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Research Article

Culture of cobia *Rachycentron canadum* in a recirculation aquaculture system in northern Chile

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ABSTRACT. An innovative aquaculture project involving the thermal seawater effluent of a thermoelectric power plant and a recirculating aquaculture system (RAS) was implemented in the Atacama Desert, the driest in the world located in northern Chile to produce the warm water pelagic fish cobia (*Rachycentron canadum* Linnaeus, 1766). An experimental land-based fish farm was built consisting of nine independent RAS provided with adequate temperature (28°C) and salinity (32) for cobia growth and overall aquaculture performance. Under these conditions, cobia was raised from egg to an average weight of 4 ± 0.4 kg in 12 months. Growth rates were similarly high for all the batches, and mortalities from weaning up to harvest sizes never exceeded 6%. Besides, no antibiotics were ever used, and no infectious diseases ever detected during the four years experimental phase reported herein. The batches of eggs arrived in Chile in 2012 and 2014. After three years, 12 t of cobia were consistently produced per every eight months' cycle. During this period, successful reproduction and routine volitional spawning of broodstock were achieved, producing offspring from F1 and F2 generations. The biological potential and economic feasibility of the RAS concept for raising cobia in temperate, desert regions was demonstrated and is described. Farm management, multi-trophic aquaculture, animal welfare, proactive health management, zero water effluent discharge, and total recycling of wastes are also discussed as a means of expanding the concept into a commercial phase.

Keywords: *Rachycentron canadum*; cobia; culture; closed system; industry; northern Chile

INTRODUCTION

Cobia is a pelagic fish and the only representative species of the family Rachycentridae (*Rachycentron canadum* Linnaeus, 1766). This warm water fish is found worldwide in temperate coastal and continental shelf waters, except for the eastern and central Pacific regions (Briggs, 1960; Shaffer & Nakamura, 1987). *R. canadum* is known in the USA as cobia but also bears different vernacular names such as ling, sergeant fish, black salmon, lemon fish, bonito, lingcod, among others. In different regions of the world it is named as bonito negro (Argentina); black kingfish (Australia); bijupirá or ceixupirá (Brazil); cobia (Chile and China); bacalao or medregal (Colombia and Cuba); mafou (France); black kingfish (India); sugi (Japan); kobievye or serzhant-ryby (Russia) (Shaffer & Nakamura, 1987). Water temperature seems to be the primary factor in determining the range of distribution of cobia, as the specimens caught for research purposes were gathered mainly in waters with temperatures ranging between 16 to 32°C, but they seem to prefer tempe-ratures above 20°C (Kaiser & Holt, 2005). During the cold months of the year throughout their range, cobia either migrate to warmer waters in a north-south pattern or move further offshore to deeper waters (Shaffer & Nakamura, 1987). In terms of salinity, and based on where the specimens were captured, the species tolerate salinities from 22 to

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44, however in culture conditions some individuals have been exposed down to 5 with no evident problem (Kaiser & Holt, 2005).

Cobia is not abundant in their natural habitat, and they do not show a shoaling behavior; therefore, they are not fished commercially at a large scale. Cobia considered a delicious table fare, is a prized catch and trophy for both commercial and recreational fishers, mainly in the Caribbean Sea, which accounts for most of the reported landings in USA waters (Kaiser & Holt, 2005).

The three main characteristics that made cobia an interesting farming fish are its rapid growth rate, the excellent flesh quality and the limited availability from the wild. These features have stimulated its production through aquaculture procedures, particularly in the Caribbean Sea, USA and Asia regions (Holt *et al.*, 2007; Benetti *et al.*, 2008a; 2010a,b) reaching a significant worldwide production that top around 40,000 t (FAO, 2015).

The aquaculture industry is well developed in Chile, with salmon and rainbow trout *Oncorhynchus mykiss* being the main species cultured in the cold seawaters of the country's southern region. However, further efforts have been directed toward innovating with farming technology for other fish species like congrio colorado *Genypterus chilensis* and palometa *Seriola lalandi*. Chile, as an extended country with more than 5,000 km of coastline, offers many different scenarios for aquaculture, from the glaciers and fjords in the extreme south to a temperate coastal shoreline in the driest desert in the world in the northern part of the country. However, aquaculture has been traditionally developed in coastal marine concessions, mainly in the country's southern regions (Katz, 2006; Katz *et al.*, 2011; Iizuka & Katz, 2012). Therefore, innovations in the north region that could take advantage of the coastal desert climate are necessary to explore.

Recirculation aquaculture systems (RAS) have been successfully developed in Chile, allowing better control of the environment and fish production by reducing risks compared to flow through and cage systems (Nieto *et al.*, 2010). The temperate coastal climate of the north of Chile allows the implementation of a RAS for a warm water fish using the effluents from thermoelectric power plants. Cobia is a non-native species to Chile, requiring that a RAS had to be developed and built for their experimental culture. In the north of the country, Mejillones area, there is a high concentration of thermoelectric power plants that discharge warm seawater to the ocean, leading to the design and construction of the RAS in the region.

