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Determining oxygen consumption rate and asphyxiation point in *Chanodichthys mongolicus* using an improved respirometer chamber*

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Abstract Knowledge of oxygen consumption rates and asphyxiation points in fish is important to determine appropriate stocking and water quality management in aquaculture. The oxygen consumption rate and asphyxiation point in *Chanodichthys mongolicus* were detected under laboratory conditions using an improved respirometer chamber. The results revealed that more accurate estimates can be obtained by adjusting the volume of the respirometer chamber, which may avoid system errors caused by either repeatedly adjusting fish density or selecting different equipment specifications. The oxygen consumption rate and asphyxiation point of *C. mongolicus* increased with increasing water temperature and decreasing fish size. Changes in the *C. mongolicus* oxygen consumption rate were divided into three stages at water temperatures of 11–33°C: (1) a low temperature oxygen consumption rate stage when water temperature was 11–19°C, (2) the optimum temperature oxygen consumption rate stage when water temperature was 19–23°C, and (3) a high temperature oxygen consumption rate stage when water temperature was >27°C. The temperature quotients (Q_{10}) obtained suggested that *C. mongolicus* preferred a temperature range of 19–23°C. At 19°C, *C. mongolicus* exhibited higher oxygen consumption rates during the day when the maximum values were observed at 10:00 and 14:00 than at night when the minimum occurred at 02:00.

Keyword: *Chanodichthys mongolicus*; respirometer chamber; oxygen consumption rate; asphyxiation point

1 INTRODUCTION

Most metabolic activity in fish is related to oxygen utilization (Miyashima et al., 2012; Cao and Wang, 2015). Oxygen consumption rates and asphyxiation points in fish are affected by external environmental factors and regulated internally (Fidhiany and Winckler, 1998); they directly and indirectly reflect the metabolic rule and the physiological and living conditions (Dai et al., 1999; Zhang et al., 2009; Castanheira et al., 2011). The oxygen metabolic status in fish can be divided into standard, active, and routine metabolism (Handå et al., 2013). Standard metabolic oxygen consumption rate refers to the oxygen consumption rate without spontaneous activity, the routine metabolic oxygen consumption rate refers to the oxygen consumption rate with spontaneous activity, and the active metabolism refers to the oxygen consumption rate with forced activity (Merino et al., 2009). Standard and active metabolism are primarily studied in the laboratory (Qiao et al., 2005; Wan et al., 2005; Sun et al., 2010), whereas routine metabolism is always studied in either tanks or ponds (bait casting) (Thomas and Piedrahita, 1997; Cook et al., 2000; Salas et al., 2008; Merino et al., 2009; Castanheira et al., 2011; Nerici et al., 2012; Clark et al., 2013). The asphyxiation point reflects a fish's oxygen tolerance, which guides culture production (Wan et al., 2005; Li et al., 2014).

Oxygen consumption rate can be detected under laboratory conditions using the closed running water

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method, and the asphyxiation point can be measured using the hydrostatic closed method (Wrona and Davies, 1984). Thus, two different experimental devices are needed to measure these values separately. Experimental fish oxygen consumption rates can be calculated using iodometric methods, electrode methods, oxygen mini sensors, and chemical optical sensors (Shen, 2001; Clark et al., 2013) by measuring the difference in dissolved oxygen concentration of inlet and outlet water in a container of experimental fish. Oxygen consumption rate measuring devices have improved continuously since 1943 (Scholander et al., 1943; Wrona and Davies, 1984; Cockcroft and Davidson, 1989; Clark et al., 2013). The primary respirometer bottle (Chen and Shih, 1955), Plexiglas device (Zhang et al., 1982), and transparent plastic respirometer chamber (Li, 1991) were developed to improve the respirometer (Song et al., 1997; Lei, 2002; Sun et al., 2010; Xu et al., 2012; Yang et al., 2012) and homemade oxygen consumption rate devices (Du et al., 2013; Mamun et al., 2013; Qiu et al., 2014). However, these oxygen consumption rate devices are not compatible with experiments on fish because they differ in body size: the density of experimental fish must be repeatedly adjusted according to the test temperature, flow velocity, and other parameters (Dalvi et al., 2009; Lin et al., 2012; Tejpal et al., 2014). Alternatively, other devices with various specifications can be employed, and a reasonable match ensures scientifically credible results. Accordingly, to avoid the deficiencies in existing oxygen consumption rate devices, we developed a home-made volume-adjustable oxygen consumption rate device to measure the oxygen consumption rate and asphyxiation point in *C. mongolicus* under laboratory conditions.

