

Natural spawning and larval rearing of the longfin yellowtail (*Seriola rivoliana* Valenciennes, 1833) in captivity in Indonesia

¹Ketut Sugama, ¹Haryanti Haryanti, ³Gede Iwan Setiabudi, ²Jhon Harianto Hutapea, ²Gusti Ngurah Permana, ¹Ahmad Muzaki, ⁴Romy Suprpto, ¹Isti Koesharyani, ⁵Sarwono Sarwono, ⁶Thor Sutan Yasin

¹ Research Center for Marine Aquaculture, National Research and Innovation Agency of Indonesia, Jalan Raya Bogor Km. 46, Nangewer, Bogor, Indonesia; ² Research Center for Marine Aquaculture, National Research and Innovation Agency of Indonesia, Malaka, Kec. Pemenang, Kabupaten Lombok Utara, Nusa Tenggara Barat, 83352, Indonesia; ³ Ganesha University, Ministry of Research, Technology and Education, Jalan Udayana No 11, Singaraja-Bali, Indonesia; ⁴ Research Center for Freshwater, National Research and Innovation Agency of Indonesia, Jalan Raya Bogor Km. 46, Nangewer, Bogor, Indonesia; ⁵ Ambon Mariculture Development Center, Jalan Leo Watimena, Waiheru Kec Baguala, Kota Ambon Maluku, Indonesia; ⁶ Forever Ocean Indonesia, Wineru, Likupang Timur, Kabupaten Minahasa, North Sulawesi, Indonesia. Corresponding author: H. Haryanti, hary016@brin.go.id

Abstract. The objective of this study was to observe the natural spawning and larval rearing performance of the longfin yellowtail, *Seriola rivoliana*, in captivity. The broodstocks of *S. rivoliana* with a body weight of 6.4 - 7.1 kg and 5.9 - 6.8 kg were cultured in two tanks of 100-ton capacity with flow through system. The fish spawned naturally in July to September 2023 and 2024 without any hormone injection in both hatcheries. The number of fertilized eggs ranged between 51-510 x 10³ and 0-410 x 10³ and hatching rate ranged between 16.67-82.35 % and 0.00-79.61 % in hatchery 1 and 2, respectively. The fertilized eggs are non-adhesive and pelagic, with the size of 1.12 ± 0.11 mm and hatched between 30-34 h after fertilization at a water temperature of 28 ± 0.4°C. The newly hatched larvae measured 3.26 ± 0.16 mm, the mouth of the larvae opened 3 days after hatching. The larval rearing trials were done twice, where in the first and second trials were introduced at a stocking density of 10 ind L⁻¹. In the first trial the initial feeding was conducted with S-strain rotifer followed by L-strain rotifer, *Artemia* sp. nauplii and weaning with micro diet, while in the second trial S-strain rotifer was replaced by copepod (*Acartia* sp. nauplii), and each trial had 2 replicates. The result has shown that there is no difference in growth rate between the two trials but survival in the second trial (3.10%) was slightly higher than in the first trial (2.21%) after 30 days after hatching, but not significantly different. To achieve successful rearing, more studies of larval rearing methodology are needed, especially for the water management, feeding regime and nutritional requirements of the *S. rivoliana* larvae.

Key Words: aquaculture, broodstock, fish reproduction.

Introduction. Amberjacks (*Seriola* spp.) are important species for marine aquaculture development because of their fast growth and high flesh quality. The amberjack species such as the Japanese amberjack, *Seriola quinqueradiata* has been produced for a long time through aquaculture activities (Sawada et al 2025). Other cultured *Seriola* species are yellowtail kingfish (*Seriola lalandi*) in Japan and Australia, longfin yellowtail (*Seriola rivoliana*) in the United States, greater amberjack (*Seriola dumerili*) in Japan, the Mediterranean and more recently Vietnam, and Pacific yellowtail (*Seriola mazatlana*) in North and Central America (Sicuro & Luzzana 2016). Unfortunately, the source of fingerlings is mostly from wild caught fish (Sawada et al 2025). Recently, the population of wild fingerlings in some areas has been declining and became a main obstacle for increasing marine aquaculture production. Marine aquaculture production is expected to

solve the problem of the gap between demand and supply of seafood (Cai et al 2023). The technology of artificial fish seed production has been developed for several species of marine fish including species of Japanese and greater amberjacks; therefore, larvae and juvenile of amberjacks are available for grow out activities. Longfin yellowtail (*Seriola rivoliana* Valenciennes, 1833), belongs to the genus *Seriola* and Carangidae family (Fricke et al 2022). The demand of *Seriola* species in the global market is increasing, therefore this species has been targeted for the diversification of the marine aquaculture industry development (Cai et al 2023). The government of Indonesia proposed to promote the diversification of national aquaculture with native fish species, one of it is the longfin yellowtail, *Seriola rivoliana*, which has characteristic advantages making it a suitable candidate for aquaculture: large size, fast growth and a worldwide market (Cai et al 2023; Yang et al 2016; Sicuro & Luzzana 2016; Blanco et al 2022). The species is naturally distributed along tropical and subtropical waters including Indonesian waters (Figure 1A). In Indonesia, longfin yellowtail is frequently captured by fisherman, but no attempt has been made to conduct research on spawning, larval rearing and grow-out until marketable size (2-4 kg). An attempt to raise F1 broodstock has produced less-fertile fish (Quiñones-Arreola et al 2015). Successful maturation and spawning have been achieved with the use of gonadotropin-releasing hormone agonist (GnRHa) loaded into controlled-release devices (Roo et al 2014). However, producing a large number of larvae is still the most difficult process (Roo et al 2015), and therefore the development of suitable technology is important.

