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The Patterns of Oxygen Consumption in Six Species of Marine Fish

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Oxygen consumption of marine fishes according to different water temperatures, fish population densities and body weights was measured in the respiratory chamber for the following six species: the olive flounder *Paralichthys olivaceus*, the tiger puffer *Takifugu rubripes*, the rockfish *Sebastes schlegeli*, the sea bass *Lateolabrax japonicus*, the red seabream *Pagrus major* and the black seabream *Acanthopagrus schlegeli*. Also the lethal concentration of dissolved oxygen in them was determined.

Oxygen consumption in each fish species increased as the water temperature increased. The relationship between the oxygen consumption rate (Oc, ml/kg · hr) and the water temperature (T, ℃) for each species appeared as the following equations demonstrate; olive flounder: $Oc=34.0515T-339.5987$ ($r^2=0.9730$), tiger puffer: $Oc=34.4941T-479.8732$ ($r^2=0.9483$), rockfish: $Oc=44.7970T-634.2627$ ($r^2=0.9718$), sea bass: $Oc=26.1488T-318.0633$ ($r^2=0.9316$), red seabream: $Oc=61.1020T-722.8926$ ($r^2=0.9805$), black seabream: $Oc=75.1460T-947.9370$ ($r^2=0.9392$). The oxygen consumption of fish with different population densities decreased as the number of fish increased. As the body weight of the olive flounder increased, the mass-specific oxygen consumption decreased. The relationship between oxygen consumption and body weight (W; g) was expressed as $Oc=2532.0268W-0.6565$ ($r^2=0.9229$). The levels of lethal dissolved oxygen in the olive flounder, rockfish, tiger puffer and red seabream were 0.66, 0.79, 0.75 and 1.36 ml/l, respectively.

Key Words : commercial marine fish, oxygen consumption, respiration, group effect, lethal DO

Introduction

Fish, like other animals, must have an adequate supply of oxygen in their tissues so that oxidation resulting in the release of energy from food can occur. This energy becomes available to do the biochemical work required for the numerous physiological functions that constitute life after suitable biochemical transformations occur (Reinert, 1980). Thus in the case of fish culture, dissolved oxygen (DO) has been considered as one of the most important factors to determining the carrying capacity and production of fish (Itazawa, 1971; Jorgensen et al., 1991; Erez, 1990). In addition, DO becomes a parameter for the determination of the population densities in fish culture and the transportation of live fishes, and the amount of feed required (Kawamoto, 1977).

Oxygen requirement of fishes, however, is affected by various factors (e.g., size, species, population density, water temperature, pH and salinity, etc.). In many studies, it has been suggested that the oxygen consumption of fishes varied according to different conditions (Kawamoto, 1977; Imabayashi and Takahashi, 1987). In Korea, Wi and Chang (1976) studied the oxygen consumption of the conger eel and the tiger puffer during live fish transportation. Most of these studies, however, dealt with non-commercial fish, or freshwater fish. Therefore, available informa-

Table 1. Species, numbers and size of fishes used in each experiment

Exp. No.	Species	No. of fish	Total length (Mean ± SD) (cm)	Body weight (Mean ± SD) (g)
I	Olive flounder (*Paralichthys olivaceus*)	5	7.97 ± 1.03	3.34 ± 1.45
	Tiger puffer (*Takifugu rubripes*)	5	6.16 ± 0.46	5.75 ± 0.87
	Rockfish (*Sebastes schlegeli*)	5	5.86 ± 0.35	3.45 ± 0.61
	Sea bass (*Lateolabrax japonicus*)	5	9.46 ± 0.31	7.40 ± 1.11
	Red seabream (*Pagrus major*)	5	4.95 ± 0.48	2.13 ± 0.77
	Black seabream (*Acanthopagrus schlegeli*)	5	4.60 ± 0.49	1.40 ± 0.43
II	Rockfish (*Sebastes schlegeli*)	30	5.73 ± 0.34	3.22 ± 0.78
	Sea bass (*Lateolabrax japonicus*)	30	7.18 ± 0.75	4.79 ± 0.40
	Red seabream (*Pagrus major*)	30	7.40 ± 0.55	4.89 ± 1.22
	Black seabream (*Acanthopagrus schlegeli*)	30	4.49 ± 0.42	1.28 ± 0.33
III	Olive flounder (*Paralichthys olivaceus*)	1	8.8	5
		1	13.0	9
		1	15.4	30
		1	20.3	87
		1	25.6	201
		1	33.5	398
IV	Olive flounder (*Paralichthys olivaceus*)	10	8.44 ± 0.63	4.61 ± 1.13
	Tiger puffer (*Takifugu rubripes*)	10	6.64 ± 0.40	4.74 ± 0.61
	Rockfish (*Sebastes schlegeli*)	10	6.43 ± 0.33	5.98 ± 1.20
	Red seabream (*Pagrus major*)	10	6.72 ± 0.52	4.81 ± 1.02

