Aquaculture of Cobia (*Rachycentron canadum*) in the Americas and the Caribbean

Daniel D. Benetti*, M. Refik Orhun, Ian Zink, Fernando G. Cavalin, Bruno Sardenberg, Kevin Palmer, Bristol Denlinger, Donald Bacoat
University of Miami, Rosenstiel School of Marine and Atmospheric Science, Division of Marine Affairs and Policy, Aquaculture Program
4600 Rickenbacker Causeway, Miami, FL 33149, USA
**Corresponding author (E-mail: DBenetti@rsmas.miami.edu)*

and

Brian O'Hanlon
Snapperfarm, Inc.
Culebra, Puerto Rico

Abstract

Due to its extraordinary growth rate, overall aquaculture performance and market demand and price, cobia (*Rachycentron canadum*) is one of the species identified as having the greatest potential for commercial aquaculture throughout its distribution range in tropical regions of the Western hemisphere, particularly in the Americas and the Caribbean countries. Advances in hatchery and grow-out technology of cobia are presented in this chapter. New hatchery techniques include conditioned spawning of broodstock and intensive and semi-intensive larval rearing of cobia in tanks and ponds using probiotics. Shipping trials of cobia eggs, larvae and fingerlings are also described and discussed.

Emerging technology is being used to demonstrate the viability of raising hatchery-reared cobia in collaboration with the private sector (Snapperfarm, Inc. and AquaSense LLC) using SeaStation™ and Aquapod™submerged cages in exposed sites in Puerto Rico (US) and the Bahamas. Currently, new projects involving hatchery and grow-out of cobia are underway in Mexico, Brazil, Belize, Dominican Republic and Panama. In these countries, a more traditional approach of growing out cobia in floating cages or net pens is being applied. It is likely that lower capital and operating costs combined with ideal environment in developing Latin American and Caribbean countries will offset the high production costs needed to produce cobia in the US and other developed countries.

Following the success of cobia aquaculture in Taiwan, the technology for raising cobia from egg to market has been mastered in Western countries. The prospects for large-scale commercial aquaculture of cobia in the Americas and the Caribbean within the next decade are extraordinary.

Introduction

Cobia, *Rachycentron canadum*, (Figure 1) is an excellent candidate for commercial aquaculture development and one of the highest priority species for culture in the Gulf of Mexico (US and Mexico), the Southeastern US coast states, the Caribbean (Central America and Islands) and subtropical/tropical waters along the Atlantic coast of South America i.e. mainly Brazil (Benetti *et al*. 2003). This species has outstanding aquaculture performance, exhibiting very fast growth rates, low mortality and feed conversion rates. It has other biological characteristics suitable for culture and commands high demand and price in the market. These factors led to a rapid development of cobia culture technology during the last decade in Taiwan (Su *et al*. 2000; Liao, 2003; Liao *et al*. 2004), and subsequently in other Eastern and Western countries (Benetti *et al*. 2006).

The cobia reproductive season in the US Southeast Atlantic coast and the Gulf of Mexico region begins in April and lasts through the beginning of October; the season peaks in May and June (Lotz *et al*. 1996). The adults can reach a maximum length of 2 m and weight of 60 kg (Franks *et al*. 1996). They are opportunistic carnivores; stomach analyses show a great variety of food sources and prey types (Meyer and Franks 1996) consisting mainly of small fishes and crustaceans.

Over the last 20 years, research has been directed to the artificial propagation and rearing of cobia adults, juveniles, and larvae. Early attempts to culture cobia in the United States began in the 1970s in North Carolina using eggs collected from the wild (Hassler and Rainville 1975). Work in the U.S. on cobia as an aquaculture candidate did not begin until in the early 1990s when Connie Arnold and collaborators began

Figure 1. Cobia, *Rachycentron canadum*.

maintaining cobia in captivity at the University of Texas. Cobia juveniles were caught in the wild and successfully acclimated to captive conditions. The researchers in Port Aransas, Texas also reported on the first success of a non-hormonally induced spawning of cobia (Arnold *et al*. 2002). Similar efforts were reported thereafter from Florida, Mississippi, South Carolina, and Virginia.

Progress in cobia hatchery and offshore aquaculture technology achieved during the last 5 years is recognized for bringing this emerging industry to the verge of becoming a reality in the Americas (Arnold *et al*. 2002; Benetti *et al*. 2003, 2006; O'Hanlon *et al*. 2003; Rotman *et al*. 2003; Kaiser and Holt 2005). Indeed, the commercial aquaculture industry of cobia is in its infancy in the Americas and the Caribbean. Current production of cobia in these regions is only approximately 50 t $year^{-1}$ (~ 110,000 lb $year^{-1}$). However, the industry is developing very fast and an exponential growth is predicted for the near future. New companies beginning operations in Belize, Dominican Republic, Martinique, Mexico, Brazil, Panama, among other Latin American and Caribbean countries are poised to expand production to an estimated 1,000-3,000 t within the next 3 years and 5,000-10,000 t within the next 5 years.

Emerging technology is being used to demonstrate the economical viability of raising hatchery-reared cobia in collaboration with the private sector (Snapperfarm, Inc. and AquaSense LLC) using SeaStation™ and Aquapod™ advanced models of submerged cages in exposed sites in Puerto Rico (US) and the Bahamas. Other independent companies operating in Mexico, Belize, Dominican Republic, Martinique and new operations in Brazil and Panama are using traditional floating (gravity) cages to grow out cobia in less exposed sites. The University of Miami is collaborating with technology transfer and training in several of these ventures.

Advances in hatchery and on grow-out technology of cobia from egg to marketable size in the Americas and the Caribbean are presented and discussed in this chapter. New hatchery techniques include conditioned spawning of broodstock and intensive and semi-intensive larval rearing of cobia in tanks and ponds using probiotics. The following sections summarize the technology developed and being used at the University of Miami Experimental Hatchery (UMEH) and Snapperfarm, Inc. for cobia culture from hatchery to grow-out. The UMEH is a new, modern facility recognized as a leader in technology development and transfer (Figure 2). Snapperfarm, Inc. is as a pioneer company in the US which has been producing cobia commercially during the last five years utilizing advanced submerged systems in exposed sites.

Capture and Transport

Capture of cobia broodstock is accomplished with the help of professional fishermen who have experience in reliably finding cobia aggregations. Unlike most marine finfish, cobia does not appear to have a swim bladder as juveniles or adults, and there is no need to vent the fish after capture. Most of the capture is done within eyesight at the water surface using chum

Figure 2. The Univeristy of Miami Experimental Hatchery (UMEH) with maturation systems in the background.

and bait and traditional hook and line methods.

