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First juvenile production of Florida Pompano (*Trachinotus carolinus*) through captive reproduction and larval rearing in southeastern Mexico

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ABSTRACT. The Florida Pompano (*Trachinotus carolinus*) is an emerging species for marine aquaculture due to its rapid growth, high market value, and adaptability to captive conditions. However, the reliable production of hatchery juveniles remains a major bottleneck limiting commercial expansion. The present study evaluated the technical feasibility of captive reproduction, larval rearing, nursery rearing, and juvenile production of *T. carolinus* under tropical hatchery conditions. A captive broodstock maintained for over 3 years was hormonally induced with human chorionic gonadotropin (hCG), resulting in successful volitional spawning and the production of fertilized eggs. Larvae were reared under green-water conditions using *Nannochloropsis* sp., enriched rotifers (*Brachionus plicatilis*), and *Artemia salina* nauplii and metanauplii, followed by progressive co-feeding with microdiets. Mouth opening occurred at 3 days post hatching (dph), notochord flexion at 10 dph, and metamorphosis at 23 dph. Early juveniles reached an average body weight of 0.9 ± 0.4 g at 30 dph and were subsequently transferred to nursery systems, where high survival and sustained growth were maintained. Overall, viable juveniles were produced, demonstrating that *T. carolinus* hatchery technology can be successfully implemented under tropical conditions. These findings provide a practical foundation for juvenile supply and support the expansion of *T. carolinus* aquaculture in the Gulf of Mexico and Caribbean region.

Key words: breeding, Florida Pompano, hatchery development, juvenile production, larviculture, *Trachinotus carolinus*, tropical hatchery.

INTRODUCTION

Over the past 50 years, carangids (jacks and pompanos) have received attention as potential candidates for aquaculture in various regions of the world (Honebrink 2000, Na-Nakorn et al. 2023). Pompanos are a group of marine teleosts that includes a diverse array of 20 commercially important species in tropical and subtropical regions (Zhenzhen et al. 2014, Smith-Vaniz and Walsh 2019), at least 4 species of which are important for aquaculture (Na-Nakorn et al. 2023) in countries such as the United States, Mexico, Taiwan, and Indonesia. Most work in the United States has focused on the Florida Pompano (*Trachinotus carolinus*; Linnaeus 1766), Permit (*Trachinotus falcatus*), and Palometa (*Trachinotus goodei*) (Honebrink 2000). The potential of *T. carolinus* aquaculture has been studied since the 1950's (Weirich et al. 2021), and substantial progress in juvenile production and farming technology was achieved in the United States during the 1970's (McMaster et al. 2003). Unfortunately, the production of a reliable supply of juveniles to stock grow-out operations has limited the commercial culture of this species (Riley et al. 2009).

Trachinotus carolinus is one of the most promising carangid candidates for aquaculture due to its rapid growth, high market value, desirable flesh quality, acceptance of formulated feeds, and adaptability to a wide range of production systems, including tanks, ponds, cages, and offshore net pens (Weirich et al. 2021). Despite notable advances in farming technology, especially in the United States, the reliable supply of hatchery-produced juveniles remains one of the principal

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bottlenecks limiting the commercial expansion of *T. carolinus* aquaculture (Riley et al. 2009, Weirich et al. 2021). Consequently, the development of reproducible hatchery protocols for captive reproduction, larval rearing, nursery rearing, and juvenile production in different regions remains essential for scaling commercial production. Despite its recognized potential as a high-value marine aquaculture species, the cultivation of *T. carolinus* remains limited at pilot and commercial scales and is still in an early stage of development (Weirich et al. 2021, Morgan et al. 2024).

Reproductive dysfunction under captive conditions frequently limits seed production in marine finfish hatcheries, often requiring hormonal induction to stimulate final oocyte maturation, ovulation, spawning, and spermiation (Zohar and Mylonas 2001). Although the use of gonadotropin-releasing hormone agonists (GnRHa) has become widely accepted in captive fish reproduction (Weirich and Riley 2007), mammalian human chorionic gonadotropin (hCG) continues to be used in many pompano hatchery programs because of its commercial availability, low cost, chemical stability, and effectiveness when broodstock exhibit advanced gonadal development (Table 1).

Currently, in marine hatcheries, GnRHa-based therapies are widely recognized as the standard approach for reproductive induction by activating the hypothalamic–pituitary–gonadal axis (Mylonas and Zohar 2001, Zohar et al. 2022). Nevertheless, hCG remains operationally relevant in aquaculture because of its direct gonadotropic action during advanced ovarian development and its proven effectiveness in several marine fishes, including pompanos (Kloth 1980, Main et al. 2007, Gopakumar et al. 2012, Ranjan et al. 2018, Wills et al. 2023). However, hCG has proven to be a technically feasible and practical alternative for *T. carolinus* broodstock management, particularly in emerging aquaculture regions where GnRHa availability may be limited or economically restrictive.

Pompano larviculture remains one of the principal bottlenecks in marine fish hatchery production due to the high physiological sensitivity of larvae during first feeding, organogenesis, and metamorphosis. Consequently, successful Pompano larval rearing requires careful coordination of larval stage, prey size, nutritional quality, and environmental stability to ensure optimal survival and growth (Riley et al. 2009, Ma et al. 2014a, Ma et al. 2014b). In Mexico and Latin America, one of the main limitations for the expansion of *T. carolinus* aquaculture is the lack of standardized protocols for reliable juvenile production under hatchery conditions. Therefore, the present study evaluated the technical feasibility of captive reproduction, larval rearing, and juvenile production of *T. carolinus* under hatchery conditions in southeastern

Table 1. Reproductive conditions and spawning performance reported for *Trachinotus* species.

