

Article

Artificial Reproduction, Larval Rearing, and Gonadal Development of the F1 Generation in Shrimp Scad (*Alepes djedaba*)

Jinhui Wu ¹ , Wenjun Chen ², Shaosen Yang ¹, Yongbiao Huang ², Jujing Wang ², Xiaoxiao Zhang ¹, Jun Zhao ² and Junjie Wang ^{2,*} 

¹ Guangdong Agricultural Technology Extension Center, Guangzhou 510520, China

² Guangzhou Key Laboratory of Subtropical Biodiversity and Biomonitoring, School of Life Science, South China Normal University, Guangzhou 510631, China;

* Correspondence: 20185210@m.scnu.edu.cn

Abstract

Alepes djedaba is a coastal fish species of high economic value. However, information on its early developmental biology remains incomplete, which limits its application in large-scale seed production. In this study, fertilized eggs were obtained through hormone-induced spawning. Under controlled conditions, microscopic observation and histological sectioning were used to systematically record and analyze embryonic development, larval growth characteristics, and the gonadal development potential of the artificially bred first-generation (F1) offspring. The results showed that the fertilized eggs of *A. djedaba* are spherical and pelagic with a single oil globule. The egg diameter is $(672.02 \pm 10.03) \mu\text{m}$, and the oil globule diameter is $(189.76 \pm 8.82) \mu\text{m}$. At a water temperature of $24.50\text{--}24.97^\circ\text{C}$, embryonic development is divided into 6 periods (20 stages), taking 19 h 28 min to complete hatching with an average hatching rate of $22.9\% \pm 15.6\%$. The total length of newly hatched larvae is $(1.43 \pm 0.09) \text{ mm}$, with an average daily growth of 0.39 mm from 0 to 21 days post-hatching (DPH). Furthermore, the testes of the F1 generation cultured in captivity exhibit complete tissue structures and mature spermatozoa, while the ovaries show orderly development primarily dominated by stage II–III oocytes with some early stage IV oocytes. This confirms at the histocytological level that the artificially bred offspring possess normal gonadal development, providing strong evidence of its reproductive potential. This study clarifies the key stages of early development and the adaptability of *A. djedaba* in captive environments, providing critical theoretical support and basic data for subsequent large-scale seed production and larval rearing optimization.

Keywords: *Alepes djedaba*; fertilized eggs; embryonic development; post-embryonic development

Key Contribution: First systematic ontogenetic clarification of *Alepes djedaba* embryonic and larval development, with histological verification of F1 captive gonadal maturity, providing valuable evidence of its reproductive potential.



Academic Editor: S.S.S. Sarma

Received: 9 June 2026

Revised: 24 July 2026

Accepted: 27 July 2026

Published: 29 July 2026

Copyright: © 2026 by the authors.

Licensee MDPI, Basel, Switzerland.

This article is an open access article distributed under the terms and conditions of the [Creative Commons Attribution \(CC BY\)](https://creativecommons.org/licenses/by/4.0/) license.

1. Introduction

Alepes djedaba is a small-to-medium-sized coastal marine fish belonging to the family Carangidae [1], which is widely distributed from the Indo-Pacific to the Mediterranean Sea, including the East China Sea, South China Sea, and Yellow Sea [2]. In recent years, significant progress has been made in the basic biological research of this species, including

its molecular phylogenetics and reproductive biology [3,4]. Studies show that the minimum length at first sexual maturity for females is 149–193 mm, and the absolute fecundity ranges from 15,004 to 640,800 eggs [3]. However, this natural reproductive potential is currently threatened by severe biological hazards; for instance, infections by the newly discovered gonad-infecting nematode *Philometra arabiensis* can cause severe and irreversible ovarian damage [5].

Regarding other wild survival pressures, *A. djedaba* is confronted with overfishing, environmental pollution, and wider pathological threats, such as the muscle-infecting myxozoan *Kudoa javanensis* [6] and skin-damaging isopod parasites [7]. In terms of nutritional value and trophic ecology, *A. djedaba* features premium muscle quality with high protein (20.60–21.50%) and low fat (0.40–1.10%) content [3], and functions as a carnivorous predator primarily preying on small fishes, crustaceans, and cephalopods [2]. Due to its position in the food web, this carnivorous diet facilitates the biomagnification of environmental toxins, as evidenced by recent ecotoxicological detections of microplastics and polycyclic aromatic hydrocarbons accumulated in the muscle tissues of wild coastal populations [8]. Furthermore, the stability of its myofibrillar proteins decreases significantly during storage and transport [9]. This biochemical fragility, combined with the high pathogen load in wild stocks, severely constrains traditional aquaculture practices that rely on harvesting and transporting wild-caught juveniles, leading to high mortality rates and compromised meat quality during subsequent captive rearing.

To alleviate the fishing pressure on wild resources and meet its significant economic demand, establishing a sustainable captive breeding program is imperative. However, a complete artificial breeding system for *A. djedaba* has not yet been established [2]. Developing such a program, which requires a fundamental understanding of the species' gonadal and embryonic development, is essential to mitigate these issues and reduce dependency on wild resources. Therefore, breakthroughs are urgently needed in key developmental technologies. Recently, significant advances have been made in the reproduction control, broodstock domestication, and larval rearing of several important carangid and marine aquaculture species, highlighting the critical role of nutritional additives on egg quality and reproductive performance [10–13]. However, there is still no systematic report on the developmental biology of *A. djedaba* at home or abroad. Existing studies have mostly focused on related species such as the Japanese scad (*Decapterus maruadsi*) [14], golden trevally (*Gnathanodon speciosus*) [15], and pompano (*Trachinotus ovatus*) [16,17].

In this study, hormone-induced spawning was performed on *A. djedaba* to systematically record its embryonic development process and comprehensively analyze the early growth characteristics and stage-specific developmental rules of larvae. Furthermore, a histological evaluation of the gonads of the first-generation (F1) offspring cultured continuously to sexual maturity was conducted for the first time. The objectives of this study are to clarify the key nodes of early development and the adaptability of *A. djedaba* in captive environments, providing critical theoretical support and basic data for subsequent large-scale seed production, larval rearing optimization, and germplasm resource conservation.

2. Materials and Methods

2.1. Experimental Materials

The experimental *A. djedaba* broodstock group consisted of 80 individuals with a sex ratio of approximately 1:1 (age: 2–3 years, average body length: 24.46 ± 0.94 cm, average body weight: 256.61 ± 32.09 g). They were cultured in cement tanks (4.5 m $\times$ 4.5 m $\times$ 2.0 m) at the Guangdong Marine Fisheries Experimental Center. The water temperature was maintained at 24.81–30.13 °C, and the salinity ranged from 20.70 to 29.60 ppt. During the intensive rearing stage, the fish were fed a formulated diet prepared by mixing frozen trash

fish, fish meal, soybean meal, shrimp powder, multivitamins, and fish oil in specific weight ratios. The gonadal development of the broodstock was checked regularly, and hormone-induced spawning experiments were conducted when the gonads reached maturity and the water temperature was suitable. To obtain fertilized eggs, a total of four hormone-induced spawning trials (comprising four distinct spawning batches) were conducted in the spring (April and May) and autumn (October) of 2025.

