Growth performance, survival, and feed efficiency of the giant freshwater prawn (*Macrobrachium rosenbergii*) under various starvation patterns

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Abstract. The purpose of this study was to evaluate the effectiveness of starvation on the growth, survival, and feed efficiency of giant freshwater prawn (*Macrobrachium rosenbergii*) (GFP) juveniles. This study used a completely randomized design, with four treatments in both individual and communal rearing patterns. The treatments consisted of different periods of starvation (0, 1, 2, and 3 days) followed by re-feeding. The GFP seeds (30±1.1 mm total length; 0.3±0.07 g body weight) were reared for 30 days individually in an aquarium (2 L) and communally in a net cage measuring 2x1x1 m^3 (600 prawns per cage). The starvation had a significant effect ($p<0.05$) on the survival of the prawns, with the best results obtained on the 1st day of starvation (91.67±6.79%) and the lowest when 0 days of starvation existed (83.94±4.48%). The starvation also had a significant effect ($p<0.05$) on feed efficiency (FCR), with the best results in the treatment of 2 days of starvation (1.8±0.39) and the lowest in the treatment of 0 days of starvation (4.6±1.48%). The data suggested that starvation for 1 to 2 days followed by re-feeding was an effective method to increase the production performance and reduce the production cost of GFP farming.

Key Words: aquaculture, effective, feeding management, production cost.

Introduction. The giant freshwater prawn (*Macrobrachium rosenbergii*) is the most popular freshwater prawn commodity in Indonesia. This prawn is the largest species of freshwater prawn from the Palaemonidae family (Wowor & Ng 2007). It has some superior aspects for farming, including a high tolerance to a wide salinity range, 0-15 ‰ (Ali & Waluyo 2015; Chand et al 2015), omnivorous feeding habit (low protein requirement in their feed), and good market demand (Zafar et al 2015). Therefore, prawn farming was developed in several types of water resources, including inland ponds, brackish water ponds, pen culture, and paddy fields (Nair et al 2013; Dewi et al 2020). The giant prawn aquaculture has been developed in many countries in the world, with a global total production of 203028 tons in 2013 (FAO 2016) and 234400 tons in 2018 (FAO 2020). Indonesia is the 10th top producer of giant prawns (Pillai et al 2021). Although giant prawns have been cultivated for more than 30 years in Indonesia, the national production of the prawns has not increased significantly. Some obstacles are faced by prawn cultivators, one of which is the high price of prawn feed.

Feeding is one of the key elements influencing fish development, welfare, and physiological performance. On the other hand, the cost of feed is the largest cost component in aquaculture, about 60-70% of the total production cost (Mitra et al 2005; Borski et al 2011). A strategy of feeding management was required to increase growth and maximize profits in aquaculture, for example by limiting or reducing feed intake (Cuvin-Aralar et al 2012). Furthermore, Yengkokpam et al (2013) stated that feed restriction was a strategy in feed management that is very beneficial for farmers. This strategy is believed to be profitable because of a phenomenon called compensatory growth, namely the occurrence of an accelerated growth rate because of the proper refeeding of fish or prawns after a certain period of time experiencing feed restrictions (Ali et al 2003). In addition, short-term feed restrictions can also reduce mortality from disease outbreaks, address poor water quality, and reduce handling stress (Shoemaker et al 2003; Davis & Gaylord 2011). Research about the effect of feed restriction on growth has been carried out, especially for several aquaculture commodities. Feed restrictions on tilapia (*Oreochromis niloticus*) were reported by several researchers with different effects, namely no compensatory growth (Cuvin-Aralar et al 2012), partial compensatory growth (Passinato et al 2015), and total compensatory growth (Gao et al 2015). This difference in results was possible due to differences in the restriction methods used, environmental conditions, and physiological conditions of the fish (Robisalmi et al 2021). On the other hand, the negative effect of starvation on fish was reported by Cahyanti et al (2015), who reported that fasting in Asian redtail catfish (*Hemibagrus nemurus*) produces slow growth, cannibalism, and low survival. There have been a few investigations into compensatory growth following feed deprivation, particularly in crustaceans. According to Li et al (2009), *Macrobrachium nipponense* can grow compensatorily and rebuild its antioxidant system after starvation and refeeding periods. Another study claimed that *Cherax quadricarinatus*, a red claw crayfish, saw 0% development after being starved for an extended period of time (Sacristan et al 2016).