Species	Sex ratio (F:M)	Weight (kg)	Temperature (°C)	Hormone	Dose	Spawning time (h)	Source
Trachinotus mookale	1:2	2.84 ± 0.10	29 ± 1	hCG	350 IU·kg^{-1}	36–38	Ranjan et al. (2018)
Trachinotus blochii	1:3	1.7–2.2	26.5–29	hCG	350 IU·kg^{-1}	30–36	Gopakumar et al. (2012)
Trachinotus carolinus	1:1		28	hCG	1,900 IU·kg^{-1}	24–26	Hoff et al. (1972)
	1:4		26–28	hCG		32.5	Kloth (1980)
		1.2–1.7	28	hCG	1,000 IU·kg^{-1}	40–48	Main et al. (2007)
				hCG	830 IU·kg^{-1}		Wills et al. (2023)
	1:4	1.6–1.4	27 ± 5	hCG	1,000 IU·kg^{-1}	34–36	Present study (2025)
	1:1	1.3–0.7	24–26	GnRHa	75 µg	36	Weirich et al. (2006)
	1:1	1.0–1.6	24–26	GnRHa	75 µg	30–36	Weirich and Riley (2007)
	1:1		24–26	GnRHa	75 µg	36	Riley et al. (2009)
			24–26	GnRHa	75 µg	36	Weirich et al. (2021)

(*continued on next page*)

Table 1. (*continued*)

Species	Eggs collected ($\times 10^6$)	Egg density (eggs·mL^{-1})	Fertilization (%)	Total egg production (eggs·female^{-1})	Eggs per female body weight (eggs·kg^{-1})	Source
Trachinotus mookale			69 ± 1.55			Ranjan et al. (2018)
Trachinotus blochii	0.08–0.184		75–95			Gopakumar et al. (2012)
Trachinotus carolinus	0.007–0.009					Hoff et al. (1972)
			52			Klot (1980)
	5.3		19.3–48.2			Main et al. (2007)
	4.4–5.8					Wills et al. (2023)
	0.5	848 ± 68.4	94.1	261,640 250,100	174,427 166,733	Present study (2026)
	2.9 0.9 0.8		86.8 71.3 87.3	174,200 230,300 123,000	131,500 109,600 88,000	Weirich et al. (2006)
			22.0–81.8	123,000– 772,000		Weirich and Riley (2007)
						Riley et al. (2009)
			>90%			Weirich et al. (2021)

Human chorionic gonadotropin (hCG); gonadotropin-releasing hormone agonists (GnRHa).

Mexico. Specifically, the study aimed to establish a hormonal induction protocol for captive broodstock conditioning, adapt existing larviculture protocols, evaluate nursery performance, and support the development of a reliable juvenile supply for future commercial aquaculture of the species.

Materials and methods

The present work was developed in the Laboratory for Marine Finfish Reproduction and Hatchery UMDI-Sisal (LARPEM) of the Faculty of Sciences of *Universidad Nacional Autónoma de México* (UNAM). The facility is located 25 km from Hunucmá and 63 km northwest of Mérida, Yucatán, on the northern coast of the Yucatán Peninsula, Mexico (21°09′50″N, 90°02′53″W). The captive reproduction of *T. carolinus* comprised 2 areas: an outdoor grow-out facility where broodstock was developed and an indoor workroom where larviculture and nursery rearing took place. All procedures were approved and conducted in accordance with the guidelines and regulations of the Institutional Animal Care and Use Committee and Ethics Committee of the Faculty of Sciences, UNAM (registration numbers: 11122025 and 2220126).

In both captive reproduction areas, water quality variables, including salinity, temperature, and dissolved oxygen, were monitored daily, whereas total ammonia nitrogen (TAN), nitrite, pH, and alkalinity were measured weekly. Dissolved oxygen and temperature were recorded using an Ecosense DO200A multiparameter probe (Yellow Springs Instruments, Yellow Springs, USA), and salinity was measured with a Scientific CTX-2 refractometer (Vee Gee Scientific, Inc., Vernon Hills, USA). Nitrite, TAN, pH, and alkalinity were determined using an HI3826 seawater test kit (Hanna Instruments, Woonsocket, USA). The natural photoperiod was maintained throughout the breeding program, with a 12:12 h light:dark cycle during spring and a 14:10 h light:dark cycle during summer.

Broodstock

In May 2023, *T. carolinus* (458.2 ± 226.8 g; n = 15) were collected along the coast of Sisal, Yucatán, Mexico using cast

nets and transported to the laboratory. The captured individuals were fed a semi-moist diet formulated with fishmeal and chemical silage of fish waste and supplemented with vitamins and minerals. The diet contained 45% protein, 10% lipids, and 30% carbohydrates. The chemically produced silage from White Grunt (*Haemulon plumieri*) processing waste was prepared according to the method of Gallardo et al. (2012) and modified by Cruz-Lopez et al. (2025). During the reproductive maturation period, the semi-moist diet was supplemented with fresh Humbold Squid (*Dosidicus gigas*) and Pacific White Shrimp (*Litopenaeus vannamei*), provided twice daily, 3 days per week, at 1.5–2.0% of the tank biomass.

The progression of gonadal maturation in females was based on the distribution of oocyte diameters. To assess gonadal maturation, fish were anaesthetized with 100 g·mL^{-1} of tricaine methanesulfonate (MS-222; Syndel, Ferndale, USA) for 3–4 min or until opercular movement was substantially reduced. Gonadal tissues were collected by biopsy using catheter tubing (internal diameter: 0.86 mm; outer diameter: 1.32 mm) (Aquatic Eco-Systems Inc., Apopka, USA) and examined under a C×L binocular compound microscope (Labomed, Los Angeles, USA) with an A35140U 4-pixel camera (OMAX Microscopes, Kent, USA) for morphometric analysis. Based on the observation of gonadal maturation, fish were categorized into reproductive maturity stages, and 2 groups were established (i.e., experimental and stock). The reproductive stages were classified as sub-adult (sexually immature fish with undeveloped gonads), maturing females (primary-growth oocytes <100 µm in diameter), mature female (gonads containing independent oocytes 300–500 µm in diameter), and mature males (oozing milt). All individuals were weighed (body weight [g]) and measured (total length [cm]) during every maturation assay. Fulton's condition factor (*K*) was calculated following the method of Anderson and Neumann (1996).

