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The Effects of Manual, Time and Sound Feeding Systems on the Growth and Production of White Shrimp (*Litopenaeus vannamei*) in Semi-intensive Farming Systems in Ecuador

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Abstract The objective of the current study was to analyze the performance of white shrimp fed using three feeding systems: manual, time feeders and sound feeders, in thirteen commercial semi-intensive farms in three areas of Guayas province (Ecuador) using 535 production lots during the period 2015~2017. The size of the ponds ranged between 3 and 23 hectares, with a depth of 1.2 m, in which the exchange of water was around 1 % a day. The initial weight of the shrimp was 0.04~0.29 g, and stocking density was around 10 shrimp per square meter. The three feeding systems used commercial diets with 35% protein content. The time feeder system gave a higher shrimp yield (1 631 kg/ha) than manual feeding (1 539 kg/ha) and the sound feeder system (1 483 kg/ha). The best results for survival were obtained with the manual system (61.7%) and the time feeder (62.9%) in comparison to sound feeder (57.0%). Current performance results with acoustic systems were lower than reported by other authors, probably because the number of feeders per hectare was low, reducing the accessibility of shrimp to feed, in fact daily feeding supplied was not improved as has occurred in other studies.
Keywords Shrimp productivity; Growth; Feeding management; Time feeder; Sound feeder

Shrimp (*Litopenaeus vannamei*) production is the most important sector of aquaculture from an economic point of view, because, with a production of 4.966 × 106 kg, it has the highest world total value at U$D 28,782 million, with a unitary value of 5.80 U$D /kg (Apromar, 2020). Shrimp is very popular with consumers with significant consumption levels because of its high quality.

Traditionally, shrimp has been produced in semi-intensive systems, although intensive and super intensive systems are increasing around the world, including RAS and biofloc, but most production is in semi-intensive systems (5~25 shrimp per square meter).

Although shrimp farming has been in exercise for over six decades now, there are nevertheless many demanding situations that want to be tackled so that the general performance of the industry can be enhanced. The principal limitation in shrimp feeding is frequently an incapacity to take a look at inventory in the course of its production cycle, inflicting problems in figuring out survival and thus biomass (Davis et al., 2006; Smith and Tabrett, 2013) which makes it in a complex task to feed shrimps properly. The feeding applied to large shrimp ponds has been a challenge within the facet of farming shrimp because it often results in overfeeding and the generation of large amounts of waste (Davis et al., 2006). As with most aquaculture species, feeding is the main production cost, thus its optimization is key to maximizing productivity. The effectiveness of the feeding system and feeding management has proven to be complex because it does not take into account other factors, such as molting, shrimp character, gender, environmental enrichment, and water quality (Bardera et al., 2019).

Several topics are related to shrimp feeding, such as nutrient composition and the ingredient level of diets and practical feeding strategy.

Nevertheless, feeding strategies could be improved in several production systems to optimize productivity. There are four main aspects in the practical feeding of shrimp: daily feed ration (Venero et al., 2007; Carvajal-Valdes et al., 2012; Roy et al., 2012), number of meals or frequency, hour of meals and feed quantity in each meal (Smith et al., 2002; Tacon et al., 2002; Carvalho and Nunes, 2006; Nunes et al., 2006; Aalimahmoudi et al., 2016; Van et al., 2017), all of which must be managed through different feeding systems: manual; by hand or air suppliers; or mechanic feeders; automatic by time or demand feeders by sound.

When a manual feeding system is selected, the farmer decides the quantity and hour of feed subject to personnel and time limitations, and the shrimp must adapt their behavior, but it is possible that the response might not be optimal. Automatic feeding systems might be a good alternative for optimizing personnel and management of shrimp production, but in order to improve the biological response, the shrimp must decide its feeding strategy itself. Additionally, some biological characteristics of shrimp, molting and night habits, suppose certain limitations for their feeding (Molina et al., 2000), which must be considered in order to optimize shrimp production.

Previous works in one-hectare intensive ponds (Napaumpaiporn et al., 2013) and in 0.1-hectare semi-intensive ponds (Jescovitch et al., 2018) have shown a positive effect in growth, feed conversion ratio (FCR) and yield using both automatic feeder with a timer and sound detection. Likewise, a significant effect on final production and economic productivity was also cited by Ullman et al. (2019a, b) and Reis et al. (2020) in 0.1 ha experimental ponds with the sound feeder, because although the cost of feeders and feed intake was higher and consequently the cost of feeding was also higher, the economic value of the final shrimp yield compensated this extra-cost. Recently, Reis et al. (2020) in 0.1 ha, have confirmed a higher yield with acoustic feeders in comparison to a time feeding system.

No information exists about the effect of automatic feeding in shrimp commercial ponds under real conditions of production, thus the objective of the current trial was to study the performance of juvenile shrimp (*L. vannamei*) fed using three feeding systems: manual, time feeder and sound feeder, in commercial semi-intensive ponds from several shrimp farms in Guayaquil (Ecuador).

1 Results

1.1 Environmental parameters

Water temperature was in the range of 21.9 ºC~36.5 ºC, with an average of 27 ºC~30 ºC, and dissolved oxygen in the range of 1.3~14.5 ppm, with an average of 4.6~7.5 ppm (Table 1). Salinity was 16 ppt in rainy/hot season (January to May) and 28 ppt in dry/cold season (June to December).

1.2 Productivity parameters

Prospective results of shrimp productivity parameters (survival, yield, DFS, FCR, final weight, cycle duration and weekly growth) considering year (Table 2) and month of starting cycle (Table 3) were analyzed. Overall results of all shrimp farms were: 68% survival, 1 718 harvested kilograms per hectare, 23.5 grams of mean final weight, 2.90%/d DFS, 2.04 FCR, 139 days production cycle duration and a growth of 1.20 grams per week.

Survival was lowest in 2017 (63%) and yield in 2016 was higher (1 815 kg/ha) than 2015 (1 700 kg /ha) and 2017 (1 640 kg/ha). The worst FCR (2.09) and weekly growth (1.12 g/w) occurred in 2015, but final weight (22.0 g) and cycle duration (126 d) were lowest in 2017.

Results of shrimp productivity in the different areas (Table 4), showed the best values on Escalante Island with higher survival (74%), harvest weight (1 896 kg/ha), lowest FCR (1.82), lowest cycle duration (131 days) and highest weekly growth (1.27 g/w).