Feed restrictions on aquatic animals can cause starvation, which has implications in growth, the immune system, and causes stress. Hunger induces metabolic stress, which modifies the metabolism to produce more energy and triggers the acute phase of protein synthesis that protects fish from oxidative and cellular damage (Caruso et al 2011). Starvation due to food restriction is used to determine significant changes in fish physiology, especially in the metabolic system, RNA/DNA, and protein ratios (Navarro & Gutierrez 1995; Hung et al 1997), and the severity can vary depending on the age of the fish and the length of the restriction diet (Gutierrez et al 1991). When fish are starved, they will use various physiological behaviors in response to meet the body's metabolic needs from energy reserves (Navarro & Gutierrez 1995).

Information about the effect of starvation on the giant freshwater prawn's performance is lacking. Therefore, this research was carried out to assess the effectiveness of starvation on the growth, survival, and feed efficiency of the giant freshwater prawn.

Material and Method. The research was conducted in the hatchery and ponds of the Institute for Fish Breeding Research Subang, West Java, Indonesia. For this investigation, juvenile giant freshwater prawns (body weight: 0.20–0.35 g; total length: 30–50 mm) were used. The prawn juveniles were obtained from a juvenile production process in the institute. Acclimatization was carried out on test prawns in glass tanks (100x50x40 cm) containing 40 L of freshwater. Prawns were manually fed prawn meals (40% crude protein) at 08:00 and 16:00 every day until satiation. Water was aerated to maintain an oxygen level of 5 mg L^{-1}, and temperature was kept at 28-30^{o}C with a thermostat heater.

The study used a complete randomized design with starvation (St) and feeding (Fd) time as treatments. The treatment consists of 0 days of St (S0), 1 day of St – 1 day of Fd (S1), 2 days of St – 2 days of Fd (S2), and 3 days of St – 3 days of Fd (S3), with four replications. The treatments also consisted of two patterns of prawn rearing. These were an individual and a communal culture system.

In the individual system, the prawn juvenile was distributed at random into 16 glass aquariums with a capacity of 2 L, each containing 1 individual. The water quality of the rearing tanks was maintained using water exchange (200 mL per day). The glass tanks were distributed randomly among the four starving methods (four replicates per treatment). The juvenile prawn was fed twice per day with a prawn feed (40% crude protein) according to the treatment. Observation of the prawn molting was conducted every morning during the treatment. Water exchange (20% volume) was done every morning to preserve the water quality of the aquarium. The experiment was carried out for 30 days.

In the communal system, the prawn rearing was conducted using 14 net cages (2x1x1 m) that were set in a 200 m^3 cement pond. A net sheet (1x1 m) was placed in each net cage as a shelter to reduce cannibalism. The initial stocking density was 600 prawns for each cage. The water quality of the pond was optimized using a small paddle wheel to maintain an oxygen level and a regular water supply (20% of pond volume). The juvenile prawns were fed twice per day with prawn feed (40% crude protein) according to the treatment. The study was done for 30 days.

The prawn growth was determined based on the total length and the body weight parameters, measured every two weeks. The survival rate and the feed conversion ratio were calculated at the end of the study. The daily mortality of the prawns in the individual rearing was recorded to calculate the survival rate. The survival was computed as follows (Kang'ombe & Brown 2008):

$$SR=(Nt/No)\ x100$$

Where: SR - the survival (%); Nt - the number of fish at the end of the study individuals); No - the number of fish at the initial of the study (individual).

The total length and body weight of the prawns were observed every two weeks to obtain the growth data (specific growth rate). The formula provided by Weatherley & Gill (1989) was used to compute the specific growth rate (SGR):

$$SGR=[(lnW2-lnW1)/(t2-t1)]x100$$

Where: SGR - specific growth rate (% day^{-1}); W1 - the average weight of fish at the start of the study (g); W2 - the average weight of fish at time t (g); t2–t1 - experimental duration.

The feed conversion ratio was calculated with the following formula (NRC 1993):

$$FCR = F / (W_t + D) - W_0)$$

Where: FCR - feed conversion ratio; Wo - the initial prawn weight (g); Wt - the prawn weight at the end of the study (g); D - the total weight of dead prawns (g); F - the total administered feed (g).

The main data consists of the length growth, the absolute weight growth, the specific growth rate, the survival rate, and the feed conversion ratio (presented as mean ± SD of replications). The data were statistically analyzed for significant differences using ANOVA with a 95% confidence level ($p<0.05$), and the Tukey's test was used for experimental comparison. The parameters of water quality during juvenile rearing were displayed descriptively.

