

## Effects of Photoperiod, Temperature, and Fish Size on Oxygen Consumption in the Black Porgy *Acanthopagrus schlegeli*

Young Jin Chang<sup>1\*</sup>, Min Hwan Jeong<sup>1</sup>, Byung Hwa Min<sup>1</sup>,  
 William H. Neill<sup>2</sup> and Lance P. Fontaine<sup>2</sup>

<sup>1</sup>Department of Aquaculture, Pukyong National University, Busan 608-737, Korea

<sup>2</sup>Department of Wildlife and Fisheries Sciences, Texas A&M University, TX 77843-2258, USA

The effects of photoperiod, temperature, and fish size on oxygen consumption (OC) in the black porgy *Acanthopagrus schlegeli*, a euryhaline marine teleost, were studied using a closed recirculating seawater system with a respiratory chamber. Fish reared in indoor recirculating seawater tanks were divided into two groups: small (15.7-55.8 g, mean 38.1±15.9 g) and large (108.7-238.8 g, mean 181.8±54.9 g) fish. The OC of the fish showed a clear diel rhythm, with higher values in the daytime and lower values at night, in accordance with light (09:00-20:59 h) and dark (21:00-08:59 h) cycles. The OC of the fish increased linearly with the water temperature. The OC was the highest at 10:00 h, one hour after the onset of daylight and was the lowest at 03:00 h, six hours after dusk. The average OC at 20°C during the light period was as high as 219.8 mg O<sub>2</sub>/kg/h in the small fish and 156.3 mg O<sub>2</sub>/kg/h in the large fish, while during the dark period it was as low as 130.5 and 110.4 mg O<sub>2</sub>/kg/h, respectively. The OC during the dark period, which showed limited variation, could be regarded as the resting OC, and was 107.6, 130.5, and 219.8 mg O<sub>2</sub>/kg/h at 15, 20, and 25°C, respectively, in small fish, and 52.3, 110.4, and 171.0 mg O<sub>2</sub>/kg/h in large fish. As the body weight of black porgy increased, the OC decreased exponentially and the relationship was expressed as  $OC = 1,222.8BW^{-0.567}$ ,  $OC = 1,113.2BW^{-0.448}$ , and  $OC = 1,495.3BW^{-0.468}$  at 15, 20, and 25°C, respectively. At a fish density of 14.5 g/L at 20°C, black porgy had the highest OC per breath compared to fish at the same density at 15 or 25°C. This suggests that the black porgy responds to the stocking density (15 kg/m<sup>3</sup>) and water temperature (20°C) conditions commonly observed in intensive aquaculture with the deepest breath and the highest metabolic activity.

Key words: Black porgy, *Acanthopagrus schlegeli*, Euryhaline marine teleost, Respiration, Oxygen consumption, Photoperiod, Temperature, Fish size, Diel rhythm

### Introduction

The oxygen consumption (OC) of land animals breathing air and fish consuming oxygen from water through the gills has long been considered a valid measure of metabolism. It is also generally accepted that the concentration of dissolved oxygen affects the metabolic rates of aquatic animals (Kusins and Mangum, 1971). Consequently, the oxygen supply in various types of flow-through and closed water systems is one of the most important parameters in aquaculture.

Many authors have demonstrated the effects of various factors on the oxygen requirements of fish, such as water temperature (Brett and Glass, 1973; Wi

and Chang, 1976), salinity (Rao, 1971; Forsberg, 1994), photoperiod (Withey and Saunders, 1973), fish size (Brett and Glass, 1973), feed amount (Brett and Groves, 1979), and stress (Smart, 1981; Barton and Schreck, 1987). In aquaculture, dissolved oxygen is considered one of the most important factors determining the carrying capacity and production (Erez et al., 1990; Itazawa and Hanyu, 1991; Jorgensen et al., 1991). Moreover, dissolved oxygen is a parameter used to determine density in fish culture (Kawamoto, 1977) and live-fish transport (Wi and Chang, 1976; Ko et al., 1995), and influences feed consumption (Buentello et al., 2000). To sustain the optimal feeding activity and health of cultured fish, the control of oxygen in culture water is very important.

As mentioned above, OC is an indirect indicator of

\*Corresponding author: yjchang@pknu.ac.kr

metabolic rate in fish (Cech, 1990) and can be used to determine the energetic costs due to changes in Salinity. The energy required for osmoregulation can significantly influence the observed growth rates in seawater- and freshwater-adapted fish (Morgan and Iwama, 1991; Ron et al., 1995; Wang et al., 1997; Chu et al., 2000; Chang et al., 2001; Hur et al., 2003). Euryhaline marine teleosts such as gray mullet *Mugil cephalus*, sea bass *Lateolabrax maculatus*, red drum *Sciaenops ocellatus*, and black porgy *Acanthopagrus schlegelii*, possess superior osmoregulatory capabilities and are able to live in a wide range of salinities from freshwater to full-strength seawater. The OC of these euryhaline species is an interesting physiological property that needs further investigation.

This study was conducted to initiate the development of a knowledge based on the optimal conditions for the euryhaline black porgy. This species has ecological and economic importance for aquaculture and stocking enhancement in the waters of East Asia. This study evaluated the effects of photoperiod, temperature, and salinity on the active and resting OC rates. Furthermore, we investigated the existence of a diel rhythm in OC.