The starting month (Table 3) was found to have a significant effect on survival, with high values in the period from May to October, 63%~67%, and also in harvested weight with higher production 1 636~1 841 kg/ha. The final weight was higher in the period from September to December, 23.3~24.5 g, but no clear effect was observed on weekly growth. Additionally, no effect was observed on FCR.

Table 1 Water parameters in shrimp ponds from Guayas (Ecuador)

Parameter	A.M.	P.M.
Temperature at Esclusas Area	-	-
Maximum value	31.7	35.5
Minimum value	22.8	23.7
Average value	27.3	28.8
Temperature at Escalante Island	-	-
Maximum value	32.5	36.5
Minimum value	21.9	21.9
Average value	28.6	29.9
Dissolved oxygen at Esclusas Area	-	-
Maximum value	8.6	14.5
Minimum value	1.5	2.6
Average value	4.6	7.5
Dissolved oxygen at Escalante Island	-	-
Maximum value	9.8	13.6
Minimum value	1.3	1.7
Average value	4.7	7.5

Table 2 Shrimp productivity obtained in different years in Guayas (Ecuador) farms

Year	Nº	Survival (%)	Yield (kg/ha)	DFS (%/day)	FCR	FW (g)	Cycle (days)	Growth (g/week)
Average	535	67.9	1 718	2.90	2.04	23.5	139	1.20
2015	41	70.2 ^{a}	1 700 ^{b}	2.69 ^{a}	2.09 ^{a}	24.1 ^{a}	152 ^{a}	1.12 ^{a}
2016	193	70.6 ^{a}	1 815 ^{a}	2.85 ^{b}	2.02 ^{b}	24.5 ^{a}	140 ^{b}	1.24 ^{b}
2017	301	63.1 ^{b}	1 640 ^{b}	3.15 ^{c}	2.02 ^{b}	22.0 ^{b}	126 ^{c}	1.24 ^{b}
Sig. Level	-	0.000 0	0.000 0	0.000 0	0.045	0.000 0	0.000 0	0.000 1

Note: Nº: Number of production cycles; DFS: Daily Feeding Supplied; FCR: Feed conversion ratio; FW: Final weight; Values in the same column with different superscripts are significantly different ($P < 0.05$)

Table 3 Shrimp productivity in regard to the initial month of production cycle in Guayas (Ecuador) farms

Month	Nº	Survival (%)	Yield (kg/ha)	DFS (%/day)	FCR	FW (g)	Cycle (days)	Growth (g/week)
January	46	59.3 ^{ab}	1 446 ^{bcd}	3.23 ^{ab}	2.00	21.8 ^{cd}	123 ^{ab}	1.28 ^{a}
February	40	58.9 ^{ab}	1 403 ^{cd}	3.26 ^{ab}	2.12	21.6 ^{cd}	127 ^{abc}	1.20 ^{ab}
March	43	55.0 ^{b}	1 307 ^{d}	3.36 ^{b}	2.07	20.9 ^{d}	121 ^{a}	1.22 ^{ab}
April	42	60.7 ^{ab}	1 492 ^{bcd}	3.05 ^{ab}	2.06	22.2 ^{cd}	133 ^{bc}	1.17 ^{ab}
May	46	62.7 ^{ab}	1 636 ^{ab}	2.90 ^{a}	2.02	22.2 ^{cd}	137 ^{c}	1.15 ^{b}
June	44	64.4 ^{a}	1 841 ^{a}	3.11 ^{ab}	2.13	22.6 ^{bc}	135 ^{bc}	1.18 ^{ab}
July	34	63.3 ^{ab}	1 746 ^{a}	3.22 ^{ab}	2.12	23.0 ^{bc}	130 ^{abc}	1.24 ^{ab}
August	54	66.8 ^{a}	1 740 ^{a}	3.11 ^{ab}	2.10	22.9 ^{bc}	133 ^{bc}	1.23 ^{ab}
September	52	64.9 ^{a}	1 650 ^{ab}	2.99 ^{ab}	2.02	23.8 ^{ab}	134 ^{bc}	1.26 ^{a}
October	40	65.8 ^{a}	1 657 ^{ab}	2.89 ^{a}	2.02	24.5 ^{a}	139 ^{c}	1.26 ^{a}
November	46	57.8 ^{ab}	1 499 ^{bcd}	3.19 ^{ab}	2.17	24.1 ^{ab}	133 ^{bc}	1.28 ^{a}
December	48	61.8 ^{ab}	1 526 ^{bc}	3.05 ^{ab}	2.11	23.3 ^{abc}	136 ^{c}	1.21 ^{ab}
Sig. Level	-	0.001 0	0.000 0	0.001 4	0.44	0.000 0	0.000 0	0.000 2

Note: Nº: Number of production cycles; DFS: Daily Feeding Supplied; FCR: Feed conversion ratio; FW: Final weight; Values in the same column with different superscripts are significantly different ($P < 0.05$)

Table 4 Shrimp productivity in several areas in Guayas (Ecuador) farms

Area	Nº	Survival (%)	Yield (kg/ha)	DFS (%/day)	FCR	FW (g)	Cycle (days)	Growth (g/week)
Esclusas	407	61.5 ^{a}	1526 ^{a}	3.10 ^{c}	2.18 ^{b}	23.1 ^{a}	139 ^{b}	1.17 ^{b}
Escalante	40	74.0 ^{b}	1896 ^{b}	2.70 ^{a}	1.82 ^{a}	23.5 ^{a}	131 ^{a}	1.27 ^{a}
Puná	88	68.4 ^{c}	1732 ^{c}	2.89 ^{b}	2.13 ^{b}	24.0 ^{a}	147 ^{c}	1.16 ^{b}
Sig. Level	-	0.000 0	0.000 0	0.000 0	0.000 0	0.063	0.000 0	0.000 0

Note: Nº: Number of production cycles; DFS: Daily Feeding Supplied; FCR: Feed conversion ratio; FW: Final weight; Values in the same column with different superscripts are significantly different ($P < 0.05$)

Pond size was found to have a significant effect in the most parameters (Table 5), thus FCR, growth and cycle duration were best in 20 ha ponds.

The effect of several feeding systems on shrimp productivity provided some statistical differences (Table 6). Survival was lower in sound feeder (57%), and the time feeder system gave a higher harvest (1 631 kg/ha) than manual feeding (1 539 kg/ha) and the sound feeder system (1 483 kg/ha). The other performance parameters did not present statistical differences.