2.2. Gonadal Tissue Sampling and Histological Preparation

The gonads of the *A. djedaba* broodstock and F1 generation were isolated. Following acute stress-induced mortality of the fish, individuals were thoroughly rinsed with fresh-water, placed on an ice plate, and dissected. The abdomen was opened from the cloaca to isolate and weigh the gonads. A total of 8 mature adult fish (5 males and 3 females) were sampled for histological analysis and gonadosomatic index (GSI) calculations. The isolated gonadal tissues were fixed in 4% paraformaldehyde (PFA) fixative. The fixed gonadal tissues were dehydrated through a graded ethanol series, cleared in xylene, and embedded in paraffin. The paraffin blocks were trimmed and cut into 5 µm sections using a Leica RM 2255 microtome (Leica Biosystems, Nussloch, Germany). The sections were stretched in a 43 °C water bath, mounted on glass slides, dried on a slide warmer at 50 °C for 30 min, and further dried in a 37 °C incubator for 48 h. Subsequently, the sections were deparaffinized in xylene, rehydrated through a graded ethanol series, stained with hematoxylin and eosin (H&E), dehydrated again in ethanol, cleared in xylene, and finally mounted with neutral resin. Microscopic images were captured using a Nikon H600L upright microscope (Nikon Corporation, Tokyo, Japan).

2.3. Fertilized Egg Collection and Hatching

Sexually mature broodstock were anesthetized with eugenol and then intramuscularly injected with human chorionic gonadotropin (HCG, 150 IU/kg) and luteinizing hormone-releasing hormone analogue (LHRH-A3, 0.8 µg/kg) during the optimal trial. The fish spawned naturally 18–22 h after injection. Across the four experimental batches, the total collected wet egg mass ranged from 35 to 230 g (equivalent to 140,000–920,000 eggs), with the highest larval yield reaching 293,000 individuals in the second batch (Table S1). Fertilized eggs were collected using a 100-mesh silk net and transferred to continuous-flow hatching tanks (3.0 m × 1.5 m × 1.5 m) for hatching under continuous aeration. Due to the large-scale nature of the hatchery concrete tanks, independent tank replications were not established; however, eggs were sampled randomly from multiple zones of the tank to minimize bias. The water temperature was maintained at 24.50–24.97 °C by ambient indoor climate conditions, and the dissolved oxygen was >5 mg/L. The hatching rate was defined as the percentage of hatched larvae relative to the total number of eggs. To establish baseline egg metrics for subsequent evaluation, the egg density was verified gravimetrically by analyzing representative wet egg sub-samples (totaling 4161 eggs with a combined mass of 0.96 g) under a microscope. Based on this gravimetric conversion, the total number of eggs for *A. djedaba* was estimated at approximately 4.30 million eggs per kilogram of wet egg mass.

2.4. Observation of Embryonic and Post-Embryonic Development

Embryonic observation: Samples of 30–50 eggs were collected every 30 min. The morphological characteristics of each developmental stage were recorded using a Leica DM2000 optical microscope equipped with an M-shot imaging system, while ambient temperature and time were recorded simultaneously.

Post-embryonic observation: Ten newly hatched larvae were sampled daily. Their external morphology, organ development, and changes in total length were observed using a Leica S8AP0 stereomicroscope.

2.5. Measurement of Egg Size and Calculation of Thermal Summation

Thirty fertilized eggs were randomly selected to measure egg diameter and oil globule diameter under a microscope. The total effective thermal summation (K) for embryonic development was calculated using the following formula [18,19]:

$$K = N \times (T - C)$$

where K is the effective thermal summation ($h \cdot ^\circ C$), N is the developmental duration (h), T is the average water temperature ($^\circ C$), and C is the developmental threshold temperature of *A. djedaba* (set at $15\text{ }^\circ C$ based on the ambient water temperature on the sampling day).

2.6. Data Analysis

Statistical analyses of egg diameter ($N = 30$), hatching time ($N = 4$ batches), and larval body length ($N = 10$) were performed using R language v4.4.2 [20]. Basic data processing and descriptive statistics were conducted using standard R packages, and all results are expressed as mean $\pm$ standard deviation (mean $\pm$ SD). All data visualizations, including the larval growth curve plot, were generated using the ggplot2 v4.0.4 package in R [21].

3. Results

3.1. Gonadal Maturity of Broodstock

Histological sections of the gonads from reproductively depleted females revealed that primary oocytes (POs) were predominantly at developmental stages II–III (Figure 1a,b). These cells exhibited translucent cytoplasm with weak basophilia; however, no extensive accumulation of deeply stained yolk granules was observed (Figure 1b). These findings indicate incomplete vitellogenesis and suboptimal physiological conditions, rendering the individual unsuitable for hormone induction. In contrast, concurrent surveys identified spontaneous ovulation in other broodstock, as evidenced by the release of mature ova upon gentle abdominal pressure. To prevent the remaining mature individuals from missing the optimal spawning window, artificial induction of ovulation was initiated to ensure overall reproductive efficiency.

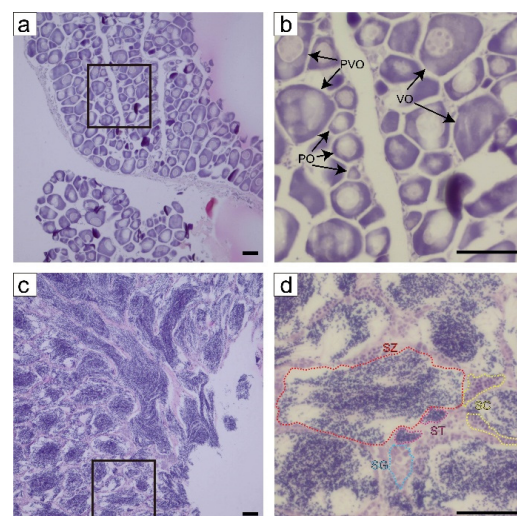


Figure 1. Histological sections of mature *Alepes djedaba* gonads. (a,b): Ovary (a: 100 $\times$, b: 400 $\times$). PO: primary growth oocyte; PVO: pre-vitellogenic oocyte; VO: vitellogenic oocyte; (c,d): Testis (c: 100 $\times$, d: 400 $\times$); SG: spermatogonia; SC: spermatocytes; ST: spermatids; SZ: Spermatozoa; Scale bars: 50 μm .

Testicular section observations revealed a radial lobular structure, and the seminiferous lobules were tightly arranged. The spermatocysts ruptured, and a large number of mature spermatozoa filled the lumina of the seminiferous tubules. The sperm heads were densely distributed as deep purple-blue dots. Only a small number of spermatids and secondary spermatocytes remained, and no obvious connective tissue hyperplasia was observed. Milt could be extruded by gently pressing the abdomen. The spermatozoa were completely mature and possessed fertilization capability. Both types of gonads were completely mature, which satisfied the broodstock requirements for artificial breeding.

3.2. Embryonic Development

Under the conditions of water temperature 24.50–24.97 °C, dissolved oxygen 7.88 mg/L, and pH 7.69, the fertilized eggs of *A. djedaba* took 19 h 28 min to complete hatching (Table 1). Under these hatching conditions, the hatching rate of *A. djedaba* was 22.9% ± 15.6%, and the total effective thermal summation for embryonic development was 481.59 °C·h.

