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Advances in hatchery and grow-out technology of cobia *Rachycentron canadum* (Linnaeus)

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Abstract

This paper describes advances in hatchery and grow-out technology of cobia (*Rachycentron canadum*, Linnaeus). In 2007, methods for capture, transport, acclimation, sampling, conditioned spawning, larval rearing, fingerling production, nursery, shipping and grow-out have been perfected. Survival rates ranging from 17.5% to 35% were achieved from egg to shipping size fingerlings (1.0 g) in 2007 at the University of Miami Experimental Fish Hatchery, with production of approximately 20 000 fingerlings per 12 000 L tank. Wild and F1 broodstock cobia have been conditioned to spawn through temperature manipulation producing viable eggs for experimental and production level larval rearing trials in several hatcheries. Brood fish have also been induced to spawn using hormones. Cobia appear to be susceptible to infestations by parasitic protozoa such as *Amyloodinium ocellatum* and to infections caused by deleterious bacteria such as *Photobacterium* spp. and *Vibrio* spp. Prophylactic methods used to prevent and control epizootic diseases at the hatchery are summarized. Improved techniques for cage management were implemented, and both novel designs of submerged cages deployed in exposed areas and traditional gravity cages in protected areas have been used for commercial ongrowing of cobia in the Americas and the Caribbean region.

Keywords: cobia, spawning, larval rearing, grow-out

Introduction

Rapid growth rates, combined with excellent overall aquaculture performance and high market demand, confer highly desirable characteristics for commercial aquaculture on cobia (*Rachycentron canadum*, Linnaeus). Following the successful aquaculture development of cobia in Taiwan (Yeh 2000; Su, Chen & Liao 2000; Liao, Huang, Tsai, Hsueh, Chang & Leaño 2004; Liao & Leaño 2005), this activity is developing fast throughout South- and Southeast-Asia, the Americas and the Caribbean regions (Benetti & Orhun 2002; Kaiser & Holt 2004; Benetti, Orhun, Zink, Cavalin, Sardenberg, Palmer, Denlinger, Bacoat Jr & O'Hanlon 2007; Liao, Leaño, Hsu & Ku 2007). With a large infrastructure already in place, both the shrimp aquaculture and fishing industries in several Latin American and Caribbean countries are benefiting from recent technological advances and implementing commercial operations of cobia. They have been raised to market for the last 5 years in the United States, Puerto Rico, Bahamas, Martinique, Mexico, Belize, Brazil and Panama (Benetti *et al.* 2007). These countries are all beginning to operate commercial farms for growing out cobia aiming at an ever-increasing market demand for high-quality seafood in the United States.

The technology for producing cobia from eggs to harvest has also been mastered in the West. Successful spawning of cobia was achieved in the United States (Franks, Ogle, Lotz, Nicholson, Barnes & Larsen 2001; Arnold, Kaiser & Holt 2002; Kilduff, DuPaul, Oesterling, Olney Jr & Tellock 2002; Benetti

2003) and technological advances in hatchery technology quickly followed (Kaiser & Holt 2005a, b; Benetti *et al.* 2007; Holt, Kaiser & Faulk 2007; Schwarz, Mclean & Craig 2007; Weirich, Stokes, Smith, Jenkins, Denson, Tomasso, Chappel & Burnside 2007).

Simultaneously with spawning success of cobia in captivity, several key larval rearing and live culture procedures have been developed and adopted for fingerlings production. These include protocols for disinfection of eggs (Tamaru, Carlstrom-Trick, Fitzgerald Jr & Bauerline 1999), feeding schedule, and management and enrichment of rotifers and *Artemia* with essential nutrients such as highly unsaturated fatty acids (Faulk & Holt 2003, 2005; Turner & Rooker 2005). In addition, weaning procedures were adopted for cobia late larvae and early juveniles (Benetti 2002). Furthermore, research aimed at evaluating economical and ecological efficiency of commercial feeds was conducted with 1–2 kg juveniles and sub-adults cobia (Denlinger 2007). These aspects are closely related to the output of nitrogenous compounds from cage culture operations and the reduction in the use of fish meal and fish oil in feeds (Chou, Su & Chen 2001; Chou, Her, Su, Hwang, Wu & Chen 2004; Zhou, Tan, Mai & Liu 2004; Wang, Liu, Tian, Mai, Du, Wang & Yang 2005; Zhou, Mai, Tan & Liu 2005; Benetti, Brand, Collins, Orhun, Benetti, O'Hanlon, Danylchuk, Alston, Rivera & Cabarcas-Nuñez 2006; Chen & Hsu 2006; Craig, Schwarz & McLean 2006; Lunger, Craig & McLean 2006; Sun, Chen, Huang & Wang 2006; Sun, Chen, Huang, Wang & Yan 2006; Denlinger 2007).