C. mongolicus or red tail, is a cyprinid fish, which can be found in the Amur, Huanghe, Huaihe, Changjiang, Qiantang, and Zhujiang Rivers, as well as other river systems in China (Jiang and Yan, 2014). It is an important food source because of its high nutritive value and delicious taste (Xu et al., 2009). However, because of the decrease in wild *C. mongolicus* and the significant increase in demand for marketing and release in recent years, *C. mongolicus* culture is becoming more and more predominant (Lin et al., 2013). A good understanding of its oxygen consumption rate and asphyxiation point is important to determine practical stocking and water quality management in the process of larval rearing and artificial enhancement. Therefore, in this study, a homemade volume-adjustable oxygen consumption rate device was employed to determine the *C. mongolicus* oxygen consumption rate and asphyxiation point to provide a scientific basis for fish farming, seed cultivation, stock enhancement, and transportation.

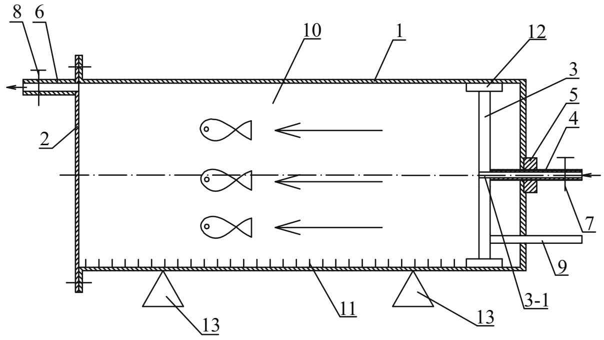

Fig.1 Volume adjustable and closed-running water respiration measurement device

1. respiratory chamber (diameter 25 cm, total length 35 cm); 2. cover plates; 3. push plate; 3-1. inlet alleyway; 4. water inlet pipe; 5. nut; 6. water outlet pipe; 7. water inlet valve; 8. water outlet valve; 9. round rod; 10. respiratory chamber volume; 11. length scales (total length 35 cm); 12. sealing rubber ring; 13. base.

2 MATERIAL AND METHOD

2.1 Fish acclimation

The experimental *C. mongolicus* were purchased from the Hulan Experimental Station, Heilongjiang River Fisheries Research Institute (Harbin, China). The 1- and 2-year-old fish used in the study were produced by propagating wild *C. mongolicus* from Jingpo Lake in Heilongjiang Province (China) and cultured in ponds. After arrival at the laboratory, the fish were divided into three body-weight groups of 0.6 g, 4 g, and 34 g and maintained in experimental aquaria for 30 days to acclimate before testing. The fish were fed ad libitum daily with commercial compound feed. The tanks were supplied with aerated tap water, with the following water quality parameters: pH 6.9±0.2; total alkalinity 1.07±0.03 mmol/L; total hardness 1.64±0.02 mmol/L; and dissolved oxygen >5 mg/L.

2.2 Determination of oxygen consumption rate

A homemade closed cylinder was employed to measure the oxygen consumption rate of the fish. The test device was made of 5-mm-thick Plexiglas, with an inner diameter of 25 cm and a length of 35 cm (Fig.1). As shown in Fig.1, the water volume in the respirometer chamber can be adjusted by rotating the screw nut (5 in Fig.1) to reposition the push plate (3 in Fig.1). A circulation pump (800 L/h, 18 W) (RONMA, Zhengzhou, China) passed water into the respirometer chamber. At a constant water mass flow rate, changing the chamber volume resulted in different hydraulic residence times (HRT). Thus, a decrease in chamber volume reduces HRT and increases fish density, thereby increasing the dissolved oxygen concentration difference between the inlet and outlet chambers.