Results and Discussion

Individual rearing. In the individual rearing, the weight and length growth of the juveniles in S0 were significantly better ($p<0.05$) than the results from S3, but there was no significant difference between S1 and S2. Nevertheless, other parameters, such as SGR, molting frequency, survival, and feed conversion ratio did not significantly differ. The prawn performance is presented in Table 1. The growth pattern of the prawn in the individual rearing system (Figure 1) was similar, although there was a tendency for longer starvation times to result in slower growth, both in the body weight and the total length.

Table 1

The prawn performance in the individual rearing system

Treatment	Parameter					
	Length growth (mm)	Weight growth (g)	SGR (% day^{-1})	Molting frequency	Survival (%)	FCR
S0	10.3±2.5[a]	0.29±0.09[a]	2.13±0.6[a]	3.3±0.58[a]	75	4.7±1.2[a]
S1	7±1[ab]	0.2±0.02[ab]	1.57±0.09[a]	2.7±0.5[a]	75	3±0[a]
S2	7.3±1.5[ab]	0.19±0.06[ab]	1.7±0.5[a]	3±1[a]	75	2.8±1[a]
S3	5.7±1 [b]	0.14±0.03[b]	1.31±0.24[a]	2.3±0.5[a]	100	3.9±0.7[a]

Note: S0 - no starvation; S1 - starvation for 1 day followed by feeding for 1 day; S2 - starvation for 2 days followed by feeding for 2 days; S3 - starvation for 3 days followed by feeding for 3 days; SGR - specific growth rate; FCR - feed conversion ratio; different superscripts in the same column indicate a significant difference ($p<0.05$).

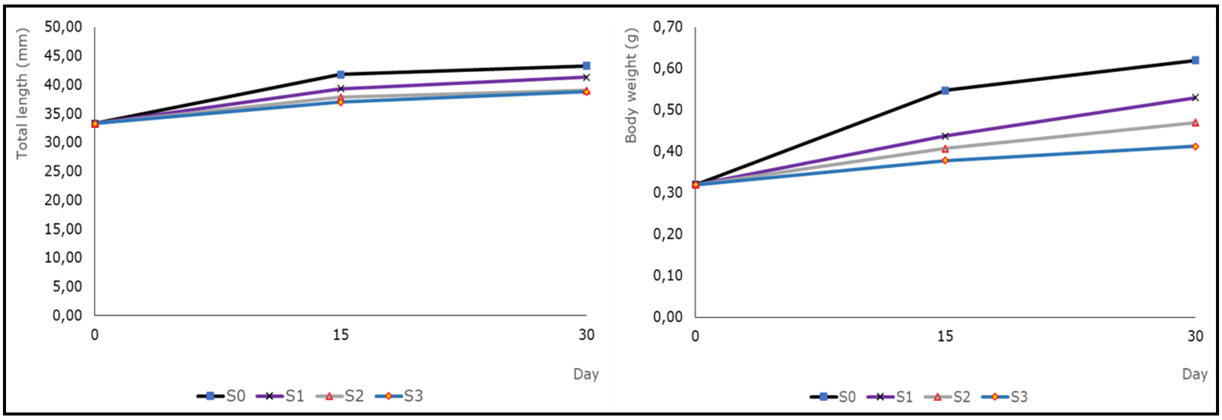

Figure 1. The total length (left) and body weight (right) of the prawn in the individual rearing system.

Communal rearing. The starvation treatment with different durations of the giant freshwater prawn in the communal rearing system did not produce significant differences in the growth characteristics (body length, body weight, and SGR) or in the survival of the prawns. However, the treatments had a significant impact on FCR (Table 2). The prawn's growth pattern in the communal rearing system was similar, although there was a tendency for longer starvation times to result in slower growth, both in body weight and total length (Figure 2).

