

## Group Effect on Oxygen Consumption of the Red Sea Bream *Pagrus major* from Postlarval to Young Stages

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**Abstract** Group effect on the respiration of red sea bream *Pagrus major* is examined at 17°C under a light condition (4500 lx). Postlarvae, juveniles and youngs were separately accommodated in respiration chamber (100-1000 ml) solitarily or in a group of 2-16 fish. In the postlarvae (7.3-10.6 mm in total length), oxygen consumption hardly changed with the number of fish. The juveniles (27.1-37.6 mm) revealed a negative group effect, which was indicated by an increase of oxygen consumption in a group of more than 4 fish. There was a significantly 1.8-fold difference between solitariness (1.51 g O<sub>2</sub>/hr/mg dry weight) and grouped 8 fish (2.71 g O<sub>2</sub>/hr/mg dry weight). In the young (52.0-65.8 mm), a higher amount of respiration was observed in grouped 8 fish. This was presumably influenced by a remarkable decrease in living space per fish. These group effects on the respiration of red sea bream well coincided with its behavioral change, e.g., group formation, which occurred apparently at the settlement from pelagic to benthic lives.

**Key words:** developmental stage, group, oxygen consumption, *Pagrus major*, solitary, territory

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### INTRODUCTION

Red sea bream *Pagrus major* is one of the most important commercial fish which is widely distributed in the shallow waters of Japan. In recent years, however, its wild populations decrease to a large extent, probably due to being over-fished and to deprivation of nursery grounds for its juveniles caused by benthic eutrophication. Therefore the shallow waters need to be stocked with a large number of the species. In the Seto Inland Sea, young individuals of 40-50 mm in total length are extensively released. These fishes are obtained by rearing the larvae and juveniles at a density of 10-25 fish/ℓ in tanks (FOSCARINI, 1988). The density is 500-1250 times higher than that of natural populations (TANAKA, 1980). Generally the fish reared at such a high density shows a different metabolism from the fish of a low density (ITAZAWA, 1991). It is reviewed by KANDA and ITAZAWA (1986) that oxygen consumption varies with the number of grouped fish. The red sea bream is studied by IMABAYASHI and TAKAHASHI (1987) indicating that its oxygen consumption increases with the number of juvenile fish settling from pelagic to benthic lives. However, group effects at other stages are not made clear.

The present study deals with the relationship between oxygen consumption and number of the grouped fish ranging from the larvae of pelagic life to the juveniles and youngs of

benthic life. The group effect at each developmental stage is discussed in relation to its behavior, e.g., group formation and swimming speed.

## MATERIALS AND METHODS

### *Hatch and rearing condition*

All of the red sea breams used for the present study were hatched out from the same stock of eggs on May 15-16 of 1989 at Hiroshima Sea Farming Center. They were subjected to experiments at the 3 developmental stages, i.e., postlarval stage of 7.3-10.6 mm in total length, juvenile stage of 27.1-37.6 mm and young stage of 52.0-65.8 mm. Fish were fed with a composed diet containing brine shrimps every day until initiation of experiments, and were kept in tanks at a density of 10-25 fish/ℓ.

### *Measurement of respiration*

Active individuals were quickly accommodated in respiration chamber solitarily or in a group. Filtrated seawater of 32‰ in salinity was used. Decreased amount of dissolved oxygen in a given time was determined both by Winkler's method and DO meter's method. The former was applied to postlarval stage, and the latter to juvenile and young stages (Fig. 1).

The measurement of respiration was conducted in an incubator (NKS Co. Ltd, LH-100-RDS), which was set up at a temperature of  $17 \pm 0.6^\circ\text{C}$  and under a light condition of 4500 lx. Duration of measurement ranged from 2.5 hr to 10 hr in the postlarvae, and from 10 min to 2 hr in juveniles and youngs (Table 1). Respiration chamber, cylindrical in shape, was made of transparent glass and ranged from 100 ml to 2000 ml in volume. Maximum density was calculated 80 fish/ℓ in postlarvae, 40 fish/ℓ in juveniles, and 16 fish/ℓ in youngs.