Oxygen consumption rates at different water temperatures of 11, 15, 19, 23, 27, 31, and 33°C were tested according to previous studies (Geng et al., 2012; Xu et al., 2012; Tang et al., 2013). Briefly, fish of three different weight groups were placed in three static respirometer chambers, which were completely submerged in a temperature-controlled aquarium. The fish were allowed to acclimate for 3 days to reach the standard metabolism and were not fed for the entire experiment. The initial test temperature was 11°C, it was then gradually increased to the respective test temperatures using an automatic temperature-control system (CHENGFA, HX-K100C, 2 KW, approximately 1°C per hour). Once the desired test temperatures had been reached, the fish were maintained for 1 day before oxygen consumption rate was measured. Dissolved oxygen concentrations were determined by the iodometric method (Shen, 2001). Each experimental group had two parallel replicate groups, and the experiment was conducted once an hour between 9:00 and 12:00 AM. Inlet and outlet water samples were collected (two parallel groups) before each trial, and the mean values were calculated. The volume of the respirometer chamber was adjusted (by moving the push plate) to maintain a dissolved oxygen difference between the water inlet and outlet of 0.3–1.5 mg/L, which was calculated by measuring the position of the push plate. Moreover, to illustrate the effect of the oxygen consumption rate detection device, we measured the difference in dissolved oxygen between the inlet and outlet water by only moving the push plate for the 4.0-g fish group.

Daily oxygen consumption rate was only measured in the 4.0-g fish at 19°C. Oxygen consumption rates were determined once every 2 h for 24 h in a 12 h:12 h light:dark cycle.

2.3 Asphyxiation point

Our test device was used to determine oxygen consumption rates (Fig.1). Inlet valve 7 and outlet valve 8 were closed to create a closed environment in chamber 10 to determine the asphyxiation point. Outlet valve 8 was opened, screw nut 5 was turned, and inlet pipe 4 moved plate 3 to squeeze water from respirometer chamber 10 into a sample bottle through outlet pipe 6 to measure dissolved oxygen in the water with air interference. Fish of three different weight groups were used to determine the asphyxiation point. The dissolved oxygen concentration at the critical hypoxic and critical asphyxiation points was also determined. The critical hypoxic, critical asphyxiation, and asphyxiation point were considered as one dissolved oxygen level when 50% and 100% of the experimental fish flipped over and lost balance (Geng et al., 2012). After sampling, the experimental fish were immediately transferred to oxygenated water for recovery.

2.4 Data analysis

The formula used to calculate oxygen consumption rate was as follows (Cao and Wang, 2015):

$$OC=(DO_{inlet}-DO_{outlet})\times V/W,$$

where OC is mass-specific oxygen consumption rate (mg O_2/(g·h)), DO_{inlet} is the dissolved oxygen concentration at the water inlet (mg/L), DO_{outlet} is the dissolved oxygen concentration at the water outlet (mg/L), V is volumetric flow (L/h) (constant at 68.57 L/h in this study), and W is total fish weight (g).

The temperature quotients (Q_{10}) were calculated to assess the effect of acclimation on oxygen consumption rate using the formula (Dalvi et al., 2009):

$$Q_{10}=(OC_2/OC_1)^{10/(Temp2-Temp1)}.$$

All data were processed and statistically analyzed in Excel™ (Version 2010, Microsoft Inc., WA, USA) and SPSS 12.0 software (SPSS Inc., IL, USA). Comparisons of different temperatures and weight groups were performed by one-way ANOVA. Descriptive statistics are expressed as mean±standard deviation. A value of P<0.05 was considered statistically significant.

3 RESULT

3.1 Effectiveness of the oxygen consumption rate detection device

The push-plate positions for determining the oxygen consumption rates for the 4.0-g fish at different water temperatures are shown in Table 1. The results revealed that the difference in dissolved oxygen between water at the inlet and outlet valves could be maintained in the appropriate range by adjusting the push-plate position to change the volume of water in

Table 1 The difference in dissolved oxygen between water at the inlet and outlet for push-plate positions in 4.0-g *C. mongolicus* (*n*=130)

Temperature (°C)	Total oxygen consumption (mg O_2/h)	Moving push-plate			Without moving push-plate	
		Push-plate position (cm)	Volume (L)	Dissolved oxygen difference (mg O_2/L)	Push-plate position (cm)	Dissolved oxygen difference (mg O_2/L)
11	14.00±0.09	6	2.94	0.30±0.07	30	0.1±0.04
15	57.52±0.22	6	2.94	0.45±0.06	30	0.1±0.02
19	60.84±0.12	6	2.94	0.78±0.11	30	0.2±0.05
23	113.19±0.06	18	8.83	1.33±0.08	30	0.8±0.06
27	144.95±0.11	18	8.83	1.64±0.17	30	1.0±0.09
31	192.86±0.19	23	11.28	1.49±0.2	30	1.2±0.04
33	173.19±0.07	23	11.28	1.08±0.04	30	1.1±0.07