Table 2

The prawn performance and feed conversion ratio (FCR) in the communal rearing system

Treatment	Parameter				
	Length growth (mm)	Weight growth (g)	SGR (% day^{-1})	Survival (%)	FCR
S0	9.4±2.5[a]	0.4±0.12[a]	2.62±0.55[a]	83.94±4.48[ab]	4.6 ±1.48[a]
S1	8.7±1.6[a]	0.34±0.04[a]	2.38±0.2[a]	91.67±6.79[a]	2.1±0.53[ab]
S2	9.1±1.7[a]	0.36±0.08[a]	2.46±0.36[a]	90.61±4.44[ab]	1.8±0.39[b]
S3	8.3±1.3[a]	0.3±0.05[a]	2.17±0.28[a]	86.56±5.16[ab]	3±1.08[ab]

Note: S0 - no starvation; S1 - starvation for 1 day followed by feeding for 1 day; S2 - starvation for 2 days followed by feeding for 2 days; S3 - starvation for 3 days followed by feeding for 3 days; SGR - specific growth rate; different superscripts in the same column indicate a significant difference ($p<0.05$).

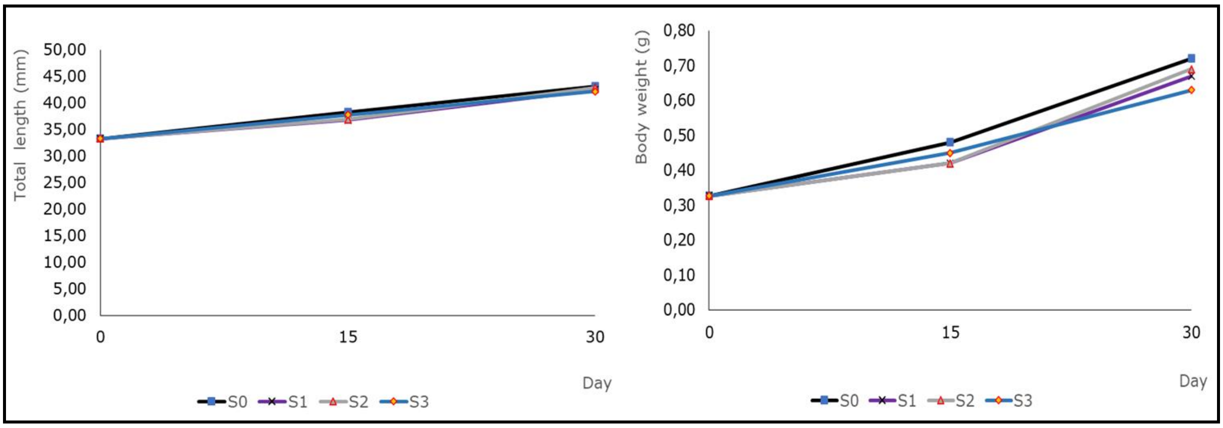

Figure 2. The total length (left) and body weight (right) of the prawn in communal rearing system.

Good feeding management is the main key to success in giant freshwater prawn farming. Excessive feeding will have an impact on the water quality of the rearing medium. The water quality greatly affects the health of giant prawns. Poor water quality results in stunted growth, reduced molting frequency, an increased population of pathogenic bacteria, and low survival. In general, the water quality in the rearing media (glass tanks and net cages) was in the optimal range for the giant prawn. The optimum level of rearing water quality was maintained using water exchange (in the individual rearing) and with new water supply (in the communal rearing). The water quality parameters during the treatment are presented in Table 3.

Table 3

The rearing water quality parameters in the individual and communal rearing system

Treatment		*Parameter*			
		DO (ppm)	*Temperature (°C)*	*pH*	*Ammonia (ppm)*
Individual	S0	2.5-5.2	26-31	7.5–8.2	nd–0.022
	S1	2.8-5.2	26-31	7.5–8.2	nd–0.022
	S2	3.1-5.2	26-31	7.5–8.2	nd–0.022
	S3	3.5-5.2	26-31	7.5–8.2	nd–0.022
Communal	S0	3.4-5.37	28-32	7.3–8.7	nd–0.05
	S1	3.4-5.37	28-32	7.3–8.5	nd–0.05
	S2	3.4-5.37	28-32	7.3–8.5	nd–0.05
	S3	3.4-5.37	28-32	7.3–8.5	nd–0.05
Boyd & Zimmerman (2010)		3-7	25-32	7–8.5	<0.5

Note: DO - dissolved oxygen; nd - not detected.