In the present work, an attempt on natural spawning and larvae rearing of *Seriola rivoliana* in tanks has been done for the first time in Indonesia. This work is the results of research collaboration among National Research and Innovation Agency of Indonesia BRIN KKI-BL Gondol, Forever Ocean Indonesia (FOI) and Ambon Mariculture Development Centre- Ministry of Marine Affairs and Fisheries of Indonesia (MOMAF).



Figure 1. Distribution range for longfin yellowtail, *Seriola rivoliana* (A) (Froese & Pauly 2025) and location of the hatchery 1 in Likupang- North Sulawesi and hatchery 2 in Ambon Island -Maluku (B) (Atlas Nasional Indonesia 2023).

Material and Method

Broodstock husbandry and spawning. In March 2022, Forever Ocean has collected longfin yellowtail, *Seriola rivoliana* (n = 110) broodstock with a body weight (BW) ranging between 3.0 and 10.0 kg, and the fish were purchased from professional fisherman. The broodstock were captured by hook and line in the Northern Coast of Sulawesi Island, Manado, Indonesia and transported to the hatchery facilities of the Forever Ocean (FO) USA company located at Likupang North Sulawesi, named as hatchery 1 (Figure 1B). The fish were kept in 3 cylindrical concrete tanks (30 tons each) with supplemented oxygen and flow through watering exchange until the stocking to the spawning tanks. Before the fish are stocked in the spawning tanks, they were treated with a freshwater bath for 5 minutes to eliminate common parasites such as skin flukes, *Benedenia* spp., *Neobenedenia* spp., *Cryptocaryon irritans* and copepods (Koesharyani et al 1999; Akita et al 2023; Uchino et al 2020). These fishes were monitored for 14 days and when the fishes look healthy and active, feeding and swimming, they were selected

then treated with antiseptic Japanese “arufazu” dip (formaldehyde, KMnO_4 , malachite green) using 100 ppm for about 30 minutes and transferred to the concrete circular broodstock tank of 100-ton capacity with flow through system in hatchery 1 (Figure 2). The number of fish selected and stocked in the broodstock tank were 32 fishes, with body weight (BW) between 6.4 and 7.1 kg (Figure 2). In hatchery 1, the broodstock tank was placed indoors under natural temperature ($28.5^\circ\text{C} - 29.5^\circ\text{C}$) and normal photoperiod 12 h L:12 h D. The other 42 fish with BW of 5.9 - 6.8 kg were transported to hatchery 2 located at Ambon Mariculture Development Center (AMDC) in Ambon Island-Maluku (Figure 1B) and stocked into a concrete circular tank of 100-ton capacity and set up outdoor.

The broodstock in both hatcheries 1 and 2 were fed twice a day at an amount of 3-5% of total biomass with fresh fish (mainly sardines and mackerel) and an additional 50% squid 3 times a week. The food was supplemented with vitamin mix at 1% dosage. Feces and uneaten feed that accumulated on the bottom tank are siphoned out at certain intervals. Broodstock tanks are continuously supplied with fresh filtered seawater at a daily exchange rate of 200%. Each tank has an overflow pipe with an egg collection tank and net (600 μm) installed for eggs collection. The water quality was monitored daily, such as water temperature, salinity, pH, dissolved oxygen (DO) by using digital apparatus (Hanna Instruments HACH HQ40D, Hanna Instruments, USA), while total ammonia (Hanna Instruments HI386n, Hanna Instruments, USA) and alkalinity (Hanna Instruments HI755, Hanna Instruments, USA) were checked once a week. The maturity stage was individually checked, weighed and sampled to determine the maturation stage and sex in April 2023. Sperm samples were taken by abdominal pressing. Eggs were collected and kept in Eppendorf tubes. The broodstock were allowed to spawn naturally without any hormone injection. Whenever spawning occurs, eggs are collected from the spawning tank outlet of eggs collection tank. The eggs were then washed with clean sea water and transferred into 500 L capacity transparent circular tanks for incubation. Unfertilized eggs that settled at the bottom of the tank were siphoned out, and only the floating (fertilized) eggs were used for hatching.