### Materials and Methods

The fish were held in indoor recirculating seawater tanks and fed a commercial diet for seabream (protein 44%, lipid 7%, fiber 4%, ash 17%, Ca 1.2%, P 2.7%) for 6 months until subjected to respirometry. The fish were divided into two groups: small and large fish weighing 15.7-55.8 g (mean  $38.1 \pm 15.9$  g, 1 year old) and 108.7-238.8 g (mean  $181.8 \pm 54.9$  g, 2 years old), respectively. A total of 11 different experiments were conducted to evaluate the effects of photoperiod (12L:12D, 24L:0D, and 0L:24D), temperature (15, 20, 25, and 30°C), and fish size on OC (Table 1).

In order to stabilize the metabolic rate, the experi-

mental fish were kept in the respiratory chamber for 12 h before recording the dissolved oxygen in the inlet and outlet water. Fish were not fed for 24 h beforehand or during the experiment. The water temperature in each experiment was controlled using a circulating water bath (JS-WBP-170RP, Johnsam, Bucheon, Korea) and the fish were exposed to a 12-h light: 12-h dark cycle (centered on 09:00 h) at an average light intensity of 1,032 lux measured at the experiment vessel surface. The physicochemical quality of the seawater (salinity 35) used in each experiment is shown in Table 2.

A closed-seawater recirculating system with a respiratory chamber was used to measure OC (Fig. 1). The respiratory chamber (RC, outer dimension 20×30×20 cm) was hexagonal and made of transparent PVC (thickness, 10 mm) with a water volume of 10.4 L and a flow rate that was kept constant during each experiment. In water reservoir I (WR I), a constant water flow (solid arrow) was maintained by controlling the circulating water, which overflowed (open arrow) upon reaching a certain height, thereby maintaining a constant volume of water flow in the respiratory chamber. The outlet water from the respiratory chamber went to water reservoir II (WR II), where it was fully aerated to 100% saturation with air. In the water bath (WB) and filtering unit (FU), temperature was controlled and the water was cleaned before reentering the respiratory chamber. In each experiment, the dissolved oxygen of the inlet water (IW) was maintained above 7.1 mg O<sub>2</sub>/L at 20°C, and each oxygen sensor (OS) measured the dissolved oxygen of the inlet water (IW) and outlet water (OW) every 10 min automatically using a multichannel monitoring system for dissolved oxygen and other parameters (OxyGuard 6, OxyGuard International A/S, Birkerød, Denmark). The data were logged into a personal computer (PC).

In the experiment to assess the effects of tempera-

Table 1. Experimental conditions and the sizes of the fish used in each experiment

| Experiment | Photoperiod (L:D hours) | Water temp. (°C) | Total length (cm) | Body weight (g) | Number of fish |
|------------|-------------------------|------------------|-------------------|-----------------|----------------|
| S1         | 12:12                   | 20               | 12.1±0.5          | 25.4±2.5        | 5              |
| S2         | 12:12                   | 30               | 9.9±0.3           | 15.7±1.8        | 5              |
| S3         | 24:0                    | 20               | 13.5±1.3          | 50.8±9.1        | 5              |
| S4         | 0:24                    | 20               | 15.0±0.7          | 55.8±7.5        | 5              |
| S5         | 12:12                   | 15-25            | 14.1              | 54.8            | 1              |
| S6         | 12:12                   | 15-25            | 13.4±0.8          | 34.7±6.7        | 3              |
| S7         | 12:12                   | 15-25            | 12.4±0.4          | 30.1±1.9        | 5              |
| L1         | 12:12                   | 15-25            | 22.5              | 210.0           | 1              |
| L2         | 12:12                   | 15-25            | 23.5              | 238.8           | 1              |
| L3         | 12:12                   | 15-25            | 19.7±1.3          | 108.7±7.0       | 3              |
| L4         | 12:12                   | 15-25            | 21.7±1.1          | 172.1±21.0      | 3              |

Table 2. Seawater quality for each experimental fish group

| Parameter            | Experimental fish |             |
|----------------------|-------------------|-------------|
|                      | Small fish        | Large fish  |
| Ammonia (mg/L)       | 0.672±0.021       | 0.704±0.051 |
| Nitrite (mg/L)       | 0.037±0.002       | 0.048±0.016 |
| Nitrate (mg/L)       | 9.1±0.3           | 9.3±0.5     |
| Hardness (mg/L)      | 5500.0±30.0       | 5540.0±17.3 |
| Conductivity (ms/cm) | 38.0±0.5          | 38.8±0.4    |

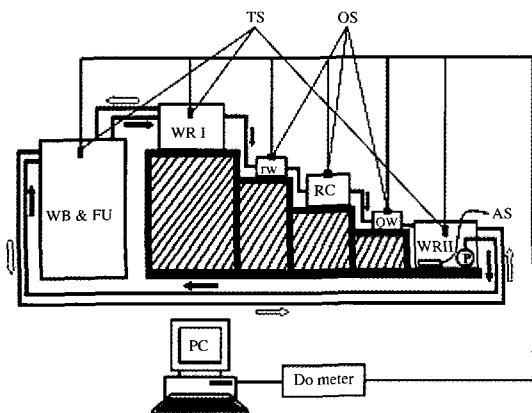


Fig. 1. Schematic diagram of the oxygen consumption measuring system. Solid and open arrows indicate circulating and overflowing water, respectively. AS, air supply; FU, filtering unit; IW, inlet water; OS, oxygen sensor; OW, outlet water; P, pump; PC, personal computer; RC, respiratory chamber; TS, temperature sensor; WB, water bath; WR I and II, water reservoirs I and II, respectively.

ture on OC, the water temperature in the respiratory chamber was increased slowly from 15°C to the target temperature at a rate of 0.6°C/h to minimize any thermal shock to the fish. In every OC experiment, the respiratory chamber was irradiated using fluorescent lights during the light period, while during the dark period the entire respiratory chamber containing the fish was covered with three sheets of black polyethylene film to exclude light from the outside. To account for possible bacterial consumption of oxygen in the system, a blank trial without fish was performed after each experiment. Corrections for any bacterial consumption were unnecessary as there was a negligible change in oxygen concentration over the hour.

