DOI: 10.31398/tpjf/28.1.2020A0007

RESEARCH ARTICLE

Growth Performance of the Mangrove Red Snapper (*Lutjanus argentimaculatus*) in Freshwater Pond Comparing Two Stocking Densities and Three Feed Types

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ABSTRACT

The mangrove red snapper *Lutjanus argentimaculatus* (Forsskål 1775) is a high value, euryhaline marine fish with potential as a species for freshwater aquaculture. This study evaluated the growth and cost efficiency of the species in a freshwater pond in two experiments with three replications: (a) comparing stocking densities: (1) 0.5; (2) 1; and (3) 3 fish fish•m^{-2} reared for six months fed three times a day with trash fish to apparent satiation; and (b) comparing feed types: (1) trash fish; (2) moist diet; and (3) formulated dry pellet at a stocking density of 1 fish•m^{-2} fed to apparent satiation three times a day for seven months. The stocking density (SD) experiment showed significantly higher weight gain, absolute growth and specific growth rate ($P<0.05$) in 0.5 fish•m^{-2} SD (184.9 g; 1.04 g•day^{-1}; 2.50%/day) than 3 fish•m^{-2} SD (172.7 g; 0.96 g•day^{-1}; 2.38 %•day^{-1}). No significant difference was detected between 0.5 fish•m^{-2} SD and 1 fish•m^{-2} nor between 1 fish•m^{-2} and 3 fish•m^{-2} ($P>0.05$). Survival rate (SR) and feed conversion ratio (FCR) were not statistically different between treatments ($P>0.05$), which ranged from 78% to 92% and 5.0 to 5.9, respectively. Cost analysis showed high net returns for 1 and 3 fish•m^{-2} SD but low in 0.5 fish•m^{-2} SD. The feeding experiment study showed that feed types significantly affected weight gain, SGR, and SR ($P<0.05$). Snappers fed with trash fish attained significantly higher mean absolute growth (298.2 g) and SGR (1.81%/day) than those fed moist feeds (232.8 g and 1.61%/day, respectively) and formulated feeds (236.1 g and 1.51%/day, respectively). The survival rate was significantly higher in snappers fed trash fish (93.33%) and dry pellets (94.00%) than fed moist feeds (81.34%). FCR in trash fish, moist and dry pellet treatment was 6.4, 6.3, and 2.7, respectively. Cost analysis showed high net returns for trash fish and formulated pellet fed snappers but low in moist diet feed treatment. Cost-benefit analysis showed the feasibility of mangrove red snapper for freshwater aquaculture at a recommended stocking density of 1 to 3 fish•m^{-2} using trash fish, moist diet, or formulated dry pellet.

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Received: *April 7, 2020*
Accepted: *December 31, 2020*

Keywords: *mangrove red snapper, freshwater aquaculture, pond culture, moist diet, formulated dry pellets*

1. INTRODUCTION

The mangrove red snapper *Lujanus argentimaculatus* (Forsskål 1775), locally known in the Philippines as *aliso*, or *mangagat*, is a highly valued food fish in the Indo-Pacific region with production coming from both the capture fisheries and aquaculture. It is a premium target species for recreational fishers in estuarine and tidal freshwater (Ovenden and Street 2003). Market demand is high, and they are highly prized in areas where they are available. Among snapper species offered in many seafood restaurants, mangrove red snapper is one of the most popular in foreign markets such as Hong Kong and Singapore (Lee and Sadovy 1998). World production of mangrove red snapper in 2016 was 9,815 tons from capture fisheries, while aquaculture production was recorded at 10,240 tons (FAO 2018). Most aquaculture production comes from Southeast Asia, where mangrove red snapper and other lutjanid species are popular species being reared in marine cages and brackish water ponds (WWF 2013; SFP 2015; Rimmer 1998). The potential of snapper as aquaculture species has been realized in many other countries where they have started their commercial production for local and export market (NSW Fisheries 1998; Velarde et al. 2012; Tropic Seafood 2020; Ballance 2018; MESA undated).

Mangrove red snapper aquaculture in the Philippines has started since the early 1980s, with hatchery-bred mangrove red snapper becoming available in the early 2000s due to the extensive studies by the Southeast Asian Fisheries Development Center/ Aquaculture Department (Emata 2003a; SEAFDEC 1997; Emata et al. 1994). Rearing in brackish water ponds was also developed (Coniza et al. 2012), with snapper production from aquaculture taking off in recent years. The annual production of mangrove red snapper in the Philippines in 2018 was 1,532 metric tons valued at PHP 246.7 M. The culture of red mangrove snapper is gaining popularity because it is a hardy and fast-growing fish and highly regarded in the market. In floating net cages in marine waters, it could grow to 700 g to 1 kg over a culture period of 6-18 months with a survival rate of more than 70% (Herrera-Ulloa et al. 2010; Castillo-Vargasmachuca et al. 2016; Velarde et al. 2012). It could grow to 300 g to 1 kg in brackish water ponds over a culture period of 6-18 months with at least 75% survival rate (Emata 2003b; Rimmer 1998; Coniza et al. 2012; SEAFDEC 1992). Mangrove red snapper is a hardy fish that could tolerate handling stress, which is a good attribute for live fish transport. It could also allow crowding such that it could be stocked at a high stocking density of 1-3 pcs$\bullet$m^{-2} in ponds without aeration and 10-50 fish$\bullet$m^{-3} in cages. With these good aquaculture parameters and the availability of hatchery-bred fingerlings, mangrove red snapper can be considered an ideal species for aquaculture.

Interestingly, snappers are marine, euryhaline species that could easily adapt and grow well in freshwater environments and could thrive from 35 ppt (marine waters) to 0 ppt (freshwater) (Froese and Pauly 2019). The culture of marine fishes like snapper in freshwater is an excellent technique to develop. The idea that areas far from the sea and an abundant freshwater supply could grow high-value marine fish will have wide application in the aquaculture industry. Presently, the Philippines has limited species in freshwater aquaculture that are of high value. The introduction of other species suitable in freshwater with high commercial value would encourage fish farmers to engage in freshwater aquaculture. Considering that *L. argentimaculatus* has a high market value with a market price of PHP 250-350 per kilo, this will be an ideal culture species for freshwater fish farmers looking for alternative species with high net returns. Although the mangrove red snapper's aquaculture is widespread in many Asian countries, rearing of the species is generally done in brackish water and marine waters. However, published literature on its growth performance and culture in freshwater is limited, particularly in the Philippine conditions. With its potential for freshwater aquaculture, a study along this line was conducted to evaluate the growth performance and cost-efficiency of the mangrove red snapper reared in a freshwater pond.

2. MATERIALS AND METHODS

The study is composed of two experiments: (1) growth performance and cost analysis of mangrove red snapper reared in a freshwater pond in three stocking densities which was conducted in 2003; and (2) growth performance and cost analysis of mangrove red snapper given three feed types reared in a freshwater pond which was done in 2005. All experiments were conducted in the National Fisheries Research and Development Institute- Freshwater Fisheries Research and Development Center (NFRDI-FFRDC in Taal, Batangas, Philippines).