After accomplishment of res-

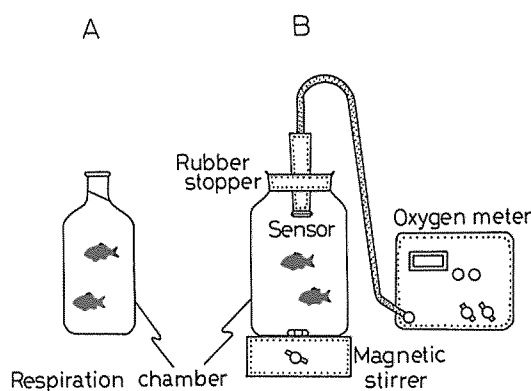


Fig. 1 Experimental arrangements to examine group effect on the respiration of red sea bream. The diagram A is used for the postlarvae, and B for the juveniles and youngs.

Table 1. Experimental records on *Pagrus major* and procedure used in this study.

Stage	Total length (mm)	Body weight (mg dry weight)	Fish in group		Duration of respiration measurement (min)	Size of respiration chamber (ml)
			Number	Density (ind./ℓ)		
Postlarva	7.3~10.6	0.48~1.55	1, 2, 4, 8, 16	5~80	150~600	100~200
Juvenile	27.1~37.6	57~158	1, 2, 4, 8	5~40	20~90	200
Young	52.0~65.8	285~626	1, 2, 4, 8	1~16	10~120	250~2000

piration measurement, all of the fish were sacrificed to determine their total length and body weight. Individuals were weighed after blotting the surface (wet weight), and they were again weighed after drying for 8 hr at 110°C (dry weight). As a result, ratio of dry weight to wet weight was estimated at 0.14 in postlarvae, at 0.18 in juveniles, and at 0.19 in youngs.

According to WINKLER's method, larval oxygen consumption  $\hat{U}$  ( g O<sub>2</sub>/hr/mg dry weight, g O<sub>2</sub>/hr/fish) was calculated by the following formula:

$$\hat{U} = (V_t - v_t) \cdot n / F / t$$

$V_t$ : dissolved oxygen concentration (g O<sub>2</sub>/ℓ) of respiration chamber after the time  $t$

$v_t$ : dissolved oxygen concentration (g O<sub>2</sub>/ℓ) of respiration chamber, containing the fish, after the time  $t$

$n$ : volume of respiration chamber (ℓ)

$F$ : number or dry weight (mg) of the fish

$t$ : time of measurement (hr)

In this calculation, volume of the fish was neglected because the fish occupied a remarkable small part (0.1%) of respiration chamber even at the maximum density.

In juveniles and youngs, oxygen concentration was measured every 0.5-2.0 min with oxygen meter (YSI Co. Ltd, Model 58), and resulted in decreasing linearly (Fig. 2). Therefore, their oxygen consumptions  $\hat{U}$  were shown as follows:

$$\hat{U} = 60 \cdot b \cdot n / F$$

$b$ : rate of decrease in dissolved oxygen concentration

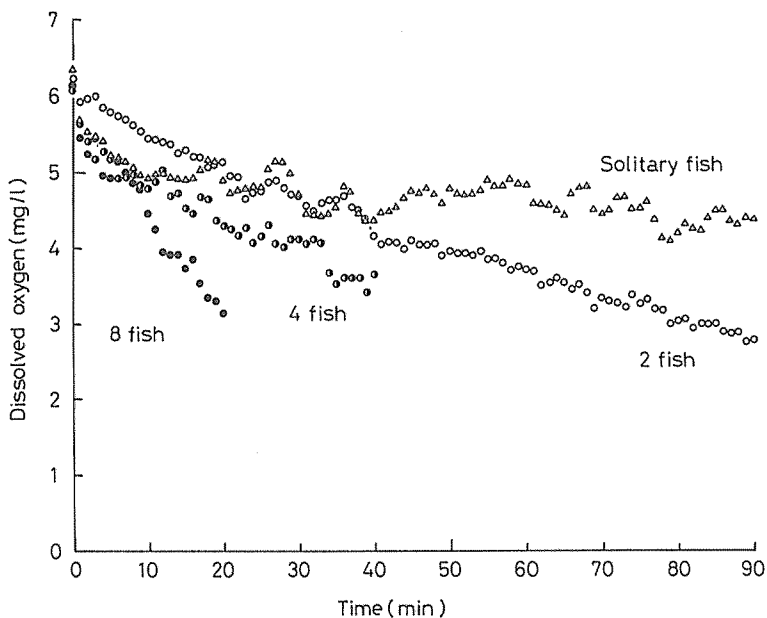


Fig. 2 Patterns of decreasing dissolved oxygen owing to the respiration of juvenile red sea bream enclosed in respiration chamber. Amount of dissolved oxygen was measured every 1.0 min with oxygen meter.

