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SHORT COMMUNICATION

Effects of Rearing Temperature on Growth and Survival of Blackthroat Seaperch, *Doederleinia berycoides* (Hilgendorf, 1879), Post-Flexion Larvae and Juveniles

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Abstract

In post-flexion larval and juvenile stages of hatchery-reared blackthroat seaperch *Doederleinia berycoides* (Hilgendorf, 1879), the influence of water temperature on growth and survival was examined to identify the optimal rearing temperatures. Temperature treatments were conducted separately for pelagic post-flexion larvae (32 days post hatching [dph]) and settled juveniles (69 dph). Fish were transferred to four replicate 30 L tanks (30 larvae or 15 juveniles per tank) and reared for 15 days under five temperatures (13, 16, 19, 22 and 25 °C) maintained by using heaters and coolers. The mean survival rates (± SD) of post-flexion larvae were high (>73 %) for all temperatures (13 °C: 73.3 ± 6.9 %, 16 °C: 76.7 ± 6.8 %, 19 °C: 80.8 ± 10.7 %, 22 °C: 79.2.7 ± 2.8 %, 25 °C: 71.7 ± 4.4 %). Growth increased at higher temperatures and was significantly faster at 22 and 25 °C ($P < 0.05$) than lower temperatures. For juveniles, mean survival rates were significantly higher at 16–25 °C (>90%: 16 °C: 91.7 ± 1.7 %, 19 °C: 95.0 ± 3.2 %, 22 °C: 91.7 ± 1.7 %, 25 °C: 91.7 ± 5.0 %) than at 13 °C (71.7 ± 7.9 %) ($P < 0.05$). Juvenile growth, like that of post-flexion larvae, was faster at 22 and 25 °C. These results suggest that maintaining a high rearing temperature (22–25 °C) is important for enhancing the growth for post-flexion larvae and juveniles of blackthroat seaperch and reducing the rearing period to the size of release seedlings.

Keywords: rosy seabass, optimal temperature, early life stages, seedling production, hatchery-reared fish

Introduction

The blackthroat seaperch *Doederleinia berycoides* (Hilgendorf, 1879) is a warm water demersal fish species which is distributed in the eastern Indian Ocean, East China Sea, Japan Sea and western part of the Pacific Ocean (Yamada et al., 2007). In Japanese coastal waters, it mainly inhabits the edge and slopes of the continental shelf at depths ranging between 80 and 150 m (Yamada et al., 2007), and is caught using bottom trawlers, longlines and gill nets (Yagi, 2016). The habitat temperature of blackthroat seaperch caught by a trawl in the coastal waters off Niigata prefecture in the Japan Sea ranges from 7–19 °C (Kawamura, 2009).

The commercial value of blackthroat seaperch is very high, and the market price of large fish can be higher than JPY9,000 (USD63) per kg (Fisheries Technology Department; Kyoto Prefectural Agriculture Forestry and Fisheries Technology Center, 2019). In southwestern Japan Sea, stock levels in biomass of this species have been high and constant in recent years (Kanamoto et al., 2022). However, as the commercial value of this species has increased in recent years, a greater number of immature young fish smaller than 18 cm (0 to less than 2 years old) are being caught and landed in fish markets (Kanesaka, 2018), potentially leading to overfishing of the stock (Kanesaka, 2018; Kanamoto et al., 2020, 2022). Therefore, fishery management is necessary to ensure the long-term sustainability of stocks. Since 2012, mobile protection areas have been adopted in Shimane prefecture to reduce the fishing pressure on small blackthroat seaperch (Kanesaka, 2018; Kanamoto et al., 2020). Also, the optimal mesh size and improving the cod-end of bottom trawlers to reduce the bycatch of young blackthroat seaperch has been investigated (Hamabe et al., 2010; Kumaki et al., 2020).