I: Experiment of oxygen consumption according to different water temperature, II: Experiment of oxygen consumption according to different fish population densities, III: Experiment of oxygen consumption according to different body weights of the olive flounder, IV: Experiment of the lethal dissolved oxygen concentration.

tion is not sufficient in the aquaculture of commercial marine fishes. Moreover, there was not reliable information of the lethal dissolved oxygen level on marine fishes.

We have investigated oxygen consumption of the olive flounder *Paralichthys olivaceus*, the tiger puffer *Takifugu rubripes*, the rockfish *Sebastes schlegeli*, the sea bass *Lateolabrax japonicus*, the red seabream *Pagrus major* and the black seabream *Acanthopagrus schlegeli* according to different water temperatures, fish population densities and body weights, and determined the levels of the lethal DO of these species.

Materials and Methods

The fishes used in each experiment were obtained from the Yochon Hatchery, the National Fisheriers Research and Development Agency, the Cheju Aquaculture Farm of Dongwon Industry Co. and the Dongyang Aquaculture Farm, besides the sea bass collected from Sachun Bay. The number of fish, total length and body weight of the fishes used in each experiment are shown in Table 1. These fishes had been acclimated for at least 14 days in a closed recirculation system before the experiment.

The respiratory chambers, used for the measurement of oxygen consumption, are transparent cylindrical chambers (1.5 l), and the respiratory chambers, used for oxygen consumption with each body weight of the olive flounder, are acryl rectangular chambers of 0.63, 0.75, 3.60, 4.50 and 8.19 l, respectively. All mass-specific oxygen consumption (ml/kg · hr., hereinafter referred to as oxygen consumption) was calculated by the equation of Tamura (1940) using a closed-flow device as follows:

$$Oc=\frac{(Ci-Co)\times E}{W}$$

Oc: oxygen consumption, ml/kg · hr.
Ci: DO of inflowing water, ml/l
Co: DO of outflowing water, ml/l
E: volume of flowing water, l/hr.
W: body weight of the fish, kg

So as to determine the lethal DO level, we used an airtight acryl rectangular chamber of 4.50 l (Fig. 1).

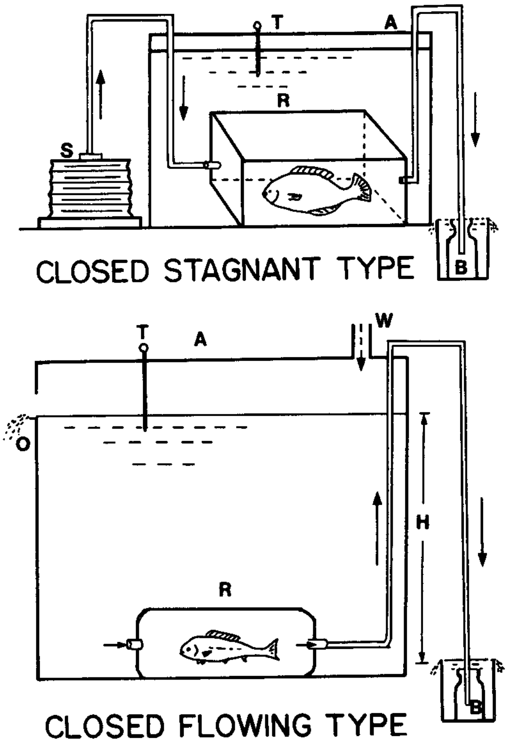

Fig. 1. Two types of apparatus for determination of the oxygen consumption. A: water tank, B: sample bottle, H: difference of water level, O: overflow, R: respiration chamber, S: water supply chamber, T: thermometer, W: water supply.