Concurrently, a more proactive culture strategy for cobia was adopted, aimed at combating the vulnerability of practically all life stages of cobia to bacterial diseases and parasitic infections with prophylactic treatments (Chen, Kou, Wu, Wang & Su 2001; Rajan, Lopez, Lin & Yang 2001; Lopez, Rajan, Lin, Kuo & Yang 2002; Rajan, Lin, Ho & Yang 2003; Ho, Kim, Cruz-Lacierda & Nagasawa 2004; Liu, Lin, Chuang & Lee 2004; Lin, Chen, Chen, Chen, Chou, Chen, Su & Yang 2006).

Biological attributes allied to market and technological advances have been driving cobia's aquaculture development in several countries throughout the world. This paper describes advances in cobia aquaculture technology in the Americas and the Caribbean with focus on recent progress attained at the University of Miami Experimental Hatchery (UMEH). Relevant information and data from hatchery and cage culture operations of cobia belonging to the private and government sectors in the United States, Mexico and Brazil are also presented.

Materials and methods

Broodstock systems

The maturation systems at UMEH consist of two 80 m^3 circular fibreglass glass tanks, with a gentle slope of 5° to the centre drain. Each tank is operated as an independent system. Water is circulated in each system by a 2.0 hp centrifugal pump (Hayward™, Hayward industries, http://www.haywardnet.com/aboveground/products/pumps/) that draws water through a 50 mm (2 in.) PVC pipe from a 500 L plastic sump tank. The sump itself receives water directly from the main/culture tank through a 100-mm-diameter PVC pipe by gravity. The sump can also be used to control the water level in the main tank. Water is pumped through a 100 mm PVC pipe back to the main tank after passing through a mechanical and chemical filter, a UV filter and a heat exchanger/pump. The mechanical filtration consists of a sand filter housing filled with a broken glass filter medium (Vitroclean™, Trivitro Corporation, Kent, WA, USA) capable of removing particles down to 10 μm in diameter. After the mechanical filtration, the water is disinfected by a 200 W UV filter (Gamma UV™, Vista, California, Current USA, http://current-usa.com/) and enters a titanium core heat pump that controls temperature (heating or chilling) before returning to the culture tank. One of the systems is equipped with a 2 hp model (Titan™ HP-2, Aqualogic, San Diego, CA, USA) and the other with a 5.7 kW model (Heatwave™ H155, Aquacal, St Petersburg, FL, USA). Each maturation tank has also a 1 m^3 cylindrical fibreglass tank, used as a trickle biofilter, and filled with plastic medium to provide a large surface area for bacterial growth. In addition, one system is equipped with a Skim™ (AquaEco S.R.I., Cadelcosco Sopra, Italy) foam fractionator/protein skimmer/biofilter for additional filtration.

Approximately 20% of the recirculated water after the pump and heat exchanger enters the biofilter through jet sprays at approximately 1000 L h^{-1} and is returned by gravity back into the system. Sediments such as uneaten foods, organic waste and unfertilized eggs are drawn out of the tank via the centre drain during the process of water recirculation and are trapped in a 1.25 mm screen divider placed in the sump. The glass media of the mechanical filter traps particles larger than 25 μm in

diameter. A 150 mm diameter PVC pipe, located at the surface of each maturation tank, is used as a skimmer to collect floating eggs and guide them by overflow into an outside egg collector. The egg collectors serve also as foam-fractionators due to their surface skimming action. In order to maintain high water quality and make up for the slow but continuous discharge of water, new filtered seawater is added to account for the daily loss of about 10% of total water volume.

The maturation systems used for spawning cobia are based on and slightly modified from those successfully used for other species of subtropical and tropical marine fish and described in details by Benetti (1997) and Benetti, Alarcon, Stevens, Rotman, Banner-Stevens, Zimmermann, Feeley, Matzie, Orhun, O'Hanlon and Eldridge (2001). The systems described have proven reliability and similar ones are being successfully used for spawning cobia in commercial hatcheries in the United States and Latin American countries.