Five spawning trials were conducted with the experimental group of *T. carolinus* broodstock (Fig. 1). During the 2023 spawning season, 2 trials were performed using hCG (Choriomon; IBSA Group, Lugano, Switzerland). During the 2024 season, 1 trial using hCG and 1 trial without hormonal induction (using only salt solution) were conducted. During the 2025 season, 1 trial was conducted using sexually mature females containing vitellogenic oocytes (mean diameter > 450 µm) and spermiating (oozing) males selected for hormonal induction. The sex ratio (female:male) used in the induced spawning trials was 1:4. Selected individuals were administered a single high dose of hCG (females: 1,000 IU·kg^{-1}; males: 500 IU·kg^{-1}) and stocked together in the same tank (500 L) for spawning. The hormonal doses were selected based on previous studies conducted with other pompano species (Table 1). All injections were administered intramuscularly, approximately midway between the lateral line and the first dorsal fin spine between 15:00 and 18:00 h (Fig. 1).

The spawned eggs were collected from the 500-L tanks by passing the surface water through a mesh screen (500 µm) positioned below the outflow of the spawning tank. The eggs were removed from the collectors using a scoop net 8 h after spawning during the embryo somitogenesis stage. The total number of eggs from each spawning was determined, and the eggs were stocked in an aerating tank for incubation and hatching.

Larviculture

Floating and sinking eggs were quantified volumetrically, and only viable floating eggs (egg diameter: 917.4 ± 38.6 µm; oil droplet diameter: 244.9 ± 13.4 µm) were used. Incubation (200 mL of eggs [~169,600 eggs]) and larval rearing (84.8 eggs·L in 2,000 L) were conducted in cylindrical fiberglass tanks (5 m^3) with black, non-reflective walls and white bottoms. Seawater was treated by sand filtration, multi-cartridge filtration (1 µm), and UV sterilization (UVA-24B [24 gpm]; Polaris Scientific, Chino Hills, USA). During incubation and larval culture, temperature was maintained at 28.1 ± 0.5 °C, dissolved oxygen at 5.1 ± 0.4 mg·L^{-1}, salinity at 36.5 ± 0.5 g·L^{-1}, alkalinity at 3.4 ± 1.5, pH at 7.6 ± 0.1, nitrate at 2.0 ± 0.1 mg·L^{-1}, and TAN at 0.1 ± 0.2 mg·L^{-1}.

A larviculture protocol was implemented that included seawater quality monitoring, environmental control, tank cleaning, feeding, and continuous behavioral observations (Morgan et al. 2024). Microalgae were added as part of the rearing protocol, and live food was provided using semi-continuous systems for rotifers (*Brachionus plicatilis*), following the method of Rojo-Cebreros et al. (2017), and artemia (*Artemia salina*). Larvae were reared with continuous



Figure 1. Spawning induction of Florida Pompano (*Trachinotus carolinus*) with mammalian human chorionic gonadotropin (hCG) (Choriomon; IBSA Group, Lugano, Switzerland). Single-dose hormonal induction (1,000 IU·kg^{-1} for females and 500 IU kg^{-1} for males) during the 2023–2025 seasons.

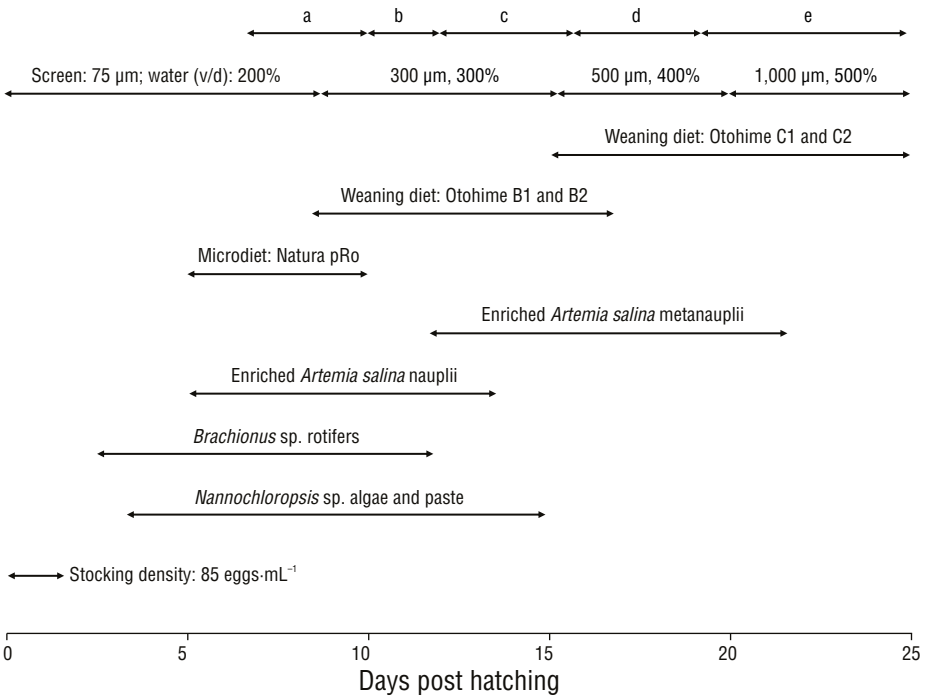


Figure 2. Larviculture protocol for Florida Pompano (*Trachinotus carolinus*). *Nannochloropsis* sp. algae and paste (500,000 cel·mL^{-1}); *Brachionus* sp. rotifers (>100 µm, 2–6 rotifers·mL^{-1}); *Artemia salina* nauplii (250 µm, 1–4 nauplii·mL^{-1}); enriched *A. salina* metanauplii (>600 µm, 2–10 metanauplii·mL^{-1}), Natura pRo mircodiet (100–250 µm); Otohime B1 (250–360 µm) and B2 (360–650 µm) dry diets; and Otohime C1(580–840 µm) and C2 (840–1410 µm) weaning diets. Larval development stages are indicated by the upper bar: preflexion (**a**), flexion (**b**), post-flexion (**c**), metamorphosis (**d**), and juvenile (**e**). Created with BioRender (Toronto, Canada).

access to live and formulated feeds, controlled water turbulence, and reduced water depth to enhance feeding success. During the first days of rearing, particular attention was paid to monitoring larval development and ensuring successful feeding (Fig. 2).