Another method to manage fishery production is stock enhancement (Molony et al., 2003; Bell et al., 2008; Aritaki and Mushiake, 2021). Due to its high value and strong demand, blackthroat seaperch is receiving more attention as a promising candidate for stock enhancement in Japan. The artificial production of blackthroat seaperch juveniles was successful for the first time in Japan in 2013 (Yamada et al., 2015). A total of about 220,000 juveniles have been experimentally released in Toyama Bay, Japan from 2018 to March 2023 by the Fisheries Research Institute, Toyama Prefectural Agricultural, Forestry & Fisheries Research Center (hereinafter referred to as Toyama Prefectural Fisheries Research Institute) (Fukunishi, 2023). However, one of the problems of *D. berycoides* seedling production is that the growth of hatchery reared fish is very slow under ambient water temperature conditions, and the average total length (TL) of juveniles does not reach 40 mm after 100 days post hatching (dph) (Iida, 2015), leading to an increase of production and labour costs. Therefore, it is necessary to determine the optimal temperature for growth in early life stages of this species to improve seedling production efficiency and shorten the rearing period prior to release into the marine environment.

Despite the increasing demand for artificially produced blackthroat seaperch, information about their early life history remains scarce. Although their distribution pattern during the early life stages is less well understood, pelagic larvae were collected in the 0 to 50 m layer (Yagi et al., 2014, 2021), while juveniles smaller than 25 mm total length (TL) occurred close to the bottom at a depth of 95 m in the Japan Sea (Yagi, 2021).

There have been only a few published papers on the biology in early life stages of this species from laboratory experiments, except for studies on embryonic and larval development (Yagi et al., 2015), otolith daily increment formation (Yagi et al., 2021) and artificial production of seedlings (egg husbandry, prey size and the effects of temperature on larval survival and growth) (Yamada et al., 2015).

Temperature is a critical environmental factor that influences the growth, survival, metabolic rate, energy expenditure and recruitment in fish (Brett, 1979; Houde, 1989; Blaxter, 1992). For successful cultivation of good quality seedlings, it is necessary to determine the optimal temperature of the target species. It has been reported that the optimal temperature differs between larvae and juveniles in several fish species, such as California halibut *Paralichthys californicus* (Ayres, 1859) (Gadomski and Caddel, 1991), Atlantic cod *Gadus morhua* Linnaeus, 1758 (Steinarsson and Björnsson, 1999; Björnsson et al., 2001), nase *Chondrostoma nasus* (Linnaeus, 1758) (Keckeis et al., 2005) and pigfish *Orthopristis chrysoptera* (Linnaeus, 1766) (Faulk et al., 2018). As blackthroat seaperch juveniles dwell in deeper and colder areas compared to that of larvae, it is hypothesised that the optimal rearing temperature shifts to lower temperatures after settlement in the juvenile stage. Thus, it is necessary to identify the optimum water temperature for both the larval and juvenile stages of *D. berycoides* to optimise the efficiency of mass production in culture systems.

To date, Yamada et al. (2015) conducted rearing experiments at 18 °C, 21 °C and 24 °C from eggs to juveniles of blackthroat seaperch and showed that the survival rates of larvae decreased sharply from yolk-sac stage to post-flexion stage (18 °C: 0.03 % at 38 dph, 21 °C: 0.14 % at 45 dph, 24 °C: 0.3 % at 31 dph). They compared TL among temperatures by using fish at the same age from yolk-sac to flexion stages and demonstrated that the larval growth tends to be faster at higher temperatures in flexion stages (18 °C < 21 °C at 21 dph, 21 °C < 24 °C at 19 dph). However, they could not compare the growth among temperatures at post-flexion larval and juvenile stages precisely, due to the low survival rates, and thus the optimal temperatures in these developmental stages are still unclear. Therefore, the purpose of present study was to investigate the effect of water temperature on growth and survival of post-flexion larvae and juveniles in blackthroat seaperch.

Materials and Methods

Ethical approval

The experiments were conducted in accordance with ethical guidelines for animal experiments established by the National Research Institute of Fisheries Science, Japan Fisheries Research and Education Agency (17.11.2023).

Fish husbandry

Eggs and sperm of blackthroat seaperch were extracted into separate clean dry bowls by gently putting pressure with hands on the abdomen of wild adults (male: 226 mm TL, female: 361 mm TL) soon after they were caught by gill nets in the waters off Toyama city on 4 October 2018. Eggs were artificially fertilised by the dry method on the fishing vessel immediately. Fertilised eggs were packed in a 10 L vinyl bag with oxygen and filtered seawater sterilised by ultraviolet radiation (hereinafter called seawater). After the fishing vessel returned to a fishing port (about 1 h 30 min post-fertilisation), the eggs were transported for 30 min in a motor vehicle to Toyama Prefectural Fisheries Research Institute (Namerikawa, Toyama, Japan), where all laboratory experiments were conducted.