Broodstock capture and transport

All wild cobia broodstock were collected from the waters of the Gulf of Mexico and Atlantic Ocean off the Florida Keys, FL, USA. Fish were collected with the assistance of local fishermen, due to their practical knowledge of the species and their ability to easily find aggregations. Captured adult cobia were transported in 500–1000 L tanks at a maximum stocking density of 50 kg m^{-3}, temperatures of 22–24 °C and oxygen levels ranging from 7 to 12 mg L^{-1}. Ice packs were used for lowering temperature. A submersible pump, a 12 V DC diaphragm compressor and oxygen bottles fitted with valves, hoses and air stones were used to provide water circulation and supply of air and pure oxygen respectively. Clove oil (eugenol) in doses of 10–40 ppm was used to anaesthetize the broodstock fish and to facilitate their handling, sampling and transfer. The dosage depended on the level of anaesthesia desired. At 24–30 °C, light sedation of cobia can be obtained at 10 ppm whereas deep anaesthesia is achieved with 40 ppm.

Acclimation, prophylaxis, quarantine and stocking

Upon arrival at the hatchery, cobia were initially treated with a freshwater bath for 2 min and subsequently placed in a 100 ppm formalin bath for about 3 min to remove parasites and treat external lesions. These lesions are common in fish collected from the wild and can become infected if not treated before acclimation. Fish were kept in quarantine for acclimation to captivity for about 1–2 weeks. If fish exhibited lesions or bleeding, oxytetracycline baths at 50 ppm were administered as prophylaxis for 3 h each day for 5 consecutive days. Methods used were modified from procedures described previously by Benetti and Feeley (1999) and Benetti and Alarcon (2000).

Following transport, acclimation, prophylaxis and quarantine, 10–14 fish weighing 3–20 kg each were transferred to the maturation tanks at an approximate sex ratio of 2:1 (males:females). Total biomass in each 80 tonne tank ranged from 85 to 150 kg, i.e. a biomass density of 1.06–1.87 kg m^{-3}, with each fish roughly averaging 12 kg. The tanks were covered (approximately 95% shade cloth) to provide shade, control algal growth at the bottom and provide adequate light levels, ranging from 200 to 2000 lx.

Feeds and feeding of broodstock fish

Broodstock fish were fed a diet of frozen cut fish (mainly sardines of the family *Clupeidae* and goggle eyes or scad of the family *Carangidae*) and market squid (*Loligo*) once daily to satiation six times a week. Daily ration corresponded to approximately 2–4% of their total biomass. Fish and squid were usually fed on alternate days and were thawed just before being fed to the fish. The diet was complemented with a vitamin and mineral mix incorporated at approximately 1% of the daily ration two times a week.

Spawning, egg collection and incubation

Both wild and F1 broodstock cobia were conditioned to spawn naturally through temperature manipulation. Temperature regimens in the maturation tanks were set to follow the natural temperature fluctuations in the ocean during the spring and summer in the Southeast US. The spawning season of cobia in the region is from May through August. Both tanks were on natural photoperiod. Temperature progressively increased at approximately 1 °C per month from the low 20's (20–21 °C) in January to about 26–27 °C by June and thereafter was set to stay between 26 and 28 °C for the reminder of the season via the heat pumps.

Fish spawned at nightfall and eggs were either collected from the egg collectors starting shortly, e.g. 30 min, after spawning or the next morning. In each spawning event, eggs were collected and treated with a 100 ppm formalin bath for 1 h either between the eight-cell stage to the 128-cell stage (2–3 h post fertilization) or at the early embryo stage (12 h post fertilization). Fertilized eggs were incubated in 1000 L conical-bottomed, fibreglass tanks. Stocking density in the incubator tanks ranged from 100 to 500 eggs L^{-1}. Strong aeration was supplied by a 3/4 hp rotary vane compressor (Sweetwater™, Aquatic Ecosystems, Apopka, FL, USA) through an air ring placed around the centre bottom of the incubators. Pure oxygen was also provided as needed to maintain oxygen levels at or above saturation levels. Eggs were maintained with flow-through filtered seawater at a daily turnover rate of 1000%. Eggs were counted volumetrically using a 2 L graduated cylinder and checked under the dissecting microscope to determine the total number of eggs spawned and fertilization rates respectively. Hatch rates were determined by volumetric sampling and visual counts of yolk-sac larvae 1 day post hatch (DPH). Final numbers were the averages of three samples.

