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CULTURE OF DORADO SERIOLA LALANDI IN RECIRCULATING AQUACULTURE SYSTEMS LOW COST IN THE NORTH OF CHILE

Roberto Ávila
\`\`Centro de Investigación Aplicada del Mar S.A.\`\`, Iquique, Chile.
Doctorate in Aquaculture Cooperative Program of \`\`Universidad de Chile\`\`, \`\`Universidad Católica del Norte\`\` and \`\`Pontificia Universidad Católica de Valparaíso\`\`.
Program for the Attraction and Insertion of Advanced Human Capital of CONICYT.

Jorge Oliva
\`\`Centro de Investigación Aplicada del Mar S.A.\`\`, Avenida Arturo Prat 33, Iquique, Chile.

María Pizarro
\`\`Centro de Investigación Aplicada del Mar S.A.\`\`, Avenida Arturo Prat 33, Iquique, Chile.

Carlos Merino
\`\`Centro de Investigación Aplicada del Mar S.A.\`\`, Avenida Arturo Prat 33, Iquique, Chile.

Cristián Araneda
Department of Animal Production, Faculty of Sciences Agronómicas, Universidad de Chile. La Pintana, Chile.

Arnaldo Vilaxa
Faculty of Sciences, Department of Biology, Center for Marine and Limnological Studies. Universidad de Tarapacá. Arica, Chile.

Abstract: Chile is considered worldwide as an aquaculture country. However, around 79% of its annual production is linked to salmon farming (FAO, 2018). The Program for the Diversification of Chilean Aquaculture (PDACH) seeks to contribute to the aquaculture and commercialization of marine fish with high export potential. The PDACH identifies in Seriola lalandi a resource with aquaculture potential for the northern zone of Chile. Several investigations have been developed around the resource, however, there are still important challenges and gaps to address (ie technologies for fattening and their associated production costs). With the exception of Orellana el al. (2014), current knowledge, It has focused mainly on conditioning broodstock and obtaining larvae and juveniles with little development of technologies for the fattening phase. The purpose of this research was to obtain a transferable technological solution that would optimize culture parameters for fattening Seriola lalandi in low-cost recirculating aquaculture systems (SAR) whose associated production price was lower than the sale price (7.0 USD kg). The Pilot Fattening Unit (UPE) was designed and built with low-cost SAR technology. Two pilot crops were carried out between April 2014 and December 2016 (in total 960 days of cultivation) to evaluate the proposed system. The productive costs associated with the technology developed were 8.48 USD kg; However, the results obtained allowed us to make an economic projection whose production costs decreased to 5.28 USD kg based on the reduction of feed and juvenile items.

Keywords: Yellowtail Kingfish, SAR, growth

INTRODUCTION

Aquaculture is one of the main economic activities in Chile. Being thesalmonthe main farmed aquatic species. The National Council of Innovation for Competitiveness (CNIC) through the program for the diversification of Chilean aquaculture (PDACH) seeks the production of non-salmonid fish, with high export potential. The PDACH identified the golden marine fish Seriola lalandi Cuvier & Valenciennes, 1833 as a resource with aquaculture potential for the northern zone of Chile, including Arica.

Important investigations have been developed around S. lalandi (Bowyer et al., 2014; Orellana et al., 2014). However, the existing biography is meager for fattening technologies and associated production costs in this species. The objective of this research was to obtain a low-cost technological solution that would optimize culture parameters for fattening of S. lalandi in northern Chile, whose associated production value was less than 7.0 USD kg.

MATERIALS AND METHODS

The investigation demanded the location of a Pilot Fattening Unit (UPE) on land, in the city of Arica, XV region; Latitude 18°28'2"S, Longitude 70°17'52"W.

DESIGN OF LOW-COST RECIRCULATING AQUACULTURE SYSTEM (SAR).

UPE was designed and built, consisting of 6 Australian-type culture ponds with a diameter of 9 m and a volume of 90 m3 each. Each culture pond had a treatment unit with low-cost SAR technology for culture water.