Molecular identification of pompano species

Five late-stage larvae (17 days post hatching [dph], 12.3 ± 1.75 mm) were sent to *Laboratorio de Recursos Nectónicos y Ecología de Arrecifes* (LRNEA–CIBNOR, S.C.) for molecular species identification. A DNA fragment (724 bp) was analyzed and compared against sequences available in the GenBank database using the BLASTn algorithm.

Nursery rearing

Weaning was completed at 23 dph, and early juveniles were successfully transitioned to Otohime microdiets (B2, C1, and C2; Marubeni Nisshin Feed Co., Ltd., Tokyo, Japan) by 30 dph. Subsequently, juveniles reached sizes and body weights that allowed their classification into 3 groups: small, medium, and large. These early juveniles were then reared in 3, 5-m^3 cylindrical fiberglass nursery tanks for an additional 10 weeks. During the nursery phase, fish were fed Gemma Silk (Skretting, Stavanger, Norway) diets (particle size: 0.8, 1.0, 1.5, 2.0, 2.5, and 3.0 mm [crude protein: 57%; lipids: 15%]). Feeding was conducted 3 times daily to apparent satiation, ~5–10 body weight·day^{-1} (Cunha et al. 2013, Hamed et al. 2016). Water flow, drainage screens, feed size, feeding frequency, size grading, biomass monitoring, juvenile distribution schedules, and other zootechnical considerations were adjusted based on the results of weekly biometric evaluations of each group.

Biometric assessments were conducted weekly by measuring the total length and body weight of 50 juveniles per size group. When additional size grading was considered necessary, total biomass was recorded, and fish were re-classified using the corresponding mechanical graders. Daily monitoring included feed intake, mortality, dissolved oxygen concentration, temperature, salinity, and photoperiod. In addition, key water quality variables, including TAN, pH, nitrite, nitrate, and alkalinity, were evaluated weekly to ensure optimal environmental conditions for juvenile growth and survival, using the aforementioned tools. The nursery phase concluded when juveniles had achieved the desired physiological condition and resistance to handling stress and had met the performance criteria for transfer to grow-out programs.

Statistical analysis

Descriptive statistics were used to summarize the data, including means and standard deviations (SD), where appropriate. No inferential statistical tests were performed, as the objective was to provide a descriptive characterization of the production and rearing outcomes. All data analyses and graphical representations were performed using SigmaPlot v. 11.0 (Systat Software, Inc., San Jose, USA).

Results

Captive reproduction

During 2023–2024, a reproductively viable *T. carolinus* broodstock was successfully established under controlled culture conditions. As part of this process, juveniles progressively matured into functional broodstock, including the transition of 1 individual into a mature male during the 2024 reproductive season. Overall survival remained high, with only 3 mortalities recorded (2 immature individuals and 1 female), all attributable to routine handling procedures (sampling and anesthesia) rather than diseases or hormonal induction. Growth performance during broodstock development indicated a marked increase in body weight, with females gaining 600.2 ± 180.4 g (1,178.7 ± 393.2 g to 1,603.2 ± 359.8 g) and males gaining 209.0 ± 219.2 g (883.5 ± 123.7 g to 1,092.5 ± 342.9 g). The *K* value remained relatively stable throughout the study (females: 2.8 ± 0.2; males: 2.9 ± 0.4 to 3.0 ± 0.1), indicating adequate somatic condition and successful physiological conditioning of the broodstock for reproductive maturation.

In 2023, the fish were maintained in recirculating aquaculture systems under controlled conditions (dissolved oxygen: 6.5 ± 0.6 mg·L^{-1}; temperature: 27.1 ± 1.4 °C; salinity: 34 ± 1.6 g·L^{-1}; photoperiod [light:dark]: 14:10 h) to support final gonadal maturation. In all assays, spawning was induced through a single subcutaneous implantation of hCG at doses of 1,000 IU·kg^{-1} for females with oocytes >500 µm in diameter and 500 IU·kg^{-1} for spermiating males. Spawning occurred ~36 h post-induction, although reproductive performance was low.

In March 2024, high spawning performance was observed, with volitional spawns yielding 599 mL of eggs, a fertilization rate of 94.1%, and an egg density of 886.3 eggs·mL^{-1}. Semen quality was high, with sperm motility reaching 96% and concentrations reaching 3.72 × 1,010 sperm·mL^{-1}. The placebo test using salt solution did not result in spawning, reflecting the important role of hormonal induction in triggering reproductive responses in *T. carolinus* (Fig. 1).

In June 2025, the broodstock group was hormonally induced, and the protocol produced high-quality pelagic eggs with homogeneous morphology, fertilization rates reaching 90.2%, and a hatching success of 83.6%, with hatching consistently occurring ~28 h post fertilization. Egg production reached 615 mL per spawn, with an egg density of 848 eggs·mL^{-1}, a mean egg diameter of 917.4 ± 38.6 µm, and a mean lipid droplet diameter of 244.9 ± 13.4 µm. Larval survival to first feeding reached 55.8 ± 7.5%. Sperm analyses indicated high reproductive capacity, with motility values reaching 96% and sperm concentrations exceeding 3.7 × 1,010 spermatozoa·mL^{-1}.