Larval rearing

Larval rearing trials were conducted in four 12 000 L circular, cone-bottomed fibreglass tanks. Temperature of the flow-through seawater ranged between 28 and 32 °C. Daily turnover rate of 100–600% was used throughout the larval rearing and nursery stages (1–30 DPH). Vigorous aeration was provided by four air stones powered by blowers and a central air-hose powered by a compressor. Pure oxygen was added to maintain dissolved oxygen above saturation levels (7–9 mg L^{-1}). Water circulation and aeration were increased over time as larvae grew, and used in combination to create a current and hydrodynamic pattern that induced larvae and fingerlings to swim constantly at 1–2 body lengths s^{-1}. Water quality was kept at desirable levels, with total ammonia-nitrogen and pH maintained at $\leq$ 0.1 mg L^{-1} and around 8.0, respectively. A natural light cycle was used in the greenhouse where the larval rearing tanks are located. The greenhouse was shaded with 80% reflective cloth. Yolk-sac larvae (1–3 DPH) were stocked at 5–10 larvae L^{-1} into the 12 m^3 larval rearing tanks. Standard protocol consisted of three to five live feed additions per day, as needed, to maintain proper concentrations of microalgae (*Isochrysis galbana* at ~10 000 cells mL^{-1}), enriched rotifers (*Brachionus plicatilis* at 5 mL^{-1}) and enriched *Artemia* nauplii (at 0.1–1.0 mL^{-1}). Cobia larvae were fed *'ad libitum'* using a 'pulse feeding' technique. Microalgae and rotifers were added between 2 and 10 (DPH), and *Artemia* nauplii were added from 7 DPH through 22 DPH.

Prophylaxis (50–75 ppm formalin bath for 1 h as needed) and daily additions of probiotics (Ecopro™, EcoMicrobials, LLC., Miami, FL, USA) administered at concentrations between 10^3 and 10^5 mL^{-1} of colony forming units in the live feeds before feeding of larvae were important components of the protocol.

Tanks were cleaned daily by siphoning of the bottom and skimming of the water surface. Larvae were sampled daily and dissected under the microscope to observe any signs of pathogenic organisms, particularly the ectoparasite *Amyloodinium ocellatum* (Brown 1931). Microbiological media such as TCBS, Marine and Tryptic Soy Agar media were used to monitor the density of bacterial populations of *Vibrio* sp. and *Photobacterium damselae* subsp. *piscicida* (Gauthier, Lafay, Ruimy, Breittmayer, Nicolas, Gaurthier & Christen 1995).

Weaning and nursery

Weaning of cobia larvae began 16–18 DPH at temperatures ranging from 28–32 °C. Post-larvae were weaned onto starter diets following adaptations of established protocols (Benetti 2002). The protocol for weaning and nursery of cobia at UMEH encompassed almost constant feeding (6–10 times day^{-1}) with high-quality starter feeds such as Otohime™ (Marubeni Nisshin Feed, Tokyo, Japan) and Geema™ (Skretting, Canada Bayside-New Brunswick, Canada, http://www.skretting.com/) under a natural 13–14 light/11–10 dark cycle throughout the weaning and early nursery period. Fingerlings were initially manually and later mechanically graded daily by size.

Results and discussion

Broodstock management

Cobia broodstock were successfully transported from the Florida Keys to the UMEH facilities, anaesthetized, sampled, acclimated, treated with prophylaxis and quarantined. Transport time between capture and UMEH facilities was about 4–6 h with survival

> 90%. Using the methods described, over 100 cobia, ranging from 3 to 20 kg in weight, were successfully transported for several hours in a number of different situations in the United States, Mexico and Brazil. On one occasion, 11 cobia, weighing 2–4 kg, were transported by truck for 38 h from Florida to Rhode Island in the United States using a 500 L tank with 100% survival. In Brazil, 48 h truck transportation of cobia broodstock between Bahia and São Paulo states was successfully accomplished using the methods described and not exceeding fish biomass of 50 kg m^{-3} in the tanks.