Table 1. Embryonic development characteristics of *Alepes djedaba*. Developmental timing begins from the first cleavage.

Developmental Stage	Developmental Time (h)	Characteristics
2-cell stage	0.00	The blastodisc cleaves into 2 blastomeres of equal size and morphology.
4-cell stage	0.23	The blastodisc further cleaves into 4 blastomeres of equal size and morphology.
8-cell stage	0.50	The blastodisc cleaves into 8 blastomeres, and morphological differences begin to appear.
16-cell stage	0.75	The 4th cleavage occurs, forming 4 rows of blastomeres with varied morphologies.
32-cell stage	1.03	The blastodisc cells cleave again, and their volume becomes smaller.
Multi-cell stage	1.18	The blastodisc cleaves into multiple cells.
Early morula stage	1.72	The blastodisc cells elevate, presenting a morula-like shape.
Late morula stage	2.00	Marginal cells increase through division, and the blastodisc becomes round.
Blastula stage	3.50	The blastodisc cells become smaller, gradually forming the blastoderm layer.
Early gastrula stage	4.33	The blastodisc cells expand gradually, forming the germ ring.
Mid-gastrula stage	5.08	The germ ring is formed, and the embryonic shield thickens.
Late gastrula stage	6.18	The embryonic shield narrows, and blastoderm cells cover most of the yolk sac.
Blastopore closure stage	8.50	The blastopore begins to close, and the embryo body rudiment is initially formed.
Head primordium formation stage	10.07	The embryo body extends toward one end, and the head primordium begins to form.
Optic primordium formation stage	10.82	Optic primordia begin to appear on both sides of the head primordium.
Optic vesicle appearance stage	12.23	The optic primordium expands, and the optic vesicle appears.
Heart appearance stage	14.77	The heart primordium forms beneath the terminal end of the head.
Lens appearance stage	16.80	The lens is formed and begins to become clearly visible.
Heartbeat stage	18.00	The heart begins to beat regularly.
Pre-hatching stage	19.47	The whole embryo body curves and begins to twist, and pigment spots appear on the body surface.

3.2.1. Cleavage Stage

The eggs of *A. djedaba* are spherical, transparent, and pelagic, with a single oil globule. During this stage, the egg diameter is $672.02 \pm 10.03 \mu\text{m}$, and the oil globule diameter is $189.76 \pm 8.82 \mu\text{m}$. The fertilized eggs divide continuously within 1 h 2 min, sequentially progressing through the 2-cell, 4-cell, 8-cell, 16-cell, and 32-cell stages. Morphological and size differences exist among the blastomeres at different stages, but the overall process follows a regular pattern (Figure 2a–h).



Figure 2. Developmental blueprint of *Alepes djedaba* from the cleavage stage to the hatching stage. (a) 2-cell stage; (b) 4-cell stage; (c) 8-cell stage; (d) 16-cell stage; (e) 32-cell stage; (f) multi-cell stage; (g) early morula stage; (h) late morula stage; (i) blastula stage; (j) early gastrula stage; (k) mid-gastrula stage; (l) late gastrula stage; (m) blastopore closure stage; (n) head primordium formation stage; (o) optic primordium formation stage; (p) optic vesicle formation stage; (q) heart appearance stage; (r) lens appearance stage; (s) heartbeat stage; (t) pre-hatching stage.

3.2.2. Blastula Stage

During the blastula stage, the cells continue to divide, and the volume of individual blastomeres decreases. A distinct blastocoel appears, and the blastodisc gradually flattens from its previously elevated shape (Figure 2i).

3.2.3. Gastrula Stage

During the gastrula stage, the blastoderm cells continuously expand toward the vegetal pole, gradually forming the germ ring. As development progresses, the coverage proportion of the yolk sac by the blastoderm cells increases from approximately 1/2 in the early stage to 2/3 in the middle stage and finally reaches about 3/4 in the late stage. Concurrently, the cells in the embryonic shield region gradually thicken to form a distinct protrusion, laying the foundation for subsequent embryonic axis establishment and organogenesis (Figure 2j–l).

3.2.4. Neurula Stage

During this stage, the blastopore begins to close. Following the closure of the blastopore, the embryo body begins to take shape, and the head primordium gradually expands and forms (Figure 2m,n).

3.2.5. Organogenesis Stage

After the embryo enters the organogenesis stage, major organs such as the optic primordium, heart, and lens are formed one after another. The optic vesicle expands gradually, and the heart primordium appears and beats regularly (Figure 2o–s).

3.2.6. Hatching Stage

This stage represents the period when the embryo is about to rupture the egg membrane. Blood circulation is obvious, and the embryo body gradually twists, presenting an overall “C” shape. Pigment spots appear on the body surface, marking the final stage of embryonic development into a larva (Figure 2t).

3.3. Post-Embryonic Development

After hatching from the fertilized eggs, *A. djedaba* enters the post-embryonic larval development stage. The larvae were transferred to indoor cement tanks and cultured at a density of 5000 individuals/m³, with the water temperature maintained at 24.81–30.13 °C, salinity at 20.70–29.60 ppt, dissolved oxygen at 7.35–8.31 mg/L, and pH at 7.13–7.15. Rotifers were fed during the early rearing stage; copepods were introduced during the middle stage, and a combination of copepods and formulated diets specialized for marine fish larvae was provided during the late stage. The developmental characteristics of the larvae were recorded up to 21 days post-hatching (DPH).

3.3.1. 0–3 Days Post-Hatching

During the initial stage after hatching (0–2 DPH), the *A. djedaba* larvae are minuscule and transparent, exhibiting weak swimming capability. The head and tail structures are incompletely developed, showing an overall round or elliptical shape, and a residual yolk sac is visible on the body surface. The mouthparts are not fully formed, and their morphology remains unclear. The eye structure is in the early stage of development and is not yet fully mature, with an indistinct retina. As development progresses, the eye structure gradually improves, and relevant tissues such as the retina are sequentially formed. The mouth begins to develop and gradually exhibits opening characteristics, but it still has a small mouth gape and is not completely formed; the larvae rely primarily on the yolk

for nutrition. During this stage, the abdomen is relatively flat, and no clear outline of the digestive organs is observed (Figure 3a–c).

