

後期仔魚期および稚魚期のマダイの酸素消費量,特に群効果 について

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Oxygen Consumption of Postlarval and Juvenile Red Sea Bream, *Pagrus major*, with Special Reference to Group Effect

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The oxygen consumption of fish increases with growth and this relation is generally expressed as the following allometry, $y = ax^b$ (y : oxygen consumption, x : body size, a, b : coefficient). However, it is reported that the oxygen consumption is largely influenced not only by abiotic factors such as water temperature^{1,2)}, but also by biotic factors such as the presence of other fish of either the same or the different species. These effects are known almost in freshwater fishes³⁾. Therefore, the change of oxygen consumption when fish are put into assemblage is regarded to be an important indicator for the ecological relation, which is generally referred to as group effect, in addition to the physiological condition.

Red sea bream, *Pagrus major*, is one of the most important marine demersal fish for sea farming species in Japan, especially in the Inland Sea. The larval fish, which builds a territory for a while after a shift to benthic life⁴⁾, is reared at a very high density (10 to 25 fish · ℓ^{-1}) in large tanks^{5,6)}, in order to stock coastal waters with the fish. Thus the density is estimated to be 500 to 1,250 times higher than in natural nursery ground⁷⁾. Such a high density produces possibly a rapid increase in oxygen consumption. However, there has been only few studies on the oxygen consumption of the species at postlarval and juvenile stages^{8,9)}, in particular no study considering the group effect.

This study deals with the change in the oxygen consumption of postlarval and juvenile red sea bream in relation to the size of body and the number in a group.

Materials and Methods

The larvae used for present study were obtained from a same pair of parents and hatched on May 2 1985, after which they were reared by the supply of rotifers and brine shrimps at the Takehara Station, Hiroshima Sea Farming Fisheries Association⁶⁾. About 500 larvae of a mean total length of 7.9 mm (28th day after hatching) were transferred to the black tank (30 ℓ) and fed with brine shrimps at the same temperature of 18°C and salinity of 33.4‰ as those in the Takehara Station during the experiment. The measurement of the fish oxygen consumption was made in an incubator (NKS Co. Ltd., LH-100-RDS) which was kept at a temperature of 15.5 to 16.5°C and was under a dark condition. Several fish were enclosed in the small bottle (oxygen bottle of about 100 ml) filled with 33.4‰ seawater passed through a filter paper (mesh size : 1 μm) and were left in the incubator for a given time. The decreased amount of dissolved oxygen in the bottle water during the experiment was determined according to WINKLER'S method. The rate of oxygen consumption (\dot{V}) was

calculated by the following formula:

$$\dot{V} = (V_t - v_t) \cdot n \cdot F^{-1} \cdot t^{-1} \quad (\mu\ell \cdot \text{hr}^{-1} \cdot \text{fish}^{-1}, \text{ or } \mu\ell \cdot \text{hr}^{-1} \cdot \text{mg}^{-1})$$

V_t : dissolved oxygen concentration ($\mu\ell \cdot \ell^{-1}$) of the seawater at the t time (hr) after the experiment

v_t : dissolved oxygen concentration ($\mu\ell \cdot \ell^{-1}$) of the seawater, including the fish, at the t time (hr) after the experiment

n : volume of oxygen bottle (ℓ)

F : number or body weight (mg) of the fish

t : period of experiment (hr)

In this case, the maximum fish size of 74.6 mg used for the study corresponded to 0.0684 to 0.0704 ml in volume on the basis of the specific gravity of fish (1.06 to 1.09)¹⁰ and occupied an only small part (about 0.07%) of oxygen bottle. Accordingly the volume of fish body was negligible in the estimation of fish oxygen consumption by the above formula.

Group effect (G.E.) on the oxygen consumption was expressed by the following formula:

$$\text{G.E.} = (\dot{V} \text{ in solitary fish} - \dot{V} \text{ in grouped fish}) / (\dot{V} \text{ in solitary fish}) \quad (\mu\ell \cdot \text{hr}^{-1} \cdot \text{mg}^{-1})$$

In this way the group effect was compared by oxygen consumption per unit body weight among groups of different numbers, because the size of fish varied to a considerable extent even at the same developmental stage.

