (B)	5.3-7.5	5.4-7.3	4.3-6.8	4.2-6.3

Table 7

Temperature range (°C) in the morning, noon, and afternoon during rearing period of corydoras fish in stocking density and water exchange (WE) treatments

Density	*WE*	*Temperature (°C)*			
(fish/m²)	*(%)*	*Morning*	*Noon*	*Afternoon*	*Night*
3000	50 (A)	25.6-26.4	26.0-27.8	26.6-28.1	25.6-26.7
	100 (B)	25.7-26.3	25.9-27.9	26.7-28.1	25.7-26.5
4500	50 (A)	25.6-26.4	26.0-27.8	26.7-28.2	25.8-26.7
	100 (B)	26.7-26.4	25.9-27.9	26.6-28.2	25.7-26.5
6000	50 (A)	26.7-26.4	26.0-27.9	26.6-28.3	25.5-26.7
	100 (B)	26.7-26.4	25.9-27.7	26.7-28.3	25.7-26.7

Table 8

pH range in the morning, noon, and afternoon during rearing period of corydoras fish in stocking density and water exchange treatments

Density	*WE*	*pH*			
(fish/m²)	*(%)*	*Morning*	*Noon*	*Afternoon*	*Night*
3000	50 (A)	6.7-7.3	6.7-7.4	7.1-7.8	6.9-7.4
	100 (B)	6.9-7.2	6.4-7.3	7.2-7.8	6.6-7.6
4500	50 (A)	6.9-7.7	6.4-7.4	7.3-7.9	6.6-7.4
	100 (B)	6.6-7.2	6.7-7.8	7.0-7.8	6.8-7.6
6000	50 (A)	6.9-7.3	6.5-7.4	7.4-7.7	7.0-7.8
	100 (B)	6.6-7.8	6.6-7.8	7.0-7.8	6.7-7.7

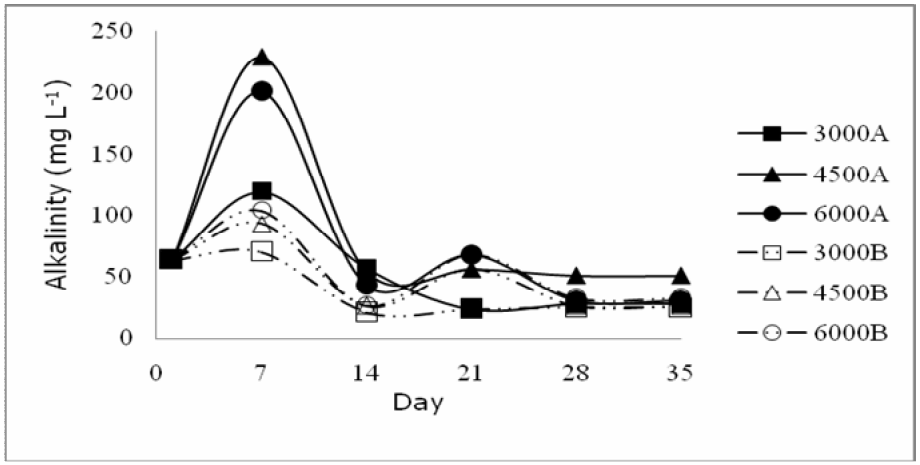

Figure 1. Alkalinity rate of corydoras fish culture in stocking density and water exchange treatments.

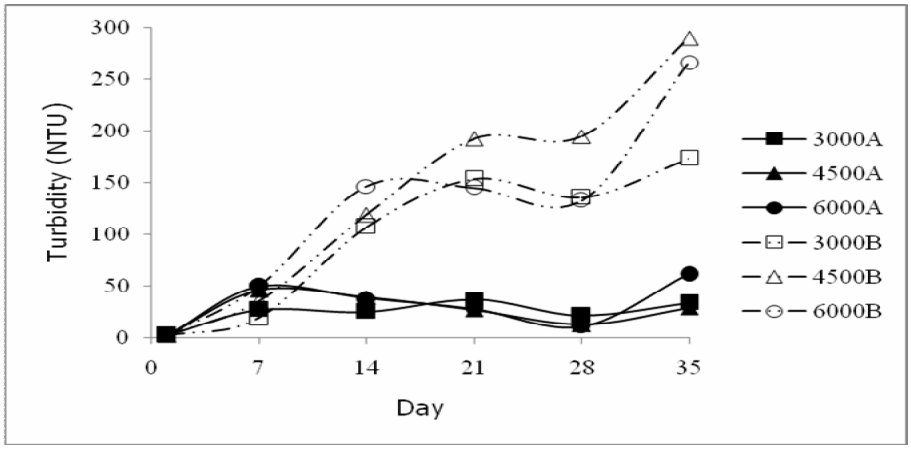

Figure 2. Turbidity rate of corydoras fish culture in stocking density and water exchange treatments.