Nevertheless, the sound feeder was not tried in all farms (only 5 of the 13 farms), and moreover the number of shrimps lots in three feeding systems was not equilibrated, 259 with manual feeder, 243 with time feeder and only 33 with sound feeder. Considering exclusively the five farms with three feeding systems at a more equilibrated number (115 with manual feeder, 121 with time feeder and 33 with sound feeder) the results of performance parameters did not present differences (Table 7). Growth, final weight, feed supplied, and FCR showed similar values, but the duration cycle was slightly lower in sound feeder, and survival and the yield in time feeder were somewhat better (62% and 1 614 kg/ha) than manual (57% and 1 440 kg/ha), as well as sound feeder (57% and 1 483 kg/ha), although results in several farms were different (Figure 1).

The cluster analysis (Figure 2) showed an expected grouping of performance parameters, survival with yield, final weight with days of cycle, DFS with FCR, and separately, the weekly growth.

Table 5 Shrimp productivity in regard to pond size in Guayas (Ecuador) farms

Size Pond (ha)	Nº	Survival (%)	Yield (kg/ha)	DFS (%/day)	FCR	FW (g)	Cycle (days)	Growth (g/week)
5 (2.5-7.5)	199	61.5 ^{a}	1 562 ^{a}	3.30 ^{b}	2.23 ^{c}	22.7 ^{a}	134 ^{b}	1.20 ^{b}
10 (7.6-12.5)	205	63.1 ^{a}	1 610 ^{a}	303 ^{b}	2.08 ^{b}	23.0 ^{a}	135 ^{b}	1.20 ^{b}
15 (12.6-17.5)	95	59.3 ^{a}	1 504 ^{a}	3.15 ^{ab}	2.10 ^{b}	22.5 ^{a}	132 ^{b}	1.21 ^{b}
20 (17.6-22.5)	36	63.1 ^{a}	1 638 ^{a}	2.97 ^{a}	1.90 ^{a}	22.8 ^{a}	125 ^{a}	1.28 ^{a}
Sig. Level	-	0.170 4	0.050 3	0.000 0	0.000 0	0.339 2	0.022 4	0.039 5

Note: Nº: Number of production cycles; DFS: Daily Feeding Supplied; FCR: Feed conversion ratio; FW: Final weight; Values in the same column with different superscripts are significantly different ($P < 0.05$)

Table 6 Shrimp productivity in regard to several feeding systems in Guayas (Ecuador) farms

Feeding System	Nº	Survival (%)	Yield (kg/ha)	DFS (%/day)	FCR	FW (g)	Cycle (days)	Growth (g/week)
Manual	259	61.7 ^{a}	1 539 ^{b}	3.15 ^{a}	2.14 ^{a}	22.9 ^{a}	134 ^{a}	1.21 ^{a}
Time feeder	243	62.9 ^{a}	1 631 ^{a}	3.15 ^{a}	2.12 ^{a}	22.8 ^{a}	133 ^{a}	121 ^{a}
Sound feeder	33	57.0 ^{b}	1 483 ^{b}	3.10 ^{a}	2.04 ^{a}	22.6 ^{a}	128 ^{a}	124 ^{a}
Sig. Level	-	0.008	0.006	0.910	0.327	0.839	0.135	0.550

Note: Nº: Number of production cycles; DFS: Daily Feeding Supplied; FCR: Feed conversion ratio; FW: Final weight; Values in the same column with different superscripts are significantly different ($P < 0.05$)

Table 7 Shrimp productivity in regard to feeding system considering the five farms with the three feeding systems in Guayas (Ecuador)

Feeding system	Nº	Survival (%)	Yield (kg/ha)	DFS (%/day)	FCR	FW (g)	Cycle (days)	Growth (g/week)
Manual	115	57.5 [a]	1440 [a]	3.21 [a]	2.19 [a]	22.9 [a]	135 [a]	1.21 [a]
Time feeder	121	62.4 [a]	1614 [a]	3.14 [a]	2.14 [a]	22.9 [a]	134 [a]	1.21 [a]
Sound feeder	33	57.0 [a]	1483 [a]	3.10 [a]	2.04 [a]	22.6 [a]	128 [a]	1.24 [a]
Sig Level	-	0.052	0.051	0.560	0.126	0.817	0.185	0.651

Note: Nº: Number of production cycles; DFS: Daily Feeding Supplied; FCR: Feed conversion ratio; FW: Final weight; Values in the same column with different superscripts are significantly different (*P* < 0.05)

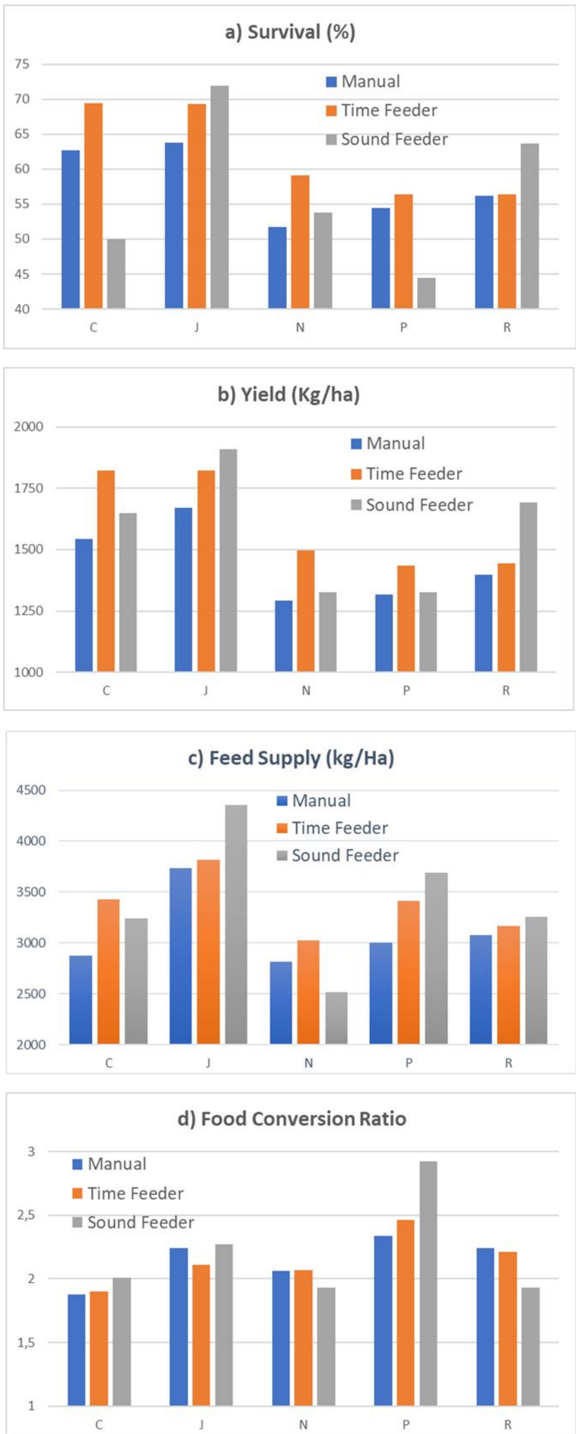

Figure 1 Survival, yield, feed supply and feed conversion ratio of shrimp in five companies with the three feeding systems in Guayas (Ecuador) farms