(g O<sub>2</sub>/l/min) of respiration chamber, containing the fish

*Indicator of group effect*

Indicator of group effect GE (%) was defined as the following formula (ITAZAWA, 1991), based on the respiration of solitary fish:

$$GE = (\hat{U}_S - \hat{U}_L) \cdot 10^2 / \hat{U}_S$$

$\hat{U}_S$ : oxygen consumption of solitary fish (g O<sub>2</sub>/hr/mg dry weight)

$\hat{U}_L$ : oxygen consumption of grouped fish (g O<sub>2</sub>/hr/mg dry weight)

In this way, group effect was compared by using the oxygen consumption per unit weight because the size of fish varied considerably between solitary and grouped fish at each developmental stage.

**RESULTS**

*Effect of oxygen saturation*

The fish enclosed in respiration chamber gradually consumed dissolved oxygen, which

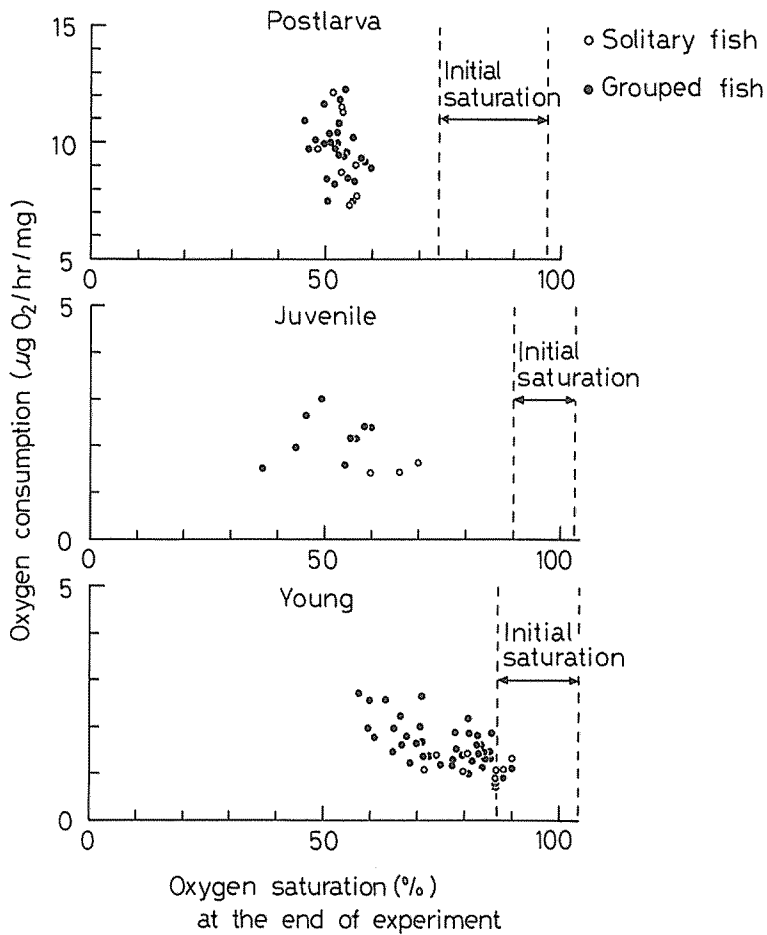


Fig. 3 Influence of decreased oxygen saturation on the oxygen consumption of red sea bream.