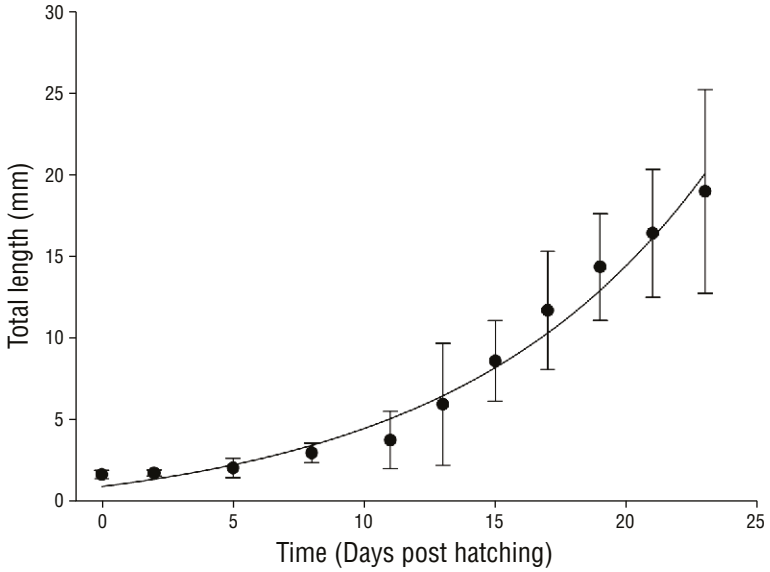


Figure 3. Exponential growth curve of total length in Florida Pompano (*Trachinotus carolinus*) larvae during the larviculture phase ($y = 1.8984e^{1.1089\times}$, $R^2 = 0.9656$; $n = 100$; mean ± SD).

Larviculture

During the larviculture phase, growth in total length followed an exponential pattern ($y = 1.8984e^{1.1089\times}$, $R^2 = 0.9656$) (Fig. 3). This pattern became particularly evident after mouth opening and the onset of effective co-feeding on rotifers and *Artemia* nauplii. Length larvae data were initially homogeneous and exhibited low dispersion during the early developmental stages; however, variability progressively increased from the midpoint of the larviculture period onward.

Feeding was based on larval demand, and feed was supplied at regular intervals throughout the day (every 4 h from 06:00 to 20:00 h). From 3 to 12 dph, larvae were fed enriched rotifers (Cavalin and Weirich 2009). Newly hatched *Artemia salina* nauplii were introduced between 5 and 15 dph, followed by enriched *A. salina* metanauplii from 12 to 23 dph. Co-feeding with live and dry diets was maintained from 8 to 23 dph to improve acceptance and survival. The transition from live to dry feed was gradual, with dry feed replacing 25% of the diet on the first day of introduction and its proportion increasing progressively each day thereafter. The production of every 1,000 *T. carolinus* juveniles required an estimated 33.3 million rotifers and 48.6 million *Artemia* nauplii or metanauplii during the larval rearing period.

Larvae were reared under these conditions until metamorphosis. Complete weaning onto formulated feed was achieved at 23 dph (Fig. 4), before transfer to subsequent culture phases. Critical mortality periods were observed during the first feeding, which were associated with the transition from endogenous to exogenous feed.

Molecular identification

Molecular species identification revealed high sequence similarity to *T. carolinus*, with >99.5% sequence identity and 89% query coverage, supporting the prior morphological identification of specimens as *T. carolinus*.

Nursery rearing

At 30 dph, a total of 8,500 juveniles were collected, with a total biomass of 6.6 kg and stocking density of 1.3 kg·m^{-3}, corresponding to a survival rate of 9% from first feeding to the end of the larviculture phase. Juveniles with a mean total length of 26.3 ± 11.0 mm and mean body weight of 0.9 ± 0.5 g were classified into 3 groups based on body size (small, medium, and large). Mechanical graders equipped with circular perforations of different diameters were used for this classification. The first grader (1.0-cm openings) allowed the passage of smaller juveniles weighing <0.5 g, whereas a second grader (1.5-cm openings) retained fish with an average body weight of ~1.0 g. The small-, medium-, and large-size groups comprised 2,958, 5,271, and 271 individuals, respectively.

At the end of the 10-week nursery phase, survival exceeded 96%, and all size groups exhibited sustained exponential growth, which reflected positive performance throughout the culture period. Growth trajectories differed among size classes, with the large-size group achieving the highest growth performance, reaching an average body weight of approximately 40 g, and showing marked growth acceleration after week 6 (Fig. 5). The medium-size group also displayed consistent growth, although greater variability was observed during the later weeks, suggesting increasing intra-group heterogeneity as culture progressed. This group attained a final average weight of 27 g. In contrast, despite their lower initial body weights, juveniles in the small-size group demonstrated substantial compensatory growth during the final weeks, reaching an average weight of ~35 g at the end of the nursery phase. Overall, these results indicate that juveniles maintained continuous growth regardless of initial size; however, clear differences in final body weight among size groups emphasize the importance of early size grading and differential management strategies to optimize production performance during the nursery and pre-grow-out phases.

Delivery and transfer to grow-out programs

Following the nursey rearing phase, *T. carolinus* juveniles of different body weights were distributed to community-based production facilities, aquaculture enterprises, and experimental biology operations, which allowed their adaptability and performance to be evaluated under diverse grow-out conditions. The receiving systems included circular

Table 2. Growth performance, productivity, and yield of Florida Pompano (*Trachinotus carolinus*) juveniles during the nursery phase (10 weeks, $n = 50$, mean ± SD).

Group	Initial density (kg·m^{-3})	Final density (kg·m^{-3})	Initial weight (g)	Final weight (g)	Feed conversion ratio (FCR)	Specific growth rate (%)	Survival (%)
Small	0.3	5.4	0.5 ± 0.2	27.5 ± 7.2	1.1 ± 0.6	2.2	96.4
Medium	0.9	5.5	0.9 ± 0.5	34.1 ± 9.1	1.1 ± 0.5	3.2	95.7
Large	0.1	3.5	1.4 ± 0.3	40.6 ± 7.3	1.2 ± 0.7	3.8	98.8

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Table 2. (*continued*)