The SARs were made up of a 500 L expansion pond (Bioplastic), which receives the effluent from the culture pond by gravity. From the expansion tank, by means of a 2 hp triphasic pump (Silent, Spain), the flow is directed towards the 50 u gravimetric filter (Emaux Tecnology) to end in the 5 m3 biological filter. By gravity, the water flow returns to the culture pond from the biofilter (Fig. 1).

SERIOLA LALANDI PILOT CULTURE

Two pilot cultures of Seriola lalandi were carried out in UPE facilities. The cultivation activities were carried out between April 2014 and December 2016.

STOCKINGS OF S. LALANDI JUVENILES IN UPE

The supply of S. lalandi juveniles for the pilot cultures carried out considered the purchase and transfer of live specimens from two sources: i) Tongoy (supplier Fundación Chile, Coquimbo region; travel distance 1,623 km, transfer time 36 hours); ii) Antofagasta (supplier Universidad de Antofagasta, Antofagasta region, travel distance 718 km, travel time 15 hours). On April 27, 2014, 4,819 juveniles of 17.4 ± 2.1 g, from Tongoy (group of test fish identified asAric-1); Subsequently, on November 17, 2015, 201 fish of 204.0 ± 17.4 g, coming from Antofagasta, entered the facilities (group of test fish identified as Aric-2).

PILOT CULTURE OF SERIOLA LALANDI IN UPE

During the pilot culture period, dissolved oxygen (DO), temperature and pH were measured in the culture water using a YSI Pro-20 equipment. TAN (Total Ammonium as Nitrogen) was determined by the Nessler method using a multi-parameter Hanna HI 83203- Aquaculture photometer.

The growth of the specimens was evaluated through the specific growth rate (SGR, for its acronym in English, Specif Growth Rates) expressed in percentage day (% d-1), as described by Brown et al. (2011):

$$SGR = \frac{[ln\,(W_f) - ln(W_i)]}{t} x100$$

Where: Wf is the final weight (g); Wi is the initial weight (g); t is the time in days (d).

The Feed Conversion Factor (FCR) was calculated based on the ratio of food consumed and weight gain as proposed by Zapata & Espejo (2008), Brown et al. (2011).

$$FCR = \frac{AL}{GP}$$

Where: AL is the food consumed (kg) and GP is the weight gain (Wf – Wi) in kg.

The daily percentage mortality (% d-1) was determined based on the daily mortality recorded with respect to the initial number of fish.

EVALUATION AND ECONOMIC PROJECTION

The production parameters obtained were used for the economic evaluation of the SAR, based on technical and market aspects, a Private Project Evaluation was carried out according to the methodology proposed by Nassir Sapag. Based on these antecedents, variables such as growth curve, feed consumption, electricity, investment in equipment and others reviewed in detail were analyzed. Sales values of Seriola lalandi and the economic viability of the project were evaluated in a base study that considered a plant with an annual production of 300 tons (scenario 1).

STATISTICAL ANALYSIS

The normality of the variables SGR, weight gain, FCR, temperature, daily mortality was corroborated with the Shapiro-Wilks test. The linear association between the variables was estimated with the Pearson (r) or Sperman (rS) correlation coefficient, depending on whether or not they presented a normal distribution. The comparison between SGR, weight gain, FCR and daily mortality were compared by means of a t test, after corroborating the homogeneity of variance with a Fligner-Killen test.

RESULTS

The evaluation of the pilot culture of Seriola lalandi began with the arrival of the juveniles at the UPE in Arica. Aric-1 recorded the following data during the transfer: fluctuating temperature from 14 to 17°C, dissolved oxygen (DO) in the range of 10 to 15 mgL-1. Survival percentage 75%. Initially, the fish were stocked in a 90 m3 pond provided with 3 nest cages of 3 m in diameter (Fig. 2). With this activity begins the pilot culture of the species Seriola lalandi in Arica (day 1 of culture in the UPE). Subsequently, on November 17, 2015, the Aric-2 juveniles entered the UPE, transfer water temperature in a range of 16.4 to 19.9°C. Dissolved oxygen in a range of 7.4 to 9.9 mgL-1, transport survival 100%.

