Title	Effects of water temperature on feeding and growth of juvenile marbled flounder Pseudopleuronectes yokohamae under laboratory conditions: evaluation by group- and individual-based methods
Author(s)	Kusakabe, Kazushi; Hata, Masaki; Shoji, Jun; Hori, Masakazu; Tomiyama, Takeshi
Citation	Fisheries Science , 83 : 215 - 219
Issue Date	2016-12-16
DOI	10.1007/s12562-016-1053-1
Self DOI	
URL	https://ir.lib.hiroshima-u.ac.jp/00049222
Right	© Japanese Society of Fisheries Science 2016 This is a post-peer-review, pre-copyedit version of an article published in Fisheries Science. The final authenticated version is available online at: https://doi.org/10.1007/s12562-016-1053-1 This is not the published version. Please cite only the published version. この論文は出版社版ではありません。引用の際には出版社版をご確認、ご利用ください。
Relation	

Effects of water temperature on feeding and growth of juvenile marbled flounder *Pseudopleuronectes yokohamae* under laboratory conditions: evaluation by group- and individual-based methods

Kazushi Kusakabe[1], Masaki Hata[1,3], Jun Shoji[1], Masakazu Hori[2], Takeshi Tomiyama[1*]

[1]Graduate School of Biosphere Science, Hiroshima University, Higashi-Hiroshima, Hiroshima 739-8528, Japan

[2]National Research Institute of Fisheries and Environment of Inland Sea, Japan Fisheries Research and Education Agency, Hatsukaichi, Hiroshima 739-1452, Japan

[3]Present address: Fisheries Division, Kagawa Prefectural Government, Takamatsu, Kagawa 760-8570, Japan

*Corresponding author: T. Tomiyama

Tel.: +81 82 4247941; email: tomiyama@hiroshima-u.ac.jp

Abstract To determine the optimal temperature for juvenile (0 year old) marbled flounder *Pseudopleuronectes yokohamae*, juveniles of 40–54 mm standard length were reared under six temperature conditions in the range 8 to 26 °C, using group-based and individual-based methods. Growth of juveniles increased from 8 to 20 °C and decreased from 20 to 26 °C, irrespective of the rearing method used. Food intake was greatest at 20 and 24 °C than other temperatures, while feed conversion efficiency was greater at 20 °C than 24 °C in individual rearing. Individual rearing provided more information such as individual variations in growth and food consumption, suggesting the importance of individual-based experiments for exploring the optimal temperature for fish.

Keywords flatfish; food intake; laboratory experiment; thermal response

Introduction

Water temperature is an important factor affecting fish feeding and growth and is recognized as a controlling factor [1]. Thermal effects for a number of species have been investigated under laboratory conditions [2-4]. For European plaice *Pleuronectes platessa* and European flounder *Platichthys flesus*, growth rates and food intake are greatest at 18–20 °C [5]. For Japanese flounder *Paralichthys olivaceus*, growth rates and food intake increase from 20 to 25 °C and decrease from 25 to 30 °C [6]. Such responses to temperature are species specific, and are important for predicting the impact of climate change on vital rates (e.g. growth, feeding and metabolism) of the fish species.

The optimal temperature for fish has been examined in laboratory experiments in which multiple juveniles were kept in temperature-conditioned aquaria [5, 7]. Growth was evaluated by changes in the average size of fish, but not by changes in individual size. Food intake has also been evaluated based on the total amount consumed by multiple individuals [5-7]. Ideally, feeding and growth should be examined individually, because variability among individuals is masked under group-based estimation.

The marbled flounder *Pseudopleuronectes yokohamae*, an important pleuronectid flatfish for coastal fisheries in Japan, was used as the study organism. This species spawns around winter and juveniles occur in shallow coastal waters from March [8, 9]. Although it has been reported that larval growth of this species is faster under higher temperature conditions within the range of 10 to 18 °C [10], to the best of our knowledge, few studies have revealed the growth response of juvenile marbled flounder to temperature. This study aimed (1) to reveal the effects of water temperature on feeding and growth of marbled flounder, and (2) to compare the use of group-based and individual-based experimental protocols for assessment of the optimal temperature for juvenile flatfish.