Following acclimation and prophylaxis, broodstock cobia were stocked into maturation tanks and conditioned to spawn using environmental cues, especially temperature.

Spawning

At UMEH, cobia began spawning naturally when water temperature reached 24–26 °C in early May and continued to spawn through the end of August. Spawning occurred consistently a short time after sunset. By manipulating environmental conditions, four spawns were obtained in maturation tank 1 during the second semester of 2006; three spawns occurred naturally, whereas one was induced with human chorionic gonadotropin at a dosage of 1.000 IU kg^{-1}. In 2007, natural spawnings occurred when the temperature reached 24–25 °C. Eleven natural spawning events occurred from three F1 females weighing 3–6 kg. Between 840 000 and 1.2 million eggs were collected per spawn of F1 fish (Fig. 1), with fertilization rates ranging from 48.3% to 95%. These results are within the range of those reported by Arnold *et al.* (2002) and Kaiser and Holt (2005b) for cobia in Texas. Larger wild fish of 15–25 kg have been known to spawn > 3 million eggs at UMEH and the University of Texas (Kaiser & Holt 2005a) in the United States, Ixoye Tropicales in Mexico and at Bahia Pesca and TWB hatcheries in Brazil.

Natural spawning was routinely achieved both at UMEH and at other hatcheries in the United States (Aquaculture Center of the Florida Keys/ACFK and University of Texas, Port Aransas Laboratory), Mexico and Brazil. A summary of cobia spawning activity at UMEH by wild-caught and domesticated F-1 broodstock fish is shown in Table 1. Progress of selective breeding towards domestication shows dramatic improvement over a short period of time (3 years). Indeed, from May through August of 2007, three females F1 broodstock naturally spawned 11 times, producing approximately 15 million eggs that were used for either experimental trials or production runs by universities, government institutions and the private sector.

Figure 1 shows the relationship between natural spawnings and moon cycle. The data do not appear to corroborate anecdotal evidence linking natural spawning events of cobia to the full moon. Although spawnings mainly occurred just before or after the full moon, the fish were also observed to routinely exhibit courtship behaviour and to spawn during other moon phases. As shown in Fig. 1, cobia spawned naturally during the new moon period as well.

Given the right environmental and nutritional conditions, cobia are likely to spawn naturally in tanks and in cages. In Puerto Rico and Mexico, cobia stocked in both submerged and floating cages for ongrowing routinely spawn prematurely at approximately 10 months after stocking, when males reach ≥ 2 kg and females ≥ 3 kg. Also, four females and eight males F1 broodstock stocked in two 60 m^3 tanks (two females and four males per tank) at Ixoye Tropicales in Yucatán, Mexico, spawned

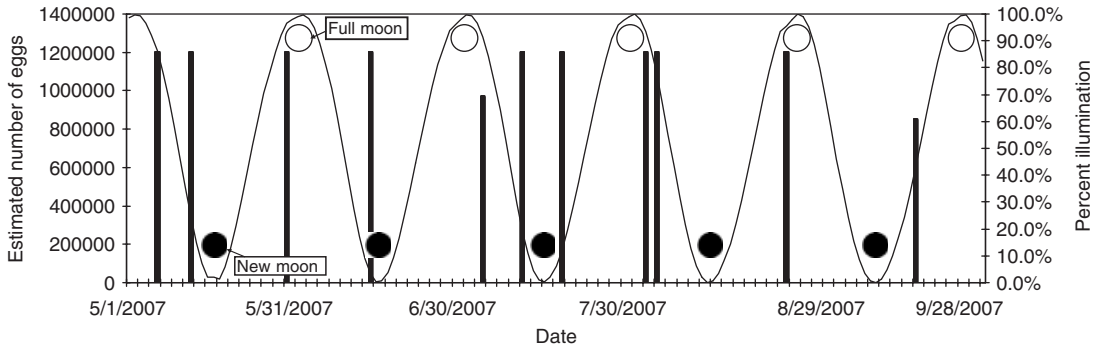

Figure 1 Relationship between natural spawnings of cobia and moon cycle in the Spring and Summer of 2007.