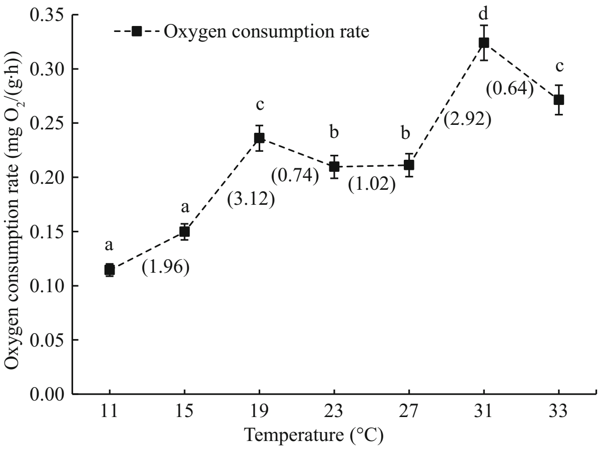

Fig.2 Oxygen consumption rate in 0.6-g *C. mongolicus* at different temperatures (*n*=340)

the respirometer chamber. The significance of adjusting the push-plate position was more obvious under low temperatures of 11–19°C, and the difference in dissolved oxygen increased from 0.1–0.3 mg/L to 0.3–0.8 mg/L, which was the appropriate condition for determining the oxygen consumption rate.

3.2 *C. mongolicus* oxygen consumption rate

The oxygen consumption rates at different temperatures for fish of different sizes under constant flow rate conditions (68.57 L/h) are shown in Figs.2–4. As shown in Fig.2, oxygen consumption rates in 0.6-g fish increased significantly at 11–19°C, then decreased at 19–27°C (P<0.05). A similar trend was observed at 27–31°C and 31–33°C. The lowest oxygen consumption rate was at 11 °C, and the highest was at 31°C. For the 4.0- and 34.4-g fish, oxygen consumption rates rose with water temperatures of 11–33°C. However, oxygen consumption rates at adjacent temperatures did not differ significantly in the 4.0-g fish (Fig.3) (P>0.05), except between 27

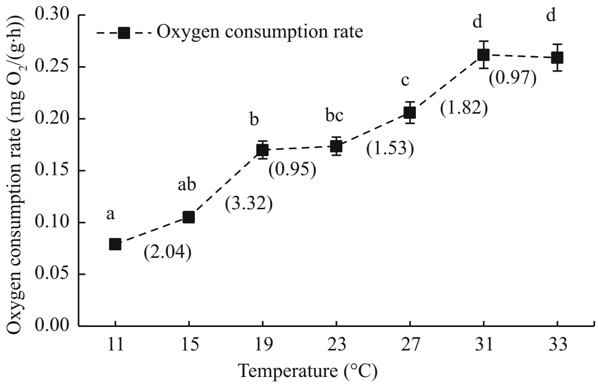

Fig.3 Oxygen consumption rates in 4.0-g *C. mongolicus* at different temperatures (*n*=130)

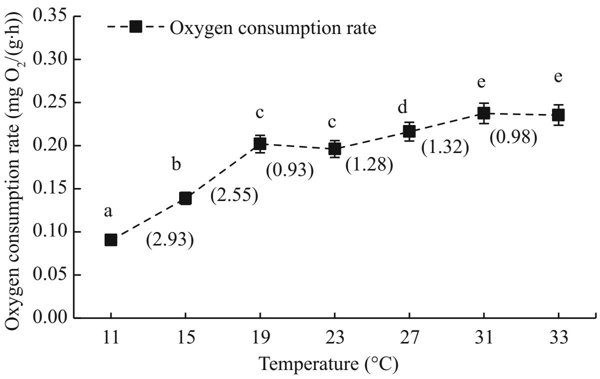

Fig.4 Oxygen consumption rates in 34.4-g *C. mongolicus* at different temperature (*n*=9)

and 31°C (P<0.05). With the exception of temperatures 19–23°C and 31–33°C, the oxygen consumption rates in the 34.4-g fish did not differ significantly (Fig.4) (P>0.05).