Good feeding management, including feeding rate and frequency, has a significant effect on the growth performance and food consumption of *M. rosenbergii* juveniles (Habashy et al 2021). Generally, both consumption and growth rates appear to increase with increasing feeding frequency. However, several studies report that reducing the rate and frequency of feeding has no significant effect on the growth and survival of the giant freshwater prawn (Heinen & Mensi 1991), the white leg shrimp (*Litopenaeus vannamei*) (Tahe 2008), sturgeon (*Acipenser persicus*) (Yarmohammadi 2015), and *Oreochromis mossambicus* (Gabriel et al 2018). In line with reducing feeding frequency, fasting or starvation was reported to be effective in increasing feed efficiency, without reducing the growth performance of fish and prawns. According to Hayward et al (1997), starvation can be utilized as a management strategy to boost growth, feed efficiency, and even reduce feed costs by inducing compensatory growth. In many fish species, strategies for reducing or limiting the amount of feed have been used to stimulate compensatory growth.

Prawn growth is strongly influenced by feed consumption because feed consumption controls the number of nutrients that enter the body and are then used for growth and other purposes. It has a significant impact on prawn development (Zonneveld et al 1991). The absolute length and weight growth of the giant freshwater prawns in S1, S2, and S3 in the individual rearing and prawns in all treatments in the communal rearing were relatively similar. This is presumably caused by a hyperphagic response of the prawns. Hyperphagia is a condition in which appetite increases after the shrimp has been fed, thereby increasing feed consumption when refeeding (Chatakondi & Yant 2001). In individual rearing, the prawn growth in S0 was twice that in S3. A similar trend was also seen in communal rearing. Although not significantly different, the prawn growth in S3 was slower than the prawn growth in other treatments. These results are in accordance with previous studies (Rachmawati et al 2010; Robisalmi et al 2021), which reported that a long fasting period affects the growth of the tilapia (*O. niloticus*). Fish that are fasted for a longer period will experience a more pronounced decrease in body energy. In starving fish, glycogen is oxidized through glycogenolysis to produce glucose. Blood glucose is maintained through the process of gluconeogenesis. These conditions will affect the appetite and growth of fish (Zonneveld et al 1991).

Prawn growth in the short time of starvation (S1 and S2) was similar to unfasted prawn growth (S0). This result agrees with the report of Santoso et al (2012), where there was no difference in the growth of tilapia during the fasting experiment. Similar growth shows that there is a compensatory growth phenomenon. The compensatory growth also happened to catfish (*Ictalurus punctatus*) that were fasted for two and three days. Catfish that fasted for two or three days had greater growth than those that were not fasted (Chatakondi & Yant 2001).

The specific growth rate of fasted prawns had a relatively similar average value to that of unfasted prawns. This is presumably because the fasted prawns adapt to "hungry" conditions, this being manifested by decreased activity and low basal metabolic rate. In this condition, the extra energy is used to pursue growth during "satiation". The mechanism causes an insignificant difference in growth rates between prawns in normal feeding and fasting conditions (Santoso et al 2012).

Compensatory growth has been reported by many researchers. It is a time of rapid development during which normal conditions are restored following unfavorable growth conditions, such as a shortage of feed (Ali et al 2003; Turano et al 2007). The compensatory growth phenomenon has been reported in many fish, such as rainbow trout (*Oncorhynchus mykiss*) (Nikki et al 2004), Atlantic salmon (*Salmo salar*) (Nicieza & Metcalfe 1997), catfish (*Ictalarus punctatusi*) (Li et al 2007), and Chinese shrimp (*Fenneropenaeus chinensis*) (Wei et al 2008). In this study, it can be concluded that giant prawns that were fasted for a certain period (S1 and S2) experienced a hyperphagic response and compensatory growth. The growth (body length and body weight) of fasted prawns was relatively similar to that of unfasted prawns (S0). However, fasting for a longer time (S3) results in slower growth than in S0, S1, and S2. The SGR of the fasted prawns in S1, S2, and S3 was relatively similar to that in S0, indicating that the fasted prawns experienced a hyperphagic response and compensatory growth.

The starvation approach can promote compensatory development, such as a time of rapid growth after a period of growth depression brought on by unfavorable conditions similar to feed deprivation (Chatakondi & Yant 2001; Turano et al 2007; Li et al 2009). Some authors suggest that the increased growth of the fish may be a function of the hyperphagic response to periods of lack of feed, with increased appetite (Nicieza & Metcalfe 1997). In this study, the growth pattern of the prawns suggested that the giant prawns fasted for a certain period (S1, S2, and S3) and reared in a communal pattern adapted to hunger conditions by reducing activity and metabolism, then experienced a hyperphagic response and compensatory growth.