Fertilised eggs were incubated in seawater flow-through 13 L buckets in water baths, as described in detail by Yamada et al. (2015). The bottom of each bucket was cut off and sealed with a fine mesh net (0.367 mm), so that fresh seawater was constantly circulated to provide enough oxygen to the fertilised eggs. Dead eggs sank to the bottom and were siphoned out from the buckets a few times during the incubation by using a pipe and tube. About 3 h before hatching, fertilised eggs were transferred to a circular hatching tank (100 L) filled with seawater with strong aeration to minimise sinking deaths. After hatching, 42,000 yolk-sac larvae were stocked in a 5 m^3(effective water volume: 4 m^3) circular fibre reinforced plastic (FRP) tank (rearing tank).

Larvae were reared by the "Hottoke-shiiku" method (a low labour, high efficiency rearing technique used in intensive culture of Japanese flounder *Paralichthys olivaceus* (Temminck and Schlegel, 1846), in which rotifers are cultured in the rearing tank (Takahashi, 1998) during the pelagic life period. At 2 dph, S-type rotifers *Brachionus plicatilis* were added to the rearing tank at a density of 15 individuals per mL after enrichment with highly unsaturated fatty acid (HUFA)-enriched freshwater *Chlorella vulgaris* (Beijerinck, 1890) (Super fresh Chlorella V-12; Chlorella Industry Co., Ltd., Tokyo, Japan), taurine (Jiangyin Huachang Food Additive Co. Ltd., Jiangyin, China) and commercial HUFA-enriched feed (Pro-Growth rich powder, USC Co., Ltd., Tokyo, Japan). To enrich and maintain the rotifer population in the rearing tank, marine microalgae, the eustigmatophyte *Nannochloropsis oculata* (Hibberd, 1981) (Yanmarine K-1, Chlorella Industry Co. Ltd, Tokyo, Japan; Nisshin Marinetech Co. Ltd., Aichi, Japan) was added to the tank every day and the density maintained at more than one million cells.mL^{-1} during the larval period. We reared larvae in still water until the density of rotifer increased to 60 individuals per mL, and then started using flowing water and adding freshwater *Chlorella vulgaris* (Super fresh Chlorella V-12; Chlorella Industry Co. Ltd., Tokyo, Japan) to maintain a high rotifer nutrition status. The amount of water flow was increased with fish growth in the range of 2 to 40 L per min by adjusting a water valve, and L-type rotifers enriched in the same manner as described above were provided 1–2 times a day to maintain a density higher than 15 individuals per mL until 42 dph. Newly hatched *Artemia* nauplii were cultured with commercial HUFA-enriched feed (Pro-Growth rich powder, USC Co., Ltd., Tokyo, Japan) and provided twice a day at an abundance of about 0.5-1 individuals per mL from 15 dph. Commercial diets (Ambrose 200, 400, 600 FEED ONE Co. Ltd., Yokohama, Japan) were provided from 20 dph depending upon the age of the fish.

Constant light for 24 h was applied from 2 to 17 dph to increase the opportunities and time for feeding to improve survival and growth. Post-flexion larvae and juveniles used in this study were reared under ambient water temperatures ranging from 18.7–25.0 °C and 16.0–25.0 °C, respectively. The developmental stages of blackthroat seaperch larvae was identified following Yagi et al. (2015), and the juvenile stage was defined as starting when the fin ray counts were complete. A water quality stabiliser made of settling shell fossil powder (particle size: 0.07 mm) (Fish Green; Green Culture Co., Ltd., Toyama, Japan), which covers the bottom residue and absorbs hydrogen sulphide, was added to the rearing tank every day at a density of 50 $g.m^{-3}$.