Materials and Methods

A laboratory experiment was conducted using hatchery-reared juvenile marbled flounder produced from wild parental fish collected in the Seto Inland Sea, western Japan. In May 2015, 96 cultured juveniles of 40–54 mm standard length (SL) at age 127 days were accommodated in a 500-l tank in Setouchi Field Science Center Takehara Station (Fisheries Research Station), Hiroshima University. After acclimation for 2 weeks, juveniles were transferred to six 100-l aquaria (16 individuals in each) filled with aerated natural seawater (salinity = 32.6) and were maintained without feeding for 24 h. The water temperature in the respective aquaria was adjusted to 8, 12, 16, 20, 24, and 26 °C by temperature controllers. The highest temperature was set at 26 °C because even though the temperature threshold of adult marbled flounder is considered to be 28 °C [11], some juveniles died at 27 °C in a preliminary experiment. A closed circulation system was used for each aquarium and no sand was used. Light intensities at the seawater surface in aquaria were 180–2135 lx during the daytime and approximately 0 lx at night. Water was added to aquaria when the water level decreased due to evaporation.

Two rearing systems, i.e. group-based and individual-based methods (ESM Fig. S1), were adopted. In the group-based method, 10 fish were kept in each aquarium. In the individual-based method, fish were isolated individually by using floating plastic cages (27 cm long, 16 cm wide, 11 cm high; top and bottom were flat without mesh, and sides were covered with 0.85-mm nylon mesh; Fig. S1). Each cage was partitioned into two compartments using a plastic board. Three cages were floated in each aquarium and six individuals were kept in the six compartments per aquarium. Prior to accommodation of juveniles, each juvenile was measured (SL [mm] and wet weight [g]).

For both group and individual rearing, excess amounts of commercial pellets (mean ± SD = 10.1 ± 1.4 mg, N = 10, Otohime S2; Marubeni Nisshin Feed, Tokyo, Japan) were fed to fish three times per day during the daytime (08:00, 12:00, and 18:00 hours). This procedure was continued for 7 days. The water temperature of each aquarium was measured at the time of feeding (N = 21, Table 1). For the individual-based method, both the number of pellets given to fish and those remaining in each compartment after 1 h were recorded, so that the food intake (the number of consumed pellets × average weight of pellets) could be assessed.

For the group-based method, neither the number of pellets given to fish nor the number of remained pellets remaining were recorded, because the relationship between food consumption and growth of juveniles cannot be assessed individually and because it was extremely difficult to count remaining pellets owing to giving numerous amount of pellets. The remaining pellets and feces were removed from the aquaria once per day (around 19:00) in order to minimize handling effects.

After 24 h from the last feeding on the 7th day, all individuals were measured again. Three group-reared fish and six individually reared fish died at 26 °C during the time from the last feeding on the 7th day to the final measurement, possibly due to an unexpected rise in temperature to 27 °C. These individuals were also included in the analyses after correcting for shrinkage in SL associated with rigor mortis (3.9 ± 1.3%, $N = 30$), although the correction may become the error source of the data. No other fish died during the experiment. For the individually reared fish, feed conversion efficiency (increment in body weight divided by the weight of consumed pellets) was determined. Growth in SL and body weight, food consumption, and feed conversion efficiency were compared between temperatures using the Steel-Dwass test. To assess the individual variation under each temperature, the coefficient of variation (CV, %) was also determined for growth in SL and body weight, food intake, and feed conversion efficiency of individually-reared juveniles.

Results

In the group-reared fish, the largest increments in average SL and average body weight were 4.7 mm and 0.8 g at 20 °C, respectively (Fig. 1). Increments in average SL and body weight were greater at 24 °C than at 16 °C.

In the individually reared fish, increments in average SL and body weight were also greatest at 20 °C (mean ± SD: 6.7 ± 1.5 mm in SL and 1.1 ± 0.2 g in body weight; Fig. 2, ESM Table S1). Food intake was significantly higher at ≥20 °C than at ≤16 °C. No significant difference was observed between 20 and 24 °C, but feed conversion efficiency was significantly greater at 20 °C than 24 °C (Fig. 2d). Feed conversion efficiency was also high at 16 °C, but food intake and growth were low at this temperature. Individual variation in the feed conversion efficiency appeared to be large at 12 °C; however, this might be attributable to the inclusion of data from one individual in which body weight decreased during the experiment and from one individual with exceptionally high feed conversion efficiency of 3.24 (Table S1). Feed conversion efficiency was lowest at 26 °C. The CV for growth, food intake, and feed conversion efficiency was consistently lowest at 20 °C in the individual reared fish (Table S2).