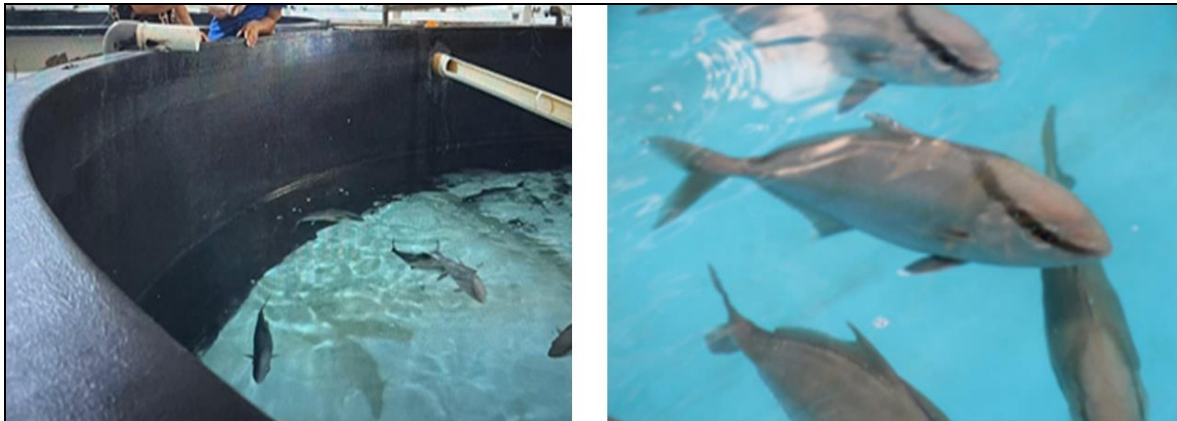


Figure 2. Broodstock tank and *Seriola rivoliana* brood fish.

Eggs collection. On each spawning, the floating eggs were collected every morning usually between 10-11 am. In the present study, the collected floating eggs mean the eggs obtained on a spawning day and does not represent the total number of released eggs and fertilization from a certain female. The total number of fertilized eggs was estimated by counting the eggs in 20 samples (10 mL). Mean egg diameter was measured with a profile projector microscope. The eggs development was examined under the microscope to monitor embryonic stage, and the fertilization rate was calculated at early stages of embryonic development (Figure 5C). The fertilization was monitored daily and was estimated as the number of floating eggs, and hatching rate was estimated as the number of hatched eggs/total number of fertilized eggs.

Live feed culture. *Nannochloropsis oculata* were cultured in 10-ton capacity square concrete tank with strong aeration and placed outdoors. The fertilizer used to mass produce *N. oculata* are ZA or $(\text{NH}_4)_2\text{SO}_4$ 80 ppm, TSP or Ca_3PO_4 30 ppm, urea or $(\text{NH}_2)_2\text{CO}$ 10 ppm, and FeCl_3 2.5 ppm, with light intensity between 9,000-15,000 lux. (Sugama et al 2012; Sugama & Koesharyani 2017).

Rotifers (S- and L- strains) were cultured using *N. oculata* (at a density of 2.4×10^3 cells/ml) 5-ton concrete tanks and *N. oculata* was renewed every day to keep the same density. Harvested rotifers were enriched for about 2–4 h using Inve-Super Selco product before feeding to the larvae. *Artemia* sp. nauplii was also used for feeding the larvae. Filtered *Artemia* sp. nauplii were enriched using the same product after 3 h post hatching by soaking them in the enrichment medium for 4 h. Both enriched rotifer and *Artemia* were washed by using clean seawater before feeding to the larvae. Copepod (*Acartia* sp.) was mass cultured using mixed green water of *N. oculata* and *Isochrysis galbana*.

Larval rearing. Two-ton capacity of round shape FRP tanks with 1.2 m depth were used for rearing the larvae. Larval rearing tanks are equipped with aeration, sand filtration systems with UV light. Sea water (35.0 ppt) was used for the larval-rearing tank and is pretreated with a sand filter and UV light. Photoperiod during larval rearing activity was 12 h L:12 h D. The larval rearing trials were done twice, where in the first and second trials fertilized floating eggs of *S. rivoliiana* were introduced with stocking density of 10 ind L^{-1} larvae. In the first trial the larvae were fed with small rotifer (S-strain 158.6 - 180.7 μm , 5 - 7 ind/ml) followed by large rotifer (L-strain, 190.4 - 238.5 μm , 8 - 10 ind/ml). In the second trial S-strain rotifer was replaced by copepod (*Acartia* sp.) and each trial had 2 replicates. One day after hatching (1 DAH), the larvae were cultured in sea water and green water consisting of *N. oculata* at density of $3 - 4 \times 10^5$ was introduced. Rotifer S-strain was introduced at 3 DAH and followed by L-strain rotifer at 5 DAH onward up to 20 DAH, and *Artemia* sp. nauplii were introduced started at 12 DAH. Artificial diets were introduced on day 20 DAH onward while feeding *Artemia* sp. nauplii. The larval rearing technique according to Sugama et al (2009) and Sugama and Koesharyani (2017) detailed protocol of larval rearing is summarized in Figure 3. To estimate the growth and survival, the fish samples were collected randomly at 1, 5, 10, 15, 20, 25, 30 DAH and measured their length-size using a microscope projector (Nikon Corp., Tokyo, Japan). The water temperature (WT), pH, salinity and dissolved oxygen (DO) was checked daily, and ammonia (NH_3) was checked every 3 days during the larval rearing period.