Table 1 Summary of cobia (*Rachycentron canadum*) spawning activity at the University of Miami Experimental Hatchery from 2005 to 2007 by wild-caught and domesticated F-1 broodstock fish (2007 only)

	2005	2006	2007	Total
Wild				
Number of tanks	1	2	1	4
Number of fish	14	26	12	52
Number of spawns	3	4	1	8
Hormone-induced spawns	–	1	1	2
F-1				
Number of tanks	–	–	1	1
Number of fish	–	–	10	10
Number of spawns			11	11
Hormone-induced spawns	–	–	–	–

Progress of selective breeding towards domestication shows dramatic improvement over the short period of time, with three females F1 broodstock naturally spawning 11 times from May through August of 2007, producing approximately 15 million fertilized eggs.

33 times between March and August of 2007. Similarly, excellent results with natural spawns were obtained in 2007 with wild broodstock cobia weighing 5–15 kg in Bahia and São Paulo States at hatcheries owned by the private company TWB S.A. However, for unknown reasons, some broodstock cobia do not spawn naturally even during their natural spawning season. This phenomenon has been observed at UMEH and at the University of Texas (J. Kaiser, pers. comm.) in the United States.

Arnold *et al.* (2002) considered 24–26 °C to be the optimal temperature range for cobia spawning in Texas, and suggested that they may cease spawning at temperatures between 28 and 30 °C. At lower latitudes such as South Florida, Mexico and Brazil, cobia begin spawning at $\geq$ 24 °C and continue to spawn at temperatures $>$ 28 °C and $<$ 32 °C. Water temperatures between 26 and 28 °C were maintained in the UMEH broodstock tanks, and were considered to be the ideal range for cobia spawning in subtropical regions.

Larval rearing

In 2007, hatch rates varied between 54.7% and 75% at the UMEH facilities. Overall reported hatching rates for hatcheries in Mexico and Brazil ranged broadly between 50% and 90%. At temperatures $\geq$ 27–28 °C, eggs hatch 21–24 h post fertilization and first feeding of larvae occurs at 3 DPH.

Several larval rearing trials of cobia were conducted with survival rates ranging from $<$ 3% in 2002 to $>$ 30% in 2007, producing commercial numbers of fingerlings that were shipped and stocked in both submerged and traditional cages for grow-out. In 2006, within 27 DPH, fully weaned fingerlings measuring 4–6 cm in total length and 1 g in wet weight were ready to be shipped out and survival rates were $\leq$ 5%. In 2007, 100% of 23 DPH post-larvae were successfully weaned onto starter diets with survival rates of approximately 50%. Survival rates ranging from 17.5% to 35% were achieved from egg to shipping size fingerlings (1.0 g). Between 10 000 and 25 000 cobia fingerlings measuring 3–5 cm total length and weighing 0.5–1.5 g wet weight were produced in each 12 m^3 tank at UMEH. Using similar techniques in collaboration with Ixoye Tropicales in Yucatan, Mexico, eight larval rearing runs in 2007 produced approximately 80 000 fingerlings that were stocked for grow-out in floating cages deployed in the Gulf of Mexico (T. Batista, pers. comm.).

Major problems faced during early developmental stages of cobia culture were outbreaks of the dinoflagellate *A. ocellatum*, which infest gills and skin, and *P. damselae*, which causes bacterial gill disease and bacterial enteritis. As opposed to previous years, when both pathogens caused mass mortalities of early developmental cobia at the UMEH, no diseases outbreaks were observed in the larval rearing trials of 2007. Diligent work, adequate nutrition, prophylaxis and probiotics in the live feeds before feeding of larvae were essential for the high survival and excellent health of the fingerlings produced.

At temperatures ranging from 28 to 32 °C, weaning of cobia larvae began 16–18 DPH. Ideally, it is suggested that weaning should be completed by 25 DPH, and no later than the end of the fourth week (28 DPH). Efforts should be made to follow this timeline. At higher temperatures, larvae develop faster and weaning can be started as early as at the end of the second week post hatch. At temperatures above 28 °C, it is possible to wean the post-larvae onto dry diets during the third week post-hatch and complete weaning before 25 DPH.

