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Short Paper

The effect of temperature on the early development and starvation tolerance of yellow goosefish *Lophius litulon*

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Abstract: The effect of temperature (15, 18, and 21°C) on the early development and starvation tolerance of yellow goosefish *Lophius litulon* was investigated. The periods of initiation of first feeding and starvation tolerance were shortened with increasing temperature. The period of first feeding varied from 5 days after hatching (DAH) at 15°C to 3 DAH at 21°C. Yellow goosefish larvae can survive for approximately 9−15 DAH (50% mortality period) without feeding in 15−21°C, but such an extended period of starvation is considered to increase the cumulative mortality.

Key words: First feeding; Temperature; Yellow goosefish; Yolk exhaustion

Kawasaki (1983) reported decadal scale switches in the abundance and composition of plankton and fish (so-called regime shifts) in the population dynamics of various taxa. Thereafter, the effect of regime shifts on the population dynamics of commercially important fish species have been broadly discussed (Overland et al. (2008) and references therein). Natural mortality rates of fish are highest in the early life stages, therefore population dynamics of fish are most susceptible to fluctuations of survival during that period (e.g. Houde 1997; 2002). Temperature has important effects on larval fish growth and development from the viewpoint of yolk utilization, initiation of first feeding as well as starvation tolerance, and subsequent potential survival (Fukuhara 1990; Fuiman 2002; Martell et al. 2005). Blaxter (1992) suggested that increase of temperature will change the timing of ecological events such as the spring phytoplankton bloom and subsequent zooplankton response so influencing the match or mismatch of fish larvae with that of their food supply and their predators. The relationship between successful recruitment leading to stock development of fishes and temperature in early life stages have been predicted (Nissling 2004; Petereit et al. 2008).

Yellow goosefish *Lophius litulon* is an important demersal fish that is distributed in Japan from south Hokkaido to Kyushu, the Bo-Hai Sea, the Yellow Sea and the East China Sea (Yamada et al. 2007). Catches of this species tend to widely fluctuate (Tominaga 1991; Suzuuchi 1993; Kawano 2010), and Nihira (2004) reported that their catch is closely related to regime shifts. For sustainable catch of this resource, it is necessary to clarify the trophic interactions of this species. There are some previous reports about age and growth (Takeya et al. 2017), maturation (Yoneda et al. 2001) and feeding habits (Kosaka 1966; Kawano 2011; Park et al. 2014). Though, the collection of the eggs and larvae (Mito 1963; Kim 1976; Hoshino et al. 2006), and the development processes in larval stages (Kim 1976) have been reported, there is still only a poor understanding of the early life stages. Most of Lophiidae are believed to release their eggs in large mucoid masses called egg veils (Mito 1963; Everly 2002), egg veils of yellow goosefish have been collected in the field at 16−20°C (15.9°C: Mito (1963); 18.2°C: Kim (1976); 19−20°C: Hoshino et al. (2006)). The larvae were collected in the intertidal zone at Haeundae, Busan from late June to early July (SST: 18.2°C, Kim 1976), however the effect of temperature on the early development of yellow goosefish has not yet been clarified. This study investigated the effect of temperature on the early development and starvation tolerance of yellow goosefish. We estimated the potential period that newly hatched larvae were able to survive without encountering appropriate environmental conditions in relation to food availability and ambient water temperature.

An egg veil of yellow goosefish (volume: ca. 20,000 cm^3) was collected in the Tsugaru Strait off Aomori Prefecture (SST: 14.3°C), on 25 May 2016. A part of the egg veil (Fig. 1a, volume: ca. 1,000 cm^3) was kept in a plastic bag containing 10 *l* of seawater (15°C) with oxygen and then transported to Hokkaido University, Hakodate by truck and ship. The egg