Results and Discussion

Influence of hypoxia on the oxygen consumption The oxygen of seawater with a saturation of 80 to 90% decreased to the minimum level of 20% during the period of experiment (1 to 14.5 hr) due to the consumption by red sea bream, but the rate of oxygen consumption

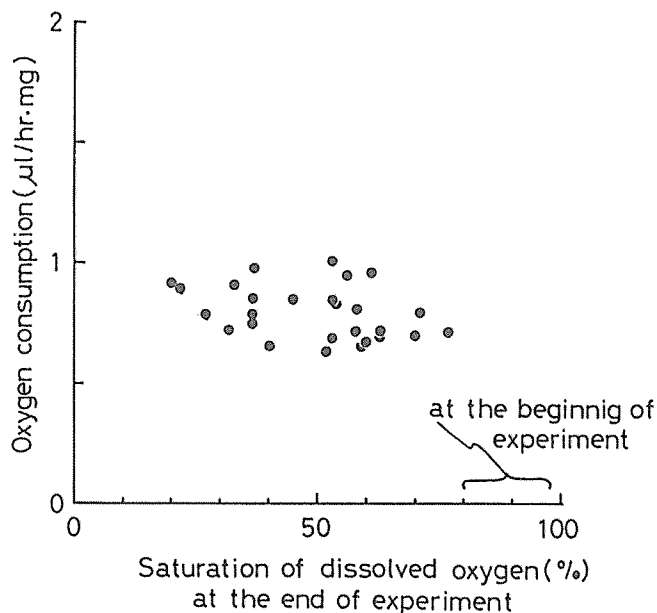


Fig.1. Influence of decreasing oxygen saturation on the oxygen consumption in red sea bream.

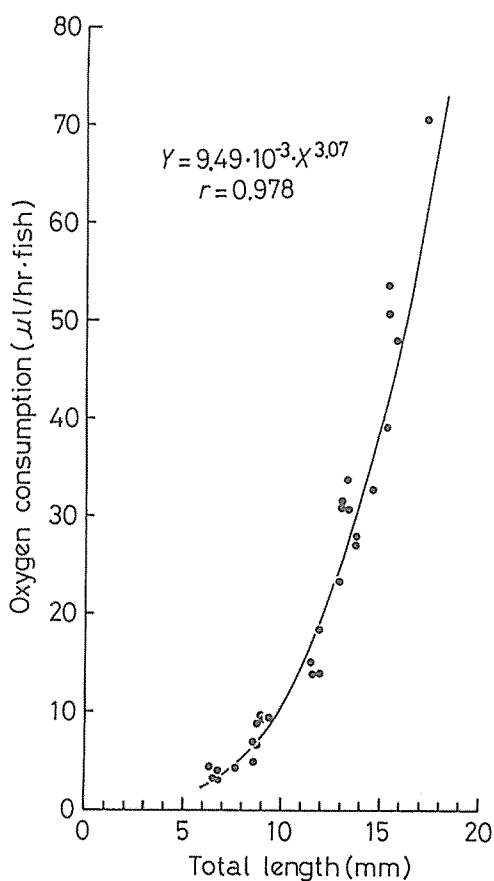


Fig.2. Relationship between total length and oxygen consumption per fish in red sea bream.

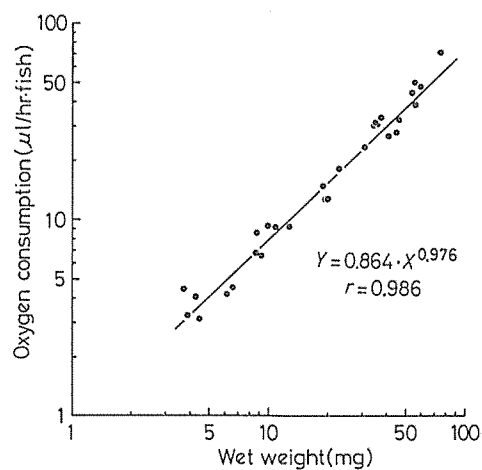


Fig.3. Relationship between body weight and oxygen consumption per fish in red sea bream.

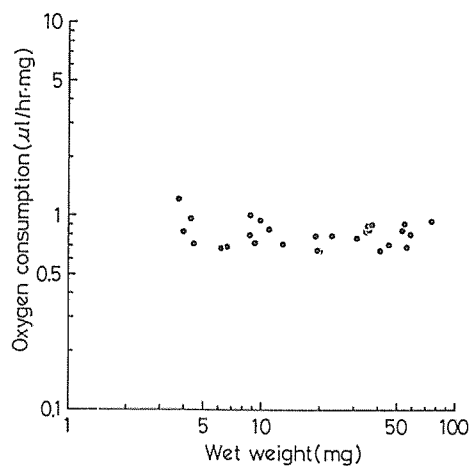


Fig.4. Relationship between body weight and oxygen consumption per unit weight in red sea bream.

hardly correlated to final saturation values within a range of 0.63 to $1.01 \mu\text{l} \cdot \text{hr}^{-1} \cdot \text{mg}^{-1}$ (Fig. 1). This implied that the rate of oxygen consumption was independent of oxygen content of ambient water within a measured range of body size. At the oxygen saturation lower than 30%, the fish began to die gradually and so was excluded from the study.