Ongrowing in offshore submerged cages and traditional gravity cages

Open ocean aquaculture of cobia is a new activity in the Americas and the Caribbean region. Snapperfarm, in collaboration with the University of Miami

Table 2 Summary of cobia (*Rachycentron canadum*) aquaculture activities in the Americas and the Caribbean

Country	Hatchery	Production (# fingerlings)	Ongrowing	Production (tonnes)	System (cage type)
United States	Yes	400 000	Yes	100	Submerged*,†
Belize	No‡	N/A	Yes	300	Gravity
Dominican Republic	No‡	N/A	Yes	100	Gravity
Mexico	Yes	100 000	Yes	100	Gravity
Martinique	No	N/A	Yes	100	Gravity
Bahamas	Yes§	N/A	Yes	<50	Submerged*
Panama	No‡	N/A	Yes	<50	Gravity
Brazil	Yes§	20 000	Yes	<10	Gravity
Total		520 000		810	

Production numbers are estimates for 2007.
*SeaStation 3000.
†Aquapod.
‡Hatchery under construction.
§First year operating.

Aquaculture Program, has pioneered cobia aquaculture in these regions. Using cobia fingerlings originally produced at the Aquaculture Center of the Florida Keys in Marathon, FL, USA, the company has been conducting an open ocean aquaculture demonstration project off the coast of Culebra, Puerto Rico since 2002. Since then, cobia aquaculture has been rapidly developing in these regions with a number of farms now operating in several countries, notably in the Bahamas, Martinique, Mexico, Belize, Dominican Republic, Brazil and Panama (Table 2).

Cobia have been extensively grown both commercially and experimentally in cages and tanks throughout the world, including China (the biggest world producer at $\geq$15 000 metric tonnes), Taiwan, Vietnam, Thailand, Japan, Indonesia, Iran and La Reunion Island in the Indian Ocean. Growth rates of cobia have been reported by a number of authors (Su *et al.* 2000; Liao *et al.* 2004, 2007; Gaumet, Babet, Bettes, Toullec, Schires & Bosc 2007; Nakamura 2007). Growth rates reportedly vary broadly, depending on culture conditions, with cobia achieving between 2 and 6 kg in 12 months. For instance, in Okinawa, Japan, at temperatures ranging from 19 to 30 °C, cobia grew to 4–5 kg in 18 months (Nakamura 2007). At UMEH, cobia grown at densities of 2–3 kg m^3 in tanks at 20–32 °C reached only about 2 kg in 12 months, and 3–6 kg in 24 months.

Within stocking densities ranging from 5 to 15 kg m^{-3}, there are clear indications that the overall aquaculture performance of cobia decreases with increased stocking densities (Benetti *et al.* 2007). At higher stocking densities, growth and survival rates decrease and food conversion ratios (FCR) increase. It has been reported by Liao *et al.* (2004) and Benetti *et al.* (2006, 2007) that cobia may grow to up to 6 kg in 1 year when stocked at low stocking densities (e.g. 3 kg m^{-3}). Similar growth rates are being achieved in Mexico with cobia stocked at low densities ($\leq$5 kg m^{-3}) in traditional floating cages off the coast of Campeche, in the Gulf of Mexico. However, cobia stocked in submerged cages at approximately 10 kg m^{-3} grew to approximately 2 kg average in 8 months in the Bahamas and 3 kg average in 12 months in Puerto Rico. These results are similar to those being achieved by a cobia grow-out operation run by Marine Farms off Belize.

Survival rates during the grow-out stage have varied broadly, between as low as 10% to as high as 90% throughout the Americas and the Caribbean. The main reason for the low survival rates were escapes due to shark attacks tearing holes in the nets of cages during the early stages of the industry (2002–2004) in the Bahamas and, to a lesser extent, in Puerto Rico, USA. Since then, these problems have been brought under control with the establishment of better management practices, such as efficient collection and removal of mortalities from cages, and cage systems with improved anti-predator devices. There have also been outbreaks of diseases (*Amyloodinium* spp. and *Photobacterium* spp.), particularly during the nursery stage in the cages sites. Similar problems were also reported for Taiwan by Liao (2005). In addition, episodes of mortalities of larger fish (2–4 kg) in the cages were reported, and subsequently diagnosed as caused by pale gills (anaemia), probably due to a deficiency of iron in the diet. Although the nutritional requirements of cobia are not well known

(Wang *et al.* 2005; Zink, Cavalin, Bacoat Jr, Denlinger, Palmer, Sardenberg, Kirkpatrick, Orhun & Benetti 2006), cobia has high metabolic rates to support extraordinary growth rates, and their nutritional and energetic requirements scale accordingly (Feeley 2006; Feeley, Benetti & Ault 2007).