In addition to measuring the OC under various conditions, the behavior of the fish was observed during the light and dark periods, including their position in the water and the breathing frequency of each fish. Ventilation rates were counted using opercular cover movements (Wares and Igram, 1979). The opercular cover movements were counted for 1-min intervals and expressed as the average rate calculated

from 10 records for each fish.

Fish oxygen consumption was calculated using the following formula:  $OC = (DO_{in} - DO_{out}) \times F / W$ , where OC is the oxygen consumption expressed in milligrams of oxygen per hour per kilogram of fish (*i.e.*, mg O<sub>2</sub>/kg/h). DO<sub>in</sub> and DO<sub>out</sub> are the dissolved oxygen concentration (mg O<sub>2</sub>/L) in the respective water of the inlet or outlet. F is water flow (L/min). W is the weight of the fish biomass (kg). The mean daily OC was calculated as the arithmetic mean of the 144 oxygen measurements made over 24 hours and of the 72 measurements during each light and dark period.

The results are expressed as the mean±S.D. One-way ANOVA followed by Duncan's multiple range test or Student's *t*-test and paired-samples *t*-test were used to analyze all the experimental data with the program Statistics 3.1 (Analytical Software, St. Paul, MN, USA). Significance was assumed at  $P < 0.05$ ,  $P < 0.01$ , and  $P < 0.001$  and indicated in the tables and figures using \*, \*\*, and \*\*\*, respectively.

## Results

### Behavioral response of the fish to light and dark

The black porgy swam actively in the tank and showed repeated "pursuer and pursued" behavior from each other's territory during the light period. The attack frequency was 1.6 times per min for the average individual at 20°C. Weak fish were unable to avoid attack and were so severely injured that the cranium and backbone were exposed, which was followed by death. During the dark period, however, no attack behavior was observed. Instead, all the fish swam to the bottom of the tank immediately after the onset of the dark period, where they remained motionless. When the light period began, all the fish began to swim and they resumed their attack behavior. These behavioral observations indicate that the black porgy is active during the day and rests at night.

### Diel rhythm of oxygen consumption

As shown in Fig. 2, the OC of small fish when determined every hour for three days (72 h) at 20 and 30°C showed a clear diel rhythm, with higher values in the day (09:00-20:59 h) and lower values at night (21:00-08:59 h). The OC of small fish during the light period ranged from 358.9 to 445.9 mg O<sub>2</sub>/kg/h at 20°C and 818.7 to 972.6 mg O<sub>2</sub>/kg/h at 30°C, and the values were significantly higher than those during the dark period ( $P < 0.01$ ). The average OC at 30°C was 1.6-2.4 times higher (average, 2.0 times) than at 20°C; it was 346.9 mg O<sub>2</sub>/kg/h during the light period

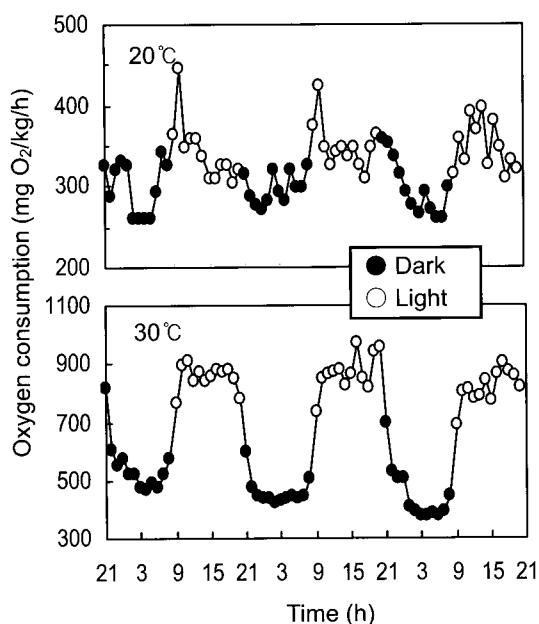


Fig. 2. Circadian change in the oxygen consumption of small black porgy *Acanthopagrus schlegeli* at water temperatures of 20 and 30°C.

and 299.1 mg O<sub>2</sub>/kg/h during the dark period at 20°C, and 845.5 mg O<sub>2</sub>/kg/h during the light period and 485.5 mg O<sub>2</sub>/kg/h during the dark period at 30°C.

At 20°C, during the light period, the average OC (346.9 mg O<sub>2</sub>/kg/h) changed abruptly from the minimum value of 304.5 mg O<sub>2</sub>/kg/h to the maximum value of 445.9 mg O<sub>2</sub>/kg/h just after the beginning of the light period, while the average OC during the light period at 30°C (845.5 mg O<sub>2</sub>/kg/h) was approximately the median value (829.2 mg O<sub>2</sub>/kg/h), and remained relatively even. In contrast, during the dark period, the average OC at 20°C (299.1 mg O<sub>2</sub>/kg/h) and especially at 30°C (485.5 mg O<sub>2</sub>/kg/h) was near the median value (310.0 mg O<sub>2</sub>/kg/h at 20°C and 489.9 mg O<sub>2</sub>/kg/h at 30°C), and was very stable.