Experimental design

Experiments were performed separately with post-flexion larvae and juveniles at five temperatures ranging from 13 to 25 °C in increments of 3 °C (i.e. 13, 16, 19, 22 and 25 °C) for 15 days for each stage in the laboratory. On the first day of the experiment, 30 post-flexion larvae (32 dph) and 20 juveniles (69 dph) were sampled randomly from the rearing tanks and TL was measured to the nearest 1 mm using a digital calliper (CD-P20S, Mitutoyo, Japan). For post-flexion larvae, the measurement was conducted under a profile projector (6C-2; Nikon, Japan). Body weight (BW) was measured by a digital scale (PB303-S, Mettler Toledo, Switzerland) to the nearest 0.001 g. Measurements were performed after fish were anesthetised with FA100 (eugenol; Bussan Animal Health Co. Ltd., Osaka, Japan), and then defined as the initial TL and BW (mean ± Standard Deviation: SD) at the start of experiments.

Black polyethylene circular tanks (30 L) were used as the experimental tanks. Four tanks were placed in a square water bath (78 × 116 × 38 cm) for each temperature treatment. Seawater was circulated in each experimental tank (working volume: 27 L). Water exchange rates were maintained at approximately 60 $mL.min^{-1}$. Moderate aeration was provided continuously by using two air stones per tank during the experiment. Two white fluorescent LED lamps (40 W, 1200 mm, LTG40YT; Beamtec Co. Ltd, Saitama, Japan) were hung above the experimental tanks for each treatment. The irradiance at the water surface of each tank was adjusted to be approximately 1000 lx, measured by an illuminance meter (ANA-F10, Tokyo Photoelectric Co. Ltd., Tokyo, Japan). The light/dark photoperiod was maintained at 12h/12h by using an electric timer throughout the experiments. Each experimental system was enclosed within opaque vinyl sheets to prevent interference of lights from neighbouring treatments.

The water temperatures at the bottom of each experimental tank were recorded every 15 min using a HOBO Pendant® MX Temperature/Light Data Logger (MX 2202; ONSET Computer Co. Ltd., Bourne MS, USA).

Larvae or juveniles were randomly scooped by a bucket (15 L) with seawater from the rearing tank and were immediately carried to the experimental apparatus. Then, 30 larvae or 15 juveniles were transferred from the bucket using a small ladle one by one to each experimental tank with through flow water at ambient temperature. Then, fish were acclimatized for about 1-2 h.

The rearing temperature was gradually altered from ambient to the five experimental temperature regimes (13, 16, 19, 22 and 25 °C) by controlling temperature of water in the bath using immersion titanium heaters (TH1-05; Toritsu Electric Co. Ltd., Tokyo, Japan) with thermostats and recirculating coolers (ZR-75E; Zensui Co. Ltd., Osaka, Japan) with a small pump (RSD-20A; Iwaki Co. Ltd., Tokyo, Japan). After this acclimation period, temperature mostly remained constant during the rest of the experiment. The mean water temperatures (± SD) for each treatment were: 13.1 ± 0.3, 15.7 ± 0.3, 18.8 ± 0.2, 21.9 ± 0.3, 24.8 ± 0.3 for post-flexion larvae and 13.2 ± 0.2, 16.1 ± 0.1, 18.7 ± 0.1, 21.6 ± 0.1, 24.9 ± 0.1 °C for juveniles. Dissolved oxygen was measured regularly in the outlet water and was kept above 6.0 $mg.L^{-1}$ throughout the experiments.

Artemia nauplii (Great Salt Lake strain, Utah, USA) enriched in the same manner described earlier were fed to larvae at a density of 0.5 $ind.mL^{-1}$ twice a day. Larvae and juveniles were fed with formulated commercial dry diet in excess (Ambrose 200, 400 for larvae, Ambrose 600 for juveniles; FEED ONE Co. Ltd., Yokohama, Japan) 3–4 times a day except for the first and last day of experiment. Residual food, faecal pellets of fish and dead fish were removed once a day. At the end of the experiment, all the fish in each tank were anesthetised with FA100 and removed from the tank, and then TL and BW were measured to the nearest 1 mm and 0.001 g and the number of surviving individuals was counted.

Statistical analyses

All results of survival, TL and BW at the end of experiment were expressed as mean percentage survival ± standard error (SE). A chi-square test complemented by a Tukey WSD multiple comparison tests were run to test for differences in survival among temperature treatments. A Dunnett test was used to determine whether the TL and BW at the end of experiments differed from those of the initial value. A one-way ANOVA followed by a Tukey HSD multiple comparison test was performed to compare differences in TL and BW among temperature treatments.