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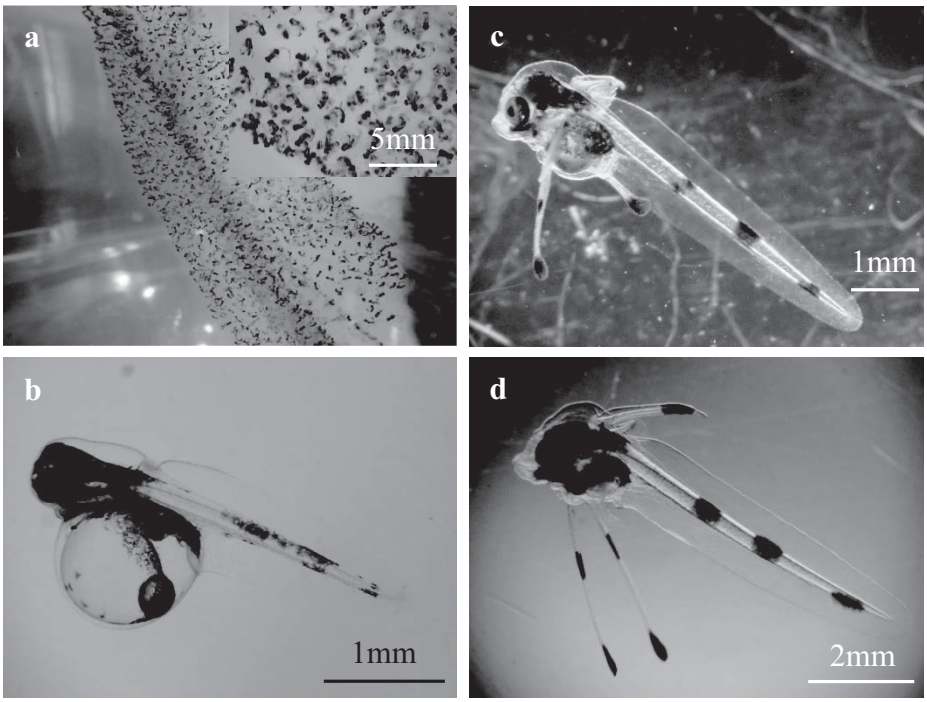

Fig. 1. Yellow goosefish *Lophius litulon* a, egg veil just before hatching, b, 1 day after hatching (DAH) larva, c, 6 DAH larva, and d, 9 DAH larva rearing at 18°C.

veil was stocked and then incubated in a 100 *l* circular shaped tank at a temperature range of 17–18°C (water exchange rate was 30%/day). Replicates of 20 newly hatched larvae (Fig. 1b) were collected and were stocked in glass beakers with 200 m*l* of artificial seawater (REI-SEA Marine II, Iwaki Co. Ltd, Japan: 17–18°C, 32–33 ppt). Four replicate beakers (each with 20 larvae) were set in temperature incubators and the water temperatures were gradually adjusted over a 24 hour period and then kept at 12, 15, 18 and 21°C. The photoperiod of 14L : 10D (as a natural light period in the Tsugaru Strait of the spawning season) was provided using fluorescent light. Twice a day (08:00–09:00 and 15:00–16:00), in two beakers for each temperature (11.8 ± 0.33°C (mean ± SD), 14.9 ± 0.38°C, 17.7 ± 0.44°C and 21.2 ± 0.44°C), we counted the number of living individuals and collected dead individuals. In the other two beakers in each temperature, observations of the morphological development and yolk exhaustion were carried out.

To estimate the developmental stage of first feeding, from 1 day after hatching (DAH) to reach the first feeding stage, rotifers *Brachionus plicatilis* sp. complex (enriched with Super Capsule A1 powder (Chlorella Industry Co., Ltd., Japan)) were given to the larvae at a density of 5.0 inds/m*l* twice a day (8:00 and 15:00) in a 30 *l* circular shaped tank at a temperature range of 17.2–19.2°C. From 11:00 to 12:00, we collected 10–20 larvae in the 30 *l* circular shaped tank and checked their stomach contents. When over 50% of the larvae reached the developmental stage in each temperature, we defined it as the first feeding day. Relationships between mean rearing temperature and time to 50% hatch period or first feeding period were analyzed using the heat summation theory as Réaumur's law model

$$D = a / (T - t_0)$$

where D is time to 50% hatch in days or start feeding days, T is the mean rearing temperature (°C), and a, t_0 are the effective accumulate temperature (degree-days) and threshold temperature (°C), respectively.