### Times of the highest and lowest oxygen consumption

In all experiments using small and large fish, the highest OC during the day occurred at 10:00 h, one hour after the onset of daylight, and the lowest OC occurred at 03:00 h, six hours after dusk (Fig. 3). However, the lowest OCs during the day cycle were observed between 22:00 and 04:00 h, with relatively high frequencies of 8.5 to 16.0%, including the highest value at 03:00 h, while the highest OC during the day was consistently at 10:00 h.

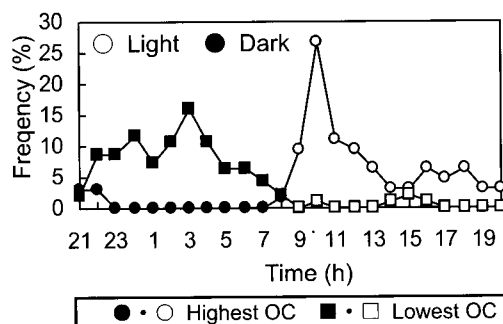


Fig. 3. Percent frequencies of the time showing the highest and lowest oxygen consumption in black porgy *Acanthopagrus schlegeli*. OC: oxygen consumption.

### Oxygen consumption and photoperiod

The OC of small black porgy (Expt. S1, S3, and S4) under three different photoperiod regimes (12L:12D, 24L:0D, and 0L:24D) at 20°C was measured continuously for 3 days and is summarized in Table 3. In the 12L:12D group, the average OC during the daylight for 3 days (346.9 mg O<sub>2</sub>/kg/h) was significantly higher than at night (299.1 mg O<sub>2</sub>/kg/h;  $P < 0.001$ ). This trend was seen in the group exposed to 24L:0D, but the difference was not significant ( $P > 0.05$ ), with the exception of significantly different

Table 3. Average oxygen consumption (mg O<sub>2</sub>/kg/h) in small black porgy *Acanthopagrus schlegeli* under three light-dark (L:D) conditions

| L:D cycle | 12L:12D      |            | 24L:0D        |            | 0L:24D        |            |              |
|-----------|--------------|------------|---------------|------------|---------------|------------|--------------|
|           | Natural time | Day        | Night         | Day        | Night         | Day        | Night        |
| Day 1     |              | 342.6±38.5 | 300.0±32.4*   | 211.2±13.7 | 138.1±12.7*** | 119.8±19.4 | 134.3±27.8   |
| Day 2     |              | 349.8±29.1 | 298.2±18.7*** | 196.0±26.2 | 185.9±35.7    | 142.0±34.8 | 170.8±32.5   |
| Day 3     |              | 348.4±30.4 | 299.1±35.0**  | 152.8±15.8 | 145.8±41.9    | 141.0±37.5 | 176.3±54.8   |
| Mean      |              | 346.9±24.5 | 299.1±17.8*** | 186.7±11.9 | 156.6±14.6*** | 134.3±17.8 | 160.5±23.4** |

Data are the mean±S.D. (n=12). The mean values with asterisks for the night under each L:D condition denote significant differences from the mean oxygen consumption during the day (\* $P < 0.05$ , \*\* $P < 0.01$ , and \*\*\* $P < 0.001$ ,  $t$ -test).

OC values between day and night for Day 1. In contrast to the results of the 12L:12D trial, the average OC during daylight in the 0L:24D group was significantly lower than that at night ( $P<0.01$ ). Consequently, with continuous darkness, the diel OC rhythm tended to disappear or show a 12-hour delay and the OC at night was similar to that in the 24L:0D group, while the OC was markedly lower during the day. The average ventilation rate of fish under 24L:0D was significantly greater than under 0L:24D (127.7 vs. 99.6 breaths/min,  $P<0.001$ ; Fig. 4).

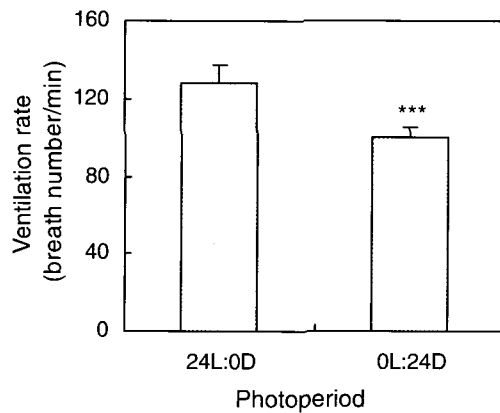


Fig. 4. Ventilation rate of small black porgy *Acanthopagrus schlegeli* under photoperiods of 24L:0D and 0L:24D at 20°C. The mean value with asterisks at 0L:24D is significantly different from that at 24L:0D (\*\*\*) ( $P<0.001$ ,  $t$ -test).