Here we report a unique and innovative system for culturing cobia that takes advantage of the RAS coupled with the seawater used to cool the boilers from a thermoelectric plant (E-CL, Engie Group). The cooling water, pumped from the seashore, gains temperature and becomes suitable for aquaculture purposes. The experimental land-based fish farm consists of nine independent RAS array that allows experimenting with different temperatures and salineties in order to establish the best culture conditions for cobia in northern Chile, as it was requested by the Chilean regulatory agency (SUBPESCA: Undersecretary of Fisheries and Aquaculture, Ministry of Economy). It was possible to close the full cycle of cobia in this experimental farm, from eggs to larvae and juveniles to adults, with subsequent reproduction success and routine volitional spawning producing F1 and F2 offspring generations.

MATERIALS AND METHODS

Study area

Mejillones south bay (23°06'S, 70°27'W) (Fig. 1), described as one of the most important geographical features of the Chilean coast, giving rise to the upwelling system of Punta Angamos, the most productive upwelling system of northern Chile (Escribano, 1998; Sobarzo & Figueroa, 2001). The area contains a significant number of thermoelectric generation plants that utilize seawater for their normal function. One important use of the seawater is to cool the boilers of the plants. After the cooling process, the warm water is discharged directly into the ocean without further use of its thermic properties. In this project, we innovate in the use of this warm-water to culture a temperate-water fish, cobia *Rachycentron canadum*.

Farm design and layout of tanks

The farm consisted of nine independent RAS. Each one consisted of four tanks. One 8 m³ as a biofilter and CO_2 stripper tank, two 8 m³ tanks on the ground level to hold the fish, and one 8 m³ underground tank used as a mechanical filter (Fig. 2).

This distribution allowed for the minimum electricity demand for pumping purposes. Water was exchanged twice hourly per fish tank, with 99% of recirculation. The main idea supporting the design and distribution of the nine units was to have a 3×3 array that allowed an experimental design of combinations of three different temperatures and three different salinities, according to what the SUBPESCA requested (Fig. 3). During the first stage to test the performance of cobia under different combinations of temperature and salinity, three sources of water were used: desalinated cold water, normal cold seawater and warm seawater from the thermoelectric plant.

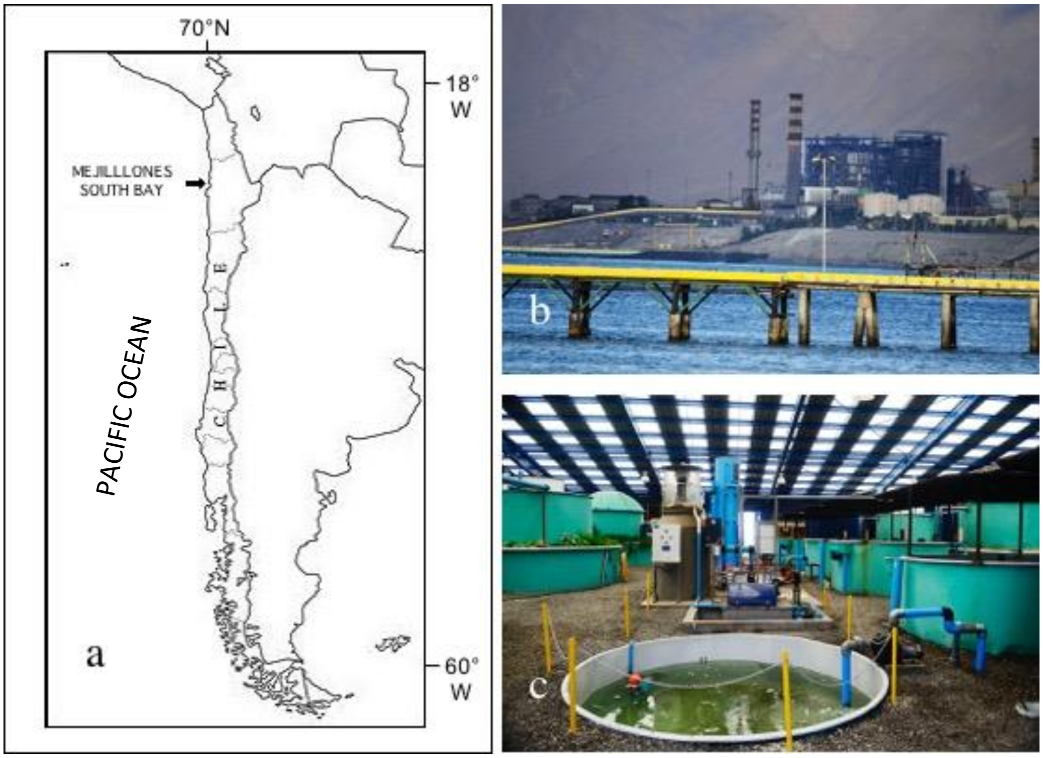

Figure 1. Localization of cobia *Rachycentron canadum* culture system. a) Map of Chile indicating the localization of Mejillones South Bay where cobia culture system is situated, b) view of Mejillones Bay where the experimental RAS is located, c) view of the indoor culture system showing the recirculation tanks and pipes.