Hatching rate was over 95% in the four temperatures (12, 15, 18 and 21°C). But in the 12°C rearing, larvae that showed low swimming activity were notably more observed than in the other rearing temperatures, and after 10 DAH (stage J: Kim (1976)), growth stagnation was observed. Hence, we discontinued the 12°C rearing experiment on 13 DAH. We observed the survival period of yellow goosefish larvae under starvation conditions at three temperatures (15, 18 and 21°C) to determine the relationship between survival and temperature. Thus, the first mortality was observed on 5.7, 4.0 and 3.7 DAH under the three ambient water temperatures (15, 18 and 21°C), respectively. The relationship between survival period of yellow goosefish larvae and water temperature is shown in Fig. 2. The mean 50% mortality period at the three temperatures (15, 18 and

21°C) was 14.6, 11.9 and 8.6 days, respectively (Fig. 3). The threshold temperature and effective accumulated temperature of the mean 50% mortality period were calculated to be 5.3°C and 142.9 degree-days. The rate of yolk exhaustion was more accelerated at the high temperature condition by 15–21°C. Kim (1976) reported that yellow goosefish larvae consumed the yolk almost completely at stages O, P (these stages are the first movement of the jaws). In this study, the first feeding was observed at the same stages (O, P), and the period was shortened with increasing temperature (Fig. 3). The threshold temperature and effective accumulated temperature of the first feeding period were calculated to be 8.7°C and 63.0 degree-days.

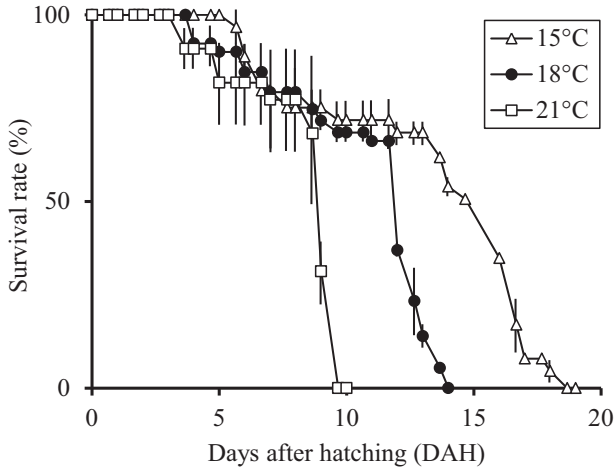

Fig. 2. Relationship between days after hatching (DAH) and survival rate for the unfed yellow goosefish larvae at three different water temperatures. Vertical bars show the standard deviation.

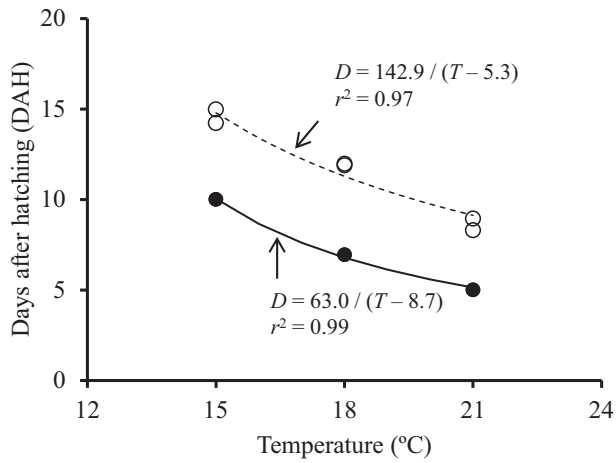

Fig. 3. Relationships between mean water temperature and 50% mortality period under starvation condition (open circles) and the developmental period from hatching to reach the first feeding stage (closed circles) in yellow goosefish. Effective degree-days model is given adjacent to the respective 50% mortality (broken line) and first feeding (thick line) period. D is time to 50% hatch in days or start feeding days, T is the mean rearing temperature (°C).

Exhaustion of endogenous reserves would be accelerated with increasing temperature. This result is supported by observations on the relationship between exhaustion of endogenous reserves and temperature (Laurence 1973; Matsuoka 2001). Survival and growth of the larvae strongly depend on temperature as well as the timing of initial feeding (Dou et al. 2005). This study suggests that yellow goosefish larvae can survive for approximately 9–15 days after hatching (50% mortality period) without feeding in 15–21°C, but such an extended period of starvation is considered to increase the cumulative mortality, e.g. "Growth-mortality hypothesis" (Anderson 1988), "Growth-predation hypothesis" (Campana 1996) and "Growth-selective mortality" (Takasuka et al. 2003). The theoretical lower critical temperature for larval development of yellow goosefish was 8.7°C. However, larvae showing low swimming activity were observed in 12°C rearing, therefore areas < 12°C may be inappropriate as nursery grounds. Further study is needed to research the effects of temperature and delayed initial feeding on the survival and growth of yellow goosefish larvae and to clarify the temperature affect by recruitment success in the field.

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