Captured fish are placed in an onboard transportation tank or live well with a lid. Ice in plastic bottles (to help maintaining adequate temperature) and a supply of pure oxygen (O_2) are provided throughout the transport. Dissolved O_2 level in the water is maintained at or above saturation, e.g. 8-12 mg L^{-1} at 26°C or slightly below. It is advised not to exceed a maximum fish density of 50 kg m^{-3} during transportation.

For handling and transfer, fish are anesthetized with 10-50 ppm clove oil (depending on the level of anesthesia required). The transfer of the fish is done using plastic bags. Once anesthetized, the fish can be weighed, measured, tagged, and sampled for assessment of sexual maturity. The gonadal sampling is accomplished by inserting a polyethylene catheter of 1.27 mm external diameter (0.97 mm internal diameter) into the genital pore (urogenital opening) of the fish (Figure 3).

Oocyte diameters larger than 500 µm are diagnostic of females in a mature spawning condition. Prophylactic treatments of 100 ppm formalin bath for 2-5 min followed by freshwater bath for

Figure 3. Gonadal sampling to determine sex and maturation stage.

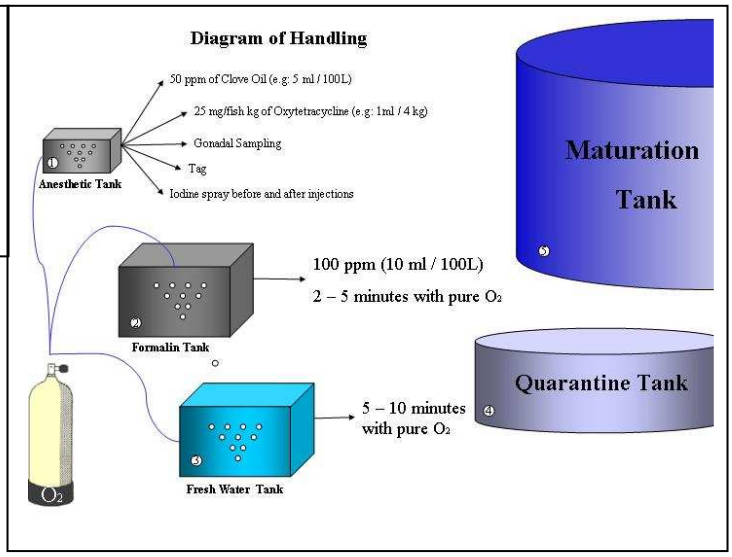

Figure 4. Photo and diagram explaining the handling procedures for transport and quarantine of cobia broodstock (modified from Cavalin 2005).

5-10 min are utilized before introduction of newly obtained broodstock into quarantine tanks (Figure 4). These treatments intend to remove any ecto-parasites from the gills and skin that may accompany fish from the wild and which could later proliferate and persist after transfer to the maturation tanks. A low concentration of clove oil (10 ppm) during the freshwater bath is enough to maintain an anesthetized state for ease of handling (Benetti and Feeley 1999). Detailed methods for capture, transport, sampling, transfer, acclimation, sampling, handling, as well as general prophylaxis and quarantine of marine fish including cobia were described by Benetti and Feeley (1999) and Benetti and Alarcón (2000).

Broodstock Management

The cobia maturation facility at the UMEH consists of two 80 m^3 circular fiberglass tanks stocked with 12-14 wild caught broodstock (6-20 kg) with a sex ratio of two males to one female. The total biomass of the tank ranges from 100 to 150 kg (1-2 kg m^{-3}). Even though previous report by Franks *et al*. (1996) and anecdotal evidence that male cobia are smaller than females, no differences in size between males and females have been detected so far.

An independent recirculating aquaculture system (RAS) is utilized for each maturation tank (Figure 5). Water exits from the center of the tank by gravity and is filtered through 300 µm bag filters before entering a sump which maintains the water level. From there a 2-hp pump pressurizes the system water (recirculated water as well as new water addition into the sump) through a glass media filter (used as a sand replacement) that is able to retain particles down to 5 µm, and then passed through a UV filter followed by a 8-hp heat pump for temperature control before returning to the tank. After passing through the heat pump, approximately 25% of the

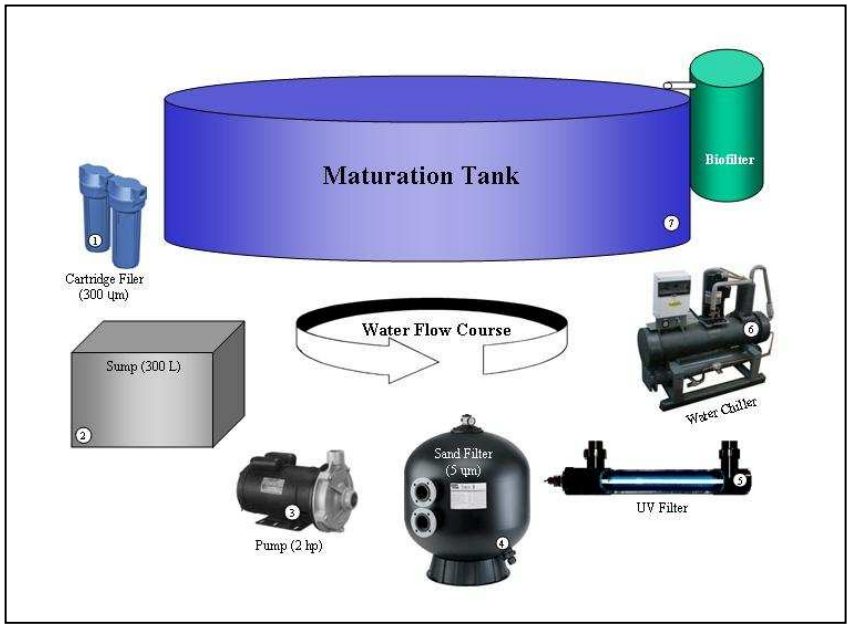

Figure 5. Schematic diagram of cobia maturation system at the University of Miami Experimental Hatchery (UMEH) (modified from Cavalin 2005).

pressurized flow is passed through a side loop consisting of a trickle biofilter and foam fractionator/protein skimmer before returning to the maturation tank.