2.1 Stocking density experiment

2.1.1 Experimental fish collection and nursery rearing

Mangrove red snapper fingerlings (2.5 g mean weight; 5.3 cm mean TL) were collected using beach seine net from the estuarine Pansipit River adjacent to Balayan Bay in Taal, Batangas, Philippines and gradually acclimated from 15 ppt (river water salinity) to freshwater (0 ppt) in 2 m x 3 m x 0.5 m concrete tanks for five days with a gradual decrease in salinity of not more than five ppt per day. Gradual acclimation of not more than 5 ppt per day would result in 100% survival during the acclimation period, based on previous acclimation test conducted prior to this study.

The fingerlings were then nursery reared in the same tanks for one month, fed three times a day (0800 hr, 1200 hr, and 1600 hr) with minced trash fish to apparent satiation during the rearing period. Water change was done every other day at a 50% exchange rate while siphoning uneaten feeds, and fecal matter was done every afternoon.

After a month of rearing in concrete tanks, snapper fingerlings were stocked in six units *hapas* (3 m x 5 m x 0.5 m) in a freshwater pond at a stocking density of 100 fingerlings per *hapa*. Fingerlings were fed to apparent satiation in the *hapas* for one month using minced trash fish given in three feeding frequencies: 0800 hr, 1200 hr, and 1600 hr.

2.1.2 Stocking and feeding

After rearing in hapas for one month, 675 snapper fingerlings were randomly stocked in nine units of non-aerated, 50 m^{-2} experimental ponds (10 m x 5 m x 1 m depth), with each of the three ponds stocked with one of the three stocking densities for study: (1) 0.5 fish•m^{-2}; (2) 1 fish•m^{-2}; and (3) 3 fish•m^{-2}. The experiment was laid out in a completely randomized design with three replications. From the group of the snappers stocked in each of the experimental ponds, ten snapper fingerlings were randomly selected using a scoop net and were individually weighed and measured for total body length (6.25 ± 0.30 g mean weight; 7.3 ± 0.7 cm mean TL). Snappers were fed to apparent satiation with chopped trash fish at about 8-10% of the body weight in three feeding frequencies: 0800 hr, 1200 hr, and 1600 hr. Trash fish used as feeds was either sardines or crucian carp, depending on the availability that could be procured from the market. The feeding experiment lasted for 180 days (six months). Based on the snappers' actual feed consumption, the recorded daily feeding rate was 10.8% to 19.5% of fish body weight on Days 1-60, 7.2% to 12.8% on Days 61-120, and 6.0% to 6.9% on Days 121-180. Each month, ten fish from each replicate pond were collected and individually weighed and measured for total length. The actual amount of feeds consumed by the snappers in each replicate were recorded daily. At the end of the feeding experiment, snappers were harvested. The number of fish recovered per replicate was counted. Ten samples from each replicate were individually weighed and measured for total length. The weight gain, absolute growth, specific growth rate, feed conversion ratio, biomass, feed efficiency, and survival rate were determined.

The initial reading of water parameters: dissolved oxygen, temperature, and depth was taken at stocking and then recorded every day until harvest. Water quality was maintained at the optimum level through regular weekly water change at a 50% exchange rate.

2.2 Feed type experiment

This study was conducted after the stocking density experiment from which the stocking density of 1 fish•m^{-2} and the use of trash fish was selected as the baseline density and feed type. Trash fish is an unsustainable feed source; hence, the need to test other viable feed types such as moist feeds and formulated pellets.

2.2.1 Experimental fish acclimation and weaning

Hatchery-bred mangrove snapper fingerlings (3.1 g mean weight, 2.5 cm mean TL) procured from SEAFDEC/AQD were stocked in three units of 3 m x 5 m x 0.5 m concrete tanks at a stocking density of 200 fingerlings•m^{-2} and acclimated from 30 ppt to 0 ppt for seven days with a gradual decrease in salinity of not more than 5 ppt per day. Each tank is a representative of each of the three feed types for study. Snapper fingerlings were fed initially with minced trash fish for a week and then weaned to their respective feeding types of study for the next two weeks. Feeding was done three times a day (0800 hr, 1200 hr, and 1600 hr) to apparent satiation for the duration of the weaning period. Weaning to moist and dry pellets was done gradually, as follows: Day 1 to 3: 25% moist or dry pellets and 75% minced trash fish; Days 4 to 6: 50% moist or dry pellets and 50% minced trash fish; Days 7 to 9: 75% moist or dry pellets and 25% minced trash fish; and Days 10-14: 100% moist or dry pellets.

2.2.2 Feeding in *hapas* and stocking in experimental ponds

After three weeks of rearing and weaning to their respective feed types in the concrete tanks, snapper fingerlings (8.45 ± 0.30 g) were stocked to nine units of non-aerated 50 m2 experimental pond units (5 m x 10 m x 1 m depth) at a stocking density of 1 fish•m^{-2}. Ten snappers from each of the experimental ponds were individually measured for initial length and weight and returned to the pond immediately after sampling. The experiment was laid in a completely randomized design with three replications. The three feed treatments for the study were: (1) trash fish; (2) moist diet; and (3) formulated dry pellets. Snappers were fed with their corresponding feed types for seven months (210 days) fed to apparent satiation in three feeding frequencies: 0800 hr, 1200 hr, and 1600 hr. Actual daily feed consumption was recorded. The trash fish used as feeds depended on the available species that could be procured from the market, either sardines or crucian carp. Formulated dry pellets were procured from SEAFDEC/AQD, formulated and manufactured in their feed manufacturing plant in Tigbauan, Iloilo, Philippines. Table 1 presents the feed ingredients used to prepare the moist feeds at

Table 1. Feed formulation of moist and formulated feeds used for the study

Feed ingredients	Moist feeds (g per 100 g feeds)	Formulated feeds, dry pellets (g per 100 g feeds)
Fish meal	17.5	35.0
Acetes	2.0	4.0
Defatted soybean meal	14.0	28.0
Rice bran	7.0	14.0
Vitamin mix	1.0	2.0
Dicalphos	1.0	2.0
Cod liver oil	1.5	3.0
Bread flour	6.0	12.0
Trash fish	50.0	

the NFRDI-FFRDC experimental site and the feed formulation of dry pellets procured from SEAFDEC/AQD. The moist diet was prepared daily by mixing the feed ingredients and minced trash fish with bread flour as the binder. The moist feeds were molded into ball shape at a size appropriate to the experimental snappers' mouth.

Regular weekly water change at a 30% rate was done to maintain optimum water quality. Pond water temperature, water depth, transparency, DO, and pH were monitored every day.