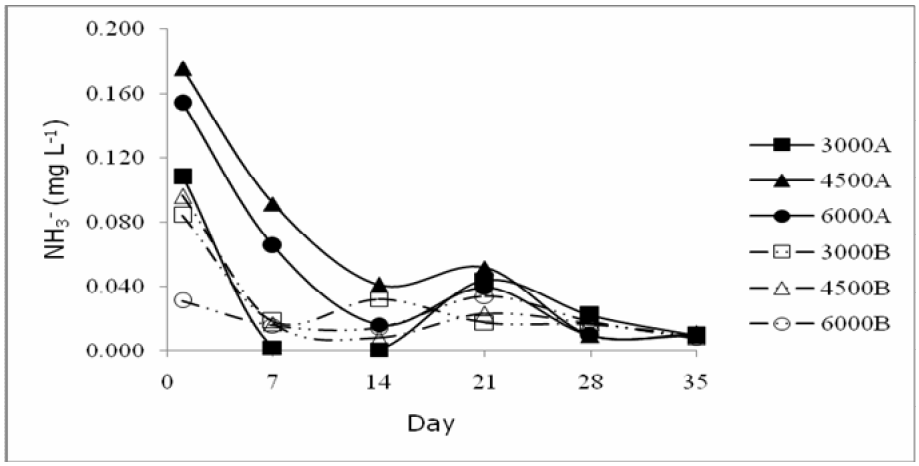

Figure 3. Ammonia (NH_3^-) level of corydoras fish culture in stocking density and water exchange treatments.

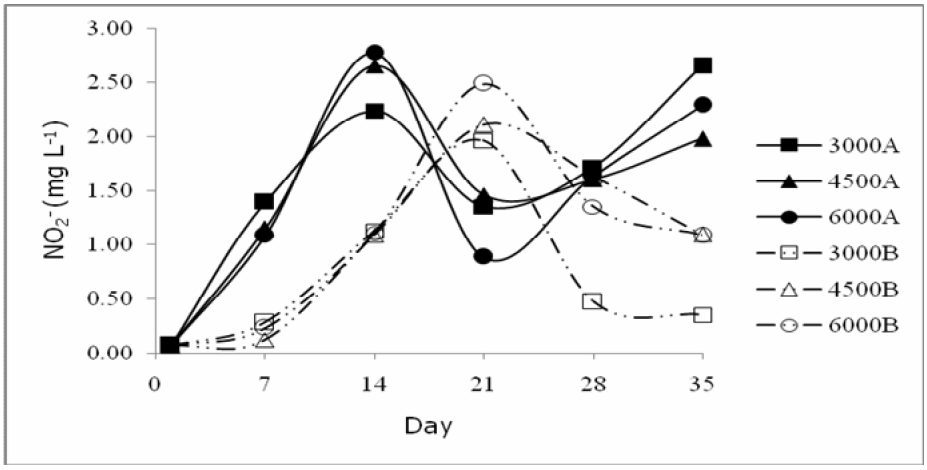

Figure 4. Nitrite (NO_2^-) level of corydoras fish culture in stocking density and water exchange treatments.

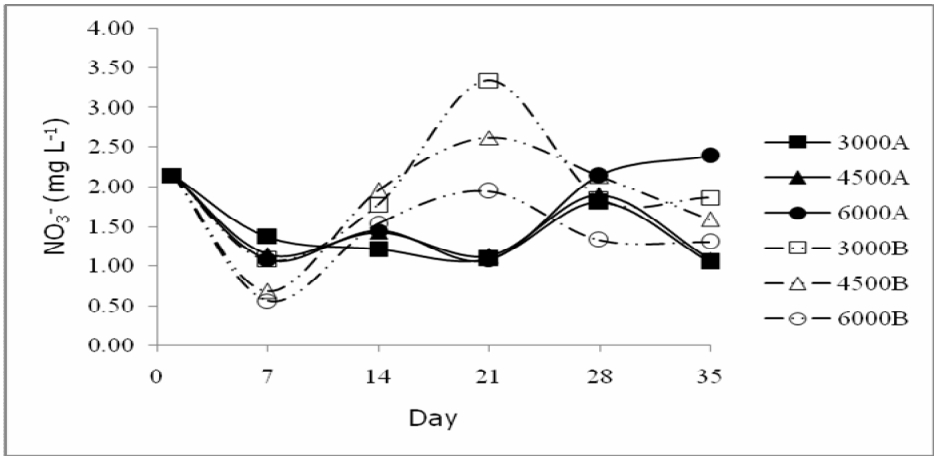

Figure 5. Nitrate (NO_3^-) level of corydoras fish culture in stocking density and water exchange treatments.