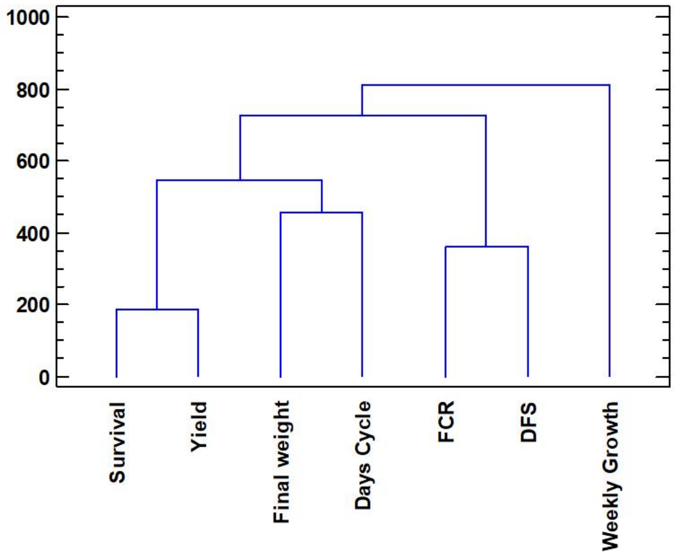

Figure 2 Cluster analysis of shrimp production in Guayas (Ecuador) farms

2 Discussion

The comparison of current results with data from the bibliography is difficult because most studies have been developed under experimental conditions in relatively small production units. Nevertheless, Ponce-Palafox et al. (2011) reported some technical parameters of semi-intensive farms on the east coast of Mexico, survival was similar (60%~65%) to results obtained in the current study but yield was lower (800~900 kg/ha) in Nayarit and Sinaloa States, although results were better (75% survival and 3 200 kg/ha) in Sonora State. Likewise, Sánchez-Zazueta et al. (2013) and González-Romero et al. (2018) reported some production parameters in semi-intensive commercial ponds of large sizes, of 1.8~3.4 ha and 1~7 ha respectively, which partially agree with the current study. The first authors obtained a weekly growth of around 1.12 g/w and the latter 1.35 g/w, very similar to the 1.20 g/w from the current study, whereas the FCR values were 1.6 and 1.35 respectively, clearly better than this current study, 2.04, from which it may be considered that growth result in the present study was acceptable, but FCR could be improved. Weekly growth was a more suitable parameter than final weight, because cycle duration varied (131~147 days) allowing for a similar final size (23~24 g) (Table 4).

The best shrimp performance was obtained on Escalante Island, where there was only a single farm, but it is not possible to explain the reason, because information about environmental parameters and production management is not available. There were no apparent differences in temperature and oxygen between the three areas, but it is possible other water parameters (salinity, pollutants, etc.) could have had some effect. Although the thirteen farms belonged to the same company it is possible that better management at the farm located on Escalante Island caused the better results.

In relation to the starting month of production cycle, the best results of survival and harvest obtained in May-October could be related to the moderate temperature during the period, 25 ºC~28 ºC, in comparison with higher temperatures in the rest of the cycles, 28 ºC~31 ºC (Figure 3). These good months are also the dry months; thus, a negative effect of rain time may exist. Shrimp yield considering the starting month presented, in general, a similar trend in three feeding systems, with a higher value in period from June to October (Figure 4). From a production management point of view, it is opportune to distribute the production throughout the year in order to have a continuous supply of commercial shrimp, as occurs in this study, the number of lots being very similar over the twelve months.

It is interesting to comment that survival and yield did not present differences, and FCR, shrimp growth and cycle duration improved in large ponds (20 ha), but there is no easy explanation, because production management may be more complex, mainly with the feeding.