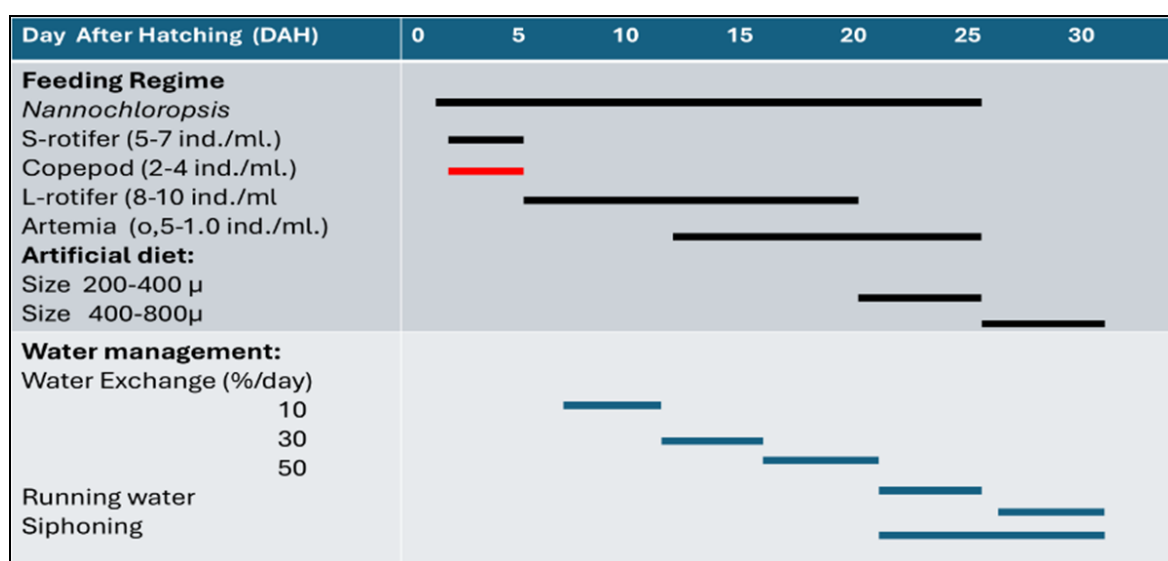


Figure 3. Feeding protocol and water management during larval rearing of *S. rivoliiana*.

Results

Broodstock husbandry and spawning. The water quality parameters in the broodstock tank at hatchery 1 were as follows: water temperature ranged between 28.7 - 29.5°C; salinity ranged between 34.5 - 35.0 ppt; pH ranged between 7.6 - 8.1; DO ranged between 5.01 - 5.55 mg L⁻¹; total ammonia ranged between 0.354 - 0.422 ppm. Unfertilized eggs first time were found and collected at the end of June 2023 and followed on August 4, 2023, the fishes began to spawn naturally without any hormonal induction in hatchery 1 and spawn eggs were fertilized and hatched normally (Figure 4A). Fertilized eggs were obtained from the end of July to early September 2023. Spawning time occurred in the morning, between 8.0 am to 9.0 am.

In hatchery 1, the number of floating (fertilized) eggs that were collected from the eggs collector varied between 51 - 510 x 10³ and hatching rate was of 16.67 to 82.35 % (Figure 4 A). In 2024 the broodstock of hatchery 1 was moved to the marine net cage, to renovate the watering system of hatchery 1, so that observation of fish spawning could not be done. While in 2023 the broodstock tank at hatchery 2 was kept outdoors and the broodstock could spawn throughout the year, in January 2024 the broodstock were moved to the indoor hatchery in a 100-ton capacity circular tank and the fish were able to spawn several times between the end of July to the end of September 2024 (Figure 4B).

The water quality parameters of hatchery 2 were: temperature ranged between 28.2 - 29.5°C; salinity ranged between 34.5 - 35.0 ppt; pH ranged between 7.8 - 8.0; DO ranged between 5.21 - 5.65 mg/l; total ammonia ranged between 0.344 - 0.445 ppm. All the water quality parameters were in normal range for fish survival, growth and reproduction. The number of fertilized egg and hatching rates in hatchery 2 ranged from 0.00 to 410 x 10³ and 0.00 to 79.61 %, respectively (Figure 4B). Based on the findings of the present study, the peak of spawning season of *S. rivoliana* in hatchery conditions occurred during the month of July to September in year 2023 and 2024.