2.3 Data Analysis

The growth of snappers was evaluated monthly by taking ten snappers from each treatment-replicates, which were weighed individually and measured for body length. Snappers were returned to the pond immediately after sampling. At the end of the experiments, all snappers were harvested, counted individually per treatment-replicate, and weighed and measured for total length. The weight gain, absolute growth, specific growth rate, biomass, feed conversion ratio, and survival rate were then determined.

The weight gain, specific growth rate, feed conversion ratio and survival rate were computed as follows:

Weight gain (g) = $\text{Weight}_{\text{final}} - \text{Weight}_{\text{initial}}$

Absolute growth (g/day)

$= (\text{Weight}_{\text{final}} - \text{Weight}_{\text{initial}})$ / no. rearing days

Specific growth rate (%/day)

$= (\ln \text{Weight}_{\text{final}} - \ln \text{Weight}_{\text{initial}})$/no. rearing days x 100

Feed Conversion Ratio =

Total feeds consumed / Total weight gain of harvested snapper

Survival Rate (%) =

Number of harvested snapper / Number of stocked snapper x 100

Biomass harvested

$= \text{Weight}_{\text{Fish1}} + \text{Weight}_{\text{Fish2}} + \text{Weight}_{\text{Fish3}} \ldots + \text{Weight}_{\text{LastFish}}$

2.4 Statistical Analysis

Results were presented as means ± standard error of the mean (SEM). Levene's test (F-max test) was used to test for homogeneity of variance. After confirming the homogeneity of variances, analysis of variance (ANOVA) was employed using a univariate general linear model to determine significant differences among treatment effects. Duncan's multiple range test (DMRT) was used to determine specific treatment mean differences. Percentage data were arcsine-transformed before ANOVA. Statistical significance was compared at the 5% probability level. All computations and analyses were carried out using SPSS version 20.

2.5 Cost Analysis

A simple cost analysis of the three feed treatments was done to assess the treatments' cost-efficiency compared in the two experimental studies. The computations for the cost analysis were as follows:

Fixed cost = depreciated cost cage + depreciated cost nets

Operating cost = fingerling cost + feed cost + repair & maintenance cost + miscellaneous cost

Total cost = fixed cost + operating cost

Sales = Biomass harvest x market price of fish

Net income = Sales – total cost

Benefit Cost ratio = Benefit / Total Cost

where: Benefit = Total income – Total cost

3. RESULTS

3.1 Water Quality

Table 2 presents the mean readings and range of water parameter readings of the experimental ponds for the culture of mangrove red snapper in the two experiments. The mean readings of the water parameters in both the stocking density and feed type experiments did not differ statistically between treatments (P>0.05).

Table 2. Mean readings and range of water parameter of rearing ponds for the culture of mangrove red snapper in two experiments: (a) comparing three stocking densities; and (b) comparing three feed types

Parameters*	Stocking Density Experiment	Feed Type Experiment
Temperature (°C)	28.9 ± 0.5 (27.3-30.6)	29.5 ± 0.3 (25.5-33.5)
Dissolved oxygen (mg•li^{-1})	6.6 ± 0.8 (5.2-8.0)	5.0 ± 0.4 (4.8-5.1)
pH	8.1 ± 0.3 (7.6-8.5)	8.0 ± 0.5 (7.6-8.5)
Transparency (cm)	42.5 ± 3.2 (30-55)	84.9 ± 5.3 (82.5-87.3)

* All parameters were not significantly different between treatments in both studies

3.2. Stocking density experiment

Figure 1 shows the monthly growth of mangrove red snapper in the three stocking densities. In all sampling periods, the mean body weight was highest in 0.5 fish•m^{-2} stocking density (SD) followed by 1 fish•m^{-2} SD and the least at 3 fish•m^{-2} SD. Analysis of variance (ANOVA) showed that mangrove red snapper at 0.5 fish•m^{-2} SD had significantly higher mean body weight (P<0.05) than snappers at 3 fish•m^{-2} but did not differ significantly from 1 fish•m^{-2} SD (P>0.05). There was no significant difference (P>0.05) in the mean body weight of mangrove red snapper between the 1 fish•m^{-2} and 3 fish•m^{-2} SD.

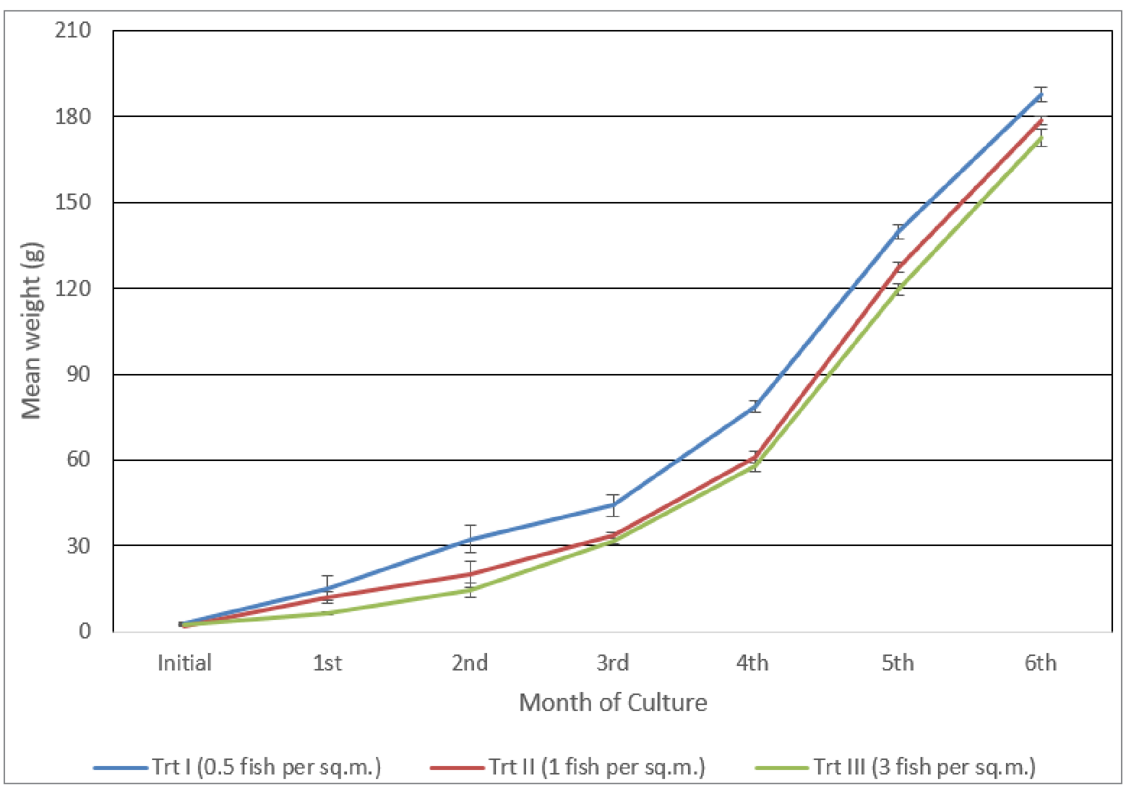

Figure 1. Mean body weight of mangrove red snapper, Lutjaus argentimaculatus reared at three stocking densities and fed trash fish for 180 days in a freshwater pond