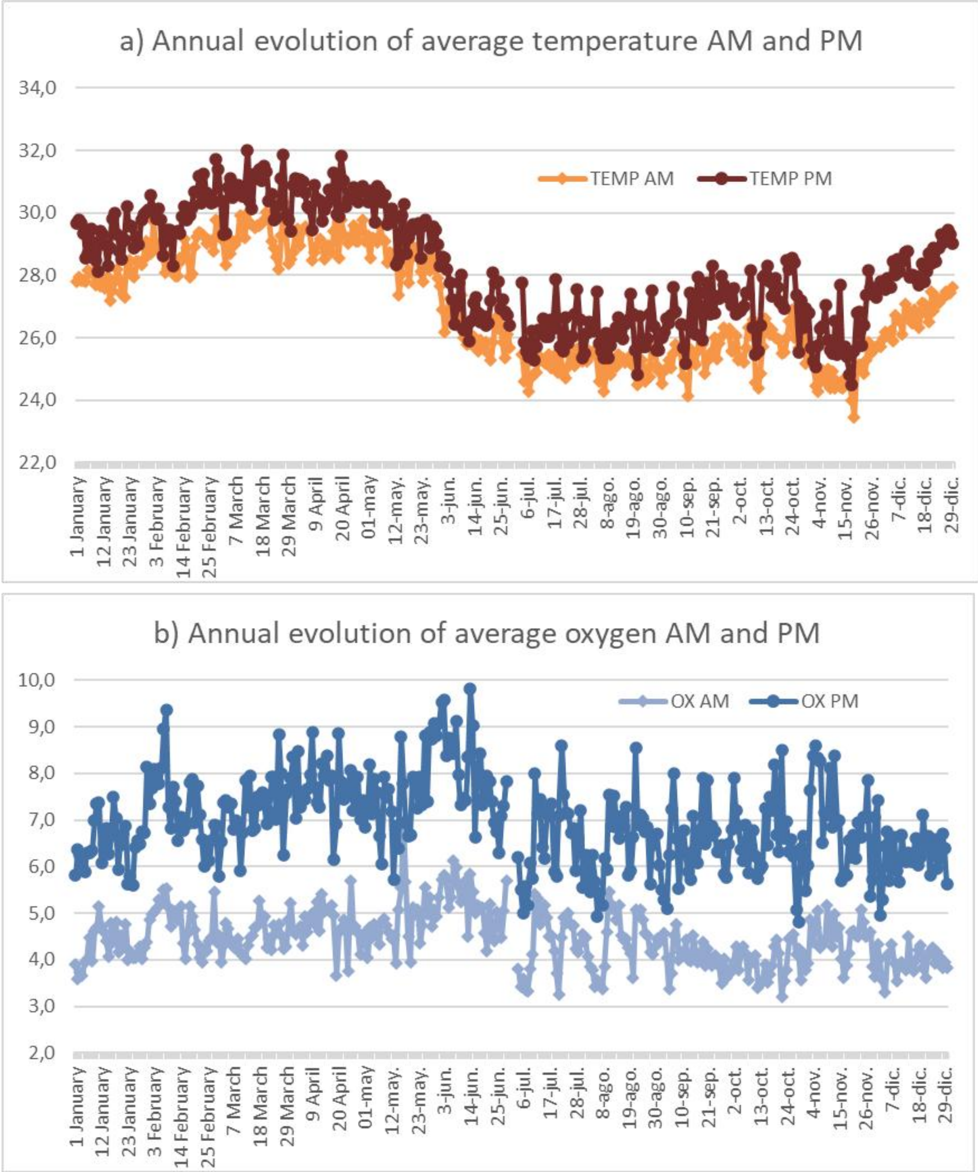

Figure 3 Annual evolution of average temperature (a) and dissolved oxygen (b) in Guayas (Ecuador) shrimp farms (AM and PM)

In turn, and from a nutritional point of view, the use of automatic feeder is favorable in shrimp production in that it distributes the feed continuously throughout the day and reduces labor costs, however, the results concerning optimal frequency with manual feeding are contradictory over several studies.

Smith et al. (2002) studied four feeding frequencies (3, 4, 5 and 6 meals/day) in black tiger shrimp (*Penaeus monodon*) using 25 00l tanks with sand bottom, and no differences appeared in growth, survival and FCR.

Carvalho and Nunes (2006) assayed five frequencies (2, 3, 4, 5 and 6 times/day from 07:00 to 17:00) in 20 m2 pond enclosures, but differences were not clear, because higher growth was obtained with 3 meals (only different with respect to 5 meals) but the best survival and FCR was with 5 meals. On the other hand, Nunes et al. (2006) studied the time restrictions at the same 5 frequencies in 500 l tanks, and 4 hours/day feed exposure were needed for optimizing growth (0.65 g/w).

Aalimahmoudi et al. (2016) also studied the effect of 2 meals (07:00 – 19:00), 4 meals (07:00 – 11:00 – 19:00 – 23:00) and 6 meals (07:00 – 10:00 – 13:00 – 17:00 – 20:00 – 23:00) in 350 l PE tanks, and they cited a better survival (90%), growth (0.87 g/w) and FCR (1.81) with 6 meals a day.

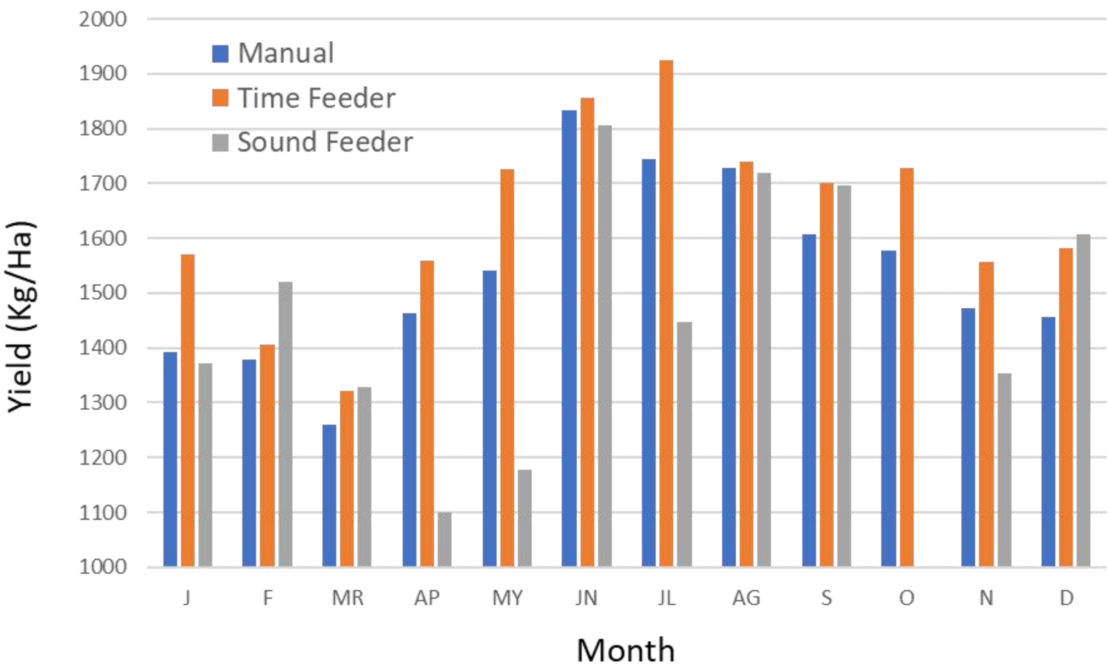

Figure 4 Shrimp yield in several months of cycle starting for the three feeding systems in Guayas (Ecuador) farms

It seems that optimal feeding strategy in an intensive system with clear water in tanks is different than in semi-intensive systems, in which it is possible to apply a lower frequency, probably because shrimp can feed to natural productivity, but in intensive systems with 1 ha lined polyethylene ponds, the use of feeders was more effective than manual feeding (Nepaumpaiporn et al., 2013). These authors reported a higher final weight (24.5 g) and better FCR (1.30) with sound feeder than manual with four meals (15.9 g and 1.55 respectively), whereas only FCR with the automatic time feeder was better than manual, and poorer than sound feeder. Results of the current trial were in agreement with data obtained by Napaumpaiporn et al. (2013) although these authors reported better growth (1.68 g/w in comparison with 1.25 g/w in the current study) and FCR, probably due to a higher control of feeding in smaller ponds (1 ha).

Likewise, Jescovitch et al. (2018) and Ullman et al. (2019b) have confirmed the higher effectiveness of sound feeder in comparison with manual feeding in two meals and time feeder in six meals, installed in 1 000 m2 ponds. The results obtained by these authors with sound feeder were extremely good, with growth of 2.24 and 2.41 g/w and FCR of 1.14 and 1.24, respectively, which were better than those obtained in the current study.