In the 0.6-g fish (Fig.2), the highest values (Q_{10}=3.12) were observed between 15°C and 19°C, followed by Q_{10}=2.92 between 27°C and 31°C. The lowest values were recorded at 19–23°C and 31–33°C. In the 4.0-g fish (Fig.3), the highest value

Table 2 Oxygen consumption rates for three *C. mongolicus* weight groups at 19°C

Temperature (°C)	Weight (g)	Total length (cm)	Number (ind.)	Oxygen consumption rate (mg O_2/(g·h))
19	0.60±0.18	4.37±0.50	340	$0.28±0.05^b$
19	4.01±0.89	7.91±0.78	130	$0.17±0.07^a$
19	34.41±9.03	15.13±1.13	9	$0.20±0.01^a$

Note: the 0.60±0.18-g fish were juveniles. Means in the same rows with different superscripts are significantly different (P<0.05).

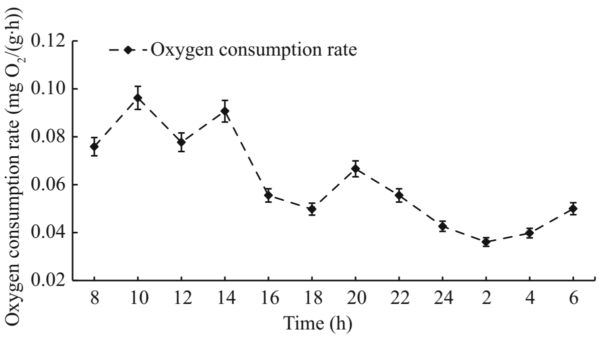

Fig.5 Daily oxygen consumption rates in 4.0-g *C. mongolicus* at 19°C (*n*=130)

(Q_{10}=3.32) appeared in the same temperature range as the 0.6-g fish, while the lowest values (Q_{10}=0.95) was between 19 and 23°C, followed by 31–33°C. In the 34.4-g fish (Fig.4), the highest value (Q_{10}=2.93) was between 11 and 15°C, followed by Q_{10}=2.55 between 15 and 19°C. The lowest value appeared in the same temperature range as the 4.0-g fish. For all three weight groups, the lowest Q_{10} value was between 19 and 23°C.

The oxygen consumption rates for the three different *C. mongolicus* weight groups are shown in Table 2. The 0.60-g fish had the highest oxygen consumption rate, which was significantly higher than the other two weight groups (P<0.05).

3.3 Daily *C. mongolicus* oxygen consumption rate rhythm

Daily oxygen consumption rates ranged between 0.036 and 0.096 mg O_2/(g·h) in fish held at 19°C and the daytime oxygen consumption rate was higher than that at night (Fig.5). The mean oxygen consumption rate during the day (8:00–18:00) was 0.074 mg O_2/(g·h), and the highest value was observed between 10:00 and 14:00. The mean oxygen consumption rate at night (20:00–06:00) was 0.048 mg O_2/(g·h), with the lowest value being observed at 2:00. The mean oxygen consumption rate during the day was 1.53 times greater than that at night.

3.4 *C. mongolicus* asphyxiation point

The initial dissolved oxygen in our device was >4.50 mg/L. The fish showed normal activity initially, but became agitated with a high respiratory rate when dissolved oxygen decreased as a result of oxygen consumption by the fish. As dissolved oxygen continuously decreased, the fish gradually lost swimming ability and eventually lay on the bottom of the chamber. Table 3 shows that the asphyxiation points of the three *C. mongolicus* weight groups increased with increasing water temperature but decreased with increasing body weight at the same water temperature. The lowest asphyxiation point was 0.41 mg/L for the largest fish (body weight, 27.17–39.76 g) at 11°C, and 1.39 mg/L for the smallest fish (body weight, 0.43–1.02 g) at 31°C.

4 DISCUSSION

4.1 Oxygen consumption rate device

The differences in dissolved oxygen between water at the inlet and outlet valves in the respirometer chamber and the water flow mass through the respirometer chamber are the two variables used to calculate oxygen consumption rate when using the closed running water method. Water flow significantly effects oxygen consumption rate based on a significant linear correlation within a certain range of flow rates, thus a constant flow of water is a prerequisite for obtaining accurate results (Stevens and Dizon, 1982). Furthermore, the differences in dissolved oxygen between water at the inlet and outlet valves in the respirometer chamber correlate with water temperature, fish body weight, and other factors. A lower water temperature and fish of smaller size may result in a smaller difference in dissolved oxygen, which requires improved measurement accuracy to minimize system errors. In this case, either fish density must be adjusted repeatedly (Saint-Paul et al., 1988; Dalvi et al., 2009; Lin et al., 2012; Tejpal et al., 2014) or equipment with other specifications must be used (Smith and Laver, 1981; Fidhiany and Winckler, 1998; Liao et al., 2004; Sun et al., 2010; Zeng et al., 2010; Dupont-Prinet et al., 2013) to maintain the differences in dissolved oxygen within an appropriate range. It was inevitable that a new systematic error would occur when comparing the experimental groups. Thus, we introduced a volume-adjustable oxygen consumption rate device that increases the differences in dissolved oxygen from 0.1–0.3 mg/L to 0.3–0.8 mg/L by changing the respirometer chamber volume with a constant water