Discussion

The present study clearly showed that juvenile marbled flounder exhibit the highest growth performance around 20 °C, as revealed by both group- and individual-based methods. Food intake was also high at 24 °C, but the increment in body weight was less than 20 °C possibly due to the higher metabolic costs at higher temperatures. Although only one aquarium was used for each temperature, the optimal temperature around 20 °C would be robust. Tsuchida [12] explored the temperature preference for many marine fish species in the laboratory, using a temperature gradient tanks. Although marbled flounder did not aggregate to a certain temperature position, the preferred temperature for marbled flounder of 54 mm SL was estimated to be 20.5 °C, which is similar to the optimal temperature estimated for marbled flounder in the present study.

Water temperature usually exceeds 20 °C from June, while juvenile marbled flounder appear in an estuary in the Seto Inland Sea from March [9]. In another estuary in the Seto Inland Sea (34°14' N, 132° 33' E), juveniles around 45 mm SL were observed from middle April with the temperature around 15 °C (Otsuki et al., unpubl. data 2015). These results indicate that the temperature juveniles experience is generally lower than the optimal temperature. Moreover, the result of individually-reared experiment showed the growth potential of juvenile marbled flounder. The highest growth rate was 1.08 mm SL d^{-1}, which has never been observed in the field [13, 14]. Growth rate is regulated by various factors such as temperature and food [1]. Thus, the growth rate of juveniles in the field should be investigated further with taking effects of temperature and food into account.

Feed conversion efficiency often exceeded 1, possibly because dry pellets were used as food for juveniles. Similar pattern was also observed for Japanese flounder [7]. To assess daily food intake of juveniles in the field from the feed conversion efficiency, dry weight in both food and body weight increment of juveniles should be used for calculating feed conversion efficiency.

Although the optimal temperature for growth of juvenile marbled flounder was common in group- and individual-based methods, average increment in body weight was higher in group-reared fish than individually-reared fish at 8–16 °C and 26 °C. Although the reason is unclear, a possible explanation for the greater growth of group-reared fish is that some fish foraging food might facilitate other individuals' feeding (social learning [15]) in the group-based method. On the contrary, the increment in body weight was higher in the individually reared fish than group-reared fish at 20 °C and 24 °C. The mechanism causing this difference is also unclear, but the individually-reared fish were not exposed to the interaction with other individuals by biting caudal fin each other [16, 17] or by competing for food. Additionally, the consistently lowest CV at 20 °C for growth, food intake, and feed conversion efficiency may suggest that individual variation becomes small under the optimal temperature condition. Another possible explanation is that CV becomes small when average value is high even if SD is the same: SD of growth and food intake were similar between temperatures but average values were greatest under 20 °C (Table S2). The individual-based method is useful for revealing thermal responses in the feeding and growth of juvenile flatfish, at least for marbled flounder. This experimental protocol can be applied to future studies investigating the effects of body size on thermal responses, since the optimal temperature generally decreases as fish grow [18-20]. Clarifying the ontogenetic changes in the optimal temperature will cue to understand the habitat shift of fish in relation to the ambient water temperature.

Acknowledgements Thanks are due to members of the Setouchi Field Science Center Takehara Station, Hiroshima University, for their assistance in laboratory experiments. We also thank Kudamatsu Sea Farming Center for providing the cultured juveniles, and two anonymous reviewers for helpful comments to the manuscript. This study was partly supported by the Ministry of Agriculture, Forestry and Fisheries of Japan.

References

1. Yamashita Y, Tanaka M, Miller JM (2001) Ecophysiology of juvenile flatfish in nursery grounds. J Sea Res 45: 205–218

2. Aritaki M, Seikai T (2004) Temperature effects on early development and occurrence of

metamorphosis-related morphological abnormalities in hatchery-reared brown sole *Pseudopleuronectes herzensteini*. Aquaculture 240: 517–530

3. Schram E, Bierman S, Teal LR, Haenen O, van de Vis H, Rijnsdorp AD (2013) Thermal preference of juvenile Dover sole (*Solea solea*) in relation to thermal acclimation and optimal growth temperature. PLoS ONE 8: e61357

4. Laurel BJ, Danley C, Haines S (2014) The effects of temperature on growth, development and settlement of northern rock sole larvae (*Lepidopsetta polyxystra*). Fish Oceanogr 23: 495–505