OPERATION OF THE LOW-COST SAR RECIRCULATING AQUACULTURE SYSTEM

The average cultivation temperature recorded in the proposed system was 21.1 ± 2.2 °C, with oscillation (maximum and minimum) in the warm to cold months from 28.1 to 15.3 °C, showing a behavior dependent on the climatic seasons (Fig. 3A). The dissolved oxygen (DO) concentration shows a stable behavior, with a mean value of 6.3 ± 0.8 mgL-1, with a maximum of 12.7 and a minimum of 2.9 mgL-1 (Fig. 3B). The variability observed for the DO is linked to environmental conditions, both temperature and load capacity of the system, the corrective actions carried out were carried out through the incorporation of oxygen (remediation activities), which allowed a stabilization of the DO concentration in the system.

The TAN (Total Ammonium as Nitrogen) average of the experimental culture period was 2.1 ± 2.4 mgL-1 registering a maximum of 8.6 mgL-1 and a minimum of 0.2 mgL-1, the maximum of concentration are related to the handling of the SAR. However, the TAN ranged between 0.5 and 1.5 mgL-1 until day 459 of culture (Fig. 3C). Subsequently, it stabilized within a range of 0.5 to 1.0 mgL-1.

The pH (Fig. 3D) presented an average value of 8.4 ± 0.3. With a maximum of 9.7 and a minimum of 7.3.

SERIOLA LALANDI PILOT CULTURE

The growth curves of Aric-1 and Aric-2 are presented in Fig. 4. The fish from Aric-1 (n= 4819) were cultured from 17.4 ± 2.1 g to 2510.7 ± 532.0 g in 960 days of fattening. The Aric-2 fish (n= 201) were cultured from 204.0 ± 17.4 g to 3409.0 ± 410.0 g in 390 days of fattening (Table 1). The relationship between SGR and temperature (Fig. 5) was positive (R2 0.88) for the Aric-2 fish. However, for Aric-1 no correlation was detected between SGR and temperature.

Feed conversion (FCR) was high for Aric-1(4,5); todue to the high mortality that affects the calculation of the FCR. This high mortality is due to events related to the testing stage of the proposed farming system (adjustment period and white march).). For Aric-2, an FCR of 1.9 was obtained (Table 1).

The percentage mortality was 3.2 and 0.3 %d-1 for Aric-1 and Aric-2 respectively (Table 1). The causes of mortality for Aric-1 (Table 2) are mainly related to: (i) predation by birds at the beginning of the study (44% of total mortality), (ii) errors in the operation of the SAR learning stage and induction (the staff did not have previous experience in aquaculture), and finally (iii) presence of green liver disease, which was reversed from day 538 of culture with changes to the diet offered. The causes of mortality in Aric-2 are associated with the presence of Zeuxapta seriolae and Benedenia seriolae. Monogeneous ectoparasites in Seriola lalandi that affect gills and skin, respectively, causing massive mortalities in the organisms.

In relation to growth (Table 1) the productive parameters of both culture groups, Aric-1 and Aric-2, are presented for a culture period of 960 and 390 days respectively. Aric-2 is selected to apply an economic evaluation because it corresponds to the period in which the management of the system stabilizes.

ECONOMIC EVALUATION

PRODUCTION COSTS

The value of the basic production module developed (culture ponds plus SAR recirculation system) is USD 16,667 (Fig. 2). Comparisons made indicate that the cubic meter of recirculated water in the proposed solution is USD 185 m-3 versus USD 900 to 1,200 m-3 for solutions available on the market (values obtained from the quote made by the supplier).

Two cost scenarios were evaluated. Scenario 1 that corresponded to the data obtained through the productive evaluation of the technological solution obtained, from which through a sensitivity analysis using the Crystal Ball program of the factors “sale price” and “food cost”, an optimized scenario is projected. through the development of technological solutions for food and juvenile items (Scenario 2) (Table 3).

DISCUSSION

The Pilot Fattening Unit (UPE) was designed and operated in order to generate technological information for the commercial scaling of Seriola lalandi in Northern Chile.

The UPE reuses crop water with 15% renewal with a low-cost technology, in contrast to what was proposed by Orellana et al. (2014), which uses a high-tech system and a low renewal rate (1%).