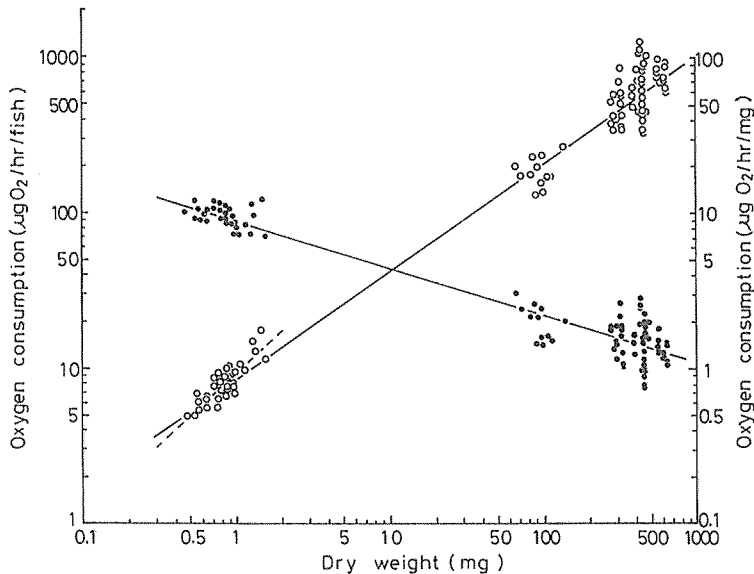


Fig. 4 Relation between body weight and respiration of red sea bream. Solid and open circles denote the oxygen consumptions per unit dry weight and per fish, respectively.

considerably saturated seawater (74–103%) at the beginning of experiment. At the end of experiment, the oxygen saturation showed a wide range, indicating 45–60% in postlarvae, 37–70% in juveniles, and 58–90% in youngs (Fig. 3). On the other hand, oxygen consumption had a high coefficient of variation at each stage, especially in juveniles (25.5%) and young (30.8%). However, their oxygen consumption hardly seemed to be vulnerable to oxygen saturation.

In juveniles and youngs, grouped fish tended to consume dissolved oxygen more largely than solitary fish.

#### *Effect of fish size*

The relation between oxygen consumption  $\hat{U}$  and fish size  $F$  was expressed as the allometry  $\hat{U}=a \cdot F^b$ , where  $a$  and  $b$  were coefficients (Fig. 4).

When the oxygen consumption ( $g O_2/hr/fish$ ) was plotted against the dry weight (mg) of fish on logallithmic coordinate, linearity of regression is clearly demonstrated as shown in Fig. 4. By applying the least square method to all of the fish, allometry was obtained as follows;

$$\hat{U}=9.03 \cdot F^{0.698} \quad (r=0.992, n=97)$$

Thus, the oxygen consumption was significantly correlated with body weight ( $P<0.01$ ). However, this was the case only in postlarvae with the formula of  $\hat{U}=9.51 \cdot F^{0.924}$  ( $r=0.876$ ,  $n=34$ ,  $P<0.01$ ), whereas juveniles and youngs didn't have significant relations ( $P>0.05$ ).

In the case of oxygen consumption expressed as  $g O_2/hr/mg$  dry weight, all of the postlarvae, juveniles and youngs showed the formula  $\hat{U}=9.04 \cdot F^{0.303}$  ( $r=0.961$ ,  $n=97$ ,  $P<0.01$ ). However there was not a significant relation between  $\hat{U}$  and  $F$  at each developmental stage ( $P>0.05$ ).

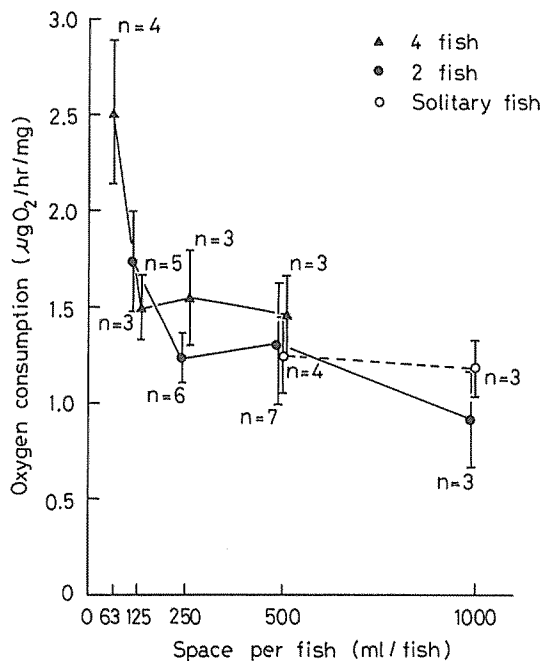


Fig. 5 Effect of space on the oxygen consumption (mean  $\pm$  S. D.) of young red sea bream.