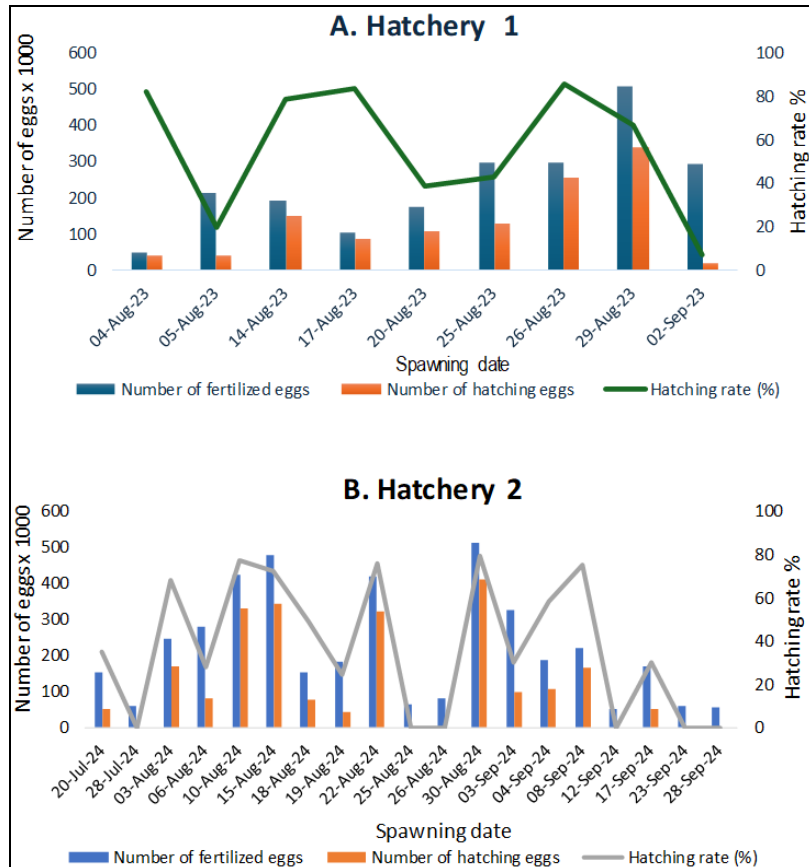


Figure 4. Spawning date, the number of fertilized eggs, the number of hatching eggs and hatching rate of *S. rivoliana* in captivity at hatchery 1 (A) and hatchery 2 (B).

Eggs hatching and larval rearing. The results of water quality parameters measurements during the larval rearing period were as follows: water temperature ranged between 28.5 - 29.0°C; salinity ranged between 34.5 - 35.0 ppt; DO ranged between 5.0 - 5.5 mg L⁻¹; pH ranged between 7.5 - 7.9; total ammonia ranged between 0.48 - 0.59 mg L⁻¹. The fertilized eggs were floating and non-adhesive with an average diameter of 1.12 ± 0.11 mm (Figure 5A) and with single oil globule measuring of 0.24 ± 0.02 mm, while the unfertilized eggs were white in color and cloudy (Figure 5B). The fertilized eggs hatched between 30 - 34 h after fertilization in water temperature of 28.9 ± 0.4°C. After hatching (1 DAH) the newly hatched larvae were stocked in the larval rearing tanks at a density of 10 ind L⁻¹. The larval tanks were siphoned to remove debris and dead eggs, then *Nannochloropsis oculata* was added to maintain a cell density of 3 - 4 10⁵ cells L⁻¹. Details of feeding schedule and water management are given in Figure 3. The fertilized eggs and embryo development are shown in Figure 5C. The average size of newly hatched larvae was 3.26 ± 0.16 mm (Figure 5D). On 3 DAH, the larvae yolk was completely absorbed, mouth was formed and eyes were pigmented (Figure 5E). On 5 DAH, average size of larvae measured 5.05 ± 0.13mm (Figure 5F) and on 10 DAH the larvae measured 6.36 ± 1.08 mm (Figure 5G). The average larvae length at 15 DAH was 8.48 ± 1.98 mm. On 20 DAH, average larvae length was 10.22 ± 2.01 mm. On 25 DAH the color of larvae becomes grey and mean total length attained was 13.32 ± 2.88 mm. By 30 DAH, the larvae tend to swim from surface to bottom of larval tank, and body color changed to become grew-yellow. At 30 DAH the larvae had metamorphosed, and size was 16.2 ± 3.05 mm in total body length with colorations like the adult fish (Figure 5H). The growth and survival of *S. rivoliana* reared with and without copepod is presented in Figure 6 and Figure 7. At 30 DAH average survival of larvae was 2.21 % and 3.10 % in the first and second trial, respectively.