The mean weight gain and specific growth rate of mangrove red snapper reared in a freshwater pond in three stocking densities for 180 days are presented in Table 3. ANOVA showed that stocking density significantly affects the fish's mean weight gain (P<0.05). Snappers in 0.5 fish•m^{-2} SD treatment had significantly higher weight gain (184.9 ± 2.5 g), absolute growth (1.04 ± 0.01 g•day^{-1}), and specific growth rate (2.28 ± 0.01 %•day^{-1}) than those reared in 3 fish•m^{-2} SD (172.7 ± 3.0 g; 0.96 ± 0.02 g•day^{-1}; 2.38 ± 0.01 %•day^{-1}). There was no significant difference (P>0.05) between snappers reared in 1 fish•m^{-2} SD and 3 fish•m^{-2} SD nor between 0.5 fish•m^{-2} SD and 1 fish•m^{-2} SD.

There was no significant difference (P>0.05) in the survival rate of snappers in the different SD (Table 3). The lowest stocking density (0.5 fish•m^{-2} SD) attained the highest survival rate of 92 ± 4.6% while snappers at 1 fish•m^{-2} SD and 5 fish•m^{-2} SD had 86 ± 2.3% and 78 ± 7.1%, respectively. The feed conversion ratio was also not affected by the stocking density (P>0.05). The highest FCR was obtained by snappers at 0.5 fish•m^{-2} SD (5.9 ± 0.1) and lowest at 3 fish•m^{-2} SD (5.0 ± 0.03). Snappers at 1 fish•m^{-2} SD attained an FCR of 5.2 ± 0.2.

Table 3. Mean weight gain, absolute growth, specific growth rate, feed conversion ratio, and survival rate of mangrove red snapper reared at three stocking densities fed with trash fish for 180 days in a freshwater pond.

Stocking density	Weight gain (g)	Absolute growth (g·day^{-1})	Specific growth rate (%·day^{-1})	Feed conversion ratio	Survival rate (%)
0.5•m^{-2}	184.9 ± 2.5^{a}	1.04 ± 0.01^{a}	2.50 ± 0.01^{a}	5.9 ± 0.1^{a}	92 ± 4.6^{a}
1•m^{-2}	178.2 ± 1.3^{ab}	0.99 ± 0.01^{ab}	2.47 ± 0.00^{ab}	5.2 ± 0.2^{a}	86 ± 2.3^{a}
3•m^{-2}	172.7 ± 3.0^{b}	0.96 ± 0.02^{b}	2.38 ± 0.01^{b}	5.0 ± 0.3^{a}	78 ± 7.1^{a}

*In a column, means superscripted by a common letter are not significantly different at 5% level

Figure 2 presents the size distribution of mangrove red snapper at harvest after 180 days of culture. The size distribution showed that both 0.5 fish•m^{-2} and 1 fish•m^{-2} SD achieved 100% of all harvested fish at more than 150 g size range. However, only 10% of the fish harvested in the 1 fish•m^{-2} SD was in the 200 g or larger size range compared to the 33.3% attained by the 0.5 fish•m^{-2} SD. The size distribution of the 3 fish•m^{-2} SD, on the other hand, showed that 13.3% of the harvested fish were within the smallest size range of 100 g to 149 g, and only 86.6% of the harvested mangrove red snappers were more than 150 g size range.

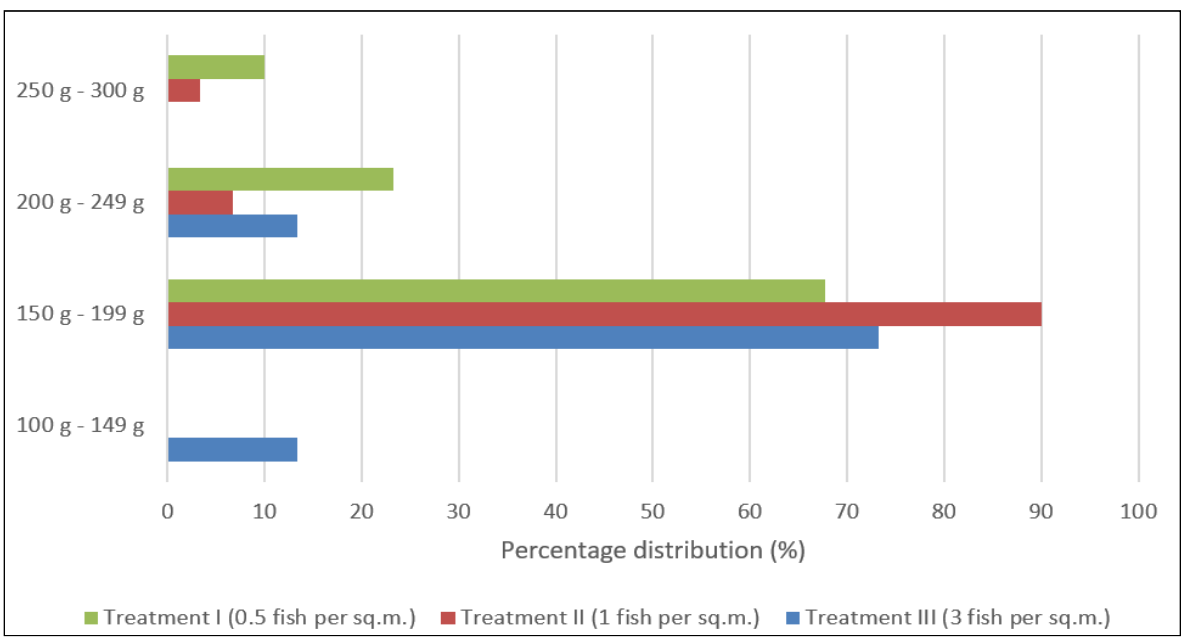

Figure 2. Size distribution of mangrove red snapper reared at three stocking densities and fed trash fish over 180 days in a freshwater pond

Table 4 presents the cost analysis of the culture of mangrove red snapper in a freshwater pond in three stocking densities, with the assumptions for the computations derived from the results of this study. The cost analysis showed that the 0.5 fish•m^{-2} SD had a low net profit of PHP 51,200 while the 1 fish•m^{-2} SD and 3 fish•m^{-2} SD had a higher net profit of PHP 143,478 to PHP 481,177 per hectare of culture area, respectively. Net profit per kg of harvested snapper was also two times larger at higher stocking densities. The cost-benefit analysis showed that all three stocking density groups are economically feasible, with a cost-benefit ratio of 0.31, 0.61, and 0.91 for the 0.5, 1.0, and 3.0 fish•m^{-2} SD, respectively.