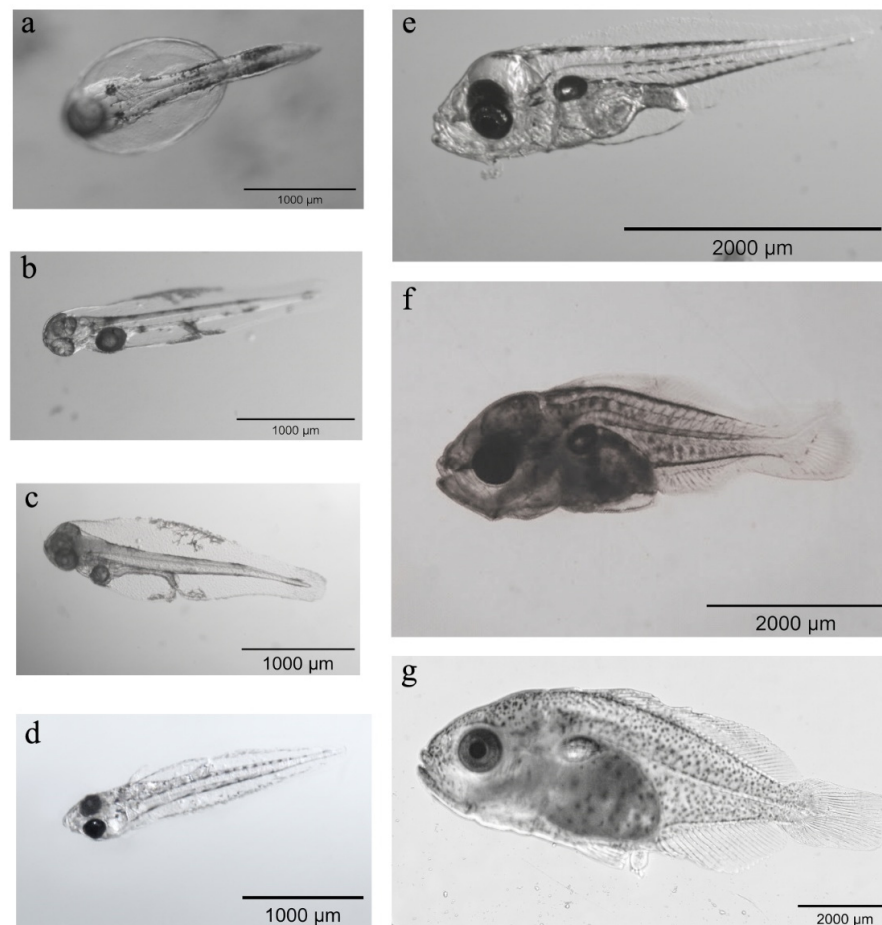


Figure 3. Morphology and growth of *Alepes djedaba* larvae post-hatching. (a) 0 DPH; (b) 1 DPH; (c) 2 DPH; (d) 3 DPH; (e) 7 DPH; (f) 14 DPH; (g) 21 DPH.

On the 3rd day post-hatching (3 DPH), the yolk sac is basically fully absorbed, and the head and tail structures gradually become distinct. The eye and mouth regions develop further, with more prominent external outlines. The proportions of the head, tail, and body length tend to become normal. The mouth gapes widen gradually to adapt to ingesting solid prey; the digestive system begins to develop, and the outlines of the relevant organs gradually become clear. The swimming ability is significantly enhanced, allowing the larvae to feed and avoid predators more flexibly in the water column (Figure 3d).

3.3.2. 4–7 Days Post-Hatching

After approximately one week of development, the internal oil globule reserves of the larvae are completely absorbed, and the swim bladder begins to form. This marks an improvement in the larvae's ability to maintain balance and regulate buoyancy in the water column. As the neuromuscular system develops further, the larvae's swimming and predator-avoidance capabilities improve significantly, allowing them to swim actively. The optic vesicle region appears black due to the heavy deposition of melanin, indicating the continuous development of the visual system. Furthermore, the primordia of the digestive system gradually appear, laying the foundation for the establishment of subsequent feeding and digestive functions (Figure 3e).

3.3.3. 8–14 Days Post-Hatching

As development continues, the body length of the larvae increases gradually, and a large number of melanophores proliferate and deposit on the trunk, forming distinct black spots. The intestine exhibits physiological twisting; the position of the dorsal fin moves gradually toward the tail; the caudal fin begins to form; the caudal peduncle becomes slender, and the caudal peduncle primordium takes shape progressively. The digestive system differentiates further, with the outlines of the stomach and intestine becoming increasingly distinct. Dark brown spots are scattered over the body surface, and melanin is widely distributed in all regions except for the terminal end of the tail. The notochord begins to flex upward, and each fin develops step by step, with the caudal fin, first dorsal fin, second dorsal fin, and anal fin all being formed (Figure 3f).

3.3.4. 15–21 Days Post-Hatching

The eyes of the larvae develop further, and pigments accumulate gradually within the eye structures, forming distinct ocular pigments. Except for the tail, pigment deposition increases significantly in other regions of the body surface, and the body color darkens gradually. The structures of the first and second dorsal fins become increasingly clear, with distinct fin ray outlines. The anal fin continues to develop and mature. The fan-shaped region of the caudal fin expands and initially exhibits deeply forked characteristics, marking the further maturation of the caudal fin structure (Figure 3g).

An acceleration of growth was observed during the third week (weekly growth of 5114.05 μm), which is approximately 3 times higher than that of the first two weeks (1581.68 and 1440.37 $\mu\text{m}/\text{week}$, respectively) (Figure S1). This acceleration is likely related to the progressive development of the visual and locomotor systems, which improves the foraging efficiency of the larvae. This result aligns with the view that the maturation of sensory-motor capabilities during ontogeny can enhance predation efficiency, thereby supporting more rapid growth.

3.4. Gonadal Maturity Evaluation of F1 Offspring

After 21 DPH, the larvae from this batch were retained as broodstock and cultured in the same cement tanks under controlled water temperatures and intensive nutritional enrichment. After approximately 11 months, micro-histological dissection and observation were performed on their gonads. As shown in Figure 4, oocyte development in the F1 female ovaries was well-synchronized, predominantly consisting of stage II–III oocytes, with some oocytes already entering early stage IV. The oocytes exhibited intact morphology and clear outlines, with the cytoplasm showing uniform eosinophilic staining. The nuclei were large and round, containing numerous nucleoli distributed mainly along the inner side of the nuclear membrane. As oocytes developed, yolk granules gradually appeared in the cytoplasm, the zona radiata thickened, and an intact follicular cell layer was visible on the outer layer. The ovarian interstitial tissues were arranged orderly, and no obvious necrosis, atrophy, or abnormal structures were observed, indicating that the gonadal development process of the F1 females was normal and possessed good developmental potential.

The F1 male testes exhibited a typical lobular structure, with clear outlines of the seminiferous lobules and a uniform distribution of connective tissues between them. A large number of spermatogenic cells at different developmental stages were visible within the seminiferous lobules. These cells were tightly arranged, with scant cytoplasm and a high nucleocytoplasmic ratio; their nuclei exhibited strong basophilia and deep staining after HE staining. Among them, spermatogonia were mostly distributed along the margins of the lobules, showing a larger volume and clearly visible nucleoli. The volumes of spermatocytes and spermatids decreased sequentially, and their nuclear staining darkened

gradually. Highly condensed spermatids and mature spermatozoa were visible within some lobular lumina, indicating that the gonadal development of F1 males was normal and possessed typical spermatogenesis capability.