Table 3 *C. mongolicus* asphyxiation points at different temperatures

Water temperature (°C)	Weight (g)	Initial dissolved oxygen (mg/L)	Critical hypoxic point (mg/L)	Critical asphyxiation point (mg/L)	Asphyxiation point (mg/L)
11	27.17–39.76	7.32±0.23	0.45	0.42	0.41
	2.54–4.78		0.60	0.53	0.45
	0.43–1.02		0.84	0.69	0.58
15	27.17–39.76	6.94±0.47	0.45	0.42	0.41
	2.54–4.78		0.62	0.60	0.52
	0.43–1.02		0.96	0.79	0.65
19	27.17–39.76	6.11±0.06	0.62	0.58	0.55
	2.54–4.78		0.79	0.64	0.62
	0.43–1.02		1.17	1.07	1.01
23	27.17–39.76	5.83±0.50	0.79	0.68	0.62
	2.54–4.78		0.83	0.68	0.63
	0.43–1.02		1.22	1.13	1.12
27	27.17–39.76	4.96±0.09	0.91	0.74	0.69
	2.54–4.78		1.13	0.92	0.85
	0.43–1.02		1.44	1.30	1.14
31	27.17–39.76	4.50±0.06	1.19	0.90	0.80
	2.54–4.78		1.41	0.96	0.89
	0.43–1.02		1.75	1.47	1.39

Note: the number fish in weight group 27.17–39.76 g was six, the number fish in weight group 2.54–4.78 g was 10, and the number of fish in weight group 0.43–1.02 g was 40.

flow rate. Thus, we could easily and accurately detect differences in oxygen consumption rates.

4.2 *C. mongolicus* oxygen consumption rate

In the present study, the effect of temperature on oxygen consumption rate can be divided into three stages according to Geng (2012): (1) a low temperature stage: the oxygen consumption rate at a temperature less than that for optimum growth and rises quickly with temperature; (2) the optimum temperature stage: the oxygen consumption rate of the fish is within the optimum temperature range and changes less with temperature; (3) the high temperature phase: oxygen consumption rate continues to rise when the temperature is higher than optimum and begins to decrease after reaching a particular temperature. Overall, fish oxygen consumption rates rise with increases in temperature within a certain range. The oxygen consumption rate by *C. mongolicus* at water temperatures of 11–33°C changed according to the above: the low temperature phase in *C. mongolicus* occurred at 11–19°C, the optimum temperature phase occurred at 19–23°C, and the high temperature phase occurred at >27°C.

It is generally accepted that with increases in temperature, fish have a higher oxygen demand, and oxygen consumption rates rise. This is because the activity of various enzymes increase with increases in temperature, as the physiological and biochemical demands of tissues increase (Chen and Shih, 1955; Qiao et al., 2005). Zhu et al. (2007) have reported that oxygen consumption rates change less in fish maintained within the appropriate water temperature range as a result of relatively stable catabolism levels. However, as temperature rises to a certain level, at which enzymatic activity is inhibited leading to metabolic disorder, oxygen consumption rates may decrease gradually (Liu et al., 2000). Our results revealed that the *C. mongolicus* oxygen consumption rate began to decrease after 31°C, indicating that metabolism had been either inhibited or impaired This result agrees with those reported for *Girella melanichthys* (Tang et al., 2013; Li et al., 2014), *Pseudorasbora parva* (Yang et al., 2013), *Sebastiscus marmoratus* (Qiu et al., 2014), and *Chalcalburnus chalcoides aralensis* (Geng et al., 2007).