All analyses except for Tukey WSD tests were run under the JMP (Ver. 5.01J) statistical software (SAS Institute Inc., Cary NC, USA). Differences were considered significant at $P < 0.05$.

Results

The initial TL and BW (mean ± SD) of post-flexion larvae were 9.48 ± 1.76 mm; 0.015 ± 0.0069 g and for juveniles were 23.45 ± 2.47 mm; 0.20 ± 0.073 g, respectively.

In post-flexion larvae, there were no significant differences in mean percentage survival among temperature treatments ($P > 0.05$, Chi-square test, Tukey WSD test), with values ranging from 71.7 % at 13 °C to 80.8 % at 19 °C (13°C: 73.3 ± 6.9 %, 16°C: 76.7 ± 6.8 %, 19°C: 80.8 ± 10.7 %, 22°C: 79.2.7 ± 2.8 %, 25°C: 71.7 ± 4.4 %) (Fig. 1).

In juveniles, the mean survival rate at 13 °C was lowest (71.7 ± 7.9 %), and differed significantly from those at 16-25 °C ($P < 0.05$, Chi-square test, Tukey WSD test). No significant difference was observed among temperatures above 16 °C (16 °C: 91.7 ± 1.7 %, 19 °C: 95.0 ± 3.2 %, 22 °C: 91.7 ± 1.7 %, 25 °C: 91.7 ± 5.0 %) ($P > 0.05$, Chi-square test, Tukey WSD test; Fig. 1).

Overall, the effects of temperature on the growth were similar between post-flexion larvae and juveniles. The mean TL of post-flexion larvae and juveniles increased significantly over the 15-day experiments in all temperature treatments ($P < 0.05$, Dunnett tests) (Fig. 1). Mean BW of both developmental stages showed the same results as TL, except for the mean BW at 13 °C in juveniles, which did not differ significantly from the initial value (Fig. 1).

Mean TL and BW at the end of the experiments differed significantly across the temperature treatments both in post-flexion larvae and juveniles ($P < 0.05$; Fig. 1). In post-flexion larvae, the values of TL significantly increased with higher temperatures up to 22 °C, and no significant difference was observed between 22 °C and

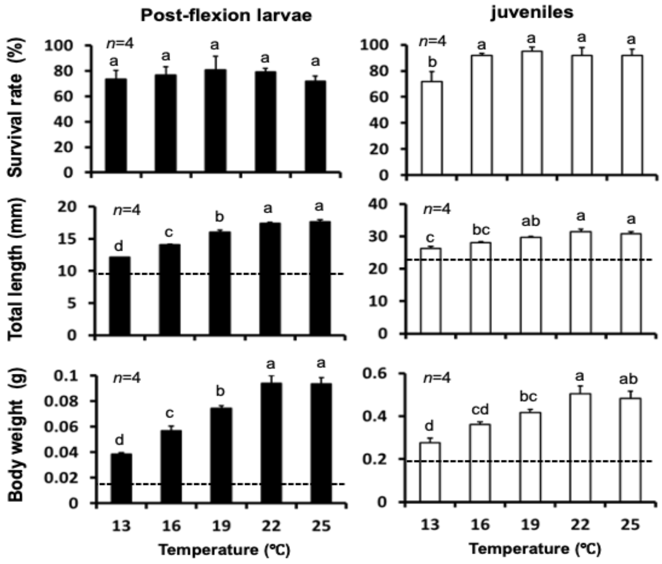

Fig.1. Mean final TL (mm), final BW (g) and survival rate (%) of blackthroat seaperch post-flexion larvae (left side: solid bars) and juveniles (right side: open bars) reared for 15 days at different temperatures. Error bars denote standard deviation (SD). Different lowercase letters indicate significant differences ($P < 0.05$) between temperature treatments. Dotted lines in the graphs of final TL and final BW for post-flexion larvae and juveniles indicate the initial values at the start of the experiments.

25 °C (*P* < 0.05, Tukey HSD test; Fig. 1). The same trend and statistical results were obtained in mean BW for the post-flexion larval stage.