Table 4. Cost analysis of mangrove red snapper reared at 0.5, 1, and 3 fish•m^{-2} SD fed trash fish for 180 days in a freshwater pond.

	0.5 fish·m^{-2} SD	1 fish·m^{-2} SD	3 fish·m^{-2} SD
Operating cost			
Fingerlings	10,000	20,000	60,000
Feeds	102,046	159,382	404,118
Labor	35,000	35,000	35,000
Pumping cost	20,000	25,000	30,000
Total cost	165,000	239,382	529,118
Sales	216,200	383,130	1,010,295
Net income	51,200	143,748	481,177
Profit per kg harvest	59.20	93.80	119.08
Benefit cost ratio	0.31	0.61	0.91

Note: All costs were calculated for a one-hectare farm using assumptions on growth, survival rate, and FCR generated from the study.

3.3. Feed type experiment

The monthly growth of the three feed treatments is shown in Figure 3. The growth trend for all treatments was relatively similar in the first four months. However, the difference in growth becomes evident on the 5th to final 7th month of culture when trash fish-fed snappers attained relatively higher mean weight than those fed moist and formulated feeds.

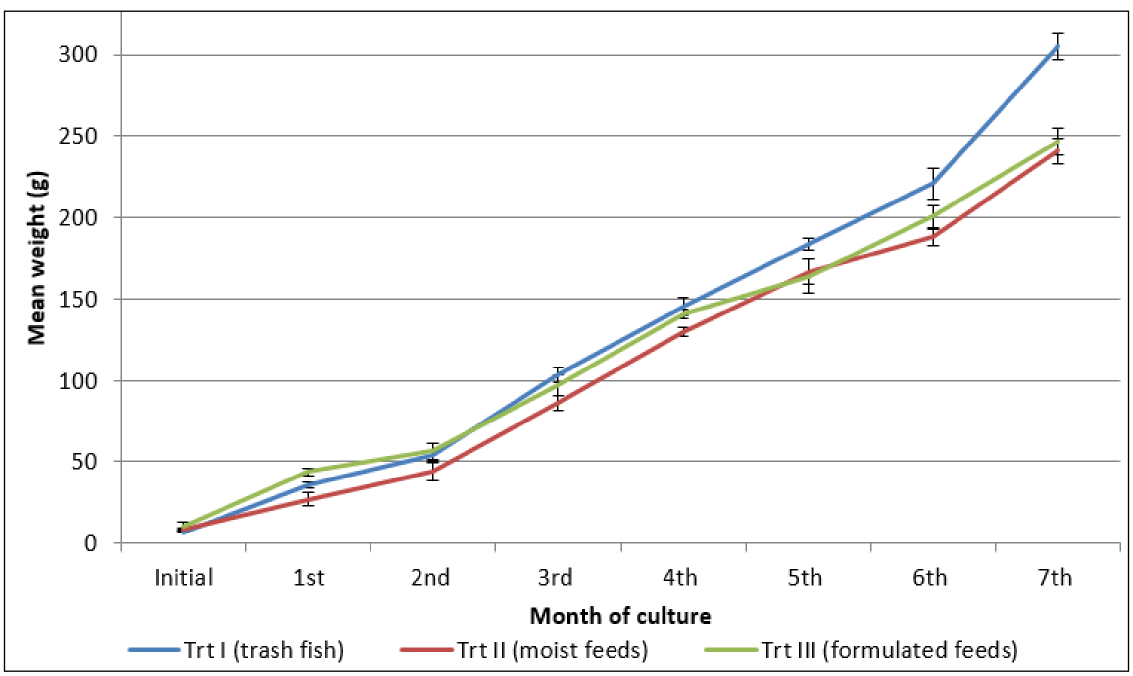

Figure 3. Mean body weight of mangrove red snapper, *Lutjaus argetimaculatus* fed three feed types at 1 fish•m^{-2} stocking density for 210 days in a freshwater pond

The mean weight gain, specific growth rate, biomass harvested, survival rate, and feed conversion ratio of mangrove red snapper reared in a freshwater pond for seven months (210 days) fed with three feed types at a stocking rate of 1 fish•m^{-2} are presented in Table 5. Results showed that the feed types had significant effects on the growth and biomass harvested of snappers (P<0.05). Snappers fed with trash fish attained the highest mean weight gain (298.2 ± 7.9 g), absolute growth (1.42 ± 0.04 g•day^{-1}), specific growth rate (1.81 ± 0.01%/day), and biomass harvested (14.23 ± 0.34 kg), which were significantly higher (P<0.05) than the other two treatments. Same growth parameters were not significantly different (P>0.05) between snappers fed moist and formulated feeds. Weight gain, absolute growth, specific growth rate, and biomass of snapper fed moist diet were 232.8 ± 7.8 g, 1.11 ± 0.04 g•day^{-1}, 1.61 ± 0.02%/day and 9.75 ± 0.70 kg, respectively. Snappers fed with formulated pellet attained weight gain of 236.1 ± 8.0 g, absolute growth of 1.12 ± 0.04 g•day^{-1}, specific growth rate of 1.51 ± 0.02 %/day, and 11.59 ± 0.51 kg biomass harvested.

Survival rate was high in all treatments, with 93.33% attained in trash-fish-fed snappers, 81.34% in moist-diet-fed treatment, and 94.00% in formulated-pellet-fed snappers. Snappers fed with trash fish and formulated pellets were not statistically different (*P*>0.05) in terms of survival rate but were both significantly higher than those fed moist diet (*P*<0.05).

The feed conversion ratio attained by mangrove red snapper fed trash fish, moist diet, and formulated pellet was 6.4 ± 0.10, 6.3± 0.08, and 2.7 ± 0.05, respectively.

Table 5. Mean weight gain, absolute growth, specific growth rate, biomass harvested, survival rate, and feed conversion ratio of mangrove red snapper reared at 1 fish•m^{-2} fed three feed types for 210 days in a freshwater pond

Feed type	Weight gain (g)	Absolute growth (g•day^{-1})	Specific growth rate (%•day^{-1})	Biomass harvested (kg)	Survival rate (%)	Feed conversion ratio
Trash fish	298.2 ± 7.9a	1.42 ± 0.04a	1.81 ± 0.01a	14.23 ± 0.34a	93.33 ± 1.33a	6.4 ± 0.10
Moist feeds	232.8 ± 7.8b	1.11 ± 0.04b	1.61 ± 0.02b	9.75 ± 0.70b	81.34 ± 7.69b	6.3 ± 0.08
Formulated pellets	236.1 ±8.0b	1.12 ± 0.04b	1.51 ±0.02b	11.59 ± 0.51b	94.00 ± 1.15a	2.7 ± 0.05

**In a column, means superscripted by a common letter are not significantly different at 5% level by DMRT*

Table 6 shows the cost per kg of feeds used in each treatment and feed cost per kg of produced snapper. Snappers fed with formulated feeds had the lowest feed cost per kg of snapper produced (PHP 85.05), although it had the highest price of feeds used. On the other hand, snappers fed with trash fish had the highest feed cost per kg snapper produced (PHP 128.00). Feed cost for moist feeds-fed snappers was PHP 94.50 per kg produced fish. Based on cost analysis (Table 7), formulated pellets had high net profit and profit per kg of harvested snapper at PHP 217,051 and PHP 93.71•kg-2, respectively, which is comparable to the trash-fish snapper with PHP 182,281 and PHP 95.65•kg-2, respectively. On the other hand, moist-diet-fed snapper had a low net profit of PHP 139,826 and PHP 71.33•kg-2. The cost-benefit analysis showed that rearing of mangrove red snapper in all three feed types is economically feasible, with a cost-benefit ratio of 0.34, 0.40, and 0.60 for the trash fish, moist diet, and formulated pellet, respectively.