Neon gobies (*Gobiosoma oceanops*) were stocked together with the broodstock fish in the maturation tank to act as a biological control for ecto-parasites. The successful use of Neon gobies as cleaner fish was reported for mutton snapper (*Lutjanus analis*) and greater amberjack (*Seriola dumerili*) (Zimmerman *et al*. 2001) and some interactions of cobia adults and neon gobies suggest that this may be useful for maintaining broodstock cobia.

The broodstock diet consists of artificial formulated feeds as well as squid, sardines and to lesser degree, shrimp. The amount of the food given to the fish is about 3-5% of biomass day^{-1}. Vitamin and mineral supplements are given every other day when frozen feed is used in order to complement any possible nutritional deficiencies in their diet.

Fish are conditioned to spawn by manipulating water temperature. By controlling the environmental conditions, spawns were obtained even shortly after capture. All spawns occurred naturally at temperature ranging from 24-30^{o} C during the natural reproduction season extending from March/April to September each year. In one occasion, when eggs were needed for stocking, a 9.8 kg female was induced to spawn via intra-muscular injection of human chorionic gonadotropin (HCG) at a dosage of 1000 I.U. kg^{-1}. The female spawned voluntarily in the tank around 32 h post-injection and fertilization occurred naturally. Approximately 1.5

million fertilized eggs were collected from this spawn.

Spawning behavior is displayed in cobia broodstock tanks quite frequently, but it becomes more active on the day of actual spawning event. Hydration of oocytes can be observed in matured females as early as 11 AM (late spring) as evidenced by extended area along the posterior abdomen. Spawning, the time when the female(s) release oocytes into the water column, occurs consistently shortly after sunset. In their pre-spawning ritual, often several male cobia can be seen literally trying to push the swollen female(s) out of the water. Fish are kept in spawning condition by maintaining tank temperatures between 25 and 28˚C. According to Arnold *et al*. (2002), 24-26°C is considered ideal for cobia in Texas and they may cease spawning at temperatures between 28 and 30°C. Similar maturation systems are used in Texas for holding and spawning cobia broodstock (Kaiser and Holt 2005). Other personal observations indicate that at lower latitudes such as S. Florida, Mexico, and Brazil, spawnings also occur in the 28-30°C range. In Puerto Rico and Mexico, cobia stocked in both submerged and floating cages for grow-out are often observed spawning naturally.

Collection, Incubation and Transport of Eggs and Yolk-sac Larvae

Eggs are collected from the maturation tank via a surface skimmer and 300-600 µm mesh screen bags, or tanks equipped with a similar screened standpipe. Eggs are taken out with a fine mesh net and brought to 1000-L incubation tanks also equipped with 500 µm mesh standpipes. Each spawning resulted in more than 1 million eggs with fertilization rates above 85%. The total volume of eggs is estimated using 2000 or 4000 ml graduated cylinders where the eggs are allowed to settle or float up. The current estimate of eggs per volume is 420 eggs ml^{-1} (J. Kaiser, Univ. Texas, personal communication). Both floating and settled (dead) eggs are counted to get an estimation of the total eggs spawned. After counting, the eggs are stocked in flow-through incubation tanks at a density of approximately 300-600 eggs L^{-1}. Eggs are then treated with 100 ppm formalin for one hour. A good indicator of potential egg quality and viability is the estimate of the percentage of eggs with irregular development in the first 1-2 h of cleavage.

Settled eggs are removed by siphoning several times during the morning after the spawning and during egg collection. A surface skimmer is installed to remove the protein and egg shells (chorion) from the surface. Chorion removal benefits from the tendency of egg shells to sink and early yolk-sac larvaes' tendency to remain in the upper area of the water column. Later separation of chorions from yolk-sac larvae may be more difficult as the larvae exhibit a more uniform distribution in the incubator tanks.

Yolk-sac larvae are used for experimental larval rearing at UMEH and/or shipped to private companies for production, or to university and research institutions for experimental trials. At temperatures above 27^{o}C, eggs hatch 21-24 h post fertilization and first feeding of larvae occur at 3 days post hatch (dph). Larval rearing is conducted both

intensively in tanks and extensively in a pond. Within 27 dph, fully weaned fingerlings measuring 4-6 cm and weighing 1 g are ready to be shipped out.

Although eggs can be shipped, it is not usually preferred primarily due to the fact that eggs may hatch during shipping, leading to water quality deterioration. Shipping 1-2-day-old yolk-sac larvae is the preferred method as the larvae appear to retain their oil globule (an energy reserve) at least two days after yolk-sac absorption. Table 1 summarizes some of the physical parameters utilized during shipments of yolk-sac larvae.

Larval and Juvenile Culture

At UMEH yolk-sac larvae are stocked (5-10 larvae L^{-1}) into 12-t circular fiberglass tanks (3.66 m diameter x 1.2 m deep). When available and as needed, live microalgae cultures of *Isochrysis* sp. and *Nannochloropsis* sp are added to larval rearing tanks to maintain the desired phytoplankton concentrations ("green water technique"). Enriched live rotifers (*Brachionus sp*.) are fed at 5-10 ml in 2-3 pulses per day accompanied by a decrease of water flow initially after addition. Overnight, flow is increased to wash-out excess metabolites released by larvae and live food organisms. Rotifers are fed for 3-7 days after first feeding (5 to 10 dph), depending on temperature. At 31ºC, cobia larvae were fed rotifers in the morning of the 3rd dph. At 5 dph, most larvae were able to capture and feed successfully on newly hatched nauplii of small sized *Artemia salina franciscana* (AF) strain. On 7 dph, larvae were able to feed on enriched 2nd-3rd instar meta nauplii of the larger sized *Artemia salina* Great Salt Lake (GSL) strain. A variety of different formulated enrichment diets for rotifers and *Artemia* meta-nauplii are available commercially which are prominently used in the Americas and the Caribbean regions.

Table 1. Results of three commercial-scale air-freight shipments of 200,000-300,000 yolk-sac larvae of cobia (2 and 3 days old).