Although the tendency was less clear compared to the results of post-flexion larvae, high temperature (22 °C, 25 °C) showed faster growth in juveniles as well (Fig. 1). The mean TLs were significantly longer at 22 °C and 25 °C than at 13 °C and 16 °C. Juveniles reared at 19 °C were significantly longer than those at 13 °C. The mean BW was significantly heavier as temperature increased up to 22 °C, but did not differ significantly between 22 °C and 25°C (*P* > 0.05, Tukey HSD test; Fig. 1).

Discussion

The results from this study show that temperature significantly influenced the growth of blackthroat seaperch in both post-flexion larvae and juveniles. Overall, high growth in length and weight was observed at 22 °C and 25 °C in both developmental stages. Survival rates for post-flexion larvae were relatively high (71.7–80.8 %) in all temperatures and no significant difference was observed among the temperature regimes. In juveniles, the survival rate at 13 °C (71.7 %) was 20 % lower than those of the other temperatures (16–25 °C: 91.7–95.0 %), and there were no significant differences in juvenile survival from 16–25 °C. Therefore, the results from this study suggest the optimal rearing temperatures of blackthroat seaperch in post-flexion larvae and juveniles are from 22 to 25 °C. As the post-flexion larval and juvenile growth and survival were high at the highest water temperature tested in this study (25 °C), we could not reveal the upper range of optimal temperature and lethal temperature for both developmental stages, and thus, further research with higher temperatures is required for better management of rearing fish.

Despite blackthroat seaperch juveniles inhabiting in a deeper and colder environment near the bottom compared to that of pelagic post-flexion larvae in the natural environment (Yagi, 2016), the optimal temperatures for growth were similar between both developmental stages under laboratory conditions. This means that under our laboratory rearing conditions, no down shift of optimal temperature was observed after settlement of the juveniles. There is a little information about the habitat temperature of wild blackthroat seaperch in the early life stages. Yagi et al. (2014) reported that the average water temperatures where some wild blackthroat seaperch larvae were caught in <50 m in water depth on three occasions in September (13 and 28) and October (28) 2012, were 26.8 ± 1.6, 26.2 ± 0.7 and 22.0 ± 0.2 °C, in coastal waters off Niigata Prefecture in the Japan Sea. These temperatures are similar to the optimal temperature of hatchery-reared *D. berycoides* larvae in the current study.

Meanwhile, wild blackthroat seaperch juveniles less than 25 mm TL, which is almost the same size of hatchery-reared juveniles in this experiment, were caught by a trawl net at 95 m depth in Wakasa Bay in November 2020, and the bottom temperature was 14.8 °C (Yagi, 2021), which is much lower compared to the optimal rearing temperatures (22–25 °C) for hatchery-reared juveniles in the present study. Therefore, this suggests that wild blackthroat seaperch juveniles in the natural environment are not likely to face water temperature conditions where the intrinsic growth potential can be exploited. If wild blackthroat seaperch juveniles were to respond to temperature in a manner similar to hatchery-reared fish in this experiment, wild juveniles growth may be slower than fish raised under laboratory conditions at the optimal temperatures (22–25 °C).

Cases where the habitat temperature of wild fish is lower than the optimal temperature for optimising growth in hatchery-reared fish have been observed in other species such as Atlantic cod, Atlantic halibut *Hippoglossus hippoglossus* (Linnaeus, 1758) and spotted wolffish *Anarhichas minor* Olafsen, 1772 (Jonassen et al., 1999, Björnsson et al., 2001, Imsland et al., 2006). Björnsson et al. (2001), who compared optimal water temperature between wild and hatchery-reared immature cod, speculated that this may be attributed to the lower food availability of wild fish in nature than that of hatchery-reared fish fed to satiation, because temperature effects food conversion efficiency of fish and optimal temperature decreases as food restriction increases (Brett et al., 1969; Jobling, 1994). Although food availability of wild blackthroat seaperch juveniles in nature is unknown, the possibility that optimal temperature may be different between wild and hatchery-reared fish in blackthroat seaperch as well needs to be considered. In addition, the vertical distribution of juvenile fish is affected by prey abundance, predators, competitors and light intensity in the natural environment (Sogard and Olla, 1993, 1996; Davis and Ottmar, 2009).