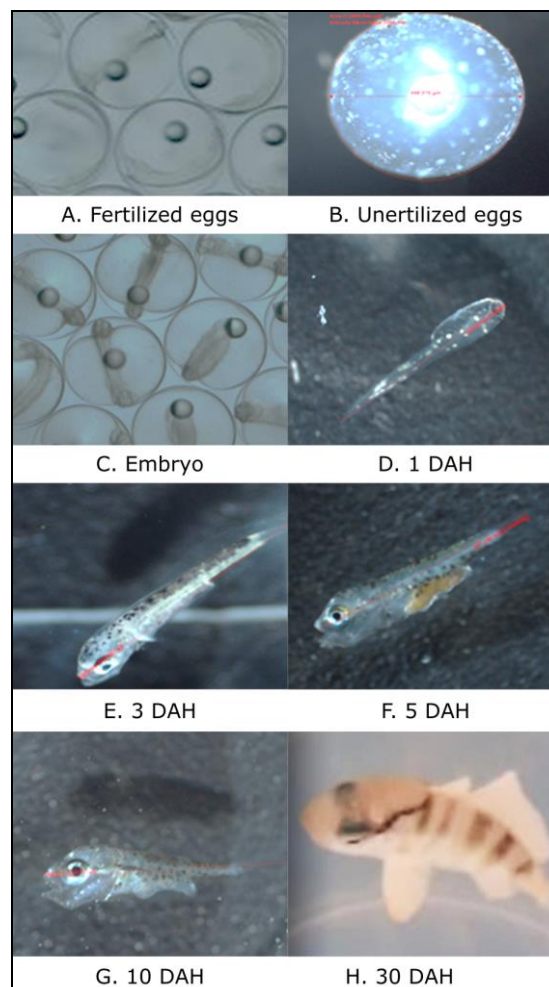


Figure 5. Embryo and larval development of *Seriola rivoliana*.

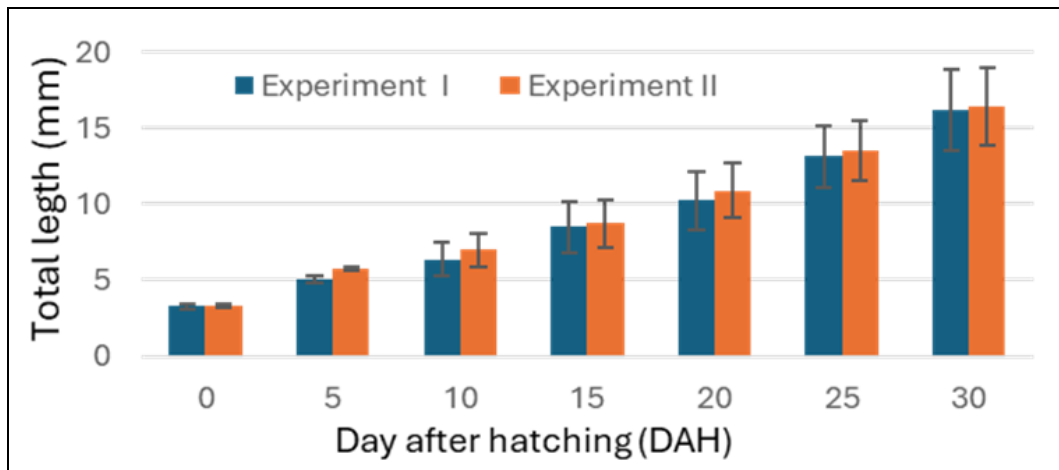


Figure 6. Growth of *Seriola rivoliana* larvae during the experiment.

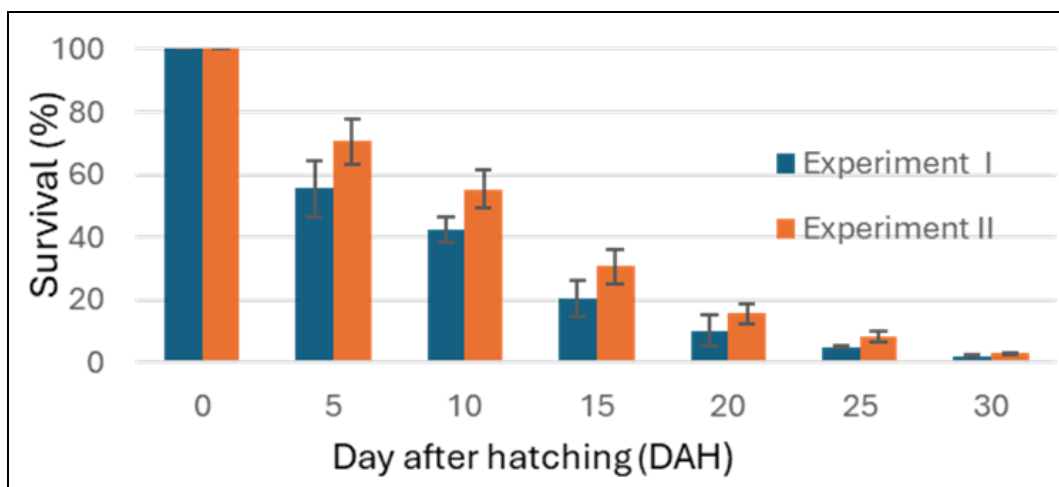


Figure 7. Survival of *Seriola rivoliana* larvae during the experiment.