Recently, Reis et al. (2020) have reported the best results of productive parameters using sound feeders, although without differences with respect to a standard feeding protocol using a time feeder but incrementing ration with 60% feed. Reis et al. (2021) have confirmed the best results of sound feeder compared time feeder using a day-time, a night-time, and 24 h feeding.

Nevertheless, in the current study survival and yield results were lower in sound feeder system (Table 7) or without differences (Table 8; Table 9). On the contrary, when particular data of survival and yield of five companies with three feeding systems are considered (Figure 1), it is possible to observe that the best results were obtained with sound feeders in two of them (J and R), which probes that sound feeders can give good results with good management.

Table 8 Shrimp productivity in regard to feeding system considering the five farms with the three feeding systems in Guayas (Ecuador)

Feeding System	Nº	Survival (%)	Yield (kg/ha)	DFS (%/day)	FCR	FW (g)	Cycle (days)	Growth (g/week)
Manual	115	57.5 ^{a}	1440 ^{a}	3.21 ^{a}	2.19 ^{a}	22.9 ^{a}	135 ^{a}	1.21 ^{a}
Time feeder	121	62.4 ^{a}	1614 ^{a}	3.14 ^{a}	2.14 ^{a}	22.9 ^{a}	134 ^{a}	1.21 ^{a}
Sound feeder	33	57.0 ^{a}	1483 ^{a}	3.10 ^{a}	2.04 ^{a}	22.6 ^{a}	128 ^{a}	1.24 ^{a}
Sig Level		0.190	0.100	0.560	0.126	0.817	0.185	0.651

Note: Nº: Number of production cycles; DFS: Daily Feeding Supplied; FCR: Feed conversion ratio; FW: Final weight; Values in the same column with different superscripts are significantly different ($P < 0.05$)

Table 9 Shrimp productivity in regard to feeding system considering only the farm with similar number of baths using the three feeding systems in Guayas (Ecuador)

Feeding System	Nº	Survival (%)	Yield (kg/ha)	DFS (%/day)	FCR	FW (g)	Cycle (days)	Growth (g/week)
Manual	20	51.7 ^{a}	1290 ^{a}	3.34 ^{a}	2.06 ^{a}	22.2 ^{a}	126 ^{a}	1.32 ^{a}
Time feeder	21	59.1 ^{a}	1498 ^{a}	3.28 ^{a}	2.07 ^{a}	22.2 ^{a}	124 ^{a}	1.27 ^{a}
Sound feeder	19	53.8 ^{a}	1325 ^{a}	3.06 ^{a}	1.93 ^{a}	22.3 ^{a}	123 ^{a}	1.27 ^{a}
Sig Level		0.194	0.140	0.444	0.417	0.995	0.909	0.776

Note: Nº: Number of production cycles; DFS: Daily Feeding Supplied; FCR: Feed conversion ratio; FW: Final weight; Values in the same column with different superscripts are significantly different ($P < 0.05$)

The reason for the low results obtained in the current study with the acoustic technique could be related to the accessibility of shrimp to feeders, because the number of feeders was two per hectare in Nepaumpaiporn et al. (2013) and one per 1 000 m^2 pond (10 per hectare) in Jescovitch et al. (2018), Ullman et al. (2019b) and Reis et al. (2020, 2021), whereas in the current study only one sound feeder per three hectares was installed and although density was lower (10 shrimp/m2 in comparison with 7, 17, 38 and 26 shrimp/m^2 respectively), the differences were great. In this sense, Ching (2020) recommended one feeder per 2 000 kg shrimp, which means 5 feeders per hectare in the study by Nepaumpaiporn et al. (2013) for a final biomass of 10 000~11 500 kg/ha, 3 feeders per hectare in the study by Ullman et al. (2019b) for a final biomass of 6400-7500 kg/ha and 0.75 feeders per hectare in the current study for a final biomass of 1 662 kg/ha. As Reis et al. (2022) have reported, when the shrimp biomass exceeds the capacity of acoustic feeders, the growth and efficiency is reduced.

The feeders allowed for an increase in the number of daily meals and for the extension of the feeding time throughout the day, but the rations must be fixed by the farmer, except when a demand feeder is used, as shrimp can then regulate their feed intake. Jescovitch et al. (2018) and Ullman et al. (2019b) reported a higher feed input with the sound feeder than manual feeding (181% and 171% respectively), but feed input with the time feeder with respect to manual feeding was lower (112% and 118%, respectively), which could explain the high growth with an optimal FCR observed in sound feeding. In the study of Reis et al. (2020) the increment of 60% rations using a time feeder improved the yield, but it was lower than yield using sound feeder, due probably to feed input being higher with sound feeder, around 1 100 kg/ha more.

Nevertheless, results for feeding rate from several authors are contradictory, thus Venero et al. (2007) obtained lower growth in tanks using two diets (30 and 40% protein) with a ration reduction of 50 % (0.95 and 1.02 g/w) and 75% (1.11 and 1.19 g/w) with respect to 100% (1.22 and 1.37 g/w), but in 1000 m2 ponds differences were not significant in 75% ration (1.28 g/w) in comparison with 100% ration (1.38 g/w). Ration of 50% was not assayed. Carvajal-Valdes et al. (2012) obtained similar results of growth (0.73~0.78 g/w) and yield (1 280~1 350 kg/ha) with a ration reduction of 50%, although FCR was better with 50% ration (1.48) than 100% ration (2.71) in pond enclosures with a density of 15 shrimp/m2. Likewise, Roy et al. (2012) reported good results of growth (1.75~2.09 g/w) and FCR (0.59~0.83) in 600 l circular tanks (connected with a natural pond) with a reduction of 40% ration. Finally, Van et al. (2017) reported low performance with a 90% ration in outdoor tanks but not in ponds.

Table 10 Feed supplied (kg/ha) in regard to feeding system considering all farms, the five farms and only the five farms with three feeding systems in Guayas (Ecuador)

Feeding System	Nº	Feed all farms (kg/ha)	Nº	Feed five farms (kg/ha)	Nº	Feed one farm (kg/ha)
Manual	256	3 283 ^{a}	114	3 136 ^{ab}	20	2 915 ^{ab}
Time feeder	243	3 401 ^{a}	121	3 391 ^{a}	21	3 027 ^{a}
Sound feeder	33	2 990 ^{b}	33	2 990 ^{b}	19	2 518 ^{b}
Sig Level		0.011		0.011		0.009

Note: Values in the same column with different superscripts are significantly different ($P < 0.05$)

In the current study, no difference in daily feed supplied was obtained, probably due to the limited access of shrimp to feeders, particularly to the sound feeder, in fact the total kilograms of supplied diet per hectare (Table 10) in sound feeding system (2 990 kg/ha) was lower than in manual (3 283 kg/ha) and timer system (3 401 kg/ha), considering all farms and only the five farms with three feeding systems (2 990, 3 136 and 3 391 kg/ha respectively), and even in farm N (2 518, 2 915 and 3 027 kg/ha respectively), thus the advantage of demand feeding was missed.