The bio-transformation of TAN to nitrite and then to nitrate, action carried out in the biofilter, was satisfactory since it stabilized in an average concentration range between 0.5 to 1.0mgL-1, similar to that established by Orellana et al. (2014) for the same species.

In a first stage of the experimental culture (day 1 to day 459) the average range oscillated between 0.5 to 1.5mgL-1. This is considered high when compared to 1.0 mgL-1 as a sizing limit (Merino, 2009).

The pH remained in a stable range of 8.0 to 8.5 during the 960 days of operation, which favors nitrifying bacteria, since they are sensitive to acidic environments (Merino, 2009). It must be noted that, for the maintenance of a basic pH, no chemical solution of the basic type was added to the SAR as a pH regulator. However, since ammonium (TAN) is found in two forms: ionized and non-ionized, the latter being the most toxic (Merino, 2009); the relative concentration of both forms is a function of pH, temperature and salinity (Ebeling et al. 2006; Reddy-Lopata et al. 2006). Specifically, non-ionized ammonium concentrations increased with pH and temperature; and decreases with higher salinity (Huchette et al. 2003).

The growth of farmed fish is directly affected by temperature (Abbink et al. 2011). In this work it was found that there is a positive relationship between temperature and SGR only in the Aric-2 planting. This can be attributed to the initial implementation of SAR, which coincides with: (i) higher concentration of TAN in the culture, and its consequent depression in fish growth (Guillen et al. 1993, Tomasso 1993, Wajsbrot et al. 1993), (ii) planting from May with a drop in temperature, but whose low SGR does not recover when the spring-summer period arrives, and finally (iii) quality of the juveniles. The SGR only increased, in Aric-1, from the change of food (incorporation of 5% Taurine) (Bowyer et al. 2013), which improved the symptoms of green liver, decreasing mortality, from day 264 of culture. Instead, the Aric-2 fish were stocked on the rising temperature curve.

At a temperature of 23°C, the fish reach their highest growth rate of 1.58 %d-1 (observed in Aric-2), antecedents consistent with what has been established by other authors (Bowyer et al. 2014), D'Antignana & Bubner 2012, Pirozzi & Booth 2009). Contrary to what was established by Abbink et al. (2011)for the temperature of maximum growth (26.5°C), it was found that at a higher temperature (24.7°C) the SGR decreases to 1.53 % d-1 and does not recover when the temperature drops again to 23°C.

The cultivation time to reach harvest weight is considered key to achieving the economic viability of commercial scaling. This work projects a final harvest weight of 3.5 kg, in 13 months of cultivation, with an initial weight of 0.2 kg in a fattening center with low-cost SAR technology, a result similar to that proposed by Kolkovski (2005).

The feed conversion (FCR), associated with the item with the highest incidence in the production cost of S. lalandi, is 1.9 for Aric-2, considered high for commercial scaling. It is projected to lower the FCR, through the local production of specific species feed that favors conversion.

The culture density used is low with respect to what was proposed by Orellana et al. (2014), a parameter that mainly affects the initial investment in a commercial scale-up.

ECONOMIC SCENARIOS

The baseline scenario yields a production cost (does not include marketing costs) of 8.48 USD kg compared to the 8.24 USD kg indicated by Orellana et al. 2014. The items with the greatest impact were food (52.9%) and juveniles (19.7%). In order to propose an optimized scenario, we worked on these items in a common point, which is the savings in freight if both items are produced in Arica (both inputs are transported between 718 and 3066 km). The use of regional raw materials also contributes to lower feed costs, formulating a specific species feed that favors the increase of SGR and FCR. By producing juveniles in Arica, freight is saved. In this scenario, the production cost per kilo projected is €4.46 kg. Orellana et al. (2014) projects a better scenario, at a cost of €5.69 kg.

In conclusion, the results of this work indicate that the pilot production cost of Seriola lalandi with the technology developed is USD 8.48 kg. However, the results allow an economic projection whose production cost decreases to USD 5.28 kg based on the reduction of food and juvenile items, proposing that the production of both items be carried out in the northern zone of Chile.