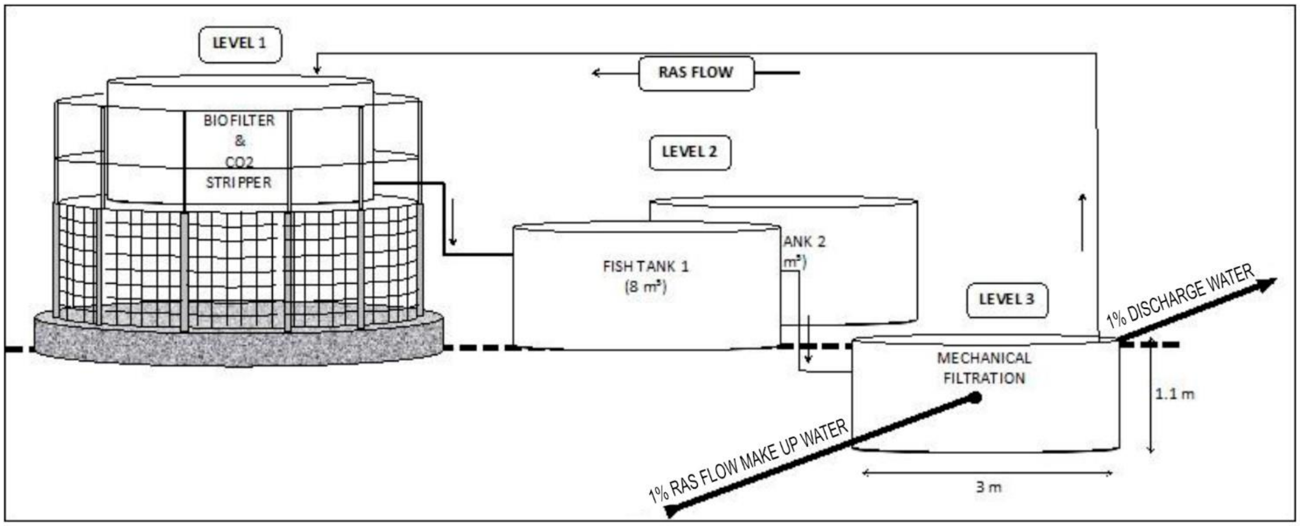

Figure 2. Schematic design of RAS showing the distribution of the four 8 m³ tanks. The biofilter was located 1.5 m over the ground, the fish tanks were located at ground levels and the filtration tank was located 1.5 m below ground levels. The tank distribution allows a minimum of electricity demand for pumping purposes. The dashed line indicates the ground level.

Source of eggs and cobia larvae: cobia fertilized eggs were obtained from the University of Miami Experimental Hatchery (UMEH) in Miami, Florida, USA. Cobia fertilized eggs and larvae were shipped by air from Miami to Mejillones (23°S, 70°W) in four batches: October 17 and December 24, 2012; June 26, 2013, and March 20, 2014; a crucial step toward the successful development of the operation since cobia is

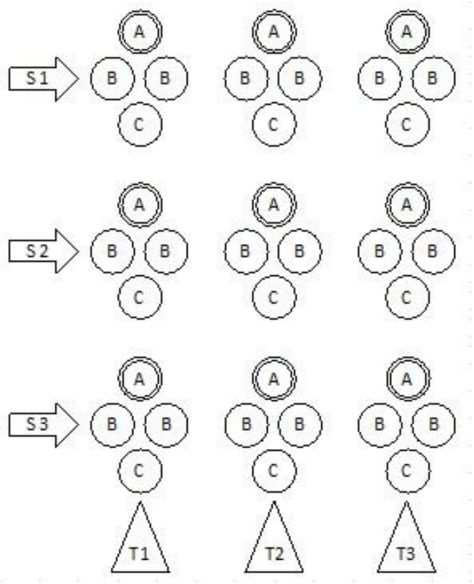

Figure 3. Schematic distribution of indoor culture with the 9 RAS systems. The distribution by a 3×3 configuration matrix allows to experiment with three salinities (S1 = 0, S2 = 22, S3 = 32) and three temperatures (T1 = 18ºC, T2 = 23ºC, T3 = 28°C). Each circle represents an 8 m³ tank. (A: biofilter and CO2 stripper; B: fish tanks, C: mechanical filter). The water recirculates from C to A 1.8 times h^{-1}; 1% of the flow is replaced all the time by the new water.

not an endemic fish of Chile (Reed, 1897; De Buen, 1961).