We measured changes of DO by the method of Kawamoto (1977) according to the lapse of time. Oxygen consumption was calculated by using the following equation:

$$Oc=\frac{(Ca-Ct)\times V}{t\times W}$$

Oc: oxygen consumption, mg/kg · hr.
Ca, Ct: DO of initial and after t hours, ml/l
t: time passed for fishes which consumed oxygen, hr.
V: water volume within the chamber, l
W: body weight of the fish, kg

Dissolved oxygen concentration was measured by the azide modification of Winkler's method (APHA, 1989), and measurement error was less than ± 0.02 ml/l. Each experiment was duplicated, respectively. The fishes were starved for 24 hours prior to the experiment and acclimated in the respiratory chamber for 3 hours before measuring the dissolved oxygen of the inflowing and outflowing water. The water exchange rate, water temperature and changes in the behavior of the fishes were observed throughout all the experiments.

In order to measure the oxygen consumption at each experimental temperature, 5 individuals of each species were accommodated in a closed flow-through system. We put a heater (1 kw) and an ice-pack into the reservoir to increase or decrease the water temperature, and the water temperature was decreased from 24.2℃ to 15.2℃, reduced by 1℃ per hour. Dissolved oxygen of the inflowing and outflowing water was measured every 2 hours to find out the effect of density on oxygen consumption. We divided the fish weight from 5 g to 398 g of the olive flounder up to 6 grades to determine oxygen consumption according to body weight, and then these were placed into 6 respiratory chambers of different sizes. Other precedures were all the same as in the density experiment.

In order to find the level of lethal DO in several species of fish, 10 individuals of each species were put into a 4.5 l airtight acryl rectangular chamber. DO was measured every 30 minutes. At the same time, the behavioral response to the decline of DO, the respiration rate per minute and the time it took the fish to die were investigated.

Statistical differences of oxygen consumption according to fish density and size were determined by analysis of variance, followed by Duncan's multiple range test ($P<0.05$). On the difference of slope against water temperature, a slope test ($P<0.01$) was performed for each species, followed by Scheffe's multiple comparison (Zar, 1984).

Results

1. Oxygen consumption in different water temperatures

Oxygen consumption in each fish species linearly increased in proportion to the elevation of water temperature (Fig. 2). At 15.2℃ the tiger puffer, rockfish, olive flounder, sea bass, black seabream and red seabream showed oxygen consumption rates of 52.40, 52.94, 54.10, 59.68, 102.45 and 172.07 ml/kg · hr, respectively. At 24℃, however, the oxygen consumption of the olive flounder, sea bass, tiger puffer, rockfish, red seabream and black seabream largely increased to 285.98, 309.57, 395.38, 488.18, 774.32 and 848.90 ml/kg · hr hr, respectively.

The relationship of oxygen consumption (Oc) and water temperature (T, ℃) for each species was expressed by a linear regressive equation as follows:

Olive flounder: $Oc=34.0515T-339.5987$ ($r^2=0.9730$)
Tiger puffer: $Oc=34.4941T-479.8732$ ($r^2=0.9483$)
Rockfish: $Oc=44.7970T-634.2627$ ($r^2=0.9718$)
Sea bass: $Oc=26.1488T-318.0633$ ($r^2=0.9316$)
Red seabream: $Oc=61.1020T-722.8926$ ($r^2=0.9805$)
Black seabream: $Oc=75.1460T-947.9370$ ($r^2=0.9392$)

The increasing rate of oxygen consumption according to increasing water temperature for each fish species was higher in turn for the black seabream, the red seabream, the rockfish, the tiger puffer, the sea bass and the olive flounder. Especially, the oxygen consumption of benthic fish, e.g., the olive flounder, was significantly different as compared with those of swimming fish, like the red seabream and the black seabream ($P<0.01$).