Discussion. The study shows that the broodstock of *S. rivoliana* reared in circular tank and placed in outdoor hatchery were unable to spawn, and the broodstock set up in indoor hatchery tank were able to spawn without hormones induction (Figure 4). Roo et al (2015) have reported the first successful breeding and larval rearing of the longfin yellowtail *Seriola rivoliana*, by hormonal induction GnRH α , 20 lg/kg in cultured mature fish. Mylonas et al (2004) and Jerez et al (2006) also have been reported on spawning of greater amberjack *Seriola dumerili* by inducing GnRH α hormone. While Kolkovski and Sakakura (2004), Mylonas et al (2004) and Moran et al (2007) reported that they have been able to induce maturation and spawning by HCG hormonal stimulation of yellowtail kingfish, *Seriola lalandi*. The use of cryopreservation on *S. lalandi* spermatozoa has been reported with fertilized and good hatching eggs (Villalobos et al 2025). In our experience working on marine finfish such as milkfish (*Chanos chanos*), barramundi (*Lates calcarifer*) and groupers (*Epinephelus* sp.) (Sugama 2007; Sugama et al 2009), the acclimatization of broodfish to captive environment, maturation, and successful spawning without hormonal injection are influenced by many biological and environmental factors. For example, cultured fish can have reproductive problems if the environmental conditions are not optimal to the proper life of fish (Mustafa et al 2015). Present results have proved the flow through water system applied with the *S. rivoliana* in this study was efficient and produced desirable conditions for *S. rivoliana* maturation and natural spawning. Moreover, the feeding, type of food and quality, oxygen, salinity, and temperature properly maintained, allowed the wild-caught broodstock to spontaneous spawn. Spontaneous spawning has also been reported in many fish species including grouper species reared in marine net cages and land based broodstock tanks (Sugama et al 2009). There are also many examples of *Seriola* species including the greater

amberjack, (*Seriola dumerili*), yellowtail amberjack (*Seriola lalandi*), Japanese amberjack (*Seriola quinqueradiata*) in which broodstock were maintained in land based concrete tanks placed in indoor hatcheries with flow through or recirculating systems (Jerez et al 2006; Yang et al 2016; Sicuro & Luzzana 2016). The present study also found that the fish could not be spawned when the broodstock fish were placed in outdoor tanks, and this could have been caused by too many disturbances by technicians who were working, cleaning and feeding tanks in the hatchery. In the present study, water quality parameters were managed and kept in the optimum condition for proper life, growth and reproduction of this species and the broodstock tanks was placed in indoor hatchery with normal photoperiod (12 h L : 12 h D) which has resulted in the natural spawning of *S. rivoliana* from July up to the end of September in 2023 and 2024. Spawning took place in the morning between 8.0 and 9.0 am.

Former reports on *Seriola* species mentioned that incubation period of eggs ranged between 21 and 40 h depending on the water incubation temperature, and the eggs of *Seriola* fishes were reported to be spherical with a single oil globule and size ranging between 0.68 and 0.83 mm in diameter. In the present study, fertilized eggs of *S. rivoliana* were observed to be non-adhesive and floating with a single oil globule with average size of 0.64 ± 0.02 mm. This finding was similar to findings of Roo et al (2014), but the larvae of *S. rivoliana* were smaller than those of *S. lalandi* (Moran et al 2007). At a temperature of 28.5°C, fertilized eggs of *S. rivoliana* hatched after 30-34 h, while in a previous study hatching occurred between 36-40 h (Roo et al 2014). In *S. rivoliana* the highest hatching rate has been reported at an incubation water temperature of 23°C, but all larvae died and the suggestion is to incubate at a water temperature of 24°C, and the larvae can survive until 100 hours after hatching (Guerrero-Cruz et al 2021). In Indonesian coastal waters the temperature is stable throughout the year and ranges between 28.5 °C and 29.5°C (Sugama & Koesharyani 2017). Therefore, we could not be able to compare the effect of hatching rate and survival at different water temperatures.

Commonly, the marine fish larvae hatch out from pelagic eggs with obvious yolk sac and oil globule which provide the energy for growth and development. When the yolk sac and oil globule are completely absorbed, the larvae transform into an exogenous nutrition stage (Williams et al 2004; Olivotto et al 2005, 2006). The yolk sac utilization pattern of *S. rivoliana* approximates other *Seriola* species and marine fish species where fish larvae contain visible oil globules. The yolk sac of *S. rivoliana* larvae were completely absorbed at 3 DAH which was like the findings of Roo et al (2014), Viader-Guerrero et al (2021), and other *Seriola* species like *S. lalandi* (Abbink et al 2012), *S. dumerili* (Papandroulakis et al 2005; Hamasaki et al 2009).