Water sources, flow rates, temperature control and lightning

The main supply was warmed (27 ± 2ºC) seawater discharged from the thermoelectric plant in Mejillones south bay. All the incoming water was treated with activated carbon, zeolites, sand filtered down to 30 µm, and then UV sterilized. The same tanks and systems were used for raising the fish throughout all developmental stages. The recirculation in the holding tanks was set to a flow of 9.6 $m^3 h^{-1}$ in the larvae tanks until weaning, and then to 16 $m^3 h^{-1}$ (two times per hour) for nursery and grow out.

The RAS is composed of 18 fish tanks, each one of 8 m³, completing a total volume of water for fish of 144 m³ (8×18). Based on an average rate of two exchanges per hour, the recirculation flow rate is 288 $m^3 h^{-1}$ (144×2). The recirculation rate is 99%, which means that every hour 1% of this flow enters the unit (2.88 $m^3 h^{-1}$), and the same 1% is eliminated. In 24 h, the water exchange is 69.1 m³, which represents a 48% daily water replacement. Oxygen concentration was 7 ± 0.3 mg L^{-1} for all tanks, and it was measured continuously in the water outflow. Natural light was provided with a 50% transparent ceiling located in a roof structure of 1,200 m^2 covering the nine RAS (Fig. 1). The experiments of temperature and salinity conditions lasted from January 26 to March 20, 2013.

Feeding

Rotifers

Enriched rotifers (*Brachionus plicatilis*) were added to the cobia larvae tanks from day 2 post-hatch (DPH) until day 13 DPH. All tanks were fed at regular intervals of 2 h six times a day by hand at a concentration of 2 rotifers mL^{-1} at the beginning, increasing up to 5 mL^{-1} at the end of the feeding period. Rotifers were cultured at 26 ± 1ºC with a salinity of 20 (seawater mixed with desalinated water) and enriched with microalgae, mainly *Nannochloropsis* sp. yeast, Protein Plus® and Algamac-3050® (Aquafauna Biomarine, USA). During this feeding period, 150 million rotifers were harvested daily for each larvae tank holding a volume of 4 m^3 (Table 1). There was an overlapping period of four days in the change from rotifers to *Artemia* and in every change of food, which is a standard husbandry method in every fish culture. Basic methods used for larval rearing of cobia were those described by Benetti *et al.* (2008b).

Artemia nauplii

Enriched Artemia (*Artemia salina*, Aquafauna Bio-Marine Inc., USA) was added to the tanks from 9 DPH until 24 DPH. All tanks were fed at regular intervals of 2 h five times a day by hand, increasing the concentration from 0.15 *Artemia* mL^{-1} at the beginning, up to 0.7 mL^{-1} at the end of *Artemia* feeding (24 DPH). *Artemia* was cultured at 26 ± 1ºC, with a salinity of 30 and was enriched with microalgae, Algamac-3050® (Biomarine Aquafauna, USA), arachidonic acid and astaxanthin (Table 1).

Weaning and growing diets

At 19 DPH larvae began to be fed with Otohime artificial diet (Otohime, Marubeni Nisshin Feed Co., Ltd., Japan) and on day 24 DPH they began to be fed with Ewos Chile starter diets (Ewos Chile Alimentos Ltda., Chile). The complete feeding strategy is shown in Table 1, which represents the way to manage the feeding according to the size of the fish's mouth while it grows. The critical step in the feeding program corresponds to the weaning stage, in which the live food is slowly replaced by artificial diet. For these purposes, we started with Otohime given its quality and adequate size, and then Ewos diet increasing its caliber as the fish grew.

Experimental trials

Temperature and salinity culture conditions

Larvae were acclimated in the recirculating tanks at a temperature of 26 ± 1ºC, with a water flow of 9.6 $m^3 h^{-1}$,

Table 1. Feeding strategy of cobia *Rachycentron canadum* in the farm.

	Days post-hatch		Feeding chart (DPH)																									
Food	From	To	1	2	3	8	9	13	14	16	17	22	23	24	25	28	29	30	32	33	35	36	37	38	41	42	45	46
Rotifers	2	13		▨	▨	▨	▨	▨																				
Artemia	9	24					▨	▨	▨	▨	▨	▨	▨	▨														
Otohime B2	17	25									▨	▨	▨	▨	▨													
Otohime C1	23	32											▨	▨	▨	▨	▨	▨	▨									
Otohime C2	30	36																▨	▨	▨	▨	▨						
Ewos St 00	24	29												▨	▨	▨	▨											
Ewos St 0	28	37														▨	▨	▨	▨	▨	▨	▨	▨					
Ewos St 1	35	45																			▨	▨	▨	▨	▨	▨	▨	
Growth	42	on																								▨	▨	▨

to establish the best water environment for culturing cobia. At this time the larvae were first fed with rotifers according to the protocols described, continuing with *Artemia* and finally the starter artificial weaning diets Otohime. All the larvae weighing 0.02 g were transferred to the experimental tanks at the density of 12 larvae L^{-1}. During their first 53 days, at the juvenile stage, 100 individuals of each tank were randomly sampled to determine and record their weight (g) using a precision balance (Sartorius, Secura 3102, Spain). During this period, the juveniles were exposed to nine different water environments by mixing different proportions of the three water sources (cold seawater, warm seawater and desalinated cold water).