On the other hand, as the oxygen consumption rates per respiration for each species were shown in Fig. 3., the amount of oxygen consumption in the olive flounder, the tiger puffer, the rockfish and the sea bass were similar within the limits of 0.015~0.045 ml/kg, but those of the red seabream and the black seabream were within the range of 0.038~0.075 ml/

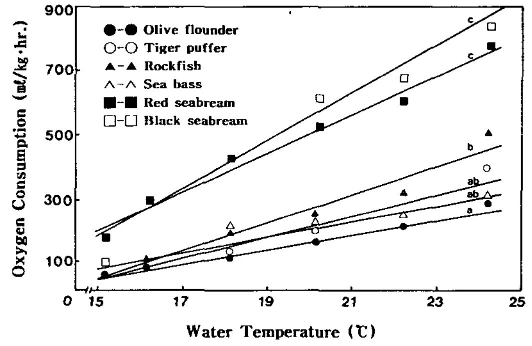

Fig. 2. The relationships between water temperature and oxygen consumption in each fish species. The different alphabets (a, b, c) mean significant difference between each slopes ($P<0.05$).

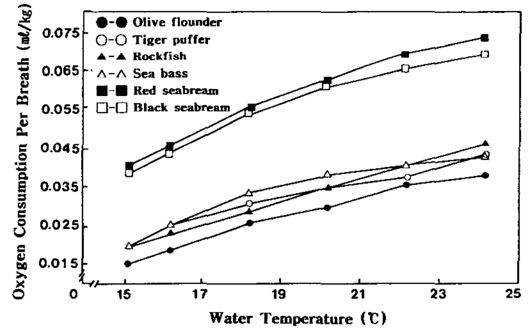

Fig. 3. The relationships between water temperature and oxygen consumption per breath in each fish species.

kg. These values were about two-fold as compared with the 4 species mentioned above.

2. Oxygen consumption according to different fish population density

In all the fish species investigated, oxygen consumption was significantly lowered ($P<0.01$) by the increase of fish population density (Fig. 4). The rockfish consumed oxygen at a rate of 468.05, 314.14, 224.49 and 221.94 ml/kg · hr in the chambers containing numbers of 3, 6, 9 and 12 individuals, respectively. Other species showed a similar tendency with those of the rockfish. However, actively swimming fishes such as the red seabream and the black seabream, were more sensitive than the benthic settling fish such as the rockfish, according to different fish population densities.

3. Oxygen consumption according to different body weight

Oxygen consumption of the olive flounder significantly decreased ($P<0.01$) as body weight increased for fish smaller than 87 g (Fig. 5). Oxygen consumption of 5 g juveniles was the highest at 920.00 ml/kg · hr, with that of 19 g fish at 466.78 ml/kg · hr, and that of 30 g fish at 264.85 ml/kg · hr, while that of 87 g fish was lowered to 79.41°ml/kg · hr and that of 201 g and 398 g body weight was shown at 73.55 and 70.21 ml/kg · hr hr, respectively. The relationship of oxygen consumption (Oc) and body weight (W, g) was expressed as an allometric equation.

$$Oc=2532.0268W^{-0.6565}\ (r^2=0.9229)$$

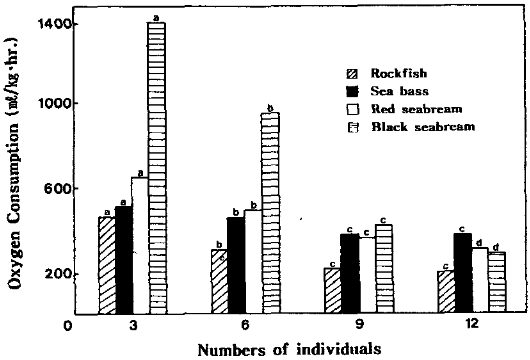

Fig. 4. The changes of oxygen consumption of the experimental fish under different fish population density. The different alphabets above column of the same pattern mean significant difference($P<0.05$).

4. Level of lethal dissolved oxygen

As dissolved oxygen was reduced, oxygen consumption gradually decreased in all observed fishes. The levels of lethal dissolved oxygen in each fish species were revealed in the order of the red seabream 1.36 ml/l, the rockfish 0.79 ml/l, tiger puffer 0.75 ml/l and the olive flounder 0.66 ml/l (Fig. 6).