In studying the effect of temperature on biological processes, Q_{10} has often been used to determine temperature effects. In the present study, the highest Q_{10} values in the three weight groups were 3.12, 3.32, and 2.93 for 0.6, 4.0 and 34.4-g fish, respectively. A higher Q_{10} probably suggests a greater susceptibility to temperature changes. The 4.0 g fish with a higher Q_{10} are more susceptible to temperature changes than 0.6-g fish and the 34.4-g fish. It has been suggested that freshwater fish exhibit physiological plasticity when they regain or approach their metabolic set-point (viz., quantitative or qualitative changes in enzyme expression) within the context of their thermally fluctuating environments, thus fish with greater plasticity in the routine metabolic rate may have a smaller Q_{10} (Dent and Lutterschmidt, 2003). In the present study, the lower Q_{10} value was observed between 19–23°C, indicating that *C. mongolicus* has a better capacity for maintaining homeostasis within this range. Although the Q_{10} value at 31–33°C was also lower, at the same time, the oxygen consumption rate was also high. The decrease in Q_{10} indicates that more energy is potentially available for growth because the metabolic rate decreased (Dalvi et al., 2009). Therefore, we suggest that the preferred temperature of *C. mongolicus* is in the range of 19–23°C.

Besides water temperature, body size also determines oxygen consumption rate. In the present study, smaller fish exhibited higher oxygen consumption rates. This can be explained by the size-specific metabolic rate, which is higher in young fish and similar results have also been observed in other fish species (Geng et al., 2012; Xu et al., 2012; Yang et al., 2012). Research has confirmed three kinds of day/night changes in oxygen consumption rate in fish: (1) oxygen consumption rate is higher during the day than at night. These fish eat more and are more active during the day, thus, require more dissolved oxygen than at night; (2) oxygen consumption rate is higher at night than during the day. These species are more active at night; thus, oxygen consumption rate is lower than during the day; (3) little difference between day and night oxygen consumption rates. These fish have similar feeding behavior and activity levels both day and night (Fan et al., 2009). Clausen (1936) reported a regular change in oxygen consumption rate during the day and night, which represents the activity cycle of fish in a normal environment: high oxygen consumption rate refers to fish eating and performing other activities, while low oxygen consumption rate refers to a decrease in feeding and other activities. Similarly, *C. mongolicus* had a higher oxygen consumption rate during the day than at night at 19°C, indicating that *C. mongolicus* primarily eats and carries out other activities during the day. Its day and night oxygen consumption rates were similar to those of *Ancherythroculter nigrocauda* (Li, 2008), but differed from *California halibut* (Merino et al., 2009). As a result, feeding during the day, particularly after 10:00 AM, will improve food utilization efficiency, and be more favorable for *C. mongolicus* growth. Transportation of fish should be avoided during this time to reduce oxygen consumption rates and improve survival rates during transport.

4.3 *C. mongolicus* asphyxiation point

Various factors affect the asphyxiation point of fish, these include differences among species, i.e., body weight, water temperature, sexual maturation, and physical and chemical properties of the water, such as pH, oxygen tension, and other factors (Du et al., 2013). Previous studies (Fan et al., 2009; Xu et al., 2009) have shown that the asphyxiation point of a fish increases with water temperature because fish have a high oxygen demand at high water temperatures. Changes in the *C. mongolicus* asphyxiation point conformed to this law at water temperatures of 11–33°C. Qiao et al. (2005) considered two effects of body weight on the asphyxiation point. One is a positive correlation between the asphyxiation point and body weight, the other is a negative correlation between the two. In the present study, the asphyxiation point of *C. mongolicus* was negatively correlated with body weight, and the capability of the fish to tolerate hypoxia improved with increasing fish size. Additionally, we found that when fish were maintained at the asphyxiation point for a long time, normal life activities could not be restored, even after transferring them to highly oxygenated water. This result was similar to that observed in *Pelteobagrus vachelli* (Wan et al., 2005).

5 CONCLUSION

The present study investigated the oxygen consumption rate and asphyxiation point in *C. mongolicus* using an improved volume-adjustable respirometer equipment. This method avoided the system errors caused by either repeatedly adjusting experimental fish densities or selecting different equipment. The oxygen consumption in *C. mongolicus* varied with different water temperatures and weight, and was higher during the day than that at night. Moreover, the *C. mongolicus* asphyxiation point increased with increased water temperature and decreased with increasing body weight. Overall, our results provide the first information of oxygen consumption in *C. mongolicus*, which may helpful for fish farming, seed cultivation, stock enhancement, and transportation of *C. mongolicus*.

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