Group	Temperature (°C)	Oxygen ($mg \cdot L^{-1}$)	Salinity ($mg \cdot L^{-1}$)	Total ammonia nitrogen	Alkalinity ($mg \cdot L^{-1}$)	pH
Small	28.2 ± 1.2	3.5 ± 1.0	36.7 ± 0.5	0.5 ± 0.7	2.5 ± 0.5	7.6 ± 0.0
Medium	28.2 ± 1.2	3.5 ± 1.4	36.7 ± 0.5	0.75 ± 0.4	2.5 ± 0.3	7.6 ± 0.0
Large	28.5 ± 1.6	4.0 ± 0.9	36.7 ± 0.5	0.2 ± 0.3	2.5 ± 0.1	7.6 ± 0.0

fiberglass tanks at a laboratory facility; circular geomembrane tanks at a land-based farm in Sisal, Yucatán; concrete nursery tanks at a shrimp farm in Alvarado, Veracruz; and marine cages located within the fishery refuge zone of Celestún, Yucatán. The diversity of stocking environments generated valuable information for future production scale-up and culture diversification strategies. Prior to transport and stocking, a sanitary inspection was conducted by the Yucatán State Aquaculture Health Committee (CESAY, A.C.; Report No. 25/068). The inspection results indicated that juveniles exhibited active swimming behavior and tested negative for parasites. Bacteriological analyses detected only normal microbiota, supporting the suitability of *T. carolinus* juveniles for transport following preventive biosecurity recommendations. All transportation operations were completed successfully, including the longest transfer, which covered ~1,000 km over 16 h and involved 4,000 fish (average weight: 3 g; stocking density: 12 $kg \cdot m^{-3}$). Survival rates during transport exceeded 98%. Transporting juveniles by sea to the offshore cages took 2.5 h and resulted in 100% survival (1,000 fish; average weight: 40 g; stocking density: 40 $kg \cdot m^{-3}$). In addition to juvenile delivery, the project provided technical training and direct assistance to producers and receiving facilities in key aspects, such as transport logistics, acclimation, feeding, handling, and biosecurity, thereby strengthening local capacities, facilitating technology adoption, and reducing production risks during the early grow-out phase.

Discussion

The successful induction of volitional spawning in captive *T. carolinus* through a single intramuscular administration of hCG demonstrates that hormonal induction can effectively overcome reproductive dysfunction. Broodstock maintained under semi-natural photothermal conditions failed to spawn spontaneously, supporting previous evidence that reproductive inhibition in captive marine fishes frequently results from disruptions in pituitary gonadotropin production or release, ultimately impairing final oocyte maturation, ovulation, and spermiation despite apparent gonadal development (Zohar and Mylonas 2001, Wills et al. 2023).

The reproductive performance obtained in the present study was generally comparable to that reported for *T. carolinus* and related *Trachinotus* species under captive conditions. Fertilization, hatching, and survival to first feeding fell within or near the ranges previously described for *T. carolinus*, Snubnose Pompano (*Trachinotus blochii*), and Indian Pompano (*Trachinotus mookalee*) hatchery production (Table 1). Similarly, egg diameter and oil droplet size were consistent with values reported for high-quality pelagic eggs, suggesting adequate broodstock nutritional and physiological status (Table 1). Spawning latency (34–36 h post induction) was also comparable to previous hormonal induction studies in *Trachinotus* species (Ranjan et al. 2018).

Importantly, broodstock maintained entirely under captive conditions remained reproductively functional despite repeated hormonal applications across multiple seasons, with no apparent reduction in spawning responsiveness. Although prolonged hCG use has been associated with potential immunoneutralization and reduced hormonal efficacy in some fish species (Mylonas and Zohar 2001), no evidence of reproductive decline was observed under the present conditions, consistent with reports indicating that hCG can repeatedly induce spawning without antibody-related inhibition in some teleosts (Van der Kraak et al. 1989). Furthermore, the successful maturation and spawning of domesticated broodstock reinforces the feasibility of long-term *T. carolinus* reproduction in tropical hatcheries, reducing dependence on wild capture for seed production and supporting the establishment of sustainable juvenile supply chains (Main et al. 2007, Weirich et al. 2021, Wills et al. 2023). However, the low survival observed at first feeding (55.8%) in the present study suggests that further research is required to improve the efficiency of the hormonal induction and breeding protocol to enhance larval quality and survival.

Although early larvae survival was low, the production of *T. carolinus* juveniles in the present study was closely associated with the implementation of a larval rearing protocol that synchronized ontogenetic development through the progressive introduction of appropriate live feeds and microdiets (Wills et al. 2023). In the present study, mouth opening and the onset of exogenous feeding occurred at ~4 dph under green-water conditions with rotifers provided as live feed (Cavalin and Weirich 2009), closely resembling the developmental timing previously reported for hatchery-reared *T. carolinus* (Riley et al. 2009, Wills et al. 2023).

The progressive transition from rotifers to *Artemia* nauplii and enriched metanauplii appeared to adequately match

increasing mouth gape and larval morphological development. Such feeding succession is particularly important in *Trachinotus* species, in which nutritional demands intensify after active swimming and notochord flexion (Riley et al. 2009, Ma et al. 2014a). In the present study, notochord flexion was observed at approximately 10 dph, whereas metamorphosis was completed around 23 dph, consistent with developmental trajectories previously described for *T. carolinus*