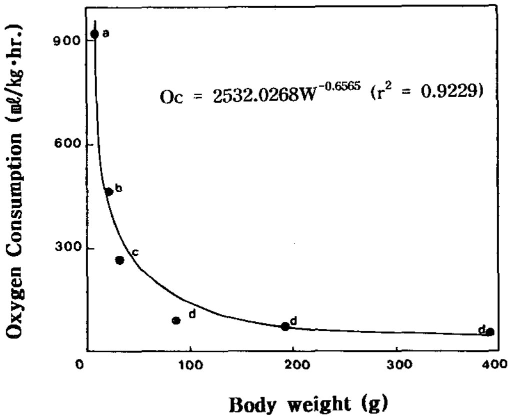

Fig. 5. The relationship between body weight and oxygen consumption of olive flounder. The different alphabets mean significant difference ($P<0.05$).

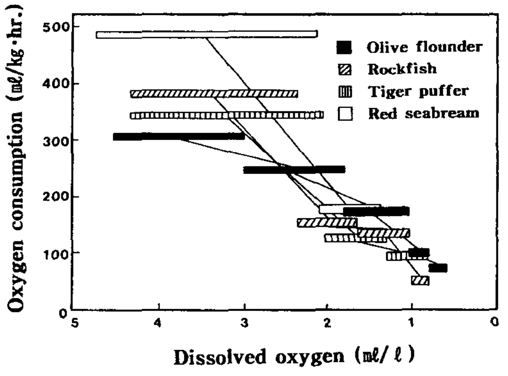

Fig. 6. The changes of oxygen consumption by decreased dissolved oxygen in each fish species.

When dissolved oxygen was reduced, every fish species showed a similar pattern of behavior. Under the conditions of decreased oxygen, the fishes showed severe unsteadiness, crazy upper and lower body movement, vomiting of food, extension and opening or shutting of the opercles, and irregular respiration within the respiratory chamber. The dying individuals displayed typical characteristics of suffocation: loss of body color, severely faded and opened opercles, with the tiger puffer showing normal form in body color and shape.

Discussion

Productivity in aquaculture depends on the feed, rearing density and dissolved oxygen for respiration. In order to obtain a satisfactory rearing effect, dissol ved oxygen of rearing water should be kept in balan ce with oxygen consumed by the fish with the decom position for the purification of organic matters (feces and feed residue) by aerobic bacteria (Sano, 1979). In tank farming, especially, this is one of the essential methods of management to supply the optimum dissolved oxygen for the metabolism of fish during periods of high water temperature. Therefore, it is very important to find out the oxygen consumption rate in propotion to the water temperature for aquacultural species.

Gardner and King (1923) reported that within the range of optimal temperature, generally, the oxygen consumption of fish was increased directly in proportion to increased temperature. Wi and Chang (1976) reported that oxygen consumption according to temperature (Oc) was expressed as a regression equation: $Oc = 6.8309T - 56.2076$ in conger eel.

The results of the present works indicate that oxygen consumption of each fish species increase in proportion to temperature, which is in accordance with the results of the previous investigators. We could find out that oxygen consumption, used as an indicator of metabolism in fish (Itazawa and Hanyu, 1991), corresponded well to the law of Q_{10}.

On the other hand, the patterns of oxygen consumption according to water temperature showed dissimilarity among the species. Oxygen consumption of benthic fish, e.g., the olive flounder, was the lowest among 6 species, while some active swimmers such as the tiger puffer and the rockfish, consumed lots more DO as compared with that of the olive flounder. The red seabream and black seabream while engaged in strong activity consumed the most DO. Thus we could know that the actively swimming species consume lots more DO as compared with the benthic settling species. Hughes (1960) suggested that the benthic species had a well developed gill pump, and achieved gas exchange through the inhalation of water without swimming, while actively swimming species exchanged gas mainly through forward movement. Thus it was clear that the active species consumed lots more energy and DO. Therefore, we had to particularly note the fluctuation of DO concentration in aquaculture of the red seabream or the black seabream among the 6 species observed in the present study.