Nevertheless, the results differ in several farms (Figure 1), because in Farm J, in which feed supplied was the highest, the survival and yield also were the best, but in Farm N feed supplied was the lowest, and performance indexes were lower. In Farm R, feed supplied was similar in all feeding systems, but sound feeder gave the best result of survival and yield. These data show that the optimum management of feed is fundamental for obtaining good results.

In fact, a significant regression was obtained for yield considering the feed supplied:

Yield = 370.1 + 0.364*Feed Supplied / Adj. R2 = 62% (Considering all farms)
Yield = 336.2 + 0.367*Feed Supplied / Adj. R2 = 72% (Considering five farms)
Yield = 370.3 + 0.364*Feed Supplied / Adj. R2 = 69% (Only farm N)

When other variables were considered in a multiple regression, the yield estimation was improved considerably, final weight and survival have a positive effect, but FCR have a negative effect:

Yield (kg/ha) = 1331.3 + 0.418*Feed Supplied + 1.641*Survival - 581.5*FCR / Adj. R2 = 96% (Considering all farms)
Yield (kg/ha) = 1286.7 + 0.429*Feed Supplied + 1.741*Survival – 570.3*FCR / Adj. R2 = 97% (Considering 5 farms)
Yield (kg/ha) = 1096.2 + 0.426*Feed Supplied + 3.177*Survival – 526.2*FCR / Adj. R2 = 97% (Only considering farm N)

Reis et al. (2021) did not obtain differences in feed input, final weight and yield using timer feeders during 12 hours in daytime, 12 hours in nighttime and 24 hours, but shrimp fed with acoustic feeders had a 26% higher feed intake, a 17% higher final weight, and a 30% higher yield, which shows that the effect of increasing feed intake origin an improvement in performance, but in the current study this effect did not occur.

The current results confirm the shrimp can regulate their feed intake, in quantity and time of day using feeding systems, because on the contrary, the results cannot be improved. Another question would be the possibility of night feeding, because most studies with feeders (Napaumpaiporn et al., 2013; Jescovitch et al., 2018; Ullman et al., 2019b) were carried out during a period from 07:00 to 19:00. Only Aalimahmoudi et al. (2016) fed shrimp at night by hand and obtained better results with 6 meals from 06:00 to 23:00. Nevertheless, Tacon et al. (2002) studied day (four meals 08:00-11:00-14:00-17:00) and night (four meals 20:00-23:00-02:00-05:00) and day-night feeding (eight meals 08:00-11:00- 14:00- 17:00- 20:00- 23:00- 02:00 – 05:00) feeding by hand in intensive outdoor 1500 l tanks with green water. Although results were very good, no differences in growth (1.95~2.16 g/w), survival (65%~79%) and FCR (1.58~2.01) were obtained. The feeding period in the current study was adequate, because the time feeder was working from 12:00 to 24:00, and the sound feeder during the whole day-night, although with the previously mentioned access limitation.

Another possible reason for lower productivity with sound feeders in the current study could be the lower oxygen concentration around feeders due to high shrimp concentrations, reducing feed use, because no artificial aeration was used. Ching (2020) recommends the installation of aerators in the feeding zone, and other authors (Nepaumpaiporn et al., 2013; Jescovitch et al., 2018; Ullman et al., 2019a, b; Reis et al., 2020) obtained good results using aerators in ponds (20-hp per hectare).

Obviously, the cost of feeders is a disadvantage (around U$D 1 000 for the time feeder and U$D 4 800 for the sound feeder), but reduction in feeding labor (around U$D 570/ha for both feeders) and mainly the increment in shrimp harvest value (around U$D 20 000 /ha) using the sound feeder, improve the profitability of shrimp production (Ullman et al., 2019a).

The topic of most interest in the current study was the evaluation of the effect of several feeding systems in real production conditions (the traditional by hand, the automatic, using time feeder, and sound demand feeders) but some problems in management have been identified, mainly in the sound system, the low number of sound feeders per hectare and the absence of aerators around the feeding area could result in low effectivity of feeders. Although shrimp companies try to improve feeding practices, in the current study the company had 256 batches fed by hand, 243 fed with time feeders and only 33 fed using sound feeders, it is important to optimize the management of new techniques to obtain good results. Recently, Darodes de Tailly et al. (2021) have proposed new techniques to improve passive acoustic in shrimp feeding, such as computer vision and telemetry.

3 Conclusion

Based on this study, authors conclude that acoustic feeding is a good alternative for improving growth, feed conversion and profitability of white shrimp in semi-intensive ponds, although some improvements would be required to obtain potential advantages. New data on sound feeding systems with aerators in the feeding area are necessary in order to estimate the optimal number of feeders per hectare or maximum amount of shrimp biomass can be fed. Likewise, the hourly registration of feeding supply of sound equipment throughout the day would be of great interest for studying the feeding behavior of shrimp in order to achieve its optimization under different production conditions at two seasons of year.

4 Material and Methods

4.1 Ponds

Data from 535 commercial lots from 13 different shrimp farms during the period 2015~2017 were used for the analysis. The farms were located in the Esclusas Area, Escalante Island and Puná Island (Guayaquil, Ecuador) (Figure 5). The specific location of farms is reserved information by the shrimp company.

The size of the ponds ranged between 3 and 23 hectares, with a depth of 1.2 m, which were fertilized with sodium nitrate (10 kg nitrogen per hectare) and inoculated with 250 kg probiotic mixture (1 kg Bacillus per ton of molasses) per hectare.

Exchange of water was around 1% a day. No aeration system was used.

4.2 Shrimp

L. vannamei initial density was around 10 shrimp per square meter. The initial weight of SPF shrimp was 0.04~0.29 grams, from five different maturation laboratories, which were stocked during each month of the year.

4.3 Feeding system

Three different feeding systems were utilized to feed shrimp: manual, time feeder and sound feeder (Table 11). Commercial diets (35% crude protein) were used and daily feeding rate was established subject to shrimp weight and temperature following the indications of the feed supplier for manual feeding and automatic feeding with time setting.