	Control					Probiotics				
	Temp. (ºC)	D.O. (mg L^{-1})	pH	Density (# L^{-1})	Surv*	Temp. (ºC)	D.O. (mg L^{-1})	pH	Density (# L^{-1})	Surv*
5-20-06 Great Bay										
Initial	22-23	15-20	8.1-8.2	700		22-23	15-20	8.1-8.2	700	
Final	20-21	15-21	7.6-7.8	700	VH	20-21	15-20	7.6-7.8	700	VH
6-12-06 Great Bay										
Initial	27.9	15.4	8.6	700		28.0	16.3	8.6	700	
Final	25.0	24.0	8.3	700	L	25.0	24.0	8.3	700	L
6-23-06 Great Bay										
Initial	29.6	15.6	8.3	700		29.8	15.7	8.3	700	
Final	25.6	23.0	7.9	700	H	25.6	23.0	7.5	700	H

* Survival: L=low; H=high; VH=very high

The bottom of the larval rearing tank is siphoned as soon as possible after feeding has begun; this is generally 6-10 dph depending upon the degree of accumulation of debris and dead larvae. Since the swimming and perceptive capabilities of pre-flexion larvae are limited, care must be taken not to accidentally remove hundreds or thousands of larvae while siphoning the tank bottom.

Cobia metamorphose from a mainly cutaneous mode of respiration to gill respiration as early as 11-15 dph, depending on temperature. This metamorphosis could lead to respiratory distress and subsequent mortality. Therefore, an increase in air and water movement is recommended, with addition of pure oxygen, to ensure proper condition for maximal respiration. A circular air-ring around the base of the center standpipe can provide water movement to keep the very small fish moving in a controllable manner. Again depending upon temperature, cobia are weaned from 15-25 dph onto commercially available formulated feeds. This commences with the replacement of *Artemia* with formulated diets of 200-350 µm particle size. This meal-like feed size also serves the purpose as preliminary stimulant for the cobia's olfactory system towards formulated feeds. Weaning is then regularly achieved onto an approximately 0.5 mm slow sinking granular diet, followed by progressive increases of slow sinking crumble/pellets from 0.65 to 0.85 mm and later to 1.5 mm feed size. Once weaning is complete, grading becomes of paramount importance to minimize cannibalism, which can still lead to substantial mortalities at this stage. Once the fingerlings reach 1g, when graded by

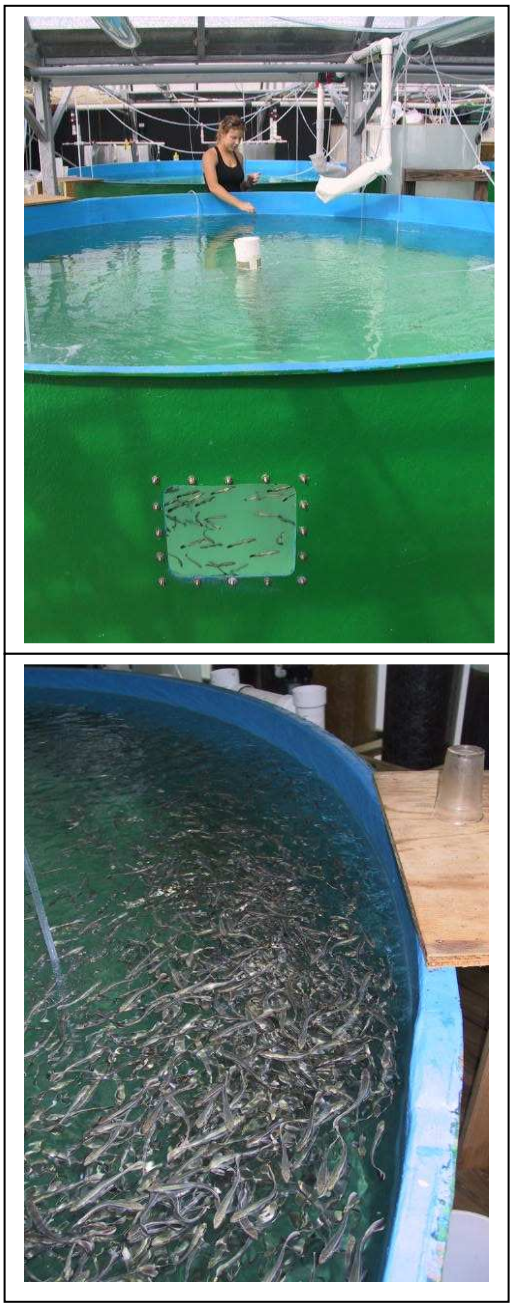

Figure 6. Feeding of cobia fingerlings at the University of Miami Experimental Hatchery (UMEH). Routine size grading and constant feeding at satiation are necessary to minimize cannibalism during post metamorphic and early fingerling stages.

size and are constantly fed, mortalities become negligible (Figures 6).

At 15 dph, an outbreak of bacterial (gill) infection was diagnosed requiring treatment with 20 mg L^{-1} oxytetracycline for 5 days. An additional 1 mg L^{-1} copper sulfate treatment for 5 days controlled an outbreak of *Amyloodinium ocellatum* during the third week post hatch. The ranges for temperature, dissolved oxygen, and pH were 28.7-30.1 ºC, 4.2-9.3 mg L^{-1}, and 7.9-8.3, respectively. At 27 dph, fingerling weight and length ranged from 0.1-0.9 g and 30-60 mm with an average stocking density of 1 juvenile L^{-1}. At 37 dph, 5,000 fingerlings averaging 2.6 g and 9 cm were shipped out, and the remainder were kept for feeding trials. In spite of the disease outbreaks, a total of 7,000 fingerlings were produced out of 100,000 yolk-sac larvae stocked in one 10-t tank. Survival rate at 37 dph with 2.6 g fingerlings was 7%. Multiple rearing trials have exemplified how susceptible cobia are to bacterial infection and ecto-parasitic infestation during early developmental stages; therefore, great attention has to be given to biosecurity during larval and juvenile production.

Other private hatcheries producing cobia fingerlings in the U.S. are the Aquaculture Center of the Florida Keys, Inc. (ACFK) in Florida and Great Bay Aquaculture LLC (GBA) in New Hampshire. These companies use different approaches to cobia larval rearing and fingerling production – both yielding good results. ACFK utilizes lower stocking densities of larvae per unit volume since large tanks (20-50 t) are available in its facilities. GBA, on the other hand, utilizes intensive, recirculating systems at higher stocking densities in less water volume. The technology of producing cobia fingerlings in hatcheries has been mastered and the demand from grow-out operators is in place in the Americas. Currently, new commercial hatcheries are being built and existing facilities are being modified to begin large-scale cobia fingerling production to accommodate the needs of an expanding industry that is expected to blossom in the near future.