Growth analysis

One batch was cultured in eight tanks at densities averaging 30 kg m^{-3} and feeding regimes ranging from 1.2 to 1.6% of the total body weight (BW) during their grow-out phase, to determine the growth of cultured individuals in the second step at a condition of 28ºC and a salinity of 32. Fifty random fish were sampled monthly to record weight gain. The feed conversion ratio (FCR) during this stage was calculated as FCR = kg food per period / (final biomass - initial biomass).

Reproduction in farm, spawning, hatching and larval survival

From October 2014, the two years old males and females began spawning volitionally in captivity. Since then, by controlling the water temperature according to Benetti *et al.* (2008a,b) and Stieglitz *et al.* (2012), the farm produced its eggs consistently, with numbers ranging from 200,000 to 1,600,000 in each batch. Data on each spawn female, based on previous investigations (Lotz *et al*., 1996; Arnold *et al*., 2002; Benetti *et al*., 2008a; Chaves-Pozo *et al*., 2008; Faulk & Holt, 2008; Gopakumar *et al*., 2011; Nguyen *et al*., 2012; Sakthivel *et al*., 2012; Valdebenito *et al*., 2012) including number of floating eggs, weight and diameter, blastomeres symmetry, larval deformities and larval survival at weaning, was collected to choose the best breeders. For this purposes, four 60 m³ tanks were installed containing each one four females and three males, all individually tagged. These broodstock fish were daily fed Ewos diets mixed with fresh fish from the region (1-3% BW daily).

Statistical analysis

All data are reported as means ± standard error (SE) throughout the text and were analyzed by one-way or two-way analysis of variance (ANOVA), at a 0.05% significance level, following confirmation of normality and homogeneity of variance. Bonferroni and Šidák *post-hoc* tests were applied when required. Statistical analysis was carried out using Prism 6.0 (Graphpad Software, Inc.).

RESULTS

Temperature and salinity culture condition test

The maximum body weight after 53 days of culture was achieved with a water temperature of 28°C and a salinity of 32. The juveniles under these conditions attained an average weight of 215.7 ± 38.8 g, maintaining significant differences from day 14 with individuals grown under the other experimental conditions maintaining the differences for the rest of the times examined (Fig. 4). At a temperature of 28ºC and a salinity of 22, the individuals achieved an average weight of 118.1 ± 24.8 g, approximately a 45.2% reduction compared with the fishes grown at a salinity of 32 (Fig. 4). Similarly, individuals grown at a 23°C and a salinity of 32 achieved a weight of 113.2 ± 27.2 g. However, individuals grew at the same temperature but in 22 salinity reached only 46.6 ± 11.7 g (Fig. 4),