Therefore, the mismatch observed between the optimal rearing temperature determined experimentally and the habitat temperature of blackthroat seaperch in nature may be partly due to biological or physical environmental factors. Further ecological investigations on the relationship between distribution and environmental factors, and predator-prey interactions in wild blackthroat seaperch juveniles are required.

From the seedling production perspective of blackthroat seaperch, our results demonstrate that it is important to keep rearing temperature high (22–25 °C) during the post-flexion larval and juvenile stages to promote faster growth and shorten the rearing period to release in the natural environment. Because the ambient surface water temperature gradually decreases from their spawning season (late summer to fall) to winter from about 26 °C to 11 °C in Toyama Bay, the optimal way to maximise growth efficiently by using ambient seawater with minimum heating cost would be to start heating when the seawater temperature decreases to 22 °C and maintain it at this temperature. It would also be effective to start seedling production at an early time in the spawning season (e.g., in August) to extend the period of high temperature rearing by using ambient seawater without requiring heating to promote faster growth.

In a previous study, Yamada et al. (2015) conducted rearing experiments at different temperatures (Exp. 1: 18 °C vs. 21 °C, Exp. 2: 18 °C vs. 21 °C vs. 24 °C) using blackthroat seaperch from eggs to juveniles. Although they did not analyse their results statistically, higher temperature had a tendency to lead to higher growth of flexion larvae in both experiments. In the first experiment, the mean TL of 21 dph flexion larve at 21 °C was 0.6 mm longer than at 18 °C (5.0 ± 0.28 mm vs 4.4 ± 0.50 mm) and the mean length of 19 dph post flexion larvae in experiment 2 at 24 °C was 0.7 mm longer than at 21 °C (5.2 ± 0.32 mm vs 4.5 ± 0.29 mm). The mean survival rate in Exp. 1 was higher at 21 °C compared to that at 18 °C from 15 to 30 dph. In Exp. 2, yolk-sac larvae at 18 °C were all dead before the mouth opening and survival rates at 7 dph was higher at 21 °C than 24 °C (21 °C: 7.1 %, 24 °C: 3.3 %), while fish at 24 °C survived longer than 21 °C (21 °C: 0.9 % at 19 dph, 24 °C: 0.3 % at 31 dph). Based on these results, the authors speculated that optimal rearing temperature for larvae may be above 21 °C after 15 dph (Yamada et al., 2015).

In conjunction with the results of the current research, in blackthroat seaperch, temperatures of at least 21 °C are likely to improve their growth and survival from larvae to juveniles. Thus, the observed slow growth of blackthroat seaperch seedlings reared under ambient water temperature by Iida (2015) may be partly due to the low water temperature from late autumn to winter. By using virtual population analysis (VPA), it is reported that recruitment success of blackthroat seaperch is positively correlated with the water temperature in August which approximates the summer spawning season of this species (Imai et al., 2017; Kanamoto et al., 2022). In Japanese coastal waters, surface water temperature is increasing at a rate of +1.28 °C.100 years^{-1} by 2023 (Japan Meteorological Agency: https://www.data.jma.go.jp/gmd/kaiyou/data/shindan/a_1/japan_warm/japan_warm.html) (Accessed 01 May 2024), and the stock level in biomass in the southwestern Japan Sea has been high and constant in recent years (Kanamoto et al., 2022). Therefore, combining these lines of evidence with the results reported in the current study, elevated water temperatures are likely positively affect the growth and survival of blackthroat seaperch larvae and juveniles, leading to increased recruitment.

Conclusion

The present study demonstrates that blackthroat seaperch post-flexion larvae and juveniles show faster growth and higher survival in the temperature range from 22 to 25 °C. If these conditions are implemented for blackthroat seaperch culture conditions they are likely to improve the efficiency of seedling mass production, leading to a reduction in production and labour costs. Furthermore, because it is important to release seedlings at an appropriate size and season for the success of stock enhancement, our results may be useful for controlling the speed of growth of blackthroat seaperch seedlings and adjusting the release size and/or timing. Further study on the optimal temperature for adult blackthoroat seaperch is needed to culture broodstock efficiently for collecting eggs or to assess whether they have growth attributes suitable for aquaculture.

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Author contributions: Yuichi Fukunishi: Designed the study, data analysis, and manuscript writing.

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