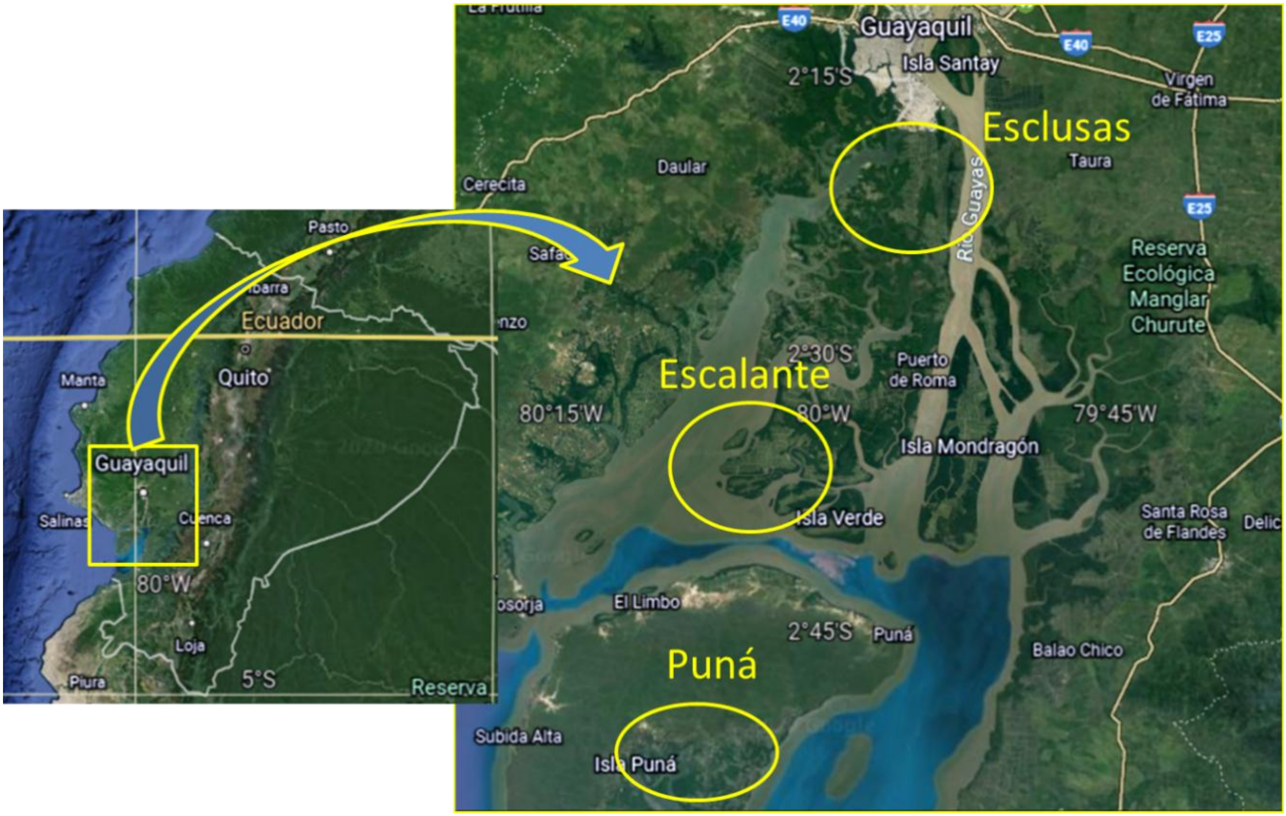

Figure 5 Location of shrimp farms in Guayas Area (Ecuador)

Table 11 Features of three feeding systems

Feature	Manual	Time feeder	Sound feeder
Feeding frequency	Twice a day, in the morning and in the afternoon	Every 5 to 15min, from 12.00 to 24.00 h	24 hours per day
Location	From a boat	Close to edges	Close to edges
Coverage	All pond	10 m diameter	12,5 m diameter
Number of feeders	0	1 per ha	1 per ha

The manual system consisted of distributing feed by hand twice a day from a boat, once in the morning and again in the afternoon.

The second feeding system involved using an automatic-solar-timed feeder (Maof Madan, Madan Technologies, Israel) with a rotating dispenser made up of two small conical tubes that delivers feed at a radius of 10 m. Feeder was located at 30 m from the edges of the pond at the rate of a feeding machine per hectare. Feed was distributed every 5min until shrimp reached 3g and then 10-15 min until harvest during 12 hours a day, from 12:00 to 24:00 (Table 11). Underwater viewfinders were used for estimating uneaten feed and adjusting ration.

The sound feeder system that integrates shrimp acoustic input through a hydrophone inside the pond and feeds based on acoustic response consists of one feeder (AQ1 SF200, AQ1 Systems Pty. Ltd., Tasmania, Australia). Each feeder has a rotating device with two short wide-mouth tubes that supply feed within a radius of 12.5 m and was placed for every three hectares, 30m away from the edge of the pond (Table 11). Feed was dispensed throughout the day.

4.4 Performance parameters

Several performance parameters were calculated to evaluate technical productivity in each pond; final survival, and total harvested weight, weekly growth, Daily Feeding Supplied (DFS) and FCR using the following expressions:

Survival (%) = 100*(Initial shrimp number – Final shrimp number) / Initial shrimp number
Weekly Growth (WG, g/w) = (Average final weight – Average initial weight) / weeks
Daily Feeding Supplied (DFS, %/d) = 100*Total feed supplied / (Average total biomass) / days
Feed Conversion Ratio (FCR) = Total feed supplied / (Total final biomass – Total initial biomass)

4.5 Statistical analysis

All performance parameters were analyzed by ANOVA using the statistical software package Statgraphics (Statistical Graphics System, Version Plus 5.1., Herndon, VA, USA). Comparison of means was made using the Student-Newman-Keuls test.

Authors' contributions

Conceptualization: Juan Carlos Valle, Miguel Jover-Cerdá; Methodology: Juan Carlos Valle, Miguel Jover-Cerdá; Formal analysis: Cesar Molina-Poveda, Miguel Jover-Cerdá; Investigation: Juan Carlos Valle; Writing - original draft preparation: Juan Carlos Valle, Miguel Jover-Cerdá; Writing - review and editing: Cesar Molina-Poveda, Miguel Jover-Cerdá; Supervision: Cesar Molina-Poveda, Miguel Jover-Cerdá. All authors read and approved the final manuscript.

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