The value of the basic production module of the developed technology (culture ponds plus SAR treatment unit) is notoriously cheaper than a recirculation system available on the market (70% less).

However, and in the opinion of the authors, for a decision to commercially scale up the species with the proposed technology, a study of food production and juveniles locally is necessary, as well as market tests.

THANKS

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Aric-1 Date	Crop days	Average weight (g)	SGR (%d-1)	crop density (kg m-3)	Mortality (%d-1)	RCF
27-Apr-14	1	17.41 ±2.90		0.9		
27-May-14	31	19.90± 6.90	0.4	1.1	0.1	1,3
27-Jun-14	62	27.40 ±6.10	1.0	1.4	0.1	1.5
29-Jul-14	94	41.10±9.60	1,3	2.0	0.1	1,3
30-Aug-14	126	59.80± 14.10	1,2	2.9	0.3	0.6
23-Sep-14	150	61.60 ±13.20	0.1	2.7	1.5	-25.3
24-Oct-14	181	70.60 ±13.80	0.3	1.9	0.2	-2.1
25-Nov-14	213	99.80 ±31.50	1.1	2.4	0.2	1.5
31-Dec-14	249	162.10 ±70.70	1,3	3.7	0.5	0.6
2-Feb-15	282	190.70 ±62.70	0.5	3.4	0.2	55.6
30-Mar-15	338	261.10 ±110.00	0.6	4.3	0.2	1,2
06-May-15	375	279.30 ±101.00	0.2	4.1	0.2	0.7
24-Jun-15	424	318.40 ±112.50	0.3	2.9	0.5	-0.6
16-Oct-15	538	421.90 ±163.80	0.2	2.5	0.2	1,2
28-Dec-15	611	673.50 ±320.40	0.6	2.5	0.3	0.5
26-jan-16	640	775.80 ±401.00	0.5	2.0	0.1	1.6
12-Feb-16	657	850.00 ±462.00	0.5	2.1	0.1	4.0
24-Mar-16	698	951.20 ±561.40	0.3	23	0.3	0.7
02-May-16	737	1417.20 ±569.90	1.0	3.0	0.2	0.6
08-Aug-16	835	1847.10±601.00	0.3	3.6	0.1	0.4
11-Dec-16	960	2510.70 ±532.00	0.2	4.5	0.0	1.0

Total			0.50		3.2	4.5

Aric-2 Date	Crop days	Average weight (g)	SGR (%d-1)	crop density (kg m-3)	Mortality (%d-1)	RCF
17-Nov-15	1	204.00 ±17.4		0.5		
28-Dec-15	42	343.00 ± 20.90	1,3	0.8	0.1	1,3
25-jan-16	70	534.00 ±21.80	1.6	1,2	0.3	1,2
16-Feb-16	92	750.00±23.60	1.5	1.5	0.3	1.4
24-Mar-16	129	1122.00 ± 266.80	1.1	2.1	0.2	1.7
02-May-16	168	1567.0 0 ±386.90	0.9	2.7	0.7	0.7
08-Aug-16	266	2360.20 ±418.90	0.4	2.8	0.1	0.6
11-Dec-16	391	3409.00 ±410.00	1,3	3.7	0.1	1.8
Total			0.7		0.3	1.9

d = days

g = grams

SGR = percentage daily growth rate

FCR = feed conversion ratio

Table 1 Comparison of productive parameters

Day of occurrence of the event	Mortality (% daily)	attributable cause
101	0.70	SAR operation setting
175	9.81	bird predation
249	0.80	bird predation
342	6.73	SAR operation error
424	0.89	bird predation
From 264 to 538	0.15 to 0.58	Sustained increase in daily mortality due to green liver disease

Table 2. Cause attributable to mortality Aric-1 experience

	Scenario 1		scenario 2	
Item	%	USD/kg	%	USD/kg
Food	52.9	4.48	47.3	2.5
youth	19.7	1.67	8.9	0.47
Electric power	11.8	1.00	19.0	1.00
variable staff	5.7	0.48	9.1	0.48
Thermal energy	2.4	0.20	3.8	0.20
Oxygen	2.2	0.19	3.1	0.17
health services	0.5	0.04	0.8	0.04
Subtotal	95.2	8.06	92.0	4.86
Permanent Staff	4.8	0.42	8.0	0.42
Kilo Production Costs	**100.0**	**8.48**	**100.0**	**5.28**