Table 6. Cost per kg of feeds used and feed cost per kg of snapper produced

Treatment	Price per kg of feeds (P)	Feed cost per kg of snapper (P)
I (trash fish)	20.00	128.00
II (moist diet)	15.00	94.50
III (formulated pellet)	31.50	85.05

Table 7. Cost analysis of mangrove red snapper reared at 1 fish•m^{-2} fed three feed types for 210 days in a freshwater pond.

	Treatment I Trash fish	Treatment II Moist diet	Treatment III Formulated pellet
Operating cost			
Fingerlings	100,000	100,000	100,000
Feeds	364,360	185,247	196,989
Labor	35,000	35,000	35,000
Pumping cost	w30,000	30,000	30,000
Total cost	529,360	350,247	361,989
Sales	711,641	490,073	579,040
Net income	182,281	139,826	217,051
Profit per kg harvest	95.65	71.33	93.71
Benefit cost ratio	0.34	0.40	0.60

Note: All costs were calculated for a one-hectare farm using assumptions on growth, survival rate, and FCR generated from the study.

The size distribution of snappers after seven months of culture is shown in Figure 4. Results showed that trash-fish-fed snappers had a relatively higher percentage of market-sized fishes at harvest, with 93.3% in the size range that is larger than 250 g. Snapper fed formulated pellet had 50.29%, and snapper fed moist diet with 43.44% falling in the 250 g up size range.

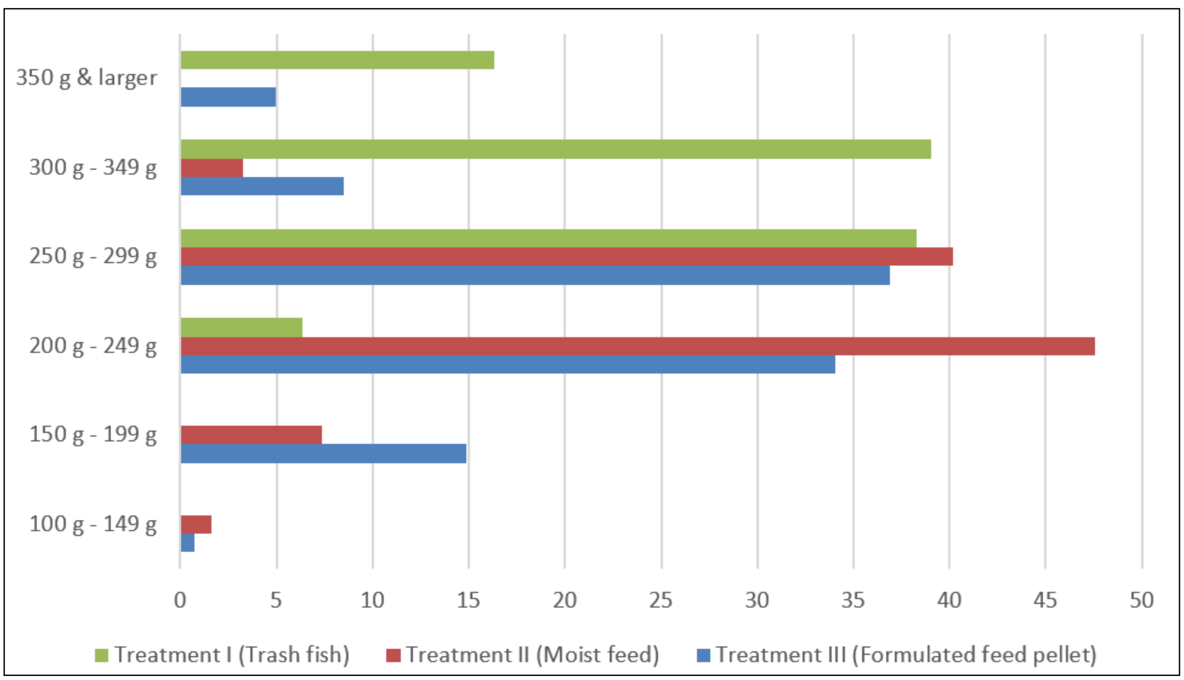

Figure 4. Size distribution of mangrove red snapper reared at 1 fish•m^{-2} fed three feed types for 210 days in a freshwater pond

4. DISCUSSION

4.1. Stocking density experiment

The present study showed that stocking density affects snappers' growth but had no significant effects on survival rate and feed conversion ratio. Growth of mangrove red snapper was within optimal growth of the species reared in ponds with weight gain and absolute growth of 170.3 g–185.6 g and 0.95–1.03 g•day-1 in six months. This growth is similar to the results of other researchers on mangrove red snapper reared in brackish water ponds (Coniza et al. 2012) and also comparable with other lutjanid species such as *Lutjanus guttatus, L. analis, L. apodus*, and *L. sp.* cultured in ponds (Rimmer 1998; SEAFDEC 1992), tanks (Cole et al. 1999), and cages (Castillo-Vargasmachuca 2012; Velarde et al. 2012; Benetti et al. 2002) reared in brackish and marine waters.