Change in the oxygen consumption with growth The oxygen consumption of red sea bream increased exponentially with growth and this relation was expressed as $\dot{V} = 9.49 \times 10^{-3} \times \text{TL}^{3.07}$ (TL : 6.5–17.3 mm) (Fig.2) and $\dot{V} = 0.864 \times W^{0.976}$ (W: 3.75–74.6 mg) (Fig.3), respectively. For example, the postlarval fish of 10 mm in total length (W: 13.5 mg) consumed ambient oxygen at a rate of $11 \mu\text{l} \cdot \text{hr}^{-1}$ per fish ($0.81 \mu\text{l} \cdot \text{hr}^{-1}$ per unit body weight). However,

the oxygen consumption per unit body weight was almost constant over a measured range of body weight, while seemed to increase slightly in the postlarval fish smaller than 10 mg (Fig.4).

It is well revealed for many kinds of animals such as fish^{11,12)} and marine crustaceans¹³⁾ that an increasing pattern of oxygen consumption with growth differs among different stages of life history. WINBERG¹¹⁾ reported that oxygen consumption per fish is directly proportional to the approximately 0.8 th power of body weight, based on the data of oxygen consumption of several freshwater and marine species. However, most of the fish studied by him are larger than 1 g and moreover the oxygen consumption curves for the smaller size are not obtained from a single species.

ITAZAWA⁹⁾, who measured the oxygen consumption of red sea bream of seven or eight sized samples, has reported that the power (b) of body weight (W) in the formula of $\dot{V} = aW^b$ is 0.794 for the fish of 7 to 342 mm in total length (W: 6 mg-610 g), but it is 0.857 when the size is limited to a smaller range of 7 to 62 mm (W: 6 mg-3.65 g). Our study indicated that the power was 0.976 at the postlarval and juvenile stages, based on 30 sized samples. Accordingly the increasing rate of oxygen consumption is suggested to be reduced with growth. The power of oxygen consumption in carp¹²⁾ also is larger in the small fish (0.96) than in the large fish (0.80), which are divided into 2 sized groups at a reflection point (W: 1 g) of W-TL relationships. This difference in the power of oxygen consumption may be accounted for by that of relative growth between both sized groups. Therefore it is considered necessary for red sea bream also that the relative growth is compared between small group (TL: 6.5-17.3 mm), which was used for our study, and large group (TL: 25-109 mm). The W-TL relationship is $W = 9.25 \times 10^{-3} \times TL^{3.17}$ (95% confidence interval for the power of TL: 3.09-3.25) in the small group and $W = 5.41 \times 10^{-3} \times TL^{3.21}$ (95% confidence interval for the power of TL: 3.19-3.33) in the large group (IMABAYASHI unpubl.), respectively. In this way, the relative growth doesn't differ significantly between both sizes of red sea bream.

It is demonstrated in carp¹⁴⁻¹⁷⁾ that the higher oxygen consumption in small fish is mainly due to the increased volume proportion of essential organs (vicera) for life, e.g. brain, kidney, intestine, hepatopancreas, of which oxygen consumptions, *in vitro*, are significantly higher than that of other organs, as compared with large fish. Whether or not this is applicable to the case of red sea bream also will be obvious after examining the relation between oxygen consumption and volume proportion of each organ as the fish grows.

Group effect on the oxygen consumption The oxygen consumptions of solitary and grouped fish were compared in terms of those per body weight at each developmental stage, because the sizes of fish used for each experiment varied slightly (Fig.5). In the fish group of a mean total length of 9.0 mm (range: 7.5-10.3 mm), the oxygen consumption of solitary fish (about $8.0 \mu\ell \cdot \text{hr}^{-1} \cdot \text{mg}^{-1}$) was 9.3% higher than that of 2-grouped fish, but in turn 19.2% lower than that of 8-grouped fish. However, as the fish grew older, the oxygen consumption increased with increasing number of fish in a group. This was evident at the juvenile stage whose total length was above 13mm. In the largest fish group of a mean of 15.4 mm, an increase in oxygen consumption with increasing number of fish in a group was larger from solitary to 2-grouped fish (15.9%) than from 2- to 4- grouped fish (5.7%) and from 4- to 8- grouped fish (7.8%).