#### Presence of a diel rhythm of oxygen consumption at three water temperatures

The small (Expt. S5) and large (Expt. L2) groups of black porgy showed a clear diel rhythm at each water temperature from the continuous OC measurements with a stepwise increase in water temperature from 15 to 25°C (Table 4, Fig. 5). The small fish consumed 139.6, 175.1, and 276.8 mg O<sub>2</sub>/kg/h at 15, 20, and 25°C, respectively, showing a linear increase in OC

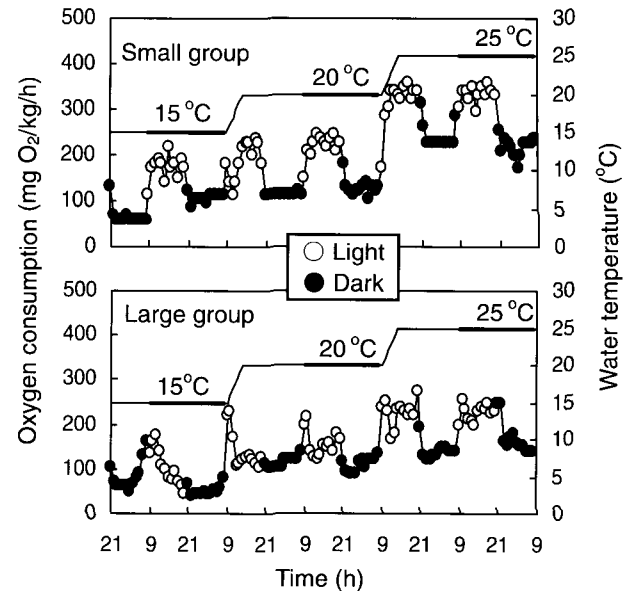


Fig. 5. Circadian change in the oxygen consumption in small and large black porgy *Acanthopagrus schlegeli* at water temperatures of 15, 20, and 25°C.

with water temperature ( $P<0.05$ ). This trend was also seen in the OC of large fish ( $P<0.001$ ).

In small fish, the average OC during the dark period was 62.7% of that during the light period, and was 62.7, 59.4, and 65.9% at 15, 20, and 25°C, respectively. The same trend was seen in the large fish, with an average value of 65.5%, and 50.1, 70.6, and 75.7% at the respective water temperatures. The average OC of large fish during the light and dark periods was 60.8 and 48.6% at 15°C, 71.1 and 84.6% at 20°C, and 67.7 and 77.8% at 25°C of the respective values of small fish, demonstrating that OC was significantly lower in larger fish.

As shown in Table 4, the changes in OC with water temperature for both fish sizes showed a linear increase in OC with water temperature. The slope (b) of the linear regression on the OC of small fish

Table 4. The mean oxygen consumption (mg O<sub>2</sub>/kg/h) in black porgy *Acanthopagrus schlegeli* at water temperatures of 15, 20, and 25°C during light and dark periods

| Water temp. (°C) | Small fish              |                         | Large fish              |                         |
|------------------|-------------------------|-------------------------|-------------------------|-------------------------|
|                  | Light period            | Dark period             | Light period            | Dark period             |
| 15               | 171.6±26.4 <sup>b</sup> | 107.6±10.2 <sup>a</sup> | 104.3±40.3 <sup>b</sup> | 52.3±11.1 <sup>a</sup>  |
| 20               | 219.8±26.2 <sup>c</sup> | 130.5±18.6 <sup>a</sup> | 156.3±28.8 <sup>c</sup> | 110.4±16.9 <sup>b</sup> |
| 25               | 333.7±19.3 <sup>d</sup> | 219.8±22.5 <sup>c</sup> | 226.0±19.2 <sup>d</sup> | 171.0±37.2 <sup>c</sup> |
| b                | 16.21                   | 11.23                   | 12.17                   | 11.87                   |
| a                | -82.50                  | -71.88                  | -81.10                  | 126.23                  |
| r <sup>2</sup>   | 0.850                   | 0.797                   | 0.737                   | 0.811                   |

Values are the mean±S.D. (n=12). The mean values of the oxygen consumption with different superscripts in the light and dark periods in each group are significantly different ( $P<0.001$ , one-way ANOVA).

( $b=16.21$ ) to water temperature during the light period was significantly higher than that in large fish ( $b=12.17$ ), while that in small fish ( $b=11.23$ ) during the dark period did not differ significantly compared to large fish ( $b=11.87$ ). This indicates that the increase in the OC of small fish is faster than that of large fish during the day.

### Ventilation rate and oxygen consumption per breath

The ventilation rates of the small (Expt. S5) and large (Expt. L2) black porgy at water temperatures of 15, 20, and 25°C are shown in Fig. 6. The linear regression between the ventilation rate and water temperature showed extremely strong direct relationships in both the small and large fish. The ventilation rates in small fish were higher than those in large fish at every temperature. Moreover, the slope of the linear regression of ventilation rate against water temperature in small fish ( $b=4.60$ ) was significantly greater than that in large fish ( $b=3.20$ ;  $P<0.01$ ), indicating that the ventilation rate increased more rapidly in small fish than in large fish.

As shown in Fig. 6, the OC per breath in the small-fish group did not show a linear relationship with water temperature, while the relationship between the OC per breath of the large-fish group was linearly related to the water temperature, as with the ventila-