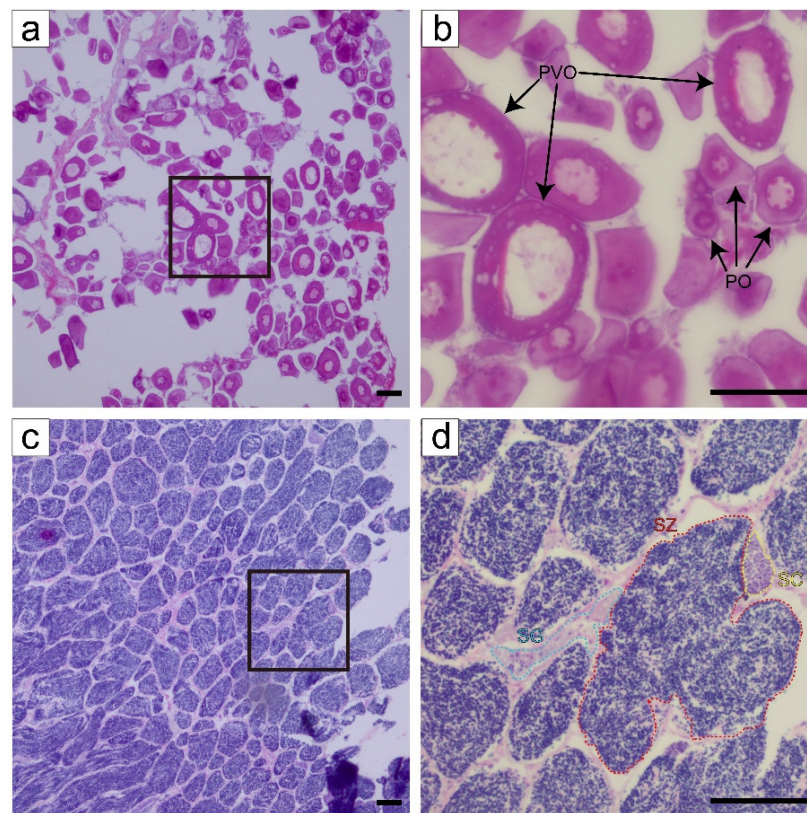


Figure 4. Histological sections of *Alepes djedaba* F1 gonads. (a,b): Ovary (a: 100 $\times$, b: 400 $\times$). PO: primary growth oocyte; PVO: pre-vitellogenic oocyte; (c,d): Testis (c: 100 $\times$, d: 400 $\times$); SG: spermatogonia; SC: spermatocytes; SZ: Spermatozoa; Scale bars: 50 μ m.

The above results demonstrate that the F1 *A. djedaba* obtained through artificial breeding possessed normal gonadal tissue structures and orderly cell development processes. Although the F1 females are still in the developmental phase toward full sexual maturity, the presence of stage II–III and early stage IV oocytes, coupled with mature spermatogenesis in males, confirms that the gonadal development of the artificially bred offspring is normal, laying a solid foundation for subsequent population self-maintenance and large-scale aquaculture.

4. Discussion

A. djedaba is an economically important fish species, but its artificial breeding technology has remained a blank. Therefore, a systematic study of its embryonic development characteristics is critical to breaking through breeding bottlenecks. This study represents the first systematic recording of the embryonic development process of *A. djedaba* through hormone-induced spawning and microscopic observation. Under the conditions of water temperature 24.50–24.97 $^{\circ}$ C, pH 7.69, salinity 20.7–29.6 ppt, and dissolved oxygen >5 mg/L, its embryonic development exhibits distinct stage-specific characteristics. This section elaborates on the division of embryonic developmental periods and provides a comprehensive comparison with related carangid fishes—namely the Japanese scad (*D. maruadsi*), golden trevally (*G. speciosus*), and pompano (*T. ovatus*)—to reveal developmental biological commonalities and differences, thereby providing theoretical support for artificial breeding.

4.1. Embryonic Development and Ecological Adaptation

The embryonic development of *A. djedaba* progresses through 6 periods and 20 characteristic stages, with the overall developmental process demonstrating distinctive efficiency and environmental adaptability. The efficient early cleavage and small egg diameter reflect a typical reproductive strategy of coastal-spawning fish [22,23]. In this study, the fertilized eggs of *A. djedaba* completed five cleavages to enter the 32-cell stage in only 1 h 2 min after fertilization, and hatching occurred in just 19 h 28 min at a water temperature of 24.50–24.97 °C. This rapid developmental speed is closely correlated with its small egg diameter of $(672.02 \pm 10.03) \mu\text{m}$. After hormone induction, micro-eggs require less energy absorption to initiate mitosis, thereby accelerating blastodisc cell differentiation [23]. From an ecological perspective, *A. djedaba* is widely distributed in coastal waters of the East China Sea, South China Sea, and Yellow Sea, where adult predators are abundant [24]. Its pelagic eggs face a high risk of predation within ocean currents. Therefore, this short-cycle hatching pattern may allow the fertilized eggs to rapidly escape the vulnerable embryonic state, which is hypothesized to be a reproductive strategy to mitigate early-stage mortality within coastal ecological niches [22].

Secondly, the highly compact organogenesis period reflects the biological requirement for prioritized development of sensory and locomotor functions [25,26]. This study revealed that the organogenesis period of *A. djedaba* is highly concentrated in the mid-to-late stages of embryonic development, accounting for approximately 30% of the total developmental duration. Crucially, the expansion of the optic primordium and the regular beating of the heart are completed in rapid succession. This temporal layout of compact differentiation between the neurula and locomotor organs exhibits high similarity and conservation to those of *D. maruadsi* and *G. speciosus*, which belong to the same family, Carangidae [14,15]. This phenomenon suggests that within a relatively short hatching period (approximately 18–19 h), these carangid fishes living under high environmental pressures in coastal zones appear to evolutionarily prioritize the rapid differentiation of sensory and locomotor systems [25,26]. This conserved developmental timing ensures that larvae possess a rudimentary visual structure and blood circulation capability at the exact moment of hatching, providing the physiological basis for immediate motility, balance maintenance, and predator avoidance post-hatching [25,26]. In contrast, *T. ovatus*, characterized by a large egg diameter and a prolonged hatching period (>40 h), exhibits a relatively relaxed pace and more ample time for embryonic organ differentiation [16].

Furthermore, the structure of the single oil globule provides critical support for survival during both the embryonic and early post-embryonic stages. A prominent single oil globule of $189.76 \pm 8.82 \mu\text{m}$ develops within the fertilized egg of *A. djedaba*. During the embryonic stage, this oil globule acts as a key organ for regulating buoyancy, enabling the fertilized egg to suspend in the water column and preventing hypoxic suffocation in seabed sediments. Moreover, post-hatching, it works in tandem with the residual yolk sac to provide the endogenous nutritional supply before mouth opening and active feeding (0–2 DPH) [18,27]. This alleviates starvation pressure on the minuscule larvae in complex marine environments, providing a critical buffer for the transition to exogenous feeding [27].