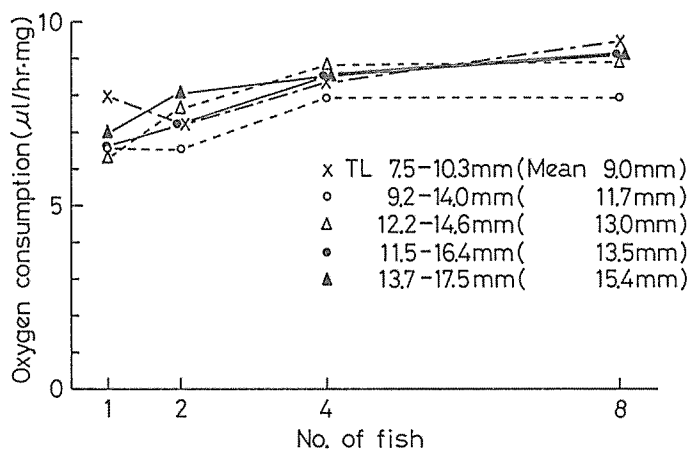


Fig.5. Change in the oxygen consumption of red sea bream with increasing number of fish in a group.

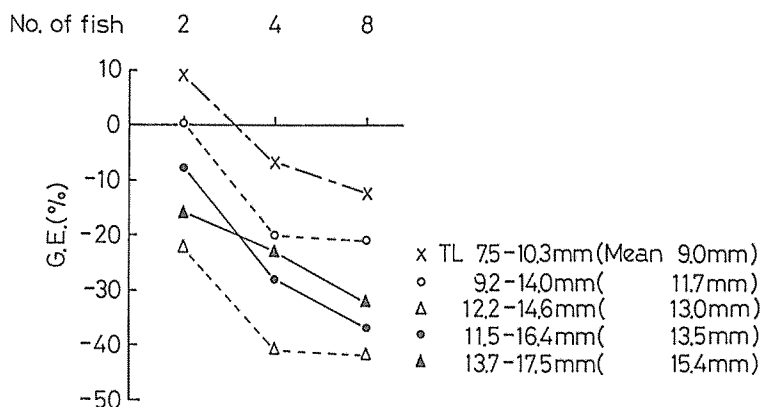


Fig.6. Change in group effect (G.E.) on the oxygen consumption of red sea bream with increasing number of fish in a group.

Group effect on the oxygen consumption was negative between solitary and grouped fish, except for the case of 2-grouped fish with a smallest size (Fig.6). In addition the negative group effect was remarkable with increasing number of cohabiting fish, and highest in the fish of a mean size of 13.0 mm, which generally shifts the habitat from planktonic to benthic lives¹⁸).

The red sea bream of postlarval stage (range: 7.5-14.0 mm), at which solitary fish consumed a greater amount of oxygen than grouped fish, is observed to form an obscure schooling. The early juvenile stage is a period of behavioral change when the fish builds a territory at a given locality such as the corner of large tank, according to the observation on its behavior in rearing tanks⁹). Thus it is suggested that group effect on the oxygen consumption is correlated with the change of behavior with growth or development.

The 2-grouped smallest fish with a positive group effect was reared at a density of

about 25 fish·ℓ⁻¹ for a month after hatching⁵⁾, and also enclosed in the small oxygen bottle at the almost similar density. The density didn't change between the rearing and experimental conditions, and thereby the 2-grouped fish are considered to be psychologically more stable and in a slower locomotion and metabolism than solitary or 4- and 8-grouped fish, and resulted in relatively lower oxygen consumption. The oxygen consumption of 2-grouped smallest fish was significantly lower than the average level estimated from the TL- \dot{V} relation (Fig.2). The influence of history of rearing density on group effect is evident in several species such as sea catfish and rainbow trout^{19,20)}.

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後期仔魚期および稚魚期のマダイの 酸素消費量，特に群効果について

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同一の親魚から産卵・ふ化した後期仔魚期および稚魚期のマダイ（全長：6.5-17.3 mm）を約100 ℓの酸素瓶に閉じ込めて，15.5-16.5℃・暗黒の条件下でその酸素消費量を測定した。

1) ほぼ飽和状態に近い濾過海水（33.4‰）の溶存酸素はマダイの呼吸によって漸次減少するが（最少飽和度：20%），マダイの酸素消費量はほぼ一定し低下しなかった。酸素飽和度が30%より低下すると，死亡する個体が出現し始めた。

2) マダイの酸素消費量（ \dot{V} ）は成長に伴って指数関数的に増大し，全長（TL：6.5-17.3 mm）に対して $\dot{V}=9.49 \times 10^{-3} \times TL^{3.07}$ ，体重（W：3.75-74.6 mg wet weight）に対して $\dot{V}=0.864 \times W^{0.976}$ を示した。このような発育初期における酸素消費量の成長に伴う増加率の値は，より進んだ発育段階について報じられている値に比して高いことが判明した。この違いを，相対成長や内臓諸器官の酸素消費量の相違から考察した。

3) 単独個体と群個体（密度：20-80 fish・ℓ⁻¹）の酸素消費量を比較すると，単独よりも群でさらに群の構成員が増加するにつれて，個体当たりの酸素消費量も増加する傾向がみられた。このような群効果は，マダイ自身の行動様式と深く関連していることが推察される。