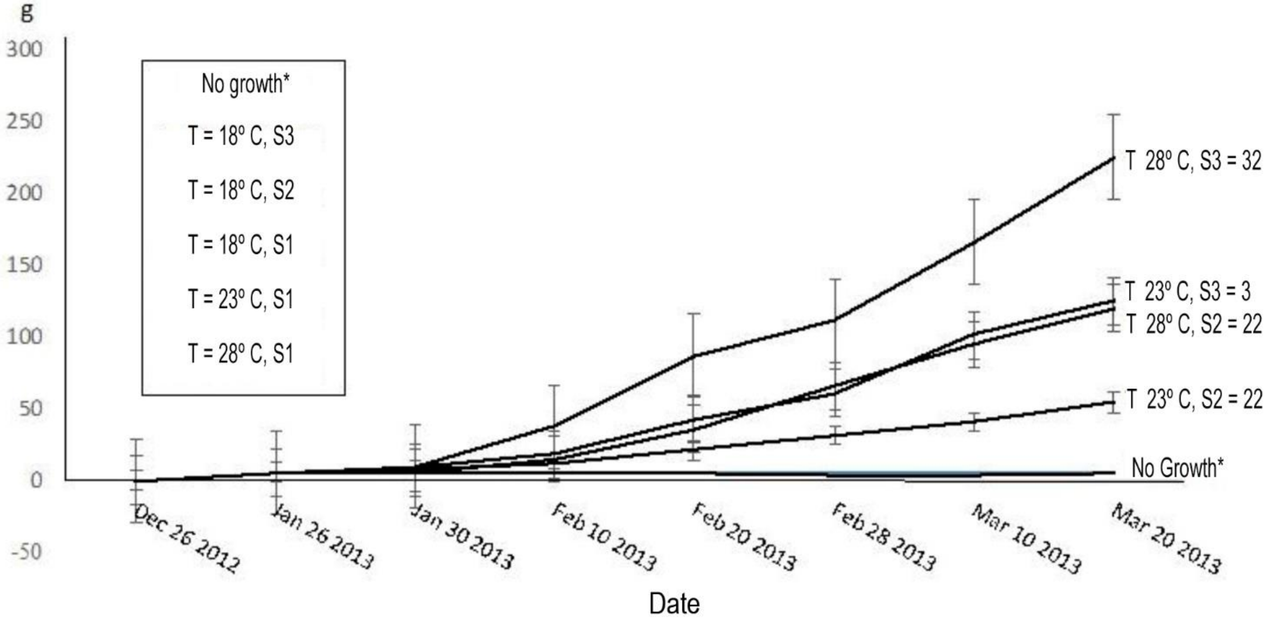

Figure 4. The growth curves (g) of cobia *Rachycentron canadum* under different temperatures (°C) and salinities (S1=0, S2=22, S3=23). Different experimental groups were cultured (see Materials and Methods). Each point in the figure represents the average weight calculated from 10 individuals per experimental condition. The individuals were sampled in seven events, from January 26 to March 20, 2013. Error bars represent standard error ($P < 0.001$); two-way ANOVA.

suggesting that salinity as much as temperature plays an important role in the growth of this species during the time and conditions of the development studied. The tanks at salinity of 0 showed 100% mortality after four days of culture (Fig. 4). The purpose of this experimental design was related to the protocols required by Chilean regulation agency, Undersecretary of Fishery and Aquaculture, in order to expose the fish to extreme conditions. As cobia is a newly introduced species, these studies are required to obtain some knowledge on the management of disposal, and to avoid the risk of an ecological hazard.

Given the results of the temperature and salinity trials obtained with the first batch of fish, all the other batches were cultured at a constant temperature of 28 ± 1°C and salinity of 30 ± 2.

Growth analysis

Once the optimum culturing conditions to raise cobia in the RAS were established, the fish were fed to satiation and kept at 28°C and salinity of 30 to analyze the growth rate under these conditions. This experience was conducted in the 8 m^3 tanks, which is not optimal for growing purposes. The stocking density was kept at 30 kg m^{-3}, to minimize the impact of this factor.

Fifty fish were monthly randomly weighed. At the beginning of the growth analysis period (March 2014), the juveniles had an average weight of 10 ± 2 g, reaching after 13 months in culture an average weight of 3,890.5 ± 230 g. The weight increased geometrically doubling every three months approximately (Fig. 5).

The experimental groups are defined as batches spawned from different females and males. They were all cultured under the same water environment conditions. So, the differences observed could be attributed to genetic characteristics of the parents, which is a matter for further studies. The results demonstrated that in eight months it is possible to obtain individuals with an average weight of 4 ± 0.4 kg, and an FCR of 1.26 ± 0.6 when fed at an average ratio of 1.38% of BW.

Reproduction in the farm: spawning, hatching and larval survival

After a period of 24 ± 2 months, the fish reached sexual maturity, evidenced by the species characteristic mating behavior and therefore, as expected, they entered a reproductive cycle

At that moment, the criterion applied to select the potential brood fish was phenotypic: external aspect, size and weight. Healthy fish with no evident clinical sign of diseases and normal skin representing the 20% of the largest sizes and weights were transferred to four 60 m^3 reproduction tanks at a ratio of 4 females:3 males, in each tank.

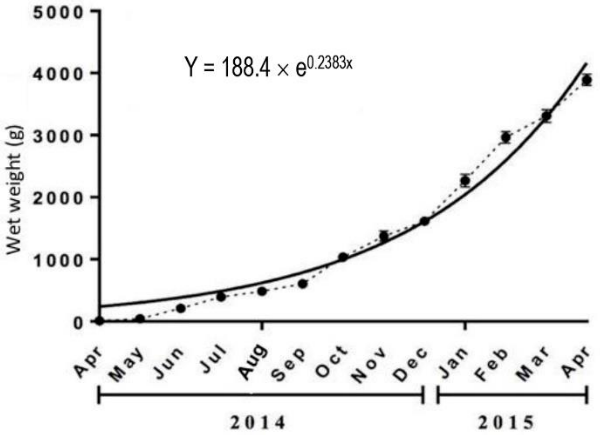

Figure 5. Growth (dotted line and polynomial regression) of *Rachycentron canadum* into adulthood under optimal conditions in the RAS. Individuals were kept in the RAS at 28°C and salinity of 32, and a stocking density of 30 kg m^{-3}. Bodyweight was monitored as indicated in the material and methods. The bars are means ± standard error.

One day before spawning, the males started their typical courtship behavior, and increased interaction among individuals of both sexes was observed. Spawning was preceded by visible distension of the female's abdomen. Once the female's abdomen showed an increase in the bulging, it was indicative of the immediacy of the spawning event. Most of the times the fishes showed an increased interaction the day before the spawning, starting around 16:00 h, and 2-3 h before spawning (generally during the night) the male was comparatively less aggressive towards the female. At this time, the male affably chased the female and displayed "leading behavior," during which the male repeatedly approached the female. This sequence was alternated by a chase and then repeated the behavioral sequence. Just before spawning, both sexes adopted a heightened courtship behavior for a period of 1 to 2 h, after which the spawnings took place. Hatching occurred between 24 and 26 h incubation after spawning at water temperatures ranging from 26 to 28°C with natural light.