Shipment of Juveniles/Fingerlings

Successful shipping of cobia juveniles conducted by commercial hatcheries suggest that the ideal size for shipping is approximately 0.5-1.0 g at biomass densities of around 4-5 kg m^{-3}.

Several small-scale shipping trials were conducted at UMEH during the summer of 2005 to develop a protocol for increasing biomass densities and lower water temperatures during shipment of cobia juveniles (1-5 g). In these trials, the use of formalin prophylactic treatments prior to shipping, and the effect of probiotic addition to the shipping water were also tested. In 2006, another series of small-scale shipping trials were conducted to test the effects of different buffers at varying concentrations, as well as the effects of different stressors that juvenile fish may face during packaging and shipping process.

Standard to all shipping trials was the addition of an ammonia blocker to the shipment water at a concentration of 0.5 g L^{-1}. Temperatures ranged from 14 to 22ºC and biomass densities up to 7 kg m^{-3} were tested. Before addition of the fish, dissolved oxygen levels of the

Table 2. Results of shipping trials of cobia juveniles at shipping temperatures of 14 and 18°C.

	Initial				Final			
	14°C		18°C		14°C		18°C	
	Box 1	Box 2	Box 1	Box 2	Box 1	Box 2	Box 1	Box 2
Temperature (°C)	14.4	14.4	18.2	18.0	9.9	9.9	15.9	15.8
D.O. (mg L^{-1})	23.5	24.3	24.1	23.7	11.5	10.9	9.9	10.4
Biomass Density (kg m^{-3})	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Survival (%)					0	0	100	100

shipping bags were increased to more than 200% saturation; air within the shipment bags was replaced with pure oxygen. The boxes were then opened the following day after a time period ranging from 12 to 20 h.

In summer 2005 trials, the first trial focused on the feasibility and survivability of decreased shipping temperatures (Table 2). Low biomass densities were utilized in order to prevent the compounding affect of high biomass density induced stress and temperature stress. Survival was 0% at 10ºC while it remained at 100% at around 16ºC, indicating shipping juvenile cobia at 16-18ºC is acceptable, but lowering the temperature below this level seems to cause too much physiological stress for the juveniles.

The next trial tested the ability of juvenile cobia to withstand increased shipping biomass. Biomass density of 3.33 kg m^{-3} was used as a control, while the treatment doubled this density to 6.67 kg m^{-3} (Table 3). Survival was 100% for both treatments, indicating that juvenile cobia are able to withstand higher shipping biomass densities than previously utilized.

A third trial was conducted to determine survivability of juvenile cobia

Table 3. Results of shipping trial of cobia juveniles at different biomass densities.

	3.33 kg m^{-3}		6.67 kg m^{-3}	
	Initial	Final	Initial	Final
Temp. (°C)	18.1	19.1	18.4	19.8
D.O. (mg L^{-1})	24.5	10.5	24.4	7.3
pH	6.96	7.6	7.0	7.4
Biom. Density (kg m^{-3})	4.2	4.25	7.1	7.12
Survival (%)		100		100

Table 4. Results of shipping trial of cobia juveniles with or without prophylactic formalin treatment (100 ppm) prior to shipping.

	Control		Formalin	
	Initial	Final	Initial	Final
Temp. (°C)	17.8	20.2	18.0	20.4
D.O. (mg L^{-1})	27.2	12.7	27.4	11.8
O_2 Saturation (%)	350	173	352	162
pH	7.8	7.3	7.7	7.2
Biom. Density (kg m^{-3})	5.8	5.8	5.6	5.6
Survival (%)		100		97

to prophylactic treatments of formalin (100 ppm) for one hour prior to temperature acclimation and subsequently shipping. Survival was 97% and 100%

Table 5. Effects of different stress interactions on juvenile cobia during shipment.

(Buffer Used)	Treatment 1 (Base Tris)		Treatment 2 (Fish Tris)		Treatment 3 (Fish Tris)		Treatment 4 (Fish Tris)	
Temperature Acclimation	No		No		No		Yes	
Anaesthetic Used	No		No		Yes		Yes	
	Initial	Final	Initial	Final	Initial	Final	Initial	Final
Temperature (^{o}C)	19.8	23.2	17.8	22.9	17.9	22.1	18.4	24.2
D.O. (mg L^{-1})	17.2	6.5	25	13.1	21.6	11.8	22.5	7.4
pH	8.7	8.2	8.4	7.5	8.4	7.4	8.4	7.3
NH_3 (mg L^{-1})*	-	18	-	21	-	26	-	25
Biomass Density (kg m^{-3})	5.4	-	5.7	-	7.5	-	6.5	-
Survival (%)		82		100		92		100
Gasping at water surface		Yes		Some		Some		No
Responsiveness**		Poor		Good		Good		Very Good

* High levels due to tris interactions with ammonia test (salicylate method).
** Response to approaching airstone.

for the treatment and the control group, respectively (Table 4). Biomass densities were also elevated to near 6 kg m^{-3} during this trial, reinforcing the previous results of the feasibility of increasing shipping biomass density.

In the summer 2006 shipping trials, different buffers were analyzed in order to maximize survival during shipping. These include Tris Base (pH 8.7) and a pre-set Tris Buffer Fish Grade (pH 8.3). Acclimation procedures varied from trial to trial in order to test this stressor, although all acclimations included the use of pure oxygen in order to ensure oxygen remained at saturation. Survival was lowest using the Tris Base as buffer (Treatment 1, Table 5). Upon opening of the boxes and re-acclimation to ambient temperature (approximately 30°C), fish in all treatments, except treatment 4, were observed to gasp at the water surface. Normal fish responsiveness to objects (approaching airstone) was observed in all treatments except those from treatment 1.

Juvenile Feeding Trials

Feeding experiments were carried out to better ascertain growth differences of cobia juveniles in relation to varying levels of dietary protein and lipid. Grow-out trials with cobia juveniles (1.5 to 110 g) were conducted at the UMEH to evaluate three different slow sinking finfish diets manufactured by U.S. feed companies. The protein and lipid formulations of the feeds differed among the two trials: Trial 1 - 50% protein and 15% lipid; and Trial 2 - 42% protein and16% lipid.

Feeding trials were conducted in 1.8-t (1.8 m diameter) indoor flow-through tanks. Ambient seawater was filtered to 5µm and salinity ranged from 32 to 36 g L^{-1} throughout the duration (3-6 weeks) of the trials. Water exchange rates ranged between 500 and 1,500% day^{-1}. Vigorous aeration was provided and supplemental oxygen ensured dissolved oxygen levels maintained near saturation

Table 6. Results of feeding trials on cobia juveniles using diets with different protein and lipid contents.