Itazawa and Hanyu (1991) presumed that the total amout of oxygen consumption was much more with multiple individuals than with a single individual, but the level of mass-specific oxygen consumption was less in the case of an individual belonging to a group rather than being singular, reversely. It has been well known as the "positive group effect". Though we did not carry out the comparative experiment concerning 1 individual versus plural individuals in the present study, our results, however, indicated that mass-specific oxygen consumption was reduced as we increased the number of individuals in the respiratory chamber in the same volume of water. Therefore, we could note the positive group effect on the oxygen consumption of the rockfish, the sea bass, the red seabream and the black seabream. In addition, the positive group effect can be found from the results of Honda (1988), who reported that several fishes in an aquarium consumed DO less than isolated fish did, one by one.

In general, the relationship between metabolic rate (M) and body weight (W) in the fish follows an allometric function of $M=aW^b$. This equation could be transformed to $M/W=aW^{b-1}$. M/W means the mass-specific oxygen consumption (Oc) in this study. The mass-specific oxygen consumption (Oc) in the olive flounder decreased inversely against an exponential function as the body weight (W) became heavier. This tendency was displayed by $Oc=2532.0268W^{-0.6565}$ ($r^2=0.9229$), this equation being similar to the $Oc=0.3W^{-0.2}$ of Osaki (1979), although the slope of our results was more oblique, meaning the fact that the difference of oxygen consumption between the fry and the adult was smaller. Therefore, we must consider the fact that the standard of optimum stocking density might change according to body weight, even though it is the same species, when we determine the proper rearing density according to the water volume of a tank in a farm.

It was a required part of the investigation to examine the level of dissolved oxygen causing the death of fish for adequtely supplying oxygen in a farm. Judging from the results of our investigation, the level of lethal dissolved oxygen concentration was highest up to 1.36 ml/l in the juveniles of the red seabream; those of the rockfish and the tiger puffer were within the range of 0.75~0.79 ml/l and that of the olive flounder was 0.68 ml/l. The level of lethal dissolved oxygen of the red seabream was presumed at 1.5 ml/l in the case of the net cage culture on the inner coast (Takahashi, 1985), and our results agreed with that. Consequently, we could suggest that the active species consumed more oxygen but sharply decreased their activities with lower concentration of dissolved oxygen.

Because the levels of oxygen consumption and lethal DO differed from each other depending on water temperature, population density and body weight, we needed to establish a standard of environmental factors in consideration of these points for successful marine fish cultivation in a tank farm. While DO was reduced at high water temperature, oxygen consumption was increased at this time; thus, more careful management was required to control the environmental aspects.

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해산어류 6종의 산소소비 경향에 관한 연구

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有用 海産魚類에 대한 酸素消費 傾向을 파악하기 위하여 넙치 *Paralichthys olivaceus*, 자주복 *Takifugu rubripes*, 조피볼락 *Sebastes schlegeli*, 농어 *Lateolabrax japonicus*, 참돔 *Pagrus major*, 감성돔 *Acanthopagrus schlegeli* 등 6種의 稚魚를 주대상으로 水溫別, 密度別, 體重別 酸素消費量 및 致死酸素量에 관한 실험을 실시하였다. 모든 어종에서 산소소비량(Oc, ml/kg · hr)은 수온(T, ℃)의 상승에 비례하여 증가하였으며, 그 경향은 다음과 같은 回歸直線式으로 표시되었다. 넙치: $Oc=34.0515T-339.5987$ ($r^2=0.9730$), 자주복: $Oc=34.4941T-479.8732$ ($r^2=0.9483$), 조피볼락: $Oc=44.7970T-634.2627$ ($r^2=0.9718$), 농어: $Oc=26.1488T-318.0633$($r^2=0.9316$), 참돔: $Oc=61.1020T-722.8926$ ($r^2=0.9805$), 감성돔: $Oc=75.1460T-947.9370$ ($r^2=0.9392$). 魚體의 收容密度가 증가함에 따라 單位體重當 酸素消費量은 감소하는 경향을 보였다. 넙치는 체중(W , g) 증가에 따라 산소소비량이 감소함으로써 $Oc=2532.0268W-0.6565$ ($r^2=0.9229$)의 관계를 나타냈다. 넙치, 조피볼락, 자주복, 참돔의 致死酸素量은 각각 0.66, 0.79, 0.75 및 1.36 ml/l였다