However, it is worth noting that the average hatching rate observed in this study was relatively low ($22.90\% \pm 15.60\%$) and exhibited high variability, reflecting an urgent need to optimize the early life history management of this species [13]. This suboptimal performance stems from intertwined endocrine, nutritional, and physical limitations. From an endocrine perspective, because this study represents the premier attempt at hormone induction for *A. djedaba*, the tentative dosage of HCG 150 IU/kg combined with LHRH-A3 0.80 $\mu\text{g/kg}$ might not have met the precise threshold required for uniform oocyte maturation. Furthermore, the acute stress associated with broodstock handling, anesthesia,

and intramuscular injection may have negatively impacted the physiological condition of the breeders, thereby compromising subsequent egg quality. This phenomenon is widely reported in the artificial breeding of other marine fishes; for example, in greater amberjack (*Seriola dumerili*) and *T. ovatus*, handling stress and sub-optimal hormonal therapies often result in variable egg quality and low initial hatching rates until species-specific domestication protocols are established [10,28]. Moving forward, to improve hatchery yields and stabilize embryonic viability, it is imperative to systematically refine these protocols by optimizing hormone regimens, enhancing broodstock diets, and implementing low-stress handling procedures.

4.2. Larval Growth and Rearing Insights

The growth and development of fish during the larval stage are closely related to the transition efficiency from endogenous to exogenous nutrition [29]. The metabolic characteristics and growth rates during this period directly determine the survival rate in artificial rearing [27,30]. In this study, the total length of newly hatched *A. djedaba* larvae was (1.43 ± 0.09) mm, which is significantly smaller than those of the related carangid species *D. maruadsi* ((1.78 ± 0.16) mm) and *T. ovatus* ((2.03 ± 0.37) mm). This indicates that *A. djedaba* faces higher environmental vulnerability and predation risks during the initial stage post-hatching. Regarding endogenous nutrition consumption, the yolk sac of *A. djedaba* larvae is basically completely absorbed by 3 DPH, which is consistent with *D. maruadsi* and *G. speciosus*. However, its oil globule absorption takes longer and can sustain up to 7 DPH, which is slower than that of *D. maruadsi* (5 DPH) and *G. speciosus* (6 DPH) (Table 2) [16,17]. This relatively slow oil globule utilization process extends the mixed nutrition period during the larval transition from endogenous to exogenous nutrition. This serves to provide a longer energy buffer during the critical stage of exogenous prey transition, thereby enhancing the starvation resistance of newly hatched larvae at initial mouth opening [27,31].

However, as the larvae transition to complete exogenous nutrition, their growth curve exhibits a significant stage-specific acceleration. In the third week (14–21 DPH), the larvae show a distinct growth inflection point, with the weekly growth reaching 5114.05 μ m, which is approximately 3 times that of the first week (1581.68 μ m) and the second week (1440.37 μ m) (Table S1). This shift in growth rate from slow to rapid suggests a close relationship with the progressive maturation of sensory and locomotor functions, as well as the improvement in foraging efficiency. Before 14 DPH, because the differentiation of related organs is incomplete, the feeding capability of the larvae is relatively low, and growth progresses slowly. Upon entering the third week, accompanied by the maturation of the visual system and locomotor organs, the larvae can lock onto and capture exogenous prey in the water column more efficiently, thereby obtaining more energy allocation to support rapid growth.

These developmental characteristics provide useful insights for the artificial seed production of *A. djedaba*. Because newly hatched larvae are minuscule and face a transition bottleneck in early feeding and starvation resistance, it is essential to maintain a high density of small-sized microparticulate diets or high-quality rotifers during the mixed nutrition and critical vulnerability periods before 7 DPH. From a hatchery management perspective, this fragile initial phase requires strictly controlled larval rearing protocols. Gentle aeration must be implemented to keep both the buoyant larvae and live prey evenly suspended without causing mechanical damage, and surface skimmers should be deployed to prevent larvae from adhering to the water surface tension due to their large oil globules. This practice helps avoid starvation risks at initial mouth opening and improves the survival rate. After the larvae reach the growth inflection point at 14 DPH, the feeding strategy should align with the developmental progress of their organ systems. Providing timely enrichment with high-protein and high-energy live prey, such as copepods, is necessary to

satisfy their nutritional requirements during the explosive growth phase [32]. Additionally, as larval mobility and feeding efficiency surge during this period, regular size-grading protocols should be introduced to mitigate the risk of cannibalism in large-scale rearing tanks. Similar rearing challenges and management strategies have been well-documented in the larviculture of other carangids. For instance, the use of surface skimmers is a standard practice in rearing *Seriola quinqueradiata* to prevent surface tension-induced mortality [33], while strict size-grading is crucial for *T. ovatus* to prevent cannibalism during its rapid growth phase [34]. Applying these established marine fish larviculture paradigms will be pivotal for successfully scaling up *A. djedaba* seed production.

Table 2. Comparison of early life-history and developmental traits among four carangid species.

Trait	<i>AlepesDjedaba</i>	<i>Gnathanodon Speciosus</i>	<i>Decapterus Maruadsi</i>	<i>Trachinotus Ovatus</i>
Egg diameter (μm)	672.02 ± 10.0	764.29 ± 14.7	763.4 ± 27.6	967.8
Hatching time (h)	19.47	18.50	19.17	41.45
Total length of newly hatched larvae (mm)	1.43 ± 0.09	1.52 ± 0.02	1.78 ± 0.16	2.03 ± 0.37
Yolk sac absorption time (DPH)	3	3	3	4
Oil globule absorption time (DPH)	7	6	5	6

4.3. Evaluation of Complete Artificial Breeding in F1 Offspring

In the large-scale breeding practice of marine economic fishes, the gonadal development status of the first-generation (F1) offspring under artificial culture conditions serves as an important standard for evaluating the successful establishment of a complete artificial breeding system [35]. During early domestication, many marine fishes often experience blockages in their reproductive endocrine axis due to the physical limitations of artificial cement tanks, the absence of natural photoperiods, and nutritional barriers in formulated feeds [36,37]. This typically manifests as gonadal degeneration, developmental arrest, or asynchronous maturation of sperm and eggs in the F1 generation. However, histological dissection results showed that the F1 *A. djedaba* cultured continuously to sexual maturity in this study exhibited favorable tissue structures and normal developmental potential.

Microscopic sections indicated that oocyte development in the F1 female ovaries was well-synchronized, predominantly consisting of stage II–III oocytes, with some cells already entering early stage IV. Furthermore, the zona radiata was thickened, and the follicular cell layer was intact. Concurrently, the F1 male testes exhibited a typical and clearly structured lobular morphology, with mature spermatozoa already condensed inside the lobular lumina. This synchronous development of sperm and eggs, along with the histological absence of degeneration or necrosis, demonstrates that *A. djedaba* has a strong capability to adapt to domestication within indoor cement tanks and on formulated diets. This study not only broke through the technical bottlenecks of hormone-induced spawning and temperature-controlled seed rearing for this species but also demonstrated the normal gonadal development and reproductive potential of the F1 generation. Although the F1 females are still in the developmental phase toward full maturity and producing the F2 generation is required to fully close the life cycle, these cellular-level findings confirm the physiological adaptability in captive environments for *A. djedaba*. This achievement marks that *A. djedaba* exhibits good potential for industrial promotion and germplasm resource conservation value. Since this is the first attempt at complete artificial breeding for this species, this research phase focused on the morphological characteristics of early ontogeny and exploring its potential for achieving life-history closure. Future studies will focus on the quantification and optimization of survival rates in large-scale rearing processes.