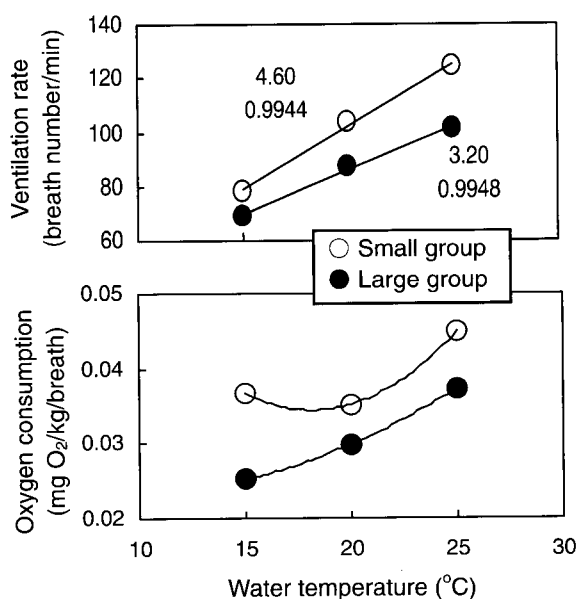


Fig. 6. Ventilation rate and oxygen consumption per breath in black porgy *Acanthopagrus schlegelii* at water temperatures of 15, 20, and 25°C. The numbers in the figure are the slope ( $b$ ) and value of  $r^2$ , respectively.

tion rate. The OC per breath in small fish was significantly greater than that in large fish at every temperature ( $P<0.001$ ).

### Oxygen consumption and body weight

Based on all the experiments using the small- and large-fish groups, the relationship between OC and body weight is shown in Fig. 7. The OC decreased exponentially with increasing body weight in black porgy, and the relationship was given by  $OC = 1,222.8BW^{-0.567}$ ,  $OC = 1,113.2BW^{-0.448}$ , and  $OC = 1,495.3BW^{-0.468}$  at 15, 20, and 25°C, respectively.

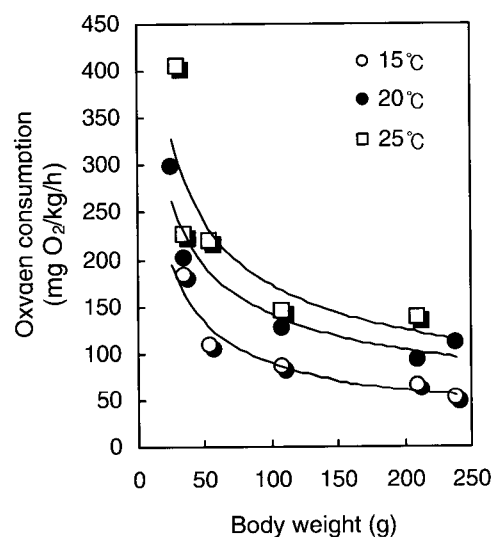


Fig. 7. Relationship between oxygen consumption and body weight in black porgy *Acanthopagrus schlegelii* at water temperatures of 15, 20, and 25°C; 15°C:  $OC = 1,222.8BW^{-0.567}$ , 20°C:  $OC = 1,113.2BW^{-0.448}$ , 25°C:  $OC = 1,495.3BW^{-0.468}$ .

### Oxygen consumption and fish density

Summarizing all the experiments using small and large fish, the relationships among OC ( $\text{mg O}_2/\text{kg/h}$ ), OC per breath ( $\text{mg O}_2/\text{kg/breath}$ ), and fish density ( $\text{g/L}$ ) are plotted in Fig. 8. At a fish density of 14.5  $\text{g/L}$ , OC was 211.5, 337.5, and 405.4  $\text{mg O}_2/\text{kg/h}$  at 15, 20, and 25°C, respectively. OC increased with water temperature and was the highest for all fish densities ( $P<0.001$ ). Furthermore, the OC per breath at this fish density also was the highest.

Black porgy at this fish density at 20°C had a significantly higher OC per breath (0.0936  $\text{mg O}_2/\text{kg/breath}$ ) than at the same density at 15°C (0.0648  $\text{mg O}_2/\text{kg/breath}$ ) or 25°C (0.0702  $\text{mg O}_2/\text{kg/breath}$ ;  $P<0.001$ ), implying that black porgy responds to rearing density and temperature with the deepest breath.

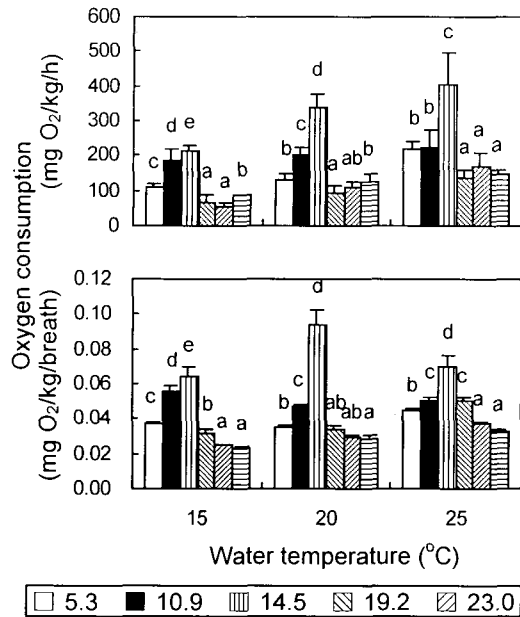


Fig. 8. Oxygen consumption per breath plotted against fish density in black porgy *Acanthopagrus schlegeli* for water temperatures of 15, 20, and 25°C. Means with different letters at each temperature are significantly different ( $P < 0.05$ , one-way ANOVA).

## Discussion

In this study, the black porgy were not fed for 24 hours before measuring OC to ensure a postabsorptive digestive state. Morgan and Iwama (1998) did not feed coho salmon *Oncorhynchus kisutch* for 48 hours before testing. Since coho salmon inhabit cold waters, they likely have a longer gastric evacuation time than black porgy living in warm waters. Since the gastric evacuation time of black rockfish *Sebastes schlegeli* was 21 hours (Myeong, 1999), we assumed the time would be shorter for black porgy because they are more active and consume more OC than black rockfish (Kim et al., 1995), although the time required to reach the postabsorptive digestive state in black porgy has yet to be determined. Therefore, oxygen metabolism due to feeding and digestion could largely be excluded from the OC calculations for black porgy in this study.