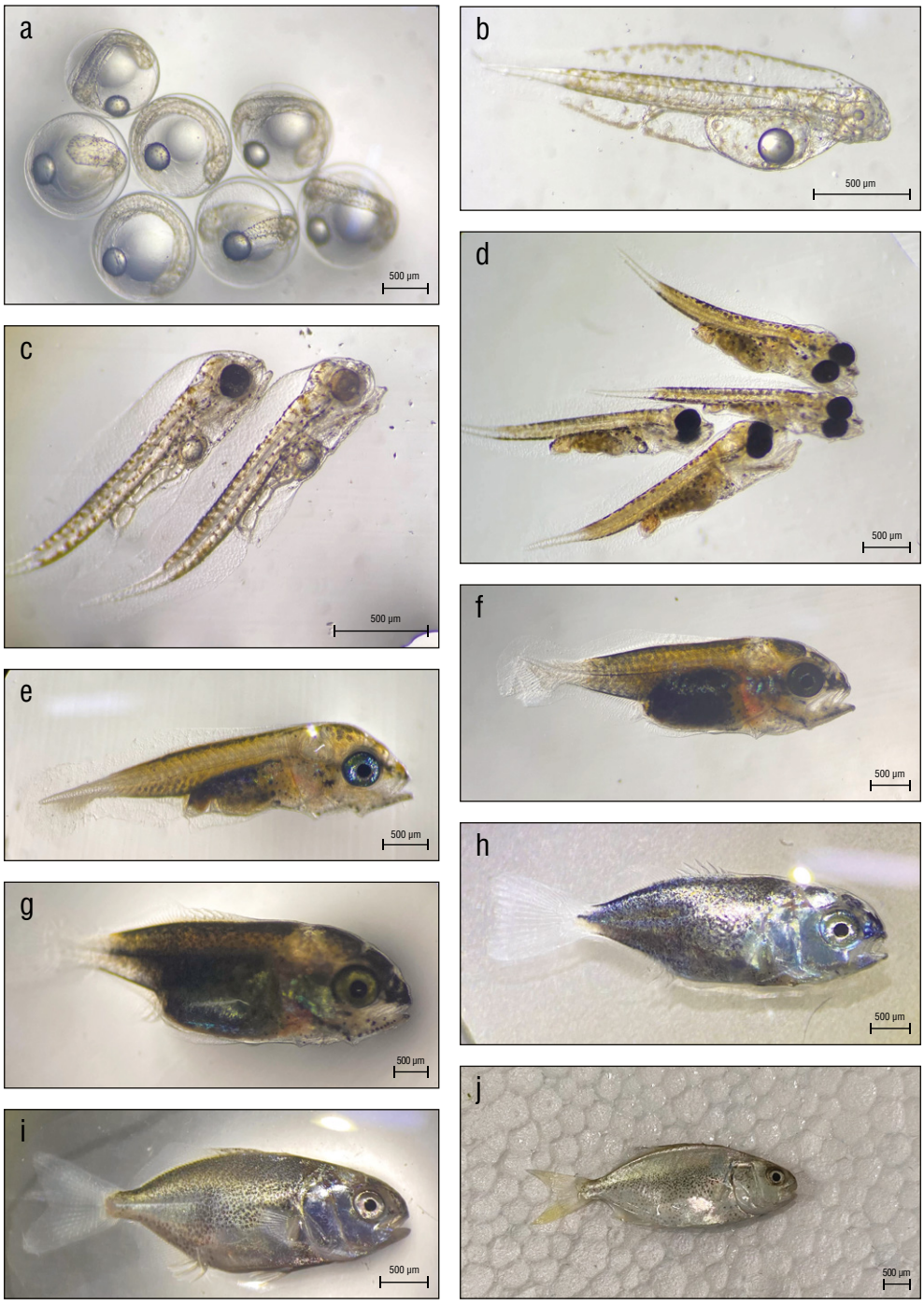


Figure 4. Early developmental stages of Florida Pompano (*Trachinotus carolinus*): embryo (0 days post hatching [dph]) (**a**); hatching (27–30 hours post hatching) (**b**); mouth opening (**c**); first feeding (3 dph) (**d**); preflexion, eye pigmentation, and appearance of caudal fin rays (6 dph) (**e**); flexion (8 dph) (**f**); appearance of dorsal and pectoral fins (9 dph) (**g**); postflexion and appearance of scales (11 dph) (**h**); metamorphosis (18 dph) (**i**); and juvenile stage (24 dph) (**j**).

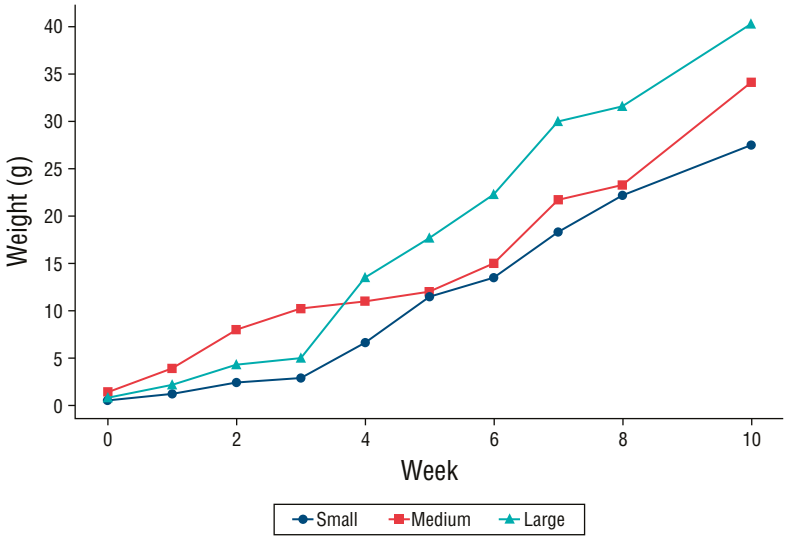


Figure 5. Growth curve of total body weight (g) in Florida Pompano (*Trachinotus carolinus*) juveniles classified into 3 groups based on body size (small, medium, and large) during the 10-week nursery phase (n = 50; mean).

and related carangids (Ma et al. 2014b, Wills et al. 2023). Furthermore, the gradual implementation of co-feeding between live prey and microdiets from 12 to 23 dph likely facilitated feed acceptance and minimized nutritional stress during weaning, a stage commonly associated with starvation, growth depression, and mortality in marine fish hatcheries. A similar sequence of early larval developmental events has been reported for *T. blochii* (Nazar et al. 2012). The exponential growth trajectory observed in the present study, together with relatively low size dispersion, further suggests that adequate nutritional management and stable rearing conditions reduced the developmental heterogeneity that frequently compromises survival during metamorphosis (Ma et al. 2014a, Ma et al. 2014b, Wills et al. 2023).