5. Conclusions

The embryonic development of *A. djedaba* progresses through 6 periods and 20 stages. Its rapid cleavage and compact organogenesis reflect the highly efficient developmental characteristics typical of carangid fishes. In this study, the artificial propagation of *A. djedaba* was achieved under controlled hatching conditions, yielding an average combined hatching rate of $22.9\% \pm 15.6\%$. Larval development showed an explosive growth inflection point during the third week (14–21 DPH), with a weekly growth increment of $5114.05 \mu\text{m}$, which is approximately three times that of the first two weeks. Furthermore, histological dissection verified that the F1 offspring reared continuously possessed intact ovarian and testicular tissue structures alongside normal germ cell development. While the F1 females were predominantly at stages II–III (with some entering early stage IV) and have not yet spawned to produce F2, their orderly germ cell development serves as compelling evidence of their reproductive potential in captive culture. Future research should further explore the developmental responses of *A. djedaba* under varied environmental regimes, focusing primarily on the impacts of factors such as temperature, salinity, and dissolved oxygen on early life stages, while deeply investigating its nutritional requirements and optimal feed formulations to comprehensively enhance survival rates and growth velocities during large-scale artificial culture.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/fishes11080448/s1>, Figure S1: Growth curve of *Alepes djedaba* larvae during early post-embryonic development.; Table S1: Summary of hormone-induced spawning trials, egg production, and larval yields of *Alepes djedaba* in 2025.

Author Contributions: Conceptualization, J.W. (Junjie Wang) and J.W. (Jinhui Wu); methodology, J.W. (Jinhui Wu), W.C. and S.Y.; software, W.C. and S.Y.; validation, Y.H., J.W. (Jujing Wang) and X.Z.; formal analysis, J.W. (Jinhui Wu) and W.C.; investigation, J.W. (Jinhui Wu), W.C., S.Y., Y.H., J.W. (Jujing Wang), X.Z. and J.Z.; resources, J.W. (Jujing Wang); data curation, J.W. (Jinhui Wu) and W.C.; writing—original draft preparation, J.W. (Jinhui Wu) and W.C.; writing—review and editing, J.W. (Jujing Wang), W.C. and S.Y.; visualization, J.W. (Jinhui Wu); supervision, J.W. (Jujing Wang); project administration, J.W. (Jujing Wang); funding acquisition, J.W. (Jujing Wang). All authors have read and agreed to the published version of the manuscript.

Funding: This research was financially supported by the Dongjiang Scholar Program, and the 2025 Research on breeding technology of candidate species for Guangdong modern marine ranching (Grant No. NJTG-20260027).

Institutional Review Board Statement: All animal experiments were carried out in accordance with the guidelines and approval of the Animal Research and Ethics Committee of School of Life Science, South China Normal University on 1 December 2018 (permissions, CAMC-2018F).

Data Availability Statement: All data generated or analyzed during this study are included in this published article.

Acknowledgments: We sincerely thank Jiabo Chen for his assistance with data analysis.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Carpenter, K.E.; Niem, V.H. *The Living Marine Resources of the Western Central Pacific: 2. Cephalopods, Crustaceans, Holothurians and Sharks*; FAO: Roma, Italy, 1998.
2. Majeed, A.; Liang, Z.; Zhu, L.; Liu, C.; Kalhor, M.A.; Saeed, F. Stock Analysis of Shrimp Scad (*Alepes Djedaba*) Fishery from Northern Arabian Sea, Balochistan Coast, Pakistan. *Pak. J. Zool.* **2022**, *54*, 2203–2212. [[CrossRef](#)]
3. Bandkar, D.S.; Nirmale, V.H.; Gurjar, U.R.; Metar, S.Y.; Pawar, R.A.; Chogale, N.D. Reproductive Biology and Feeding Dynamics of the Shrimp Scad *Alepes Djedaba* (Forsskal, 1775) from Ratnagiri, Central West Coast of India. *Indian J. Fish.* **2022**, *69*, 37–44. [[CrossRef](#)]