An increase in fish density in intensive culture can lead to decrease in water quality for fish culture and increase the water environmental impact due to high waste metabolite (Avnimelech 2007; Crab et al 2007; Emerenciano et al 2012; Luo et al 2013). The water quality in the forms of DO, pH, temperature, alkalinity and turbidity are within the tolerance range of corydoras fish (Tables 6, 7 and 8; Figures 1 and 2). *C. aeneus* as an ornamental catfish lives optimally at 24-30°C, pH of 6-8 (Axelrod et al 1988; Satyani 2005), neutral alkalinity or slightly alkaline (Axelrod et al 1988) and DO of at least 3 mg L^{-1} (Boyd 2001). Concentration of alkalinity for intensive culture should have a value of more than 20 mg L^{-1} (Wedemeyer 1996), where as 50 mg L^{-1} is good for the fish (Boyd 2007). On catfish culture (*Clarias* sp.), turbidity could reach 368 NTU, but the good range is 25-50 NTU (Ozbay & Boyd 2003).

Ammonia is a limiting factor in intensive culture since it becomes toxic to fish (Schram et al 2010). The toxicity of ammonia can cause damage to central nervous system (Randall & Tsui 2002), disorders of brain energy metabolism and damage to gills, liver, kidney, spleen and thyroid gland in fish and shrimp. Increased ammonia in the blood causes decreased red blood cells and hemoglobin (Yang et al 2010), causes physiological and feed intake disorders, as well as affects the growth (Schram et al 2010). The maximum value of ammonia obtained in this study was 0.127 mg L^{-1}, in which it is still below the danger threshold for corydoras fish culture. In general, ammonia becomes toxic to fish when it reaches above 1.5 mg L^{-1} (Yusoff et al 2011; Avnimelech 2012), but for the fresh water when it reaches 2.79 mg L^{-1} (Randall & Tsui 2002). Lethal concentration of ammonia to catfish has a wide range compared to other fish, namely from 0.74 to 3.10 mg L^{-1} (Boyd 2001), while to the African catfish (*Clarias*

gariepinus) is 0.34 mg L^{-1} (Schram et al 2010). To reduce the toxins in the water, ammonia can be oxidized to non-toxic nitrite ($NO2^-$) and nitrate ($NO3^-$) through nitrification and denitrification (Ebeling et al 2006; Hu et al 2013). Nitrite concentration at water exchange treatment of 50% day^{-1} showed the maximum increase on day-14, indicating that the first step of nitrification process, which is the conversion of ammonia to nitrite, has been running. This result is in line with the study conducted by Zhao et al (2012) on *Marsupenaeus japonicus* shrimp and De Souza et al (2014) on *Farfantepenaeus brasiliensis* shrimp which indicates that the nitrification process begins on day-15. However, at water exchange treatment of 100% day^{-1}, nitrite concentration showed the maximum increase on day-21, thus the first step of nitrification process in this treatment happened more slowly (Figure 4). Besides useful in eliminating harmful compounds, water exchange at high volume is also allegedly able to remove on harmful compounds such as nitrification bacteria. The final step of nitrification process occurs along with oxidation of nitrite to nitrate, which is indicated by a decrease in the nitrite concentration and an increase in nitrate concentration that started on day-21 (Figure 5).

A toxic level of nitrite depends on the species, size, age, and sex of fish (Zhang et al 2012), pH, DO and temperature (Kroupova et al 2005). The larger the size of the fish or the more mature the fish is, then it is more tolerant to nitrite (Zhang et al 2012). Nitrite will diffuse into red blood cells to oxidize iron in hemoglobin into methaemoglobin, and further can interfere with respiratory function in gills and skin of fish (Zhang et al 2012), consequently reducing the ability to transport oxygen in the blood and can lead to death of fish (Kroupova et al 2005). Nitrite concentration of 2 mg L^{-1} causes slow growth rate of fish and at a concentration of 4 mg L^{-1} caused acute mortality (Kroupova et al 2005; Yusoff et al 2011). Acute nitrite concentration of yellow catfish (*Pelteobagrus fulvidraco*) sized 0.029±0.049 grams is 8.74 mg L^{-1} (Zhang et al 2012). The highest value of nitrite during the rearing period was at 6000A treatment of 2.77±0.71 mg L^{-1}, in which this nitrite values are relatively high and can potentially inhibit the growth, as evidenced by relatively low length increase rate and weight gain rate at treatment 6000A. The final step of nitrification process generates a relatively non-toxic nitrate to fish, but it is safe for fish culture to not exceed 50 mg L^{-1} of nitrate (Kroupova et al 2005) because the nitrate concentration of 75 mg L^{-1} decreases the growth rate of juvenile fish (Yusoff et al 2011). The results showed that the nitrate concentration in all treatments are still in the range of tolerance for corydoras fish culture.

Conclusions. Corydoras ornamental fish culture on stocking density of 3000 fish/m^2 and 100% water exchange/day resulted in the highest gain in length and gain in weight, high survival rate and good range of water quality for fish culture.

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