5. Fonds M, Cronie R, Vethaak AD, Van der Puyl P (1992) Metabolism, food consumption and growth of plaice (*Pleuronectes platessa*) and flounder (*Platichthys flesus*) in relation to fish size and temperature. Neth J Sea Res 29: 127–143

6. Iwata N, Kikuchi K, Honda H, Kiyono M, Kurokura H (1994) Effects of temperature on the growth of Japanese flounder. Fish Sci 60: 527–531

7. Seikai T, Takeuchi T, Park GS (1997) Comparison of growth, feed efficiency, and chemical composition of juvenile flounder fed live mysids and formula feed under laboratory conditions. Fish Sci 63: 520–526

8. Joh M, Nakaya M, Yoshida N, Takatsu T (2013) Interannual growth differences and growth-selective survival in larvae and juveniles of marbled sole *Pseudopleuronectes yokohamae*. Mar Ecol Prog Ser 494: 267–279

9. Hata M, Sugimoto R, Hori M, Tomiyama T, Shoji J (2016) Occurrence, distribution and prey items of juvenile marbled sole *Pseudopleuronectes yokohamae* around a submarine groundwater seepage on a tidal flat in southwestern Japan. J Sea Res 111: 47–53

10. Mutsutani K (1988) Growth and metamorphosis of the marbled sole larvae *Limanda yohohamae* (Günter) in culture. Suisanzoshoku 36: 27–32 (in Japanese)

11. Takahashi T, Tominaga O, Maeda T (1987) Effects of water temperature on feeding and survival of righteye flounders *Limanda herzensteini* and *Limanda yokohamae*. Nippon Suisan Gakkaishi 53: 1905–1911 (in Japanese with English abstract)

12. Tsuchida S (2002) Experimental study on temperature preference of Japanese marine fish. Rep Mar Ecol Res Inst 4: 11–66 (in Japanese with English abstract)

13. Uehara S (1995) Studies on fishery ecology of coastal pleuronectid fishes. PhD thesis, University of Tokyo, Tokyo (in Japanese)

14. Iida M (2000) Studies on early life history of two pleuronectid fishes in a semi-closed bay. PhD thesis, University of Tokyo, Tokyo (in Japanese)

15. Swaney W, Kendal J, Capon H, Brown C, Laland KN (2001) Familiarity facilitates social learning of foraging behaviour in the guppy. Anim Behav 62: 591–598

16. Sugimoto K, Suzuki K, Kumagai A (2007) Influence of rearing density of juvenile marbled sole *Pleuronectes yokohamae* on fin lack caused by biting. Miyagi Pref Rep Fish Sci 7: 13–15 (in Japanese)

17. Akaba Y, Komiya T (2010) Efficiency and practicality of marking method using deformities of caudal fin in hatchery-reared marbled sole, *Pseudopleuronectes yokohamae*. Bull Chiba Pref Fish Res Ctr 5: 61–67 (in Japanese)

18. Imsland AK, Sunde LM, Folkvord A, Stefansson SO (1996) The interaction of temperature and fish size on growth of juvenile turbot. J Fish Biol 49: 926–940

19. Jonassen TM, Imsland AK, Stefansson SO (1999) The interaction of temperature and fish size on growth of juvenile halibut. J Fish Biol 54: 556–572