The production of *T. carolinus* juveniles in the present study required an estimated 33.3 million rotifers per 1,000 juveniles during larval rearing, highlighting the substantial dependence on live feed of *T. carolinus*. Rotifer requirements may be higher in other species than in *Trachinotus* species. For example, the production of 1,000 Rose Spotted Snapper (*Lutjanus guttatus*) juveniles required 83.9 million rotifers (Rojo-Cebreros et al. 2017). This is likely due to the generalist larval characteristics of *T. carolinus* (large larval size at first feeding and a short larval stage), which contrast with the specialist larval characteristics of *L. guttatus* (small larval size at first feeding and long larval stage), thereby reducing the duration of dependence on rotifers in *T. carolinus*. This characteristic of *T. carolinus* larval culture may represent an operational advantage by reducing live feed requirements and potentially lowering hatchery production costs and risks.

The nursery phase represents a critical transition in marine finfish production because it determines whether early juveniles successfully develop into robust organisms capable of tolerating subsequent handling, transport, and grow-out conditions. In the present study, *T. carolinus* juveniles exhibited high survival (>96 %), a high specific growth rate, a low feed conversion ratio (FCR), and successful adaptation to formulated feeds under the stocking density and water quality conditions (Table 2), indicating that the husbandry and feeding strategies implemented were adequate for maintaining performance (Wills et al. 2023). Nursery success was strongly supported by size grading, as size heterogeneity progressively increased after metamorphosis, consistent with previous reports for *T. carolinus* and other fast-growing carangids under culture conditions (Weirich et al. 2021). Mechanical grading likely reduced competition for feed and space, minimized dominance effects, and promoted more homogeneous growth, while smaller juveniles showed signs of compensatory growth after grading. Additionally, the gradual transition from microparticulate diets to larger pellets, together with frequent feeding schedules adjusted to fish size and behavior, likely enhanced feed adaptation and growth performance, although increasing heterogeneity in later stages suggests that repeated grading may be necessary to maintain biomass uniformity and production efficiency (Weirich et al. 2021). Notably, in the present study, the body weight of *T. carolinus* increased from 1 g to 40 g over a period of 70 days, demonstrating growth comparable to that reported for *T. blochii*, in which early juveniles of ~7 g reached 45 g within 50 days (Hamed et al. 2016).

The FCR observed during the nursery phase in the present study (1.1–1.2) was considerably lower than the values commonly reported for *T. carolinus*, suggesting highly efficient feed utilization. Feed efficiency in *T. carolinus* has generally

been regarded as relatively poor compared with that of other cultured marine fishes, with FCR values frequently exceeding 2.0, largely due to the active swimming behavior, elevated metabolic demand, short digestive tract, rapid gut evacuation rate, and feeding mechanics of *T. carolinus*, all of which may contribute to inefficient nutrient assimilation and feed wastage (Weirich et al. 2021). In addition, Corby et al. (2025) reported FCR values greater than 1.8 in early juveniles (4.82 ± 0.08 g) and late juveniles (23.21 ± 1.87 g). These results are particularly relevant considering that previous research has demonstrated that *T. carolinus* fed an experimental diet with soybean meal as the primary protein source performed similarly to individuals fed a commercially produced fishmeal-based diet, indicating considerable nutritional flexibility in this species despite its carnivorous feeding habits.

Previous evidence indicates that feeding frequency and ration strongly influence feed conversion in *T. carolinus*, with suboptimal feeding schedules resulting in poorer FCR values (Cunha et al. 2013). Although FCR values below 1.0 should be interpreted cautiously because apparent feed conversion may be influenced by feed loss and biomass estimation accuracy, these findings indicate that *T. carolinus* juveniles can achieve substantially greater feed efficiency than previously assumed when nursery management and feeding protocols are properly optimized.

Although various diseases have been documented in *T. carolinus* (Weirich et al. 2021), no evidence of cannibalism or disease outbreaks was observed during the breeding, larviculture, or nursery phases in the present study. The absence of cannibalistic behavior enabled more accurate mortality assessments, as dead individuals were not consumed by conspecifics, consistent with previous observations for this species (Wills et al. 2023).

More broadly, the successful production of 8,500 robust juveniles demonstrates that hatchery technology for *T. carolinus* can be effectively implemented under tropical Gulf of Mexico conditions using locally adapted infrastructure and commercially available production tools. Reliable juvenile availability has historically been recognized as one of the principal bottlenecks limiting the commercial expansion of *T. carolinus* aquaculture (Riley et al. 2009, Weirich et al. 2021, Wills et al. 2023). Importantly, juveniles produced in the present study tolerated grading, handling, transportation, and transfer to diverse grow-out systems with high post-transfer survival, reflecting their physiological robustness and practical suitability for downstream aquaculture operations. Collectively, these findings support the feasibility of integrating hatchery production, nursery management, and technology transfer as a foundation for the expansion and diversification of marine aquaculture in the Gulf of Mexico and Caribbean region.

Conclusions

This study demonstrated the technical feasibility of captive reproduction, larval rearing, nursery rearing, and juvenile production of *T. carolinus* under tropical hatchery conditions. The applied protocol resulted in successful induced spawning, larval development, and the production of juveniles suitable for transfer to grow-out systems. These findings establish a practical foundation for *T. carolinus* hatchery development and support the expansion of marine finfish aquaculture in the Gulf of Mexico and Caribbean region.

Declarations

Supplementary Material

This work includes no supplementary material.

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Conflict of interest

The authors declare they have no conflict of interest.

Author contributions

Conceptualization: ARC; Data curation: ARC; Formal analysis: ARC; Funding acquisition: CR, PG, and CP; Investigation: FVQ; Methodology: JS; Project administration: CR; Visualization: ARC; Writing–original draft: ARC; Writing–review & editing: CR, PG, JS, and CP.

Data availability

The data for this study are available from the corresponding author upon reasonable request.

Ethical approvals and permits for studies involving animals

This study was conducted with ethical approval from guidelines and regulations of the Institutional Animal Care and Use Committee [CM3.1][AR3.2] and were approved by the Ethics Committee of the Faculty of Sciences of *Universidad Nacional Autónoma de México* (UNAM) and with all necessary permits (11122025 and 2220126). The study complied with all corresponding regulations for the justified use of animals in research and their welfare (NOM-062-ZOO-1999).

Use of AI tools

The authors did not employ any AI tools in this work.

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