	Summer 05		Summer 06		
Feed Type	50% Protein 15% Lipid		42% Protein 16% Lipid		
Culture Period	22 days		35 days		
Temp. (^{o}C)	28.6 - 32.5		18.5 - 24.1		
Tank #	B1	C2	B2	C1	C2
IW (g)	30.2	30.1	21.4	21.4	21.3
FW (g)	95.8	62.2	17.0	27.9	37.7
ISD (g L^{-1})	0.265	0.230	0.066	0.395	0.537
FSD (g L^{-1})	1.1	1.3	0.4	1.4	1.7
WG (%)	307	461	476	266	214
SGR(%)	19	18	12	14	15
IDR	160	270	53.6	300	300
FDR	450	600	120	500	500
FCR	0.69	0.71	0.81	0.89	0.84

IW: initial weight
FW: final weight
ISD: initial stocking density = (# of fish x IW)/tank volume
FSD: final stocking density = (# of fish x FW)/tank volume
WG: weight gain = (FW-IW)/IW x 100
SGR: specific growth rate = 100 x ln(FW/IW)/culture period
IDR: initial daily ration
FDR: final daily ration
FCR: food conversion ratio = total feed consumed/WG

throughout the experiments. Temperature (Table 6) regimes differed among the trials due to seasonal fluctuations. Fish were fed continuously throughout the day (0800 hrs to 1700 hrs) via automatic belt feeders. Average fish size and biomass density differed in the individual tanks both within and between trials (except trial 3) due to prior grading of fish into similar size classes (Table 6). Thus, different feed sizes were used for each

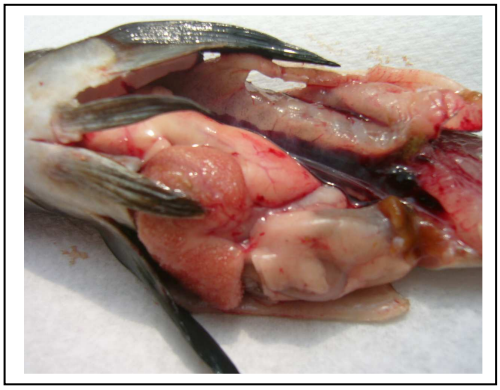

Figure 7. Excessive intraperitoneal fatty deposits in juvenile cobia.

trial: 1.5-4.0 mm for Trial 1; and 1.5-3.0 mm for Trial 2.

Table 6 shows a summary of the data on temperature, biomass, growth, feeding ratio, and food conversion ratios (FCR). Exponential growth functions were fit to the growth weight data. The differential temperature regimes influenced the instantaneous growth coefficients for weight of the exponential regressions; the winter of 2006 trial growth coefficients (tank B1 = 0.0499, tank C1 = 0.0372, tank C2 = 0.0331) were substantially lower than those computed for the summer of 2005 trial exponential fits (B1 = 0.0678, C2 = 0.0814). Specific growth rates (SGR) were high for both trials and FCRs were very low. SGR was suppressed during the winter trial while FCR exhibited an opposite trend of suppression during the summer trial. The two diets were well accepted by the juvenile cobia of the size range used in the trials, as there were no obvious indications of feed rejection. Survival throughout both trials was high with the lowest survival rate being 97.2% during the winter 2006 trial. Mortalities that did

occur seem not to be related with nutritional problems.

Diets containing 44.5% protein have been found to optimize growth of cobia (Chou *et al.* 2001). The diets tested in these trials contained 50 % and 42% protein for the summer and winter trials, respectively. Lipid levels of 5.8% were estimated to promote maximal growth and further increases in lipid levels do not seem to improve growth (Chou *et al.* 2001). The diet formulations contained relatively high percentages of lipid (15% for the summer trials and 16% in the winter trials). It has been suggested that lipid levels above 15% negatively affect growth of cobia juveniles (Wang *et al*. 2005). Significant increases in muscle and liver lipid levels, viscera somatic index, intraperitoneal fat ratio, and hepatosomatic index occur as dietary lipid levels increased from 5 to 15% (Wang *et al.* 2005). Although no investigation of the intraperitoneal cavity was conducted in the summer 2005 trials, observations of individuals from the winter 2005 Trial 2 revealed substantial fat deposits around the gastrointestinal tract and within the intraperitoneal cavity (Figure 7). Discoloration of the liver of these individuals also suggested that dietary lipid levels were probably too high for cobia juveniles (Zink et al. 2006).

The aquaculture performance of juvenile cobia in these preliminary trials - expressed in growth, survival and food conversion rates - was excellent. High growth rates and low feed conversion ratios ($\leq$ 1) were observed, higher even than those observed in the study conducted by Wang *et al.* (2005) which utilized lower biomass densities (0.15 g L^{-1} initial stocking density) than the current trials (Table 6). These observations seem to indicate that the tested feeds were high quality, palatable products that promoted high growth rates during grow-out of juvenile cobia.

Semi-Intensive Larval Rearing and Pond Production of Juveniles

During the spring of 2005, a semi-intensive larval rearing trial of cobia was carried out in a 1,000 m^3 saltwater pond (0.25 acre in area; Figure 8). The pond was gradually filled with 150 μm filtered seawater over the course of several days in order to produce a phytoplankton bloom that would support secondary production of zooplankton; organic and inorganic nutrients used ensured adequate nutrient availability for the phytoplankton. Zooplankton tows from nearby coastal waters provided the zooplankton inoculate; the natural zooplankton bloom was augmented with 2^{nd} instar *Artemia* nauplii.

Shortly after hatching, 500,000 yolk-sac larvae were stocked to achieve a stocking density of 0.5 larvae L^{-1}. Initial water exchange was 5% day^{-1}; this was increased at 7 dph to 15-20% day^{-1}. Water quality data, inorganic nutrient analysis, and short zooplankton tows were conducted daily in order to monitor the extensive pond system. Ranges of water quality parameters during the rearing period were 28-33.5^{o}C (temperature), 4.9-9.5 mg L^{-1} (D.O.), and 8.1-8.7 (pH).