Table 3. Cost of production per kilo of fish

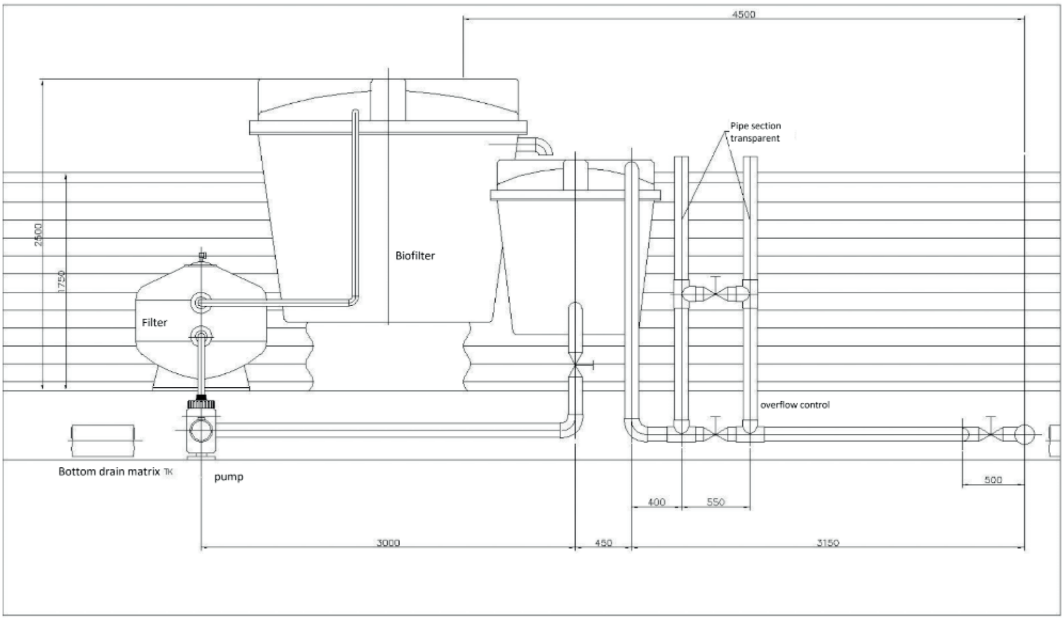

Figure 1: General design of the low-cost SAR recirculating aquaculture system

Figure 2. Culture pond with low-cost recirculation system (SAR) for Seriola lalandi provided with nest cages for stocking juveniles.