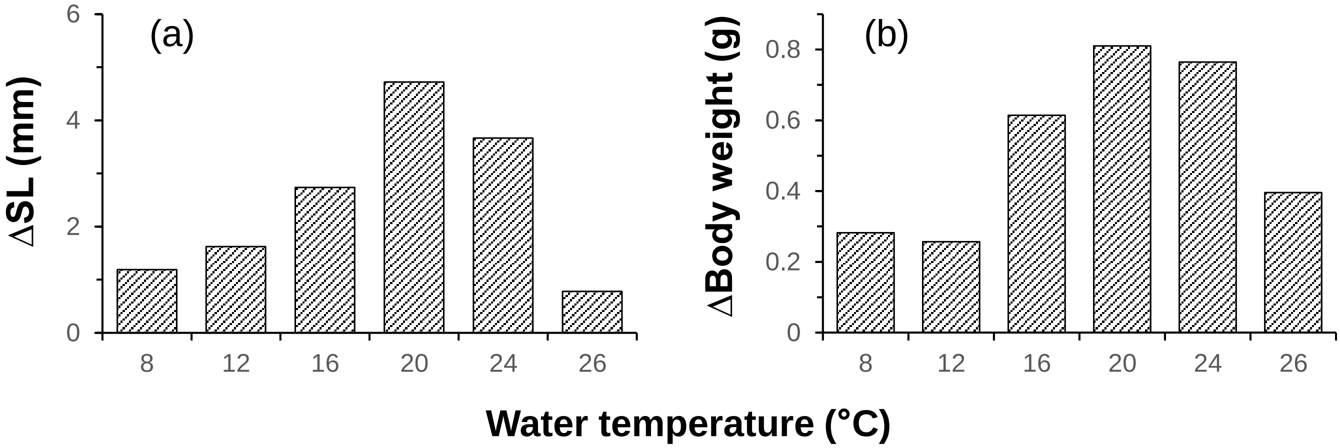
20. Björnsson B, Steinarsson A, Oddgeirsson M (2001) Optimal temperature for growth and feed conversion of immature cod (*Gadus morhua* L.). ICES J Mar Sci 58: 29–38

Figure captions

Fig. 1. Growth of juvenile marbled flounder in group-based rearing. (a) Increments in average standard length (SL), and (b) increments in average body weight.

Fig. 2. Growth and feeding of juvenile marbled flounder in individual-based rearing. (a) Increments in standard length (SL), (b) increments in body weight, (c) food intake, and (d) feed conversion efficiency. Data are shown as the mean + SD. $N = 6$ for each group. Different letters in italics indicate significant differences between groups (Steel-Dwass test, $P < 0.05$).

Fig. 1.



(a)
ΔSL (mm)
6
4
2
0
8
12
16
20
24
26
(b)
ΔBody weight (g)
0.8
0.6
0.4
0.2
0
8
12
16
20
24
26
Water temperature (°C)

Fig. 2.