The study indicated that increasing the stocking density would result in a lower growth rate of snappers. This trend is similar with many cultured fish species where stocking density were negatively correlated with growth such as in black sea turbot (Pseta maxima) (Aksungur et al. 2007); channel catfish *Ictalurus punctatus* (Allen 1974); pigfish *Orthopristis chrysoptera* (DiMaggio et al. 2014); Gulf killifish (*Fundulus grandis*) (Ofori-Mensa et al. 2018); Thai climbing perch (*Anabas testudineus*) (Khatune-Jannat et al. 2012); tilapia (*Oreochromis niloticus*) (Carro-anzalotta and McGinty 1986); Chinese sturgeon (*Acipenser sinensis*) (Zhang et al. 2019); Australian perch (*Bidyanus bidyanus*) (Rowland et al. 2006); rohu (*Labeo rohita*) (Chattopadhyay et al. 2012); silver pompano (*Trachinotus blochii*) and Pacific red snapper *Lutanus peru* (Castillllo-Vargasmachuca et al. 2012). The crowded rearing environment at the higher stocking density creates a stressful condition for the snappers. Considering that *L. argentimaculatus* is a carnivorous and predatory species (Froese and Pauly 2019), larger fish's aggressive behavior could be triggered by the closer contact within the cultured species, this behavior contributing to the suppressed growth of smaller sized fish. The role of crowding as a stress factor had been known in fish, which, accompanied by other stressors like poor water quality, organic wastes, and conspecific aggression and predation, could affect fish physiology (Harper and Wolf 2009). Although crowding by itself does not cause the decreased final weight of fish at harvest, physiological stress may contribute to this effect, as indicated in the study of Burgess and Coss (1982) on a histologic specimen of adult jewelfish (*Hemichromis bimaculatus*), which showed that moderate crowding stress was associated with morphological changes in the brain. Aside from crowding, aggression and predation are two other stressor factors that affect fish growth, and prolonged exposure to stress factors may lead to adverse effects on the animal's overall health (Barton 2002). In this study, there was an observed reduced feeding activity of smaller sized snappers due to the larger-sized fishes' aggressive behavior, particularly at the higher density of 1 fish•m^{-2} and 3 fish•m^{-2}, which affected feed intake resulting in large size variation at harvest. Similar observations were noted on yellowtails (*Seriola quinqueradiata* Temminck and Schlegel) (Sakakura and Tsukamoto 2007); salmon and trout (Vollestad and Quinn 2003); tilapia (*Oreochromis niloticus*) (Fattah et al. 2020); Asian sea bass (*Lates calcalifer*, Bloch) (Sadhu et al. 2015); and common carp (*Cyprinus carpio*) (Mizory et al. 2020). Studies mentioned in the previous sentence showed an increased aggressive behavior at higher stocking density with the highest aggression observed in the group with the largest difference in size. Conversely, Rosengren et al.'s (2016) study on salmonids observed that lowered density rendered positive effects on growth and decreased conspecific aggression. The effect of crowding and aggression on the fish growth had been shown in the size distribution of snappers in this study, with the highest stocking density of 3 fish•m^{-2} having a significant number of small sized fishes at less than 149 g. The growth of smaller fish had been suppressed by decreased feeding activity due to the larger-sized fish's aggressive behavior. Size grading of fish during the grow-out phase, which was not done in this study, is necessary for snapper culture to lessen the aggressive behavior of larger-sized snappers.

Increasing the stocking density of the experimental snappers does not affect the feed conversion ratio. However, snappers at 1 fish•m^{-2} SD (5.2) and 3 fish•m^{-2} SD (5.0) had relatively lower FCR than 0.5 fish•m^{-2} SD (5.9). This may imply that the higher stocking density to a certain level promotes better feed efficiency in snappers, which is similar to Lupatsch's (2015) observations on *Epinephelus aeneus* reared in marine tanks and by Liu et al. (2014) on *Salmo salar* reared in a recirculating system. The lower FCR in high stocking density could be explained by the reduced metabolic rate and apparent digestibility rate in the fish (Liu et al. 2014).

Similarly, the survival rate in this study was not affected by the stocking density, which was comparatively high in all treatments ranging from 78%

to 92%. This result is comparable to the survival rate in cultured snappers reported by several researchers on *Lutjanus argentimaculatus*, *L. guttatus, L. analis, L. apodus, and L. sp.* (Coniza et al. 2012; Rimmer 1998; Aquafarm 1992; Cole et al. 1999; Castillo-Vargasmachuca 2012; Velarde et al. 2012; Benetti et al. 2002).

The growth performance and cost analysis revealed that snappers reared at 1 fish•m^{-2} to 3 fish•m^{-2} SD are the optimal density for snappers' culture in a freshwater pond. The benefit-cost ratio was all positive for the three stocking densities used in the study, with an increasing BCR at the higher stocking density resulting from the higher volume of harvest. The use of trash fish as feeds entailed high operational cost, but the snapper's high market price translated into high gross sales makes it a profitable aqua business. However, the profitability of snapper culture would be dependent on the market price of trash fish to be used in the culture operations. Trash fish price of PHP 20-30 per kg could make snapper culture profitable but will not be viable if the price is higher than this range unless snappers' selling price reaches more than PHP 300 per kg. Although the 0.5 fish•m^{-2} SD obtained high growth and survival rates, it is deemed to be not viable due to very low net income and BCR, which would be very prone to losses when the price of trash fish exceeds PHP 30 per kg.

4.2. Feed type experiment

The feed type study indicated that growth, survival, and feed conversion ratio were affected by the feed type used for rearing snappers. The growth of mangrove red snapper was within optimal growth of the species reared in ponds for seven months with weight gain and absolute growth of 232.8–298.2 g and 1.11–1.81 g•day^{-1}, respectively, which is similar to the results of other studies on mangrove red snapper (Coniza et al. 2012); *Lutjanus guttatus, L. analis, L. apodus, and L. sp.* (Rimmer 1998; Aquafarm 1992; Cole et al. 1999; Castillo-Vargasmachuca 2012; Velarde et al. 2012; Benetti et al. 2002).

The present study showed that the mangrove red snapper readily accepts moist diet, dry formulated pellets, and trash fish, and snappers' growth was affected by the feed type offered. Other lutjanid species such as *Lutjanus guttatus, L. apodus, L. analis, and L. sp* consume similar feeds (Rimmer 1998; Aquafarm 1992; Cole et al. 1999; Castillo-Vargasmachuca 2012; Velarde et al. 2012; Benetti et al. 2002). Among the feed types used in this study, mangrove red snapper fed with trash fish exhibited higher growth than the other two feed types, which is similar to the observations in *L. apodus* by Cole et al. (1999) and in snappers grown in Taiwan by Rimmer (1998). Although the protein content of crucian carp (16%) (Krzynowek and Murphy 1987) and sardines (20%) (Krzynowek and Murphy 1987) fed as trash fish in this study were comparably lower than snapper formulated feeds (44%) (Catacutan et al. 2008), the growth of snappers was higher in the trash fish fed treatment. This faster growth may be attributed to the higher acceptability and feed utilization of fresh fish, being their natural feed in the wild, compared to the moist diet or artificial dry pellets used in this study. The efficient utilization of nutrients may also play a significant factor in the growth of the experimental snappers. The moist diet and formulated feeds used in this study have lower feed efficiency. Moreover, there was an observed partial rejection of moist feeds and formulated pellets from the fifth to seventh month of the culture period, which may have further contributed to the lower growth of the experimental fish. The feed rejection observed in the two feed types in this present study may be attributed to the low palatability of the feeds to snappers at the later stage of culture. It may indicate that snappers at this stage require additional feed stimulants to increase feed intake. The feeds' taste properties have a high stimulating implication on feed intake and growth (Kasumyan 1997), with olfaction and gustation as major chemosensory systems in fish (Kasumpyan and Doving 2003). Essentially, there is a need to improve the feed formulation of snapper feeds at this culture stage, particularly the addition of attractants to increase acceptability and feed intake. The inclusion of attractants to artificial diets had been known to achieve fast growth due to increased feed ingestion and higher digestibility (Kolkovski et al. 2000; Polat and Beklevik 1999; Biswas et al. 2018; Fänge and Grove 1979; Kasumyan and Doving 2003). The artificial diets used in the study may also lack the essential nutrients required by the snappers for faster growth. Adding vitamins, 26 ppm ascorbic acid and amino acid to fresh fish may help provide the essential nutrients needed by mangrove red snapper (Catacutan et al. 2011). Although the growth rate was lower in the moist and formulated feed pellets, their acceptability to the experimental snappers is an indication that these feed types may replace the use of trash fish. A better feed formulation that will address their acceptability and nutrient requirement issues is necessary to improve growth rate, feed conversion ratio, and survival rate.