During the third week of stocking, an estimated 50,000 (0.5-1.0 g) were estimated to be alive in the pond. At 22 dph, a partial harvest yielded 10,000

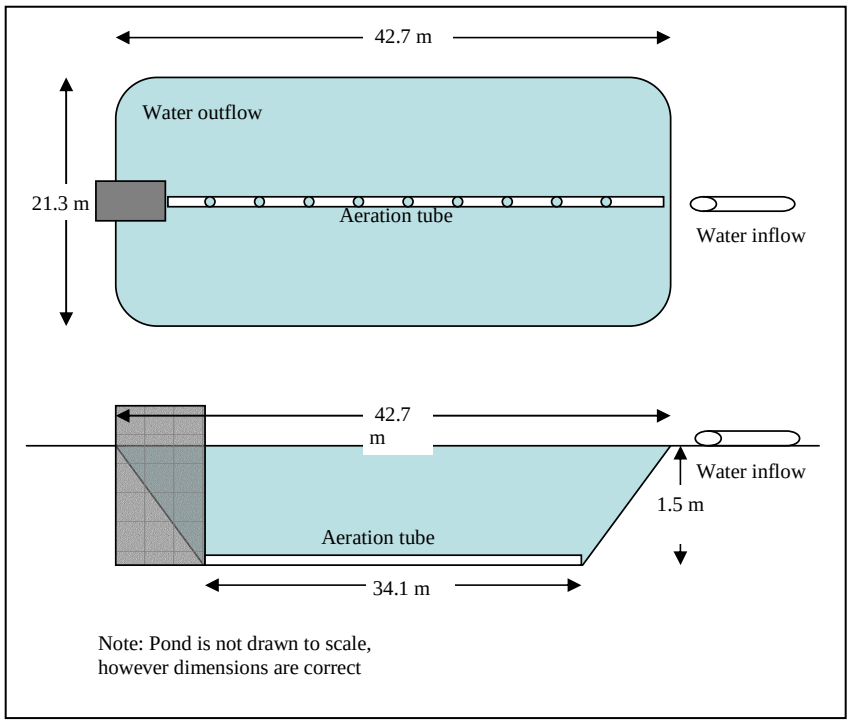

Figure 8. Schematic diagram of the pond system used for semi-intensive larval rearing of cobia.

Figure 9. Harvesting of cobia fingerlings from the pond.

fingerlings with mean weight of 1.142 g (Figure 9). The final harvest was carried out approximately a week later at 28 dph; this harvest yielded fewer fingerlings than expected, most likely due to high cannibalism that commenced during the fourth week of culture. It is therefore suggested to harvest the extensively raised fingerlings and subsequently stock them in tanks before weaning is completed, in order to exert more control over the weaning process. A total of approximately 15,000 fingerlings were harvested in this trial, with final survival estimated at 3%.

Cobia Grow-out in Open Ocean/Offshore Cages

Snapperfarm, Inc. in collaboration with the University of Miami Aquaculture Program has been conducting an open ocean aquaculture demonstration project off the coast of Culebra, Puerto Rico since the summer of 2002 (Figure 10). During this period, the company developed state of the art technology for the environmentally sustainable commercial production of marine fish in submerged open ocean cages. Recently, the company completed harvesting its third consecutive commercial crop of cobia and has its fourth, fifth and sixth crops in the water. Several tons of fresh cobia have been weekly harvested from the company's cages during the past years. The fine dining fish are harvested, processed, and packed in San Juan, Puerto Rico, then sold to markets in St. Thomas, San Juan, Miami and New York, in the USA.

Snapperfarm utilizes two different types of open ocean submersible cage systems. First is the SeaStation 3000 (Figure 11A) manufactured by Ocean

Figure 10. Cobia are raised in crystal-clear Caribbean waters in Snapperfarm's submerged cages off Culebra Island in Puerto Rico, USA.

Spar Technologies, L.L.C., a bi-conical design constructed of a steel rim and central spar covered by a Dynema™ net. It is 15 m deep, 25 m diameter, and a total useable volume of 2,700 m^3. Second is the Aquapod 3250 (Figure 11B) manufactured by Ocean Farm Technologies, Inc. It is essentially a geodesic sphere constructed of modular panels made of fiberglass reinforced plastic and covered by vinyl coated galvanized steel mesh. The total diameter of the cage is 20 m and useable volume is 3,251 m^3.

The demonstration project is unique in the Western hemisphere in respect to the species of fish being cultured. Snapperfarm's open ocean aquaculture operation is producing cobia with extraordinary growth rates, survival, and feed conversion rates with no significant environmental impact. Snapperfarm has successfully raised cobia from a 1.5 g fingerling to 6 kg in approximately 12 months (Figure 12) with a food conversion ratio (FCR) of 2.0 and survival over 75%.

Results of this project show that properly sited, planned and managed, open ocean aquaculture operations can produce significant quantities of high quality seafood without causing significant environmental impact. In fact, data from independent studies on environmental assessment being conducted by the University of Puerto Rico and University of Miami (reports are available at www.snapperfarm.com) and funded by the U.S. government (NOAA/Sea Grant) indicate that no significant impact has been detected in the oceanic waters surrounding the cages. This also suggests that future expansion of the operation can be allowed while maintaining environmental sustainability.

Snapperfarm has proven that growth of cobia in offshore submerged cages is technologically feasible and environmentally sustainable; the goal now is to demonstrate the economic viability of offshore aquaculture. The company is in the process of expanding the operation from the current three-cage demonstration phase to an eight cage commercial operation using submerged cages in exposed sites.

The University of Miami and the University of Puerto Rico conducted environmental monitoring in both operations. Sampling stations were set up at different distances and directions from the fish cages. Possible eutrophication of the local environment was evaluated monthly by measuring dissolved nitrogen and phosphorus, phytoplankton biomass, epiphyte growth potential, sinking flux of organic matter into sediment traps, organic content of the sediments, and benthic microalgal biomass. In all cases, no significant differences were found as a function of distance from the cages or relative to upstream-downstream direction. Environmental data from Puerto Rico and the Bahamas indicate that the current regime and resulting dilution of nutrients from the submerged cages do not lead to a significant change in the ecosystem near the cages (Figure 13).

Within stocking densities ranging from 5-15 kg m^{-3}, evidence to date indicates that cobia's growth, mortality and food conversion rates (FCR) are directly related to stocking densities. Growth and survival rates decrease dramatically at higher stocking densities.