4. Lin, P.-L.; Shao, K.-T. A Review of the Carangid Fishes (Family Carangidae) from Taiwan with Descriptions of Four New Records. *Zool. Stud.* **1999**, *38*, 33–68. [\[CrossRef\]](#)
5. Moravec, F.; Fazaa, H.A.; Ali, A.H.; Saud, H.A. Five Species of *Philometra* Costa, 1845 (Nematoda: Philometridae) Newly Recorded from Marine Fishes in Iraq, Including the Description of *P. Arabiensis* Sp. n. from the Ovary of the Shrimp Scad *Alepes Djedaba* (Carangidae). *Folia Parasitol.* **2022**, *69*, 031. [\[CrossRef\]](#) [\[PubMed\]](#)
6. Li, Y.-C.; Inoue, K.; Zhang, J.-Y.; Sato, H. Descriptions of Three New Species and New Host or Distribution Records of Five Species of the Genus *Kudoa* (Myxozoa: Myxosporae: Multivalvulida) in Commercial Fishes Collected from South China Sea. *Acta Parasitol.* **2022**, *67*, 976–996. [\[CrossRef\]](#) [\[PubMed\]](#)
7. Ray, D.; Mohapatra, P.; Ghorai, N.; Seth, J.K.; Mohapatra, A. Infection of the Parasitic Isopods on Commercial Fishes of the Northern Part of the East Coast of India. *J. Parasit. Dis.* **2022**, *46*, 440–453. [\[CrossRef\]](#) [\[PubMed\]](#)
8. Rahmanpour, S.; Farzaneh Ghorghani, N.; Lotfi Ashtiyani, S.M. Polycyclic Aromatic Hydrocarbon (PAH) in Four Fish Species from Different Trophic Levels in the Persian Gulf. *Environ. Monit. Assess.* **2014**, *186*, 7047–7053. [\[CrossRef\]](#) [\[PubMed\]](#)
9. Wongwichian, C.; Chaijan, M.; Klomkloa, S. Physicochemical Instability of Muscles from Two Species of Scad during Iced Storage. *Chiang Mai J. Sci.* **2013**, *40*, 681–688.
10. Corriero, A.; Wylie, M.J.; Nyuji, M.; Zupa, R.; Mylonas, C.C. Reproduction of Greater Amberjack (*Seriola Dumerili*) and Other Members of the Family Carangidae. *Rev. Aquac.* **2021**, *13*, 1781–1815. [\[CrossRef\]](#)
11. Suresh Babu, P.P.; Anuraj, A.; Shilta, M.T.; Asokan, P.K.; Vinod, K.; Praveen, N.D.; Srinivasa Rao, K.; Vaidya, N.G.; Sonali, S.M.; Pal, M.; et al. Broodstock Development, Breeding and Larval Rearing of *Acanthopagrus Berda* (Forsskal, 1775), a Suitable Species for Farming in Tropical Waters. *Aquac. Res.* **2022**, *53*, 6439–6453. [\[CrossRef\]](#)
12. de-Dios, M.A.H.; Tovar-Ramírez, D.; García, D.M.; Galaviz-Espinoza, M.A.; Zarco, M.S.; Maldonado-García, M.C. Functional Additives as a Boost to Reproductive Performance in Marine Fish: A Review. *Fishes* **2022**, *7*, 262. [\[CrossRef\]](#)
13. Na-Nakorn, U.; Kamcharoen, M.; Santos, B.S.; Torres, S.K.M.; Nakajima, M.; Senanan, W.; Gonzales-Plasus, M.M.; Zeng, C. Current Status of Carangid Aquaculture and Way Forward. *Agric. Nat. Resour.* **2023**, *57*, 541–558. [\[CrossRef\]](#)
14. Zhang, X.; Yang, S.; Zou, C.; Zhang, Y.; Huang, J.; Gan, S.; Qin, Z.; Huang, W.; Chen, Y.; Wu, J.; et al. Observation on the embryonic and post-embryonic developmental characteristics of blue round scad (*Decapterus maruadsi*). *J. Fish. China* **2025**, *49*, 019608-1. (In Chinese)
15. Huang, W.; Gan, S.; Wang, Q.; Yang, S.; Huang, J.; Zhao, Y.; Zou, C.; Huang, P.; Zhang, X.; Chen, Y.; et al. Characteristics of the embryonic and post-embryonic development of golden trevally (*Gnathanodon speciosus*). *J. Fish. China* **2024**, *48*, 049110. (In Chinese)
16. Ou, Y.; Li, J. Early embryonic development in *Trachinotus ovatus*. *J. Fish. Sci. China* **2005**, *12*, 786–789. (In Chinese)
17. Ou, Y.; He, Y.; Li, J.; Ji, L. Color variation and fins development during postembryonic development stage of *Trachinotus ovatus*. *J. Trop. Oceanogr.* **2012**, *31*, 62–66. (In Chinese) [\[CrossRef\]](#)
18. Kamler, E. Ontogeny of Yolk-Feeding Fish: An Ecological Perspective. *Rev. Fish Biol. Fish.* **2002**, *12*, 79–103. [\[CrossRef\]](#)
19. Pepin, P. Effect of Temperature and Size on Development, Mortality, and Survival Rates of the Pelagic Early Life History Stages of Marine Fish. *Can. J. Fish. Aquat. Sci.* **1991**, *48*, 503–518. [\[CrossRef\]](#)
20. Ihaka, R.; Gentleman, R. R: A Language for Data Analysis and Graphics. *J. Comput. Graph. Stat.* **1996**, *5*, 299–314. [\[CrossRef\]](#)
21. Wickham, H. Ggplot2. *Wiley Interdiscip. Rev. Comput. Stat.* **2011**, *3*, 180–185. [\[CrossRef\]](#)
22. Bailey, K.M.; Houde, E.D. Predation on Eggs and Larvae of Marine Fishes and the Recruitment Problem. In *Advances in Marine Biology*; Elsevier: Amsterdam, The Netherlands, 1989; Volume 25, pp. 1–83.
23. Hirst, A.; López-Urrutia, A. Effects of Evolution on Egg Development Time. *Mar. Ecol. Prog. Ser.* **2006**, *326*, 29–35. [\[CrossRef\]](#)
24. Yang, B.; Herrmann, B.; Wan, R. Effects of Codend Mesh-Shape and Size on the Size Selectivity of Demersal Trawl Targeting Banded Scad (*Alepes Djedaba*) in the Beibu Gulf, South China Sea. *J. Mar. Sci. Eng.* **2023**, *11*, 1390. [\[CrossRef\]](#)
25. Fuiman, L.A.; Magurran, A.E. Development of Predator Defences in Fishes. *Rev. Fish Biol. Fish.* **1994**, *4*, 145–183. [\[CrossRef\]](#)
26. Downie, A.T.; Illing, B.; Faria, A.M.; Rummer, J.L. Swimming Performance of Marine Fish Larvae: Review of a Universal Trait under Ecological and Environmental Pressure. *Rev. Fish Biol. Fish.* **2020**, *30*, 93–108. [\[CrossRef\]](#)
27. Robert, D.; Shoji, J.; Sirois, P.; Takasuka, A.; Catalán, I.A.; Folkvord, A.; Ludsins, S.A.; Peck, M.A.; Sponaugle, S.; Ayón, P.M.; et al. Life in the Fast Lane: Revisiting the Fast Growth—High Survival Paradigm during the Early Life Stages of Fishes. *Fish Fish.* **2023**, *24*, 863–888. [\[CrossRef\]](#)
28. Mylonas, C.C.; Papandroulakis, N.; Smboukis, A.; Papadaki, M.; Divanach, P. Induction of Spawning of Cultured Greater Amberjack (*Seriola Dumerili*) Using GnRH Implants. *Aquaculture* **2004**, *237*, 141–154. [\[CrossRef\]](#)
29. Yúfera, M.; Darias, M.J. The Onset of Exogenous Feeding in Marine Fish Larvae. *Aquaculture* **2007**, *268*, 53–63. [\[CrossRef\]](#)
30. Rønnestad, I.; Yúfera, M.; Ueberschär, B.; Ribeiro, L.; Sæle, Ø.; Boglione, C. Feeding Behaviour and Digestive Physiology in Larval Fish: Current Knowledge, and Gaps and Bottlenecks in Research. *Rev. Aquac.* **2013**, *5*, S59–S98. [\[CrossRef\]](#)
31. Shan, X.; Quan, H.; Dou, S. Effects of Delayed First Feeding on Growth and Survival of Rock Bream *Oplegnathus Fasciatus* Larvae. *Aquaculture* **2008**, *277*, 14–23. [\[CrossRef\]](#)

32. Evjemo, J.O.; Reitan, K.I.; Olsen, Y. Copepods as Live Food Organisms in the Larval Rearing of Halibut Larvae (*Hippoglossus hippoglossus* L.) with Special Emphasis on the Nutritional Value. *Aquaculture* **2003**, *227*, 191–210. [[CrossRef](#)]
33. Sakakura, Y.; Tsukamoto, K. Onset and Development of Cannibalistic Behaviour in Early Life Stages of Yellowtail. *J. Fish Biol.* **1996**, *48*, 16–29. [[CrossRef](#)]
34. Ma, Z.; Yu, G.; Qin, J.G. (Eds.) *Ontogenetic Development of Pompano Trachinotus Ovatus*; Springer Nature: Singapore, 2022.
35. Teletchea, F.; Fontaine, P. Levels of Domestication in Fish: Implications for the Sustainable Future of Aquaculture. *Fish Fish.* **2014**, *15*, 181–195. [[CrossRef](#)]
36. Chen, J.Y.; Zeng, C.; Jerry, D.R.; Cobcroft, J.M. Recent Advances of Marine Ornamental Fish Larviculture: Broodstock Reproduction, Live Prey and Feeding Regimes, and Comparison between Demersal and Pelagic Spawners. *Rev. Aquac.* **2020**, *12*, 1518–1541. [[CrossRef](#)]
37. Taranger, G.L.; Carrillo, M.; Schulz, R.W.; Fontaine, P.; Zanuy, S.; Felip, A.; Weltzien, F.-A.; Dufour, S.; Karlsen, Ø.; Norberg, B. Control of Puberty in Farmed Fish. *Gen. Comp. Endocrinol.* **2010**, *165*, 483–515. [[CrossRef](#)] [[PubMed](#)]

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.