The hatching percentage ranged from 84.3 to 94.8% (Table 2). The hatched larvae measured 1.9 to 2.3 mm with tiny yolk sac (Fig. 6) and were active swimmers, especially when the rotifers were added to the water after 2 DPH.

Finally, after October 2014, the biggest and phenotypically best males and females were selected, sampled, tagged and stocked at a sex ratio of 3:4 males and females, respectively, into four 60 t maturation tanks with natural light and temperature control, installed for reproduction purposes. Since then and up to May 2016 there were 121 spawning's events, yielding batches from 200,000 to 1,600,000 eggs with fertilization rates ranging between 47.7 and 97.1%, which provided the basis for a study intended to select the broodstock fish for a breeding program.

Table 2. Local spawning data of cobia *Rachycentron canadum* on the farm.

Local spawning data	1º	2º	3º
Spawning date	04-oct-2014	05-oct-2014	14-nov-2014
Nº of floating eggs	230,000	350,000	290,000
Nº of sinking eggs	28,500	22,000	16,500
Nº total eggs	258,500	372,000	306,500
% fertilization	89	94.1	94.6
Nº of hatched larvae	207,000	295,000	275,000
% of hatching	90	84.3	94.8
% abnormal larvae	2.5	3.1	2.8
Nº of larvae at weaning	18,000	31,100	30,100
% of larvae at weaning	8.7	10.5	10.9

DISCUSSION

The experimental phase 1 (pilot stage) was to design and build a RAS to introduce a non-native species. Warm water effluents of a thermoelectric plant in northern Chile were used in order to demonstrate the technological feasibility of raising cobia (*Rachycentron canadum*), in an ecologically sustainable manner, from egg to market size in the Atacama Desert, within two years (October 2012-November 2014).

Cobia is a tropical/subtropical marine fish species exhibiting extraordinarily fast growth rates that demand high environmental and nutritional requirements (Shaffer & Nakamura, 1987; Chou *et al.*, 2001; Faulk *et al.*, 2007; Benetti *et al.*, 2008a; Faulk & Holt, 2008). These requirements are difficult to meet, especially for first time experience. However, despite the challenges inherent (to this and any pioneer initiative), we successfully met these conditions maintaining water temperatures in the RAS at desirable levels of 26-30°C. We further managed the ammonia levels below 0.02 mg L^{-1}, even though Burkey *et al.* (2007) reported values of cobia tolerating ammonia ranging from 0.2-1.0 mg L^{-1}. In these trials, we were able to raise cobia to market size and to achieve a full reproductive cycle. Cobia was successfully grown and approached market size when fed with Otohime, and Ewos specialty diets that appear to meet their nutritional requirements as the growing curves obtained were similar when compared to similar trials reported (Benetti *et al.*, 2010b). Additional studies on ingredient digestibility and diet formulation for cobia in RAS are required to ensure that this species nutritional requirements are fully met at all stages (Chou *et al.*, 2001; Suarez *et al.*, 2013).

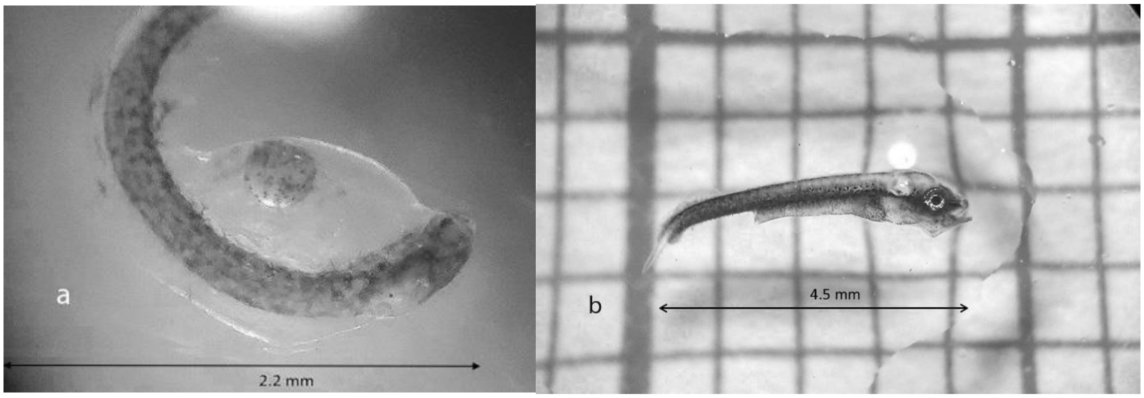

Figure 6. Development of cobia's larvae *Rachycentron canadum* developed in the RAS. a) Cobia larvae at the moment of hatching, b) cobia larvae at 6 DPH. The images are representative of the larvae obtained in three spawning events. Bar = 1 mm.