Iwama et al. (1997) suggested that the sex of the fish also affects the oxygen consumption rate. However, they could not assess the potential effect of this factor in their study on tilapia *Oreochromis mossambicus*. In our study, which used specimens weighing less than 220 g and less than 2 years old, sex did not affect the OC measurements because the black porgy is a protandrous hermaphrodite and is a functional male for the first two years of its life (Lee

et al., 2001).

Gardner and King (1923) reported that within the optimal temperature range, the OC of fish generally increases linearly with temperature. Kim et al. (1995) suggested that the OC of black porgy (mean body weight = 1.4 g) has the following linear relationship when expressed as a function of water temperature:  $OC = 75.146WT - 947.937$ . In our study, the OC of the fish also increased linearly with water temperature. Prosser and Brown (1961) stated that the standard metabolism of fish increases continuously with temperature up to lethal levels, suggesting a rate change of 2.5 times per 10°C within the physiological range. Wares and Igram (1979) suggested a threefold OC increase per 10°C for the fathead minnow *Pimephales promelas rafinesque*. Our study gave an average rate change of 2 times per 10°C. This is lower than the values suggested by Prosser and Brown (1961) and Wares and Igram (1979), but is similar to Merriman's (1970) observation that the saltwater fishpanamic frillfin *Bathygobius ramosus* had an over-all temperature coefficient of roughly two. Therefore, the black porgy appears to have a metabolic rate that is less temperature labile than that observed in many other species of fish.

Spencer (1939) and Spoor (1946) studied the relationship between activity and oxygen consumption in freshwater fishes and divided fish activity into three types: diurnal, nocturnal, and arrhythmic types. In our study, the black porgy exhibited repeated "pursuer and pursued" behavior during the light period, while no interactions were observed during the dark period. From these observations, the black porgy was assumed to be a diurnal active fish with a higher OC during the day and resting at night. Its OC was the most stable in the dark, when it did not feed or perform attack behavior. Consequently, the daytime OC is the active OC and the nighttime OC is the resting OC in the black porgy.

In this study, when the black porgy was subjected to continuous light or dark, the fish should still have exhibited an OC rhythm, although it might not match that under the original photoperiod. Interestingly, under continuous dark, the fish showed a reversed day/night OC rhythm and consumed less oxygen during the day.

As mentioned above, the black porgy showed a clear diel rhythm in OC with higher values during the day and lower values at night. In this fish, the OC was the highest at 10:00 h, one hour after light exposure. These results suggest that the energy demand of the fish is elevated on feeding in the morning, implying that the black porgy is very sensitive to light.

Comparing the OC of black porgy to the fish density, a density of 14.5 g/L at 20°C produced a higher OC per breath than at the same density at 15 or 25°C. Judging from these results, we recommend a stocking density of 15 kg/m<sup>3</sup> at a water temperature of 20°C for the artificial rearing or aquaculture production of black porgy. To elucidate the relationship between oxygen budget and stocking density to improve aquaculture productivity, more details concerning OC, such as the effects of rearing density, respiration, physiological activity and growth rate should be obtained.

### Acknowledgments

This work was supported by the Pukyong National University Research Abroad Fund in 2002.