The feed conversion ratio was not compared between feed types in this present study due to the differences in the feeds' moisture. Instead, a comparison with the results of this study with other research works on snappers fed with similar feed types was made to analyze the feed efficiency. FCR of mangrove red snapper fed trash fish in this study, 5.0 to 6.4 in six to seven months, is comparable to the same species fed trash fish reared in brackish water pond (Coniza et al. 2012) and other species of snapper reared in Taiwan (Rimmer 1998) with 7 to 9. On the other hand, the use of moist diet in this study attained an FCR of 6.3, which was higher than those reported by Rimmer (1998) on snappers cultured in cages in Taiwan fed moist feed with FCR of 2.2–2.5. Similarly, the formulated pellet fed snappers in the present study achieved an FCR of 2.7 in seven months, which is higher than those attained in red-purple snapper (*Lutjanus sp.*) at 1.96 FCR (Cremer et al. 2001) and in mutton snapper (*Lutjanus analis*) at 1.4 FCR (Benetti et al. 2002) fed dry commercial diets. The relatively higher FCR of the moist and formulated feed pellet treatments in this study compared to other research works on snappers fed with the same feed type indicated a lower feed utilization by the experimental fish, which may have contributed to the lower growth. Moreover, the partial rejection of feeds by the snappers, as earlier mentioned, has also affected the FCR due to lowered feed intake and decreased weight gain. Therefore, improvement in feed formulation is needed to improve palatability through the increased use of attractants to address the periodic rejection of the snapper of moist diet and dry pellets.

The feed type used in the study also affected the survival rate of snappers using trash fish and formulated pellets resulting in a higher survival rate. The lower survival rate in the moist feed treatment may be attributed to the agonistic behavior of the larger sized snapper and low efficiency of this feed type on fish growth. Similar to the stocking density experiment, the larger-sized fish's aggressive behavior over the smaller ones was also observed in all treatments in this feed type experiment but is most notable in the moist feeds and formulated pellets that affected growth and led to mortality in some of the snappers. The effects of the aggressive behavior are manifested in the size distribution of these two feed types, which showed a significant proportion of the fish population in the small-sized category (100–149 g and 150–199 g size group), which were the ones prone to bullying by the larger fish. Prolonged stress conditions that led to mortality may have resulted in the low survival rate, particularly for the moist diet treatment. In this aspect, spreading the feeds on a larger surface area during feeding time is recommended to reduce the fish's close contact with each other and, therefore, minimize aggression. Size grading during culture is also recommended.

Although snapper culture's operational cost is high due to feeding cost, snappers are high-value species that command a high market price that would yield high gross sales. The positive benefit-cost ratio (BCR) in all three feed treatments showed the economic potential for raising snappers in freshwater ponds using these feed types. The use of formulated pellets had the highest economic potential, having achieved the highest BCR due to lower feed cost per kg of harvested snapper. An improved feed quality with high feed acceptability and feed efficiency will increase the BCR for this feed type. On the other hand, trash fish fed snappers attained the lowest BCR despite having the highest gross sales, mainly due to high FCR that entailed high feed cost per kg of harvested fish. Moreover, the supply of trash fish is seen to be unsustainable with unpredictable prices in many areas. Therefore, the use of trash fish as feeds is only feasible in areas where they are abundant and inexpensive.

5. CONCLUSION AND RECOMMENDATION

This study showed that the high-value marine fish, mangrove red snapper, is a suitable species for freshwater aquaculture that could be reared in ponds with good growth, survival rate, FCR, and net returns. The stocking density of 1 to 3 fish•m^{-2} is recommended for this species. Mangrove red snapper could be fed with trash fish and formulated moist diet and dry pellets but weaning to the two latter feed types and gradual acclimation to freshwater for a period of one to two weeks are essential. The dependence on trash fish as feeds may become a limiting factor in the culture operations; thus, an appropriate artificial diet that is highly acceptable to fish and highly efficient must be made available for use widely by the local fish farmers. Otherwise, fish farmers will use trash fish as feeds, which is unsustainable due to declining fish catch. Moreover, it is deemed socially unacceptable because almost all fish species are now used as food fish by the local consumers. Further research on the use of feed stimulants to increase the palatability of feeds and the appetite of snappers is recommended to address the fish's periodic rejection of feeds, as observed in this study. Furthermore, a study on feed nutrition emphasizing digestibility is also needed to achieve faster growth of artificial diet fed snappers. Size grading of snappers during the rearing period may be necessary to prevent bullying behavior that may result in smaller-sized fishes and mortality. Further studies on the effect of other stocking density and feeding frequencies on mangrove red snapper's growth and survival are also recommended to achieve faster growth and lower FCR than those attained in this study. Cage aquaculture of mangrove red snapper in a freshwater environment such as impoundments or freshwater lake could also be a profitable enterprise; thus, a study on the cage culture of this species is recommended. Cages allow higher stocking density and entail lower production and investment cost. Furthermore, the local supply of hatchery-bred mangrove red snapper is still limited at present. Studies on the improvement in seed production are necessary to meet the emerging developments in snapper aquaculture.

ACKNOWLEDGMENTS

The authors are grateful to the National Fisheries Research and Development Institute for funding the project. The authors would also like to thank Ms. Leticia S. Magistrado for the support and all technical personnel of the FFRDC who have been involved in the implementation of the project. Most importantly, sincerest gratitude is expressed to the anonymous reviewers of this paper.

AUTHOR CONTRIBUTION

Muyot FB: Conceptualization, Methodology, Investigation, Formal analysis, Writing-Original draft. **Mutia MT**: Conceptualization, Methodology, Supervision, Funding acquisition, Project administration. **Magistrado ML**: Investigation, Resources. **Muyot MC**: Investigation, Resources.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

ETHICS STATEMENT

The researchers followed all institutional and national guidelines for the care and use of laboratory animals.

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