First feeding in larval fish becomes a major constraint for many species (Baensch & Tamaru 2009; Chiu et al 2018; Burgess & Callan 2018). Most of *Seriola* sp. larvae begin feeding with external food at 3 DAH. In the present study, the S-type rotifers were used as the initial feeding of larvae and from 3 DAH food can be seen in their intestine. The survival rate of larvae at 5 DAH was higher in the larvae fed by copepod (*Acartia* sp.). Regarding growth performance, the longfin yellowtail *S. rivoliana* in the present study grew comparable to the results of Roo et al (2014), and the difference in growth rate observed between the first and the second trial could be influenced by the food types in terms of quality. In the first trial when initial feeding with S-train rotifer followed with L-strain enriched rotifers and *Artemia* sp., larvae did not grow well, compared to the initial feeding by copepod (*Acartia* sp.). The results achieved with the larval rearing methodology for the *S. rivoliana* are comparable to previous studies for the rearing of the species. Embryonic development followed the stages described by Roo et al (2014) and Gutiérrez-Rodríguez et al (2014) with a survival rate from 1 DAH to 30 DAH of 2.5 % by using semi-intensive methods and 0.5 % by using intensive methods. In terms of survival rate, the results are comparable with the ones presented by Roo et al (2014) and compared with results from rearing of other *Seriola* species, the results obtained in this trial are better than that for *S. mazatlana* (Benetti & Benetti 1997), comparable with *S. lalandi* (Tachihara et al 1997), but lower than for *S. quinqueradiata* (Benetti & Benetti 1997). The highest larval mortality was observed on 4-5 DAH and the dead larvae settled to the bottom of the tank, with a mortality estimate of 30 to 50%. From 20 to 25 DAH,

the second major decline in survival was during the squamation period and the average mortality during this period was 20-30 %.

There is no doubt that more studies of larval rearing methodology, especially for the water management, feeding regime and nutritional requirements of the longfin yellowtail *S. rivoliana* are required. Refinement of the methodology related to the feeding regime, food availability and quality of the food will certainly improve productivity. Improvement of the weaning by artificial diet is also required. Emphasis should be given mainly to the texture and nutritional contents of the diet that are required by *S. rivoliana* larvae for growth and immunity.

Conclusions. This study has shown the possibility of captive breeding of *Seriola rivoliana* from July to September without hormone injection in indoor hatchery. Further research is still needed to address the problems related to mortalities encountered during the critical periods in larval rearing. As the first recorded captive spawning of *Seriola rivoliana* in Indonesia, the present study provides information for further research to improve technology for successful captive breeding of *Seriola rivoliana* and other *Seriola* species, that may be helpful for commercial aquaculture production.

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Conflict of interest. The authors declare that there is no conflict of interest.

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Authors:

Ketut Sugama, Research Center for Marine Aquaculture, National Research and Innovation Agency of Indonesia, Jalan Raya Bogor Km. 46, Nangewer, Bogor, Indonesia, e-mail: ketu005@brin.go.id

Haryanti Haryanti, Research Center for Marine Aquaculture, National Research and Innovation Agency of Indonesia, Jalan Raya Bogor Km. 46, Nangewer, Bogor, Indonesia, e-mail: hary016@brin.go.id

Gede Iwan Setiabudi, Ganesha University, Ministry of Research, Technology and Education, Jalan Udayana No 11, Singaraja-Bali, Indonesia, e-mail: iwansetiabudi@undiksha.ac.id

Jhon Harianto Hutapea, Research Center for Marine Aquaculture, National Research and Innovation Agency of Indonesia, Malaka, Kec. Pemenang, Kabupaten Lombok Utara, Nusa Tenggara Barat, 83352, Indonesia, e-mail: hutapeaharianto@gmail.com

Gusti Ngurah Permana, Research Center for Marine Aquaculture, National Research and Innovation Agency of Indonesia, Malaka, Kec. Pemenang, Kabupaten Lombok Utara, Nusa Tenggara Barat, 83352, Indonesia, e-mail: igus022@brin.go.id

Ahmad Muzaki, Research Center for Marine Aquaculture, National Research and Innovation Agency of Indonesia, Jalan Raya Bogor Km. 46, Nangewer, Bogor, Indonesia, e-mail: ahma120@brin.go.id

Rommy Suprpto, Research Center for Freshwater, National Research and Innovation Agency of Indonesia, Jalan Raya Bogor Km. 46, Nangewer, Bogor, Indonesia, e-mail: rommy.suprpto@brin.go.id

Isti Koesharyani, Research Center for Marine Aquaculture, National Research and Innovation Agency of Indonesia, Jalan Raya Bogor Km. 46, Nangewer, Bogor, Indonesia, e-mail: istisugama@yahoo.com

Sarwono Sarwono, Ambon Mariculture Development Center, Jalan Leo Watimena, Waiheru Kec Baguala, Kota Ambon Maluku, Indonesia, e-mail: sarwono_bblombok@yahoo.com

Thor Sutan Yasin, Forever Ocean Indonesia, Wineru, Likupang Timur, Kabupaten Minahasa, North Sulawesi, Indonesia, e-mail: thor.sutanassin@foreveroceans.com

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