As a consequence of such variability in survival rates, FCR have also fluctuated broadly. Food conversion ratios >2.2 have been often observed when mortality rates were high (B. O'Hanlon, pers. comm.). Conversely, FCRs as low as 1.01–1.45 have been recorded for cobia juveniles in tanks with no mortality (Denlinger 2007). Although FCRs have been steadily decreasing as management strategies improve and mortalities decrease, our data indicates that the average economic FCR of cobia being raised still ranges between 1.5 and 2.0. This is in accordance with the data provided by Nakamura (2007) for cultured cobia fed on pellets in Asia. Combined, these results suggest that further research on nutrition and the development of practical diets for this species is required.

Environmental issues related to cobia offshore farms

Environmental monitoring has not shown any cumulative impacts in the water column and at the sea floor bottom around the sites of the cobia offshore aquaculture operations in either Puerto Rico or the Bahamas (Alston, Cabarcas-Nuñez, Helsley, Bridger & Benetti 2006; Benetti *et al.* 2006, 2007; Rapp, Ramirez, Rivera, Carlo & Luciano 2007). This was qexpected as the submerged cages are deployed in exposed areas, where currents ranging from 0.5 to 1.5 knots, dissipate nutrients and other waste products and these farms are still operating at the demonstration stage with permits not allowing to exceed production of 50 tonnes year^{-1}. Results thus far show that, if properly sited, planned and managed, open ocean aquaculture operations can produce commercial quantities of high-quality seafood without causing significant environmental impact. This suggests that future expansion of the operations can be allowed while maintaining environmental sustainability. Overall, Snapperfarm has been leading the initiatives of cobia grow-out using submerged cage technology in the Americas. The company has shown that ongrowing of cobia in offshore submerged cages is technologically feasible and environmentally sustainable, although the economic viability of offshore aquaculture operations is yet to be proven. The company is in the process of expanding the operation from the current three-cage demonstration phase to an eight cage commercial operation using SeaStation 3000 and AquaPod 3250 submerged cages in exposed sites.

These submerged offshore cages have proven strong enough to withstand storms and even hurricanes (Benetti 2004), and their use is necessary in regions where hurricanes may regularly occur. Other companies are resorting to traditional surface or gravity cages to rapidly expand cobia commercial aquaculture in Belize, Brazil and Panama, where the likelihood of hurricanes occurrence is minimal. Recent debate over the likelihood of an increase in frequency and severity of hurricanes as a result of interdecadal patterns and/or global warming (Emanuel 2005; Pielke Jr, Landsea, Mayfield, Laver & Pasch 2005) merits serious attention by the aquaculture community, particularly those groups deploying traditional, gravity cages. For instance, in August and September of 2007, category 4–5 Hurricanes Dean and Felix passed in close proximity to cobia farms in Martinique, Puerto Rico, the Bahamas, Dominican Republic, Belize and Mexico. As only Snapperfarm in Puerto Rico and AquaSense LLC/Cape Eleuthera Institute in the Bahamas currently use submerged cages known to withstand hurricane force storms (Benetti 2004), the risks and the stakes were higher for the traditional operations. Indeed, cobia cages in the Dominican Republic suffered some damage and in Veracruz, Mexico, cages were destroyed with total losses of infrastructure and approximately 60 000 cobia stocked.

Problems faced, to date, were high capital and running costs combined with lack of steady fingerling supply and escapes due to shark attacks leading to major production losses both in Puerto Rico and the Bahamas. For these reasons, economic viability of open ocean aquaculture operations has not yet been reached in the Americas and the Caribbean. However, this situation is changing fast. A new cobia farm being developed in Belize by Marine Farms is harvesting 300 tonnes in 2007 and is poised to become a major producer of cobia in the region (Fish Farming International 2007). It is likely that in developing Latin American countries, traditional cage systems with lower capital and operating costs in ideal environmental conditions may likely offset the high production costs needed to produce cobia in developed countries. In conclusion, commercial open ocean aquaculture of cobia throughout the Americas and

the Caribbean countries is a reality. The prospects are extraordinary, and a fast expansion of this industry in these regions is anticipated.

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