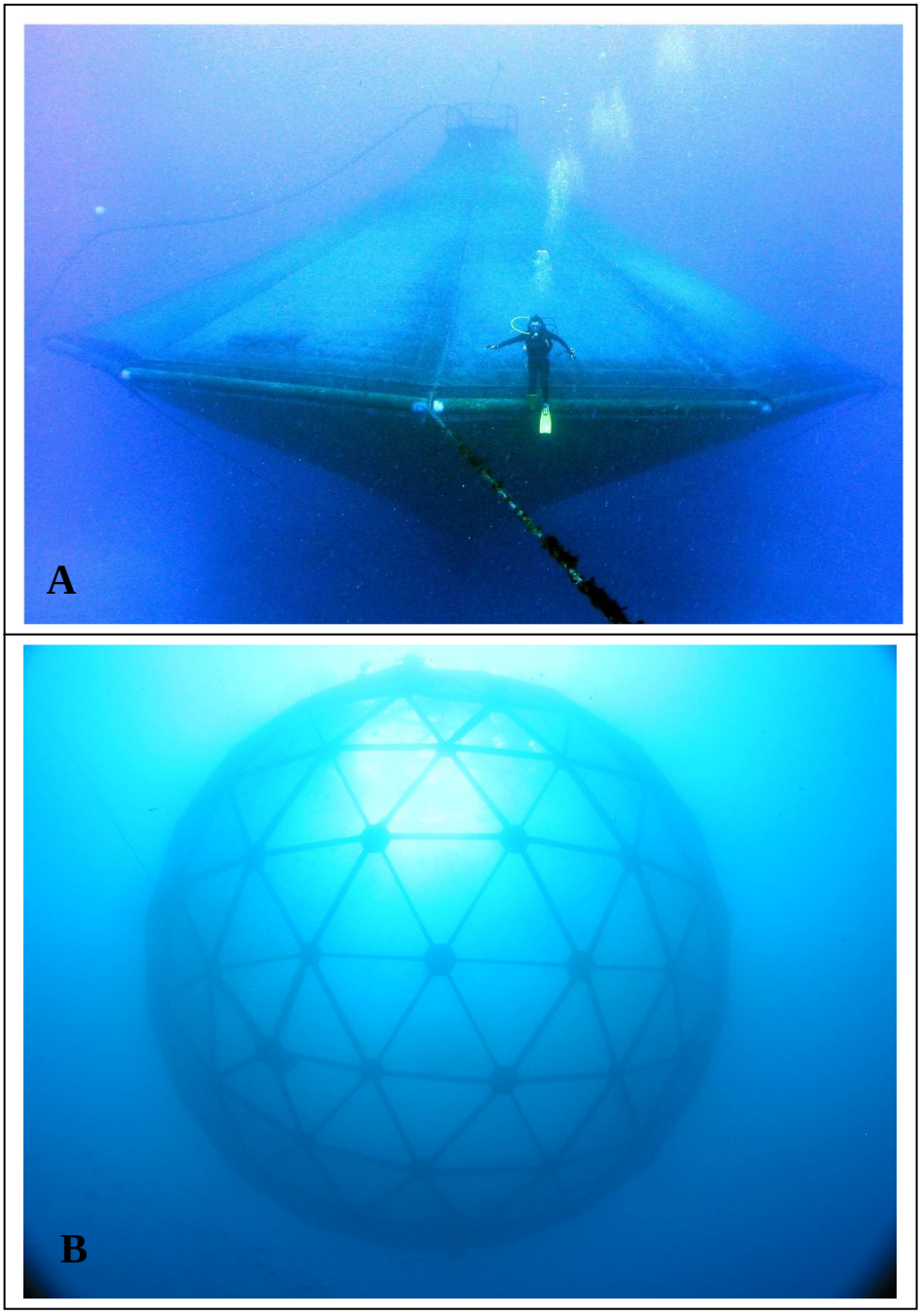

Figure 11. Snapperfarm utilizes advanced grow-out submersible off-shore cages such as the SeaStation™ with usable water volume of 2,700 m^3 (A) and the Aquapod™ with usable water volume of 3,500 m^3 (B).

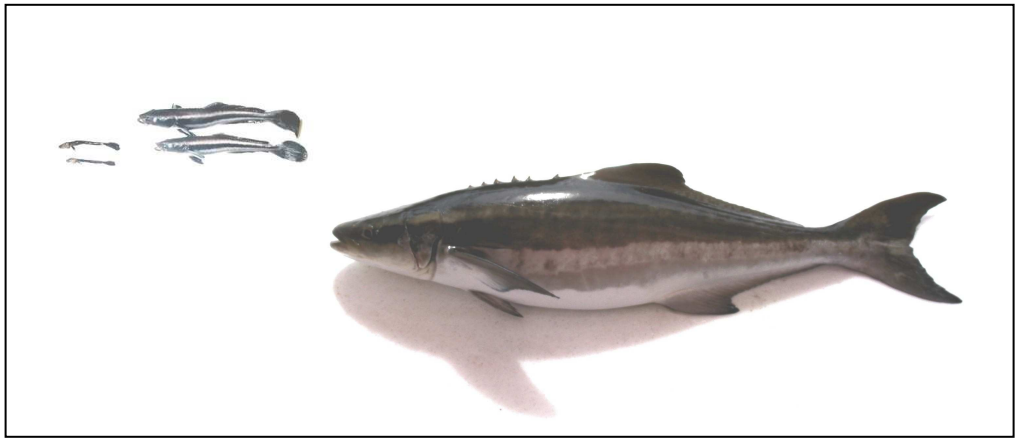

Figure 12. Cobia are stocked in Snapperfarm's submerged cages at 1.5g (left), grow to 20g after 20 days in nursery (middle) and 6kg after 300 days of grow-out (right). (Photo courtesy of Snapperfarm, Inc.).

Figure 13. Snapperfarm is successfully operating with no significant environmental impact as demonstrated by the clean, healthy white sand below one of its fully stocked cages.

As a consequence, FCR increases and smaller fish (≤ 4 kg) command lower market demand and price. Under ideal conditions (i.e., at low stocking densities and adequate temperature range of 26-30^{o} C), cobia exhibit extraordinary growth (4-6 kg in 12 months), yielding 1 kg of fish biomass when fed 1.8 kg of pellets containing 50% fish meal (FCR = 1.8). Taking into account that energy loss between trophic levels in nature results in an ecological efficiency of only around 10%, our data shows that using fishmeal to produce high-value fish for human consumption in aquaculture can be 3.7 times more efficient than this transformation in nature. The commercial, social, economic, technological and environmental prospects of expanding the industry to large-scale in the Americas and the Caribbean regions in the near future seem extraordinary.

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