From the beginning, the cobia larvae obtained from the University of Miami breeding program were successfully packed, transported, acclimated, and stoked at the thermo-electric plant in Mejillones. Larval rearing was conducted using a RAS designed and built that appears to be appropriate for this purpose, since the numbers of fingerlings and juveniles obtained was similar to previous reports of rearing larvae (Benetti *et al.*, 2008a,b).

Nine independent RAS were stocked with fingerlings from four batches of cobia from different UM genetic strains, both wild and F1 captive broodstock. The RAS flexible set-up allows for replicated and repeated grow out trials tests at different stocking densities under different salinities (1, 20 and 32) and different temperatures (18, 22 and 28°C).

Our findings demonstrated that cobia survived at very low salinities, but not at 1. In a previous study with low salinities, all fish survived reductions down to and including a salinity of 2 (Burkey *et al.*, 2007). However, within 24 h of a reduction to 1% salinity, 73% of mortality was observed. Fish that remained in salinity of 1 for more than 24 h did not feed and were abnormally oriented in the water column. All remaining fish died after 48 h of the salinity reduction to 1 (Burkey *et al.*, 2007). These findings are coincident with the results of our experiments since there was 100% mortality after 48 h exposed to a salinity of 1.

The tanks were used to fully stock cobia at several sizes ranging from 2 to 4,600 g weight at an average stocking density of 30 kg m^{-3}, ranging from 20 to 60 kg m^{-3}. Stocking densities above 30 kg m^{-3} are considered commercial level. Since there are no published studies of growing cobia in RAS, it is difficult to compare with the results obtained in sea cages, especially regarding the relationship between growth and stocking densities. The cobias of these trials reached up to 4 kg in 8 months' period, in densities from 20 to 60 kg m^{-3}. The average survival rates in all groups ranged from 85-95%. These results can be considered excellent.

According to Benetti *et al.* (2010c), published and anecdotal reports of cobia growth rates are highly variable, and some of the reported growth rates are exceptionally high. Liao *et al.* (2004) reported that cobia might grow to 6 kg in one year when stocked at low densities (3 kg m^{-3}). Similar growth rates have been achieved in México with cobia stocked at low densities (≤5 kg m^{-3}) cultured in floating cages off the coast of Campeche in the Gulf of México. Additionally, growth rates of cobia raised in floating net cages in estuarine waters (salinity 15-30) in São Paulo, Brazil ranged from 2.5 to 4.5 kg in one year and 1 g juveniles stocked at 5-10 kg m^{-3} in traditional floating cages in Belize reached 2.0-4.0 kg in one year (D. Benetti, *pers. comm.*).

At least with salmon in Chile, it is commonly accepted that better growth and survival rates can be achieved with RAS compared with any other culture system. We suggest that this concept may also be applied to cobia due to the stability of the environment and water quality parameters that can be maintained optimal for their culture. In our experimental cobia RAS, not only the growth rates were high for all the batches, but also the mortalities up to harvest never exceeded 6%, and no infectious diseases were found during the four years experimental phase. No antibiotics were ever used.

Cobia seems to be extremely adaptable regarding its spawning periods. In the wild (northern hemisphere) spawning occurs during spring and summer (Biesiot *et al.*, 1994) with peaks reported between May and June (Lotz *et al.*, 1996). On the other hand, Stieglitz *et al.* (2012) reported year-round environmentally conditioned cobia spawning's in captivity at the University of Miami Experimental Hatchery, which demonstrates the considerable plasticity of this species. Also, like any other husbandry tool, many cobia reproduction farms use HCG (Human Chorionic Gonadotropin) to induce the spawning (Franks *et al.*, 2001; Arnold *et al.*, 2002). In our study, no hormones were used; the water temperature regularly maintained at 24-25°C, was increased to 28-29°C to induce sexual activity and ensuing volitional spawning.

During the experimental trials reported in this study, we strived to minimize waste by recycling it as much as possible. The effluent water was used to irrigate a perimeter of saltwort or sea asparagus, *Salicornia*. These are succulent, high in Omega-3, salt-tolerant plants that grow on beaches and in marshes and mangrove areas. Earthworms *Eisenia foetida* were also used to recycle organic matter from fish wastes and to produce humus to fertilize the desert ground. The resulting compost product was incorporated into the *Salicornia* sp. production area to promote plant growth.

The results achieved raising cobia in RAS using the warm water of a thermoelectric plant in Mejillones indicate that a cobia production operation could potentially be carried out commercially in northern Chile in an ecologically sustainable manner. It appears that all the elements are in place to expand cobia aquaculture in RAS in an environmentally sustainable, economically viable and socially responsible in the region and wherever there is a cooling system, as processing plants and cold storage.

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