Molting, or ecdysis, is one of the most important physiological aspects of crustacean growth, including of the giant freshwater prawn (Da Silva et al 2019). This physiological process directly or indirectly impacts the lives of prawns, mainly influencing feeding, reproduction, metabolism, behavior, and sensitive acuity (Barbieri et al 2017). In this study, there was no substantial difference between the unfasted and fasted prawns in terms of the frequency of molting. This outcome is consistent with the results of Jones & Obst (2000), which claimed that crustaceans go through periods of famine while they are growing because of successive molting. However, Calvo et al (2012) revealed that prolonged famine inhibits molting, and posterior feeding shows that this process is reversible, i.e., the persistence of molting capacity. *C. quadricarinatus* juveniles can withstand prolonged hunger because they conserve energy through exuvia. Sandifer & Smith (1985) stated that the molting frequency is related to age, so the early stages of shrimp life often moult because they grow faster. Furthermore, they stated that the molting frequency is also influenced by the health condition and sex of the shrimp, the quantity and quality of food, and water quality. In this study, the molting frequency of fasted giant prawns is relatively similar to that of unfasted prawns. This result shows that fasted prawns can utilize the given feed for molting and growth. As stated by Mitra et al (2005), the giant freshwater prawn is omnivorous and coprophagous, so it can utilize natural food during periods of deficiency in pelleted food.

Most of the treatments resulted in a high survival rate. It was above 75% in individual rearing and above 80% in communal rearing. In communal rearing, the highest survival rate occurred in S1, while the lowest was in S0. The high survival of the fasted prawns in S3 showed that the organism was able to effectively utilize the given feed to carry out all physiological functions. The result agrees with that of Jones & Obst (2000), who reported that the behavioral and physiological responses of some crab species, like *Cherax destructor*, to such situations is inextricably tied to their capacity to endure during times of great scarcity of food and/or surface water. Therefore, the ability to store nutrients and save energy is likely related to survival time. The higher survival of the prawn was also reported by Stumpf et al (2020). According to their findings, *Macrobrachium borelii* may survive long-term food scarcity in both the juvenile and adult stages, at least intermittently, and be followed by a time of recovery. In relation to prawn survival, molting is a crucial physiological process that affects the survival rate. The moulted giant freshwater prawns release a molting liquid that contains amino acids, enzymes, and organic compounds resulting from the partial decomposition of the exoskeleton, with a smell that strongly stimulates the shrimp's appetite. This can evoke the cannibalism of healthy and not molting prawns to attack molting prawns (Passano 1960). In addition, prawn molting is strongly affected by water conditions in the pond. Due to prawn rearing being carried out in one pond, the water conditions among the net cages were relatively similar and the influences of the water environment on the molting process were also similar. In these conditions, the survival of the prawns was relatively similar.

SGR and FCR are the two most important indicators of feed management efficiency in aquaculture (Nadaf et al 2010). The FCR value is influenced by several factors, including survival, growth rate, prawn density, individual weight, feeding rate, and environment (Huet 1971). Specific to giant freshwater prawn farming, a lower FCR is very important to reduce production costs due to the high price of the feed. In this study, the FCR of prawns in all of the starvation treatments was relatively lower than that of the control. It means that the fasted giant prawns are more efficient in utilizing the feed given to produce growth, and starvation treatment is appropriate to be applied in giant freshwater prawn farming. This study's findings agree with those of Robisalmi et al (2021), where feed restriction (starvation) of tilapia is an effective way to reduce FCR. On the other hand, Huet (1971) stated that feed restriction did not significantly affect the FCR of white-leg shrimp.

Conclusions. The findings of this study showed that the giant freshwater prawn (*M. rosenbergii*) can attain compensatory growth following periods of starvation and re-feeding. Starvation in a short time is an effective way to reduce feed requirements without reducing the production performance of giant freshwater prawns.

Acknowledgements. This study was carried out at the Research Institute for Fish Breeding (RIFB), Ministry of Marine Affairs and Fisheries Indonesia. The authors are thankful to the Director of RIFB for encouragement and for providing facilities. Special thanks to all members of the research team on the giant freshwater prawn for close collaboration during this research.

Conflict of Interest. The authors declare that there is no conflict of interest.

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Received: 10 March 2023. Accepted: 22 April 2023. Published online: 23 July 2023.
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How to cite this article:
Khasani I., Junaeri A., Ekasanti A., Krettiawan H., Pamungkas W., 2023 Growth performance, survival, and feed efficiency of the giant freshwater prawn (*Macrobrachium rosenbergii*) under various starvation patterns. AACL Bioflux 16(4):1974-1984.