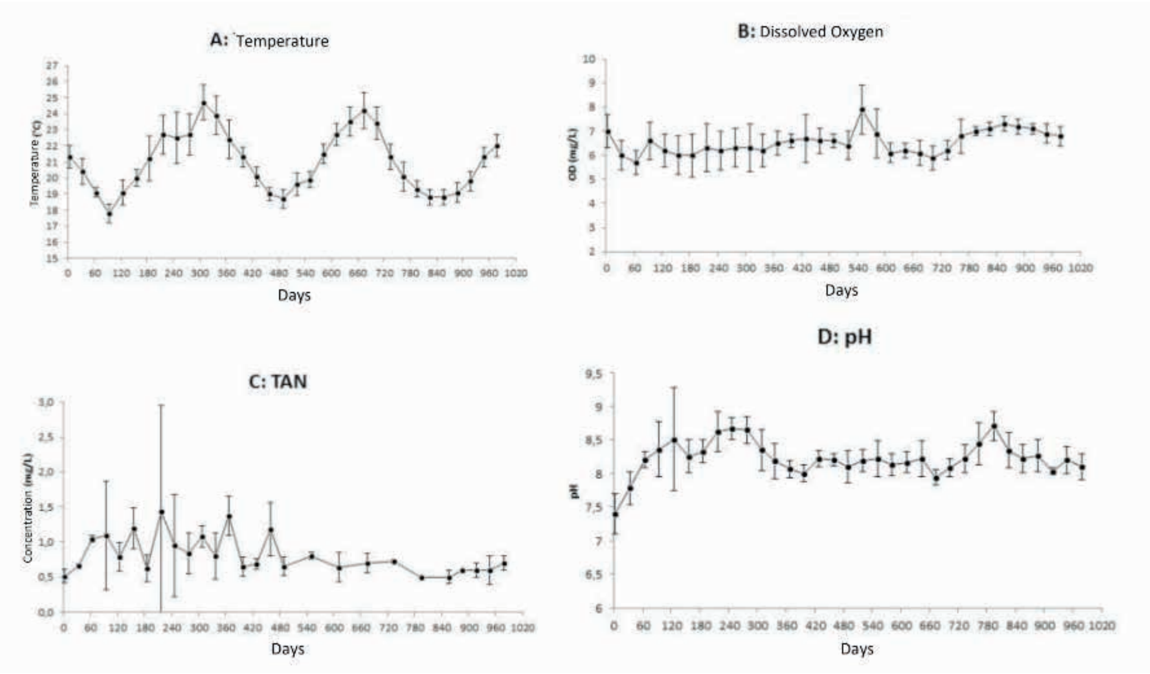

Figure 3. Variation of parameters: A) temperature (°C); B) dissolved oxygen (mgL-1); C) TAN (mgL-1) and D) pH in the culture system of Seriola lalandi. Mean and standard deviation.

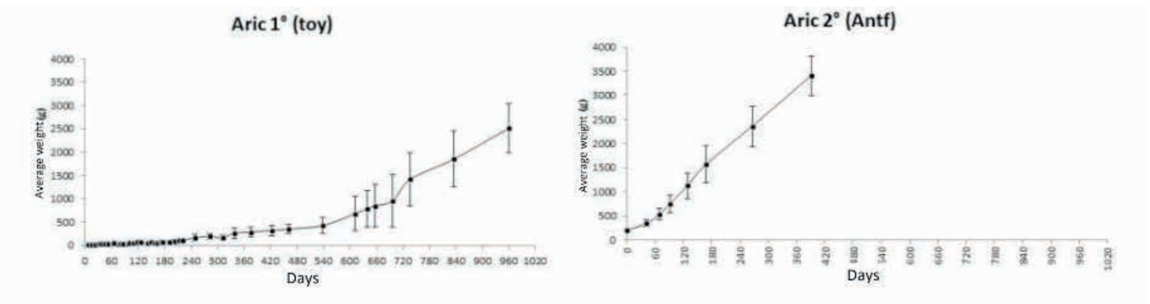

Figure 4: Mean weight (g) and standard deviation of Aric-1 and Aric-2 at 960 and 390 culture days, respectively.

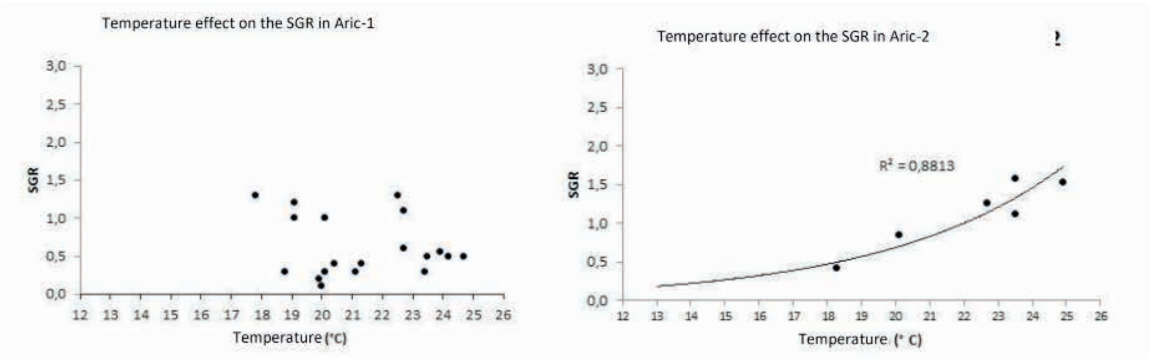

Figure 5. Effect of temperature on SGR.