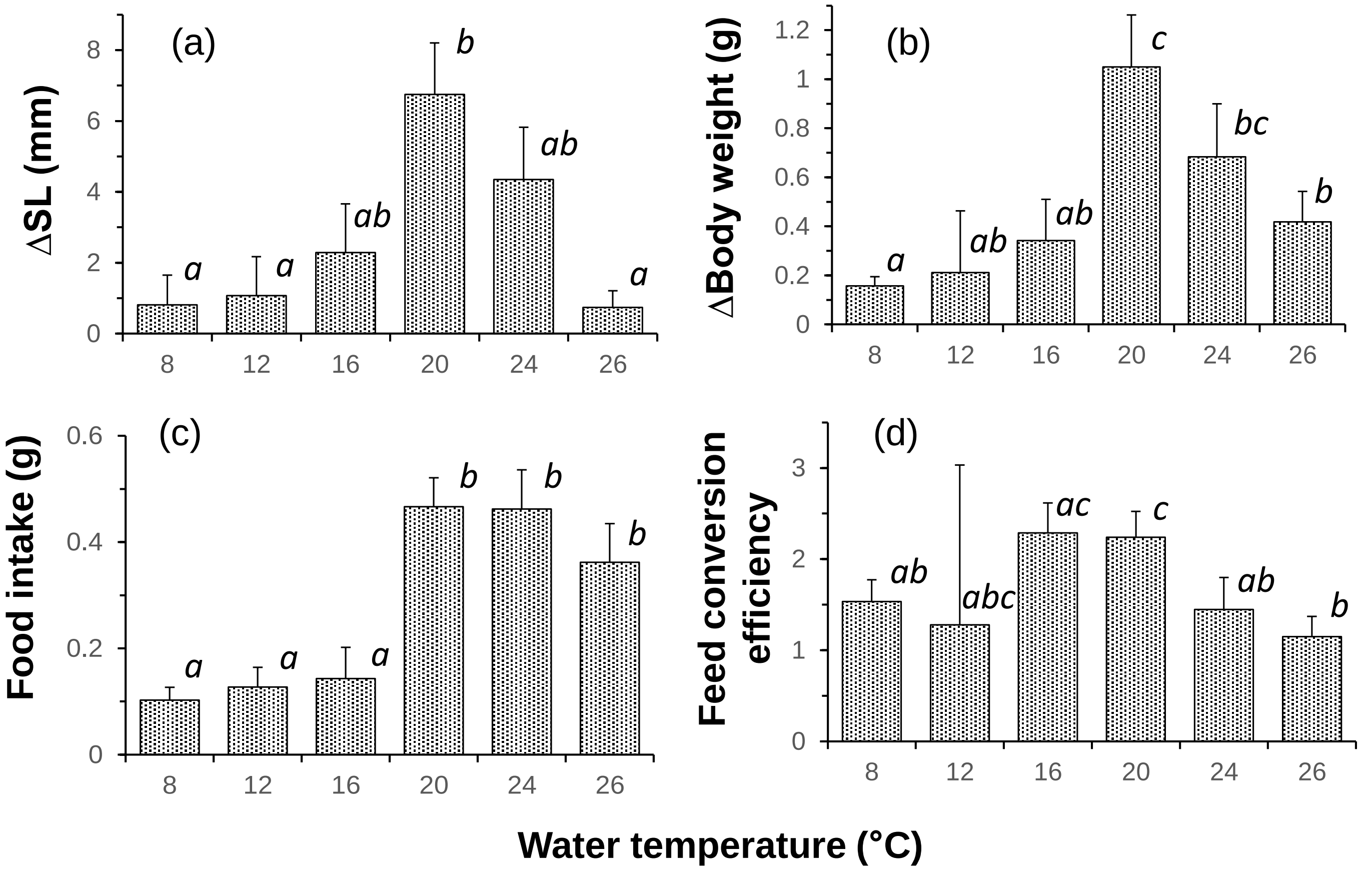

(a)
ΔSL (mm)
0
2
4
6
8
a
a
ab
b
ab
a
8
12
16
20
24
26
(b)
ΔBody weight (g)
0
0.2
0.4
0.6
0.8
1
1.2
a
ab
ab
c
bc
b
8
12
16
20
24
26
(c)
Food intake (g)
0
0.2
0.4
0.6
a
a
a
b
b
b
8
12
16
20
24
26
(d)
Feed conversion efficiency
0
1
2
3
ab
abc
ac
c
ab
b
8
12
16
20
24
26
Water temperature (°C)

Table 1 Experimental condition for feeding and growth of juvenile marbled flounder

Aquarium	Water temperature (°C)	Group-based				Individual-based			
		Initial SL (mm)	Initial BW (g)	SL at the end (mm)	BW at the end (g)	Initial SL (mm)	Initial BW (g)	SL at the end (mm)	BW at the end (g)
8	8.06 ± 0.17	47.20 ± 3.88	1.62 ± 0.40	48.39 ± 3.73	1.90 ± 0.41	48.42 ± 3.34	1.88 ± 0.46	49.24 ± 3.35	2.04 ± 0.48
12	11.94 ± 0.15	47.45 ± 3.62	1.74 ± 0.37	49.08 ± 3.43	1.99 ± 0.47	47.28 ± 2.48	1.65 ± 0.28	48.36 ± 2.22	1.87 ± 0.28
16	15.80 ± 0.20	47.10 ± 3.57	1.46 ± 0.37	49.84 ± 3.51	2.08 ± 0.47	45.12 ± 2.54	1.43 ± 0.26	47.41 ± 2.33	1.77 ± 0.29
20	20.00 ± 0.73	46.97 ± 3.10	1.56 ± 0.29	51.69 ± 2.83	2.37 ± 0.40	44.88 ± 2.25	1.41 ± 0.22	51.63 ± 2.03	2.46 ± 0.42
24	23.64 ± 0.30	46.42 ± 3.30	1.46 ± 0.30	50.08 ± 3.17	2.22 ± 0.43	45.46 ± 3.06	1.49 ± 0.29	49.81 ± 3.62	2.17 ± 0.44
26	26.09 ± 0.43	48.02 ± 2.76	1.72 ± 0.26	48.80 ± 3.12	2.12 ± 0.30	47.68 ± 2.55	1.74 ± 0.28	48.42 ± 2.57	2.16 ± 0.36

Data are shown as the mean ± SD. SL and BW indicate standard length and body wet weight, respectively. Water temperature was measured three times per day during the feeding period (7 days). Ten and six individuals were maintained in each aquarium used for group-based and individual-based rearing, respectively. Mean standard length (SL) is shown; raw data for individual-based method are presented in Table S1. No significant difference in initial SL was observed between aquaria (Kruskal-Wallis test; group-based: $P = 0.88$; individual-based: $P = 0.17$)