### References

- Barton, B.A. and C.B. Schreck. 1987. Metabolic cost of acute physical stress in juvenile steelhead. *Trans. Ame. Fish. Soc.*, 116, 257-263.
- Brett, J.R. and N.R. Glass. 1973. Oxygen consumption and critical swimming speeds of sockeye salmon (*Oncorhynchus nerka*) in relation to size and temperature. *J. Fish. Res. Bd. Can.*, 30, 379-387.
- Brett, J.R. and T.D.D. Groves. 1979. Physiological energetics. In: *Fish Physiology Vol. VIII* (ed. by W.S. Hoar, D.J. Randall and J.R. Brett). Academic Press. New York, pp. 279-352.
- Buentello, J.A., W.H. Neill and D.M. Gatlin III. 2000. Effects of water temperature and dissolved oxygen on daily feed consumption, feed utilization and growth of channel catfish (*Ictalurus punctatus*). *Aquaculture*, 182, 339-352.
- Cech, J.J., Jr. 1990. Respirometry. In: *Methods for Fish Biology* (Schreck C.B. and P.B. Moyle), eds. American Fisheries Society, Bethesda, pp. 335-362.
- Chang, Y.J., J.W. Hur and H.K. Lim. 2001. Growth and survival of juvenile grey mullet (*Mugil cephalus*) in rearing system with recirculated seawater and freshwater. *J. Aquacult.*, 14, 29-33.
- Chu, C., Y.J. Chang and J.W. Hur. 2000. Effects of supplemented salt in the diet on survival, growth and body fluid composition of juvenile grey mullet (*Mugil cephalus*) reared in freshwater. *J. Aquacult.*, 13, 317-323.
- Erez, J., M.D. Krom and T. Neuwirth. 1990. Daily oxygen variations in marine fish ponds, Elat, Israel. *Aquaculture*, 84, 289-305.
- Forsberg, O.I. 1994. Modelling oxygen consumption rates of post-smolt Atlantic salmon in commercial-scale land-based farms. *Aquacult. Internation.*, 2, 180-196.
- Gardner, J.A. and G. King. 1923. Respiratory exchange in freshwater fish. Part VI. On pike (*Esox lucius*). *Biochem. J.*, 17, 170-173.
- Hur, J.W., Y.J. Chang, B.K. Lee and J.Y. Lee. 2003. Effects of hypo-salinity on physiological response, survival and growth of cultured olive flounder (*Paralichthys olivaceus*). *Kor. J. Ichthyol.*, 15, 77-86.
- Itazawa, Y. and I. Hanyu. 1991. *Fish Physiology*. Koseisha-Koseikaku, Tokyo, Japan, pp. 621.
- Iwama, G.K., A. Takemura and K. Takano. 1997. Oxygen consumption rates of tilapia in fresh water, sea water, and hypersaline sea water. *J. Fish Biol.*, 51, 886-894.
- Jorgensen, E.H., M. Jobling and J. Christiansen. 1991. Metabolic requirements of Arctic charr, *Salvelinus alpinus* (L), under hatchery conditions. *Aquacult. Fish. Manag.*, 22, 377-378.
- Kawamoto, N. 1977. *Fish Physiology*. Koseisha-Koseikaku, Tokyo, Japan, pp. 605.
- Kim, I.N., Y.J. Chang and J.Y. Kwon. 1995. The patterns of oxygen consumption in six species of marine fish. *J. Kor. Fish. Soc.*, 28, 373-381.
- Ko, Y.S., Y.J. Chang and J.Y. Kwon. 1995. Changes of dissolved oxygen concentrations during the transportation of the olive flounder (*Paralichthys olivaceus*) seedlings. *J. Aquacult.*, 8, 251-260.
- Kusins, L.J. and C.P. Mangum. 1971. Responses to low oxygen conditions in two species of the mud snail *Nassarius*. *Comp. Biochem. Physiol.*, 39A, 421-435.
- Lee, Y.H., J.L. Du, W.S. Yuch, B.Y. Lin, J.D. Huang, C.Y. Lee, M.F. Lee, E.L. Lau, F.Y. Lee, C. Morrey, Y. Nagahama and C.F. Chang. 2001. Sex change in the protandrous black porgy, *Acanthopagrus schlegeli*: a review in gonadal development, estradiol, estrogen receptor, aromatase activity and gonadotropin. *J. Exp. Zool.*, 290, 715-726.
- Merriman, D. 1970. The califaction of a river. *Scient. Am.* 222, 42-52.
- Morgan, J.D. and G.K. Iwama. 1991. Effects of salinity on growth, metabolism, and ion regulation in juvenile rainbow and steelhead trout (*Oncorhynchus mikiss*) and fall chinook salmon (*Oncorhynchus tshawytscha*). *Can. J. Fish. Aquat. Sci.*, 48, 2083-2094.
- Morgan, J.D. and G.K. Iwama. 1998. Salinity effects on oxygen consumption, gill Na<sup>+</sup>,K<sup>+</sup>-ATPase and ion regulation in juvenile coho salmon. *J. Fish Biol.*, 53, 1110-1119.
- Myeong, J.I. 1999. Differentiation of digestive tract and digestive ability in black rockfish, *Sebastes schlegeli*. Ph.D. Thesis, Pukyong National University, Korea, pp. 109.
- Prosser, C.L. and F.A. Brown, Jr. 1961. *Comparative Animal Physiology*. 2nd ed. W.B. Saunders, Philadelphia, pp. 164.



- Rao, M.M. 1971. Influence of activity and salinity on the weight dependent oxygen consumption of the rainbow trout *Salmo gairdneri*. Mar. Biol., 8, 205-212.
- Ron, B., S.K. Shimoda, G.K. Iwama and E.G. Grau. 1995. Relationships among ration, salinity, 17- $\alpha$  methyl-testosterone and growth in the euryhaline tilapia, *Oreochromis mossambicus*. Aquaculture, 135, 185-193.
- Smart, G. 1981. Aspects of water quality producing stress in intensive fish farming. In: Stress and Fish Pickering A.D., ed. Academic Press. London, pp. 277-293.
- Spencer, W.P. 1939. Diurnal activity rhythms in freshwater fishes. Ohio. T. Sci. 39, 119-132.
- Spoor, W.A. 1946. A quantitative study of the relationship between the activity and oxygen consumption of the goldfish, and its application to the measurement of respiratory metabolism in fishes. Biol. Bull., 91, 312-325.
- Wang, J.Q., H. Lui, H. Po and L. Fan. 1997. Influence of salinity on food consumption, growth and energy conversion efficiency of common carp (*Cyprinus carpio*) fingerlings. Aquaculture, 148, 115-124.
- Wares II, W.D. and R. Igram. 1979. Oxygen consumption in the fathead minnow (*Pimephales promelas rafinesque*) - I. Effect of weight, temperature, group size, oxygen level and opercular movement rate as a function of temperature. Comp. Biochem. Physiol., 62A, 351-356.
- Wi, J.H. and Y.J. Chang. 1976. A basic study on transport of live fish (I). Bull. Fish. Res. Dev. Insti., Kor., 15, 91-108.
- Withey, K.G. and R.L. Saunders. 1973. Effect of reciprocal photoperiod regime on standard rate of oxygen consumption of postsmolt Atlantic salmon (*Salmo salar*). J. Fish. Res. Bd. Can., 30, 1898-1900.

(Received May 2005, Accepted September 2005)