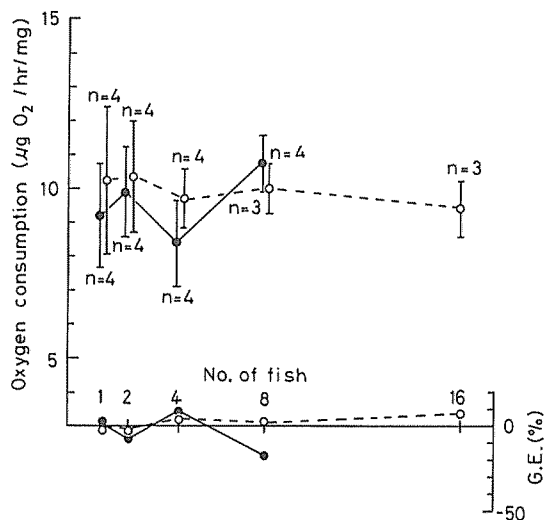


Fig. 6 Group effect on the oxygen consumption (mean  $\pm$  S. D.) of postlarval red sea bream. Solid and open circles denote the respiration chamber of 100 ml and 200 ml, respectively.

#### Effect of living space

Effect of living space on the respiration was examined in solitary and grouped young fish with a large available space. In grouped fish, the space per fish (ml/fish) was obtained by dividing volume of the chamber by number of the fish.

The oxygen consumption tended to increase with decreasing space per fish (Fig. 5). A significantly higher amount of respiration occurred at 125 ml/fish in grouped 2 fish and 63 ml/l in grouped 4 fish (U-test,  $P < 0.05$ ), both of which were estimated from 250 ml chamber. The oxygen consumptions of solitary, 2 and 4 fish didn't differ significantly at each space per fish (U-test,  $P > 0.05$ ). It was, therefore, deduced that the living space of 250–1000 ml/fish hardly influence the respiration between solitary and grouped fish.

#### Group effect

The oxygen consumption of postlarvae (mean: 9.74 g O<sub>2</sub>/hr/mg dry weight) was examined in respiration chamber of 100 and 200 ml (Fig. 6). Significant difference was not seen in the oxygen consumption from solitary to grouped 16 fish, and moreover between two various sizes of respiration chamber (U-test,  $P < 0.05$ ). Therefore, grouped 2–16 fish averaged almost zero ( $-0.31\%$ ) of GE value.

In juveniles (Fig. 7), oxygen consumption increased gradually

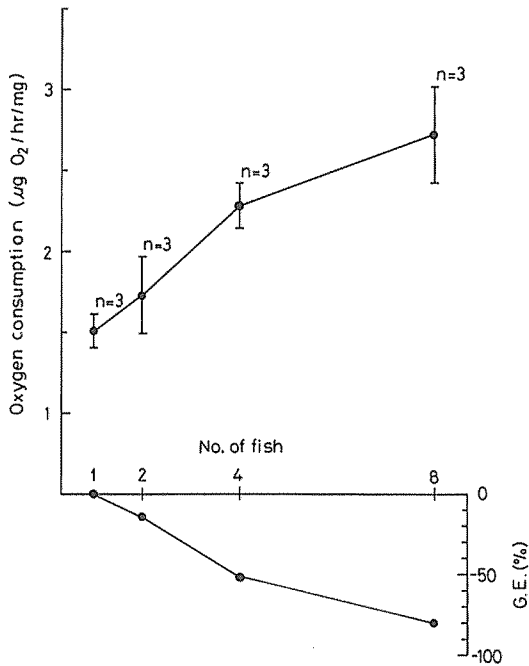


Fig. 7 Group effect on the oxygen consumption (mean $\pm$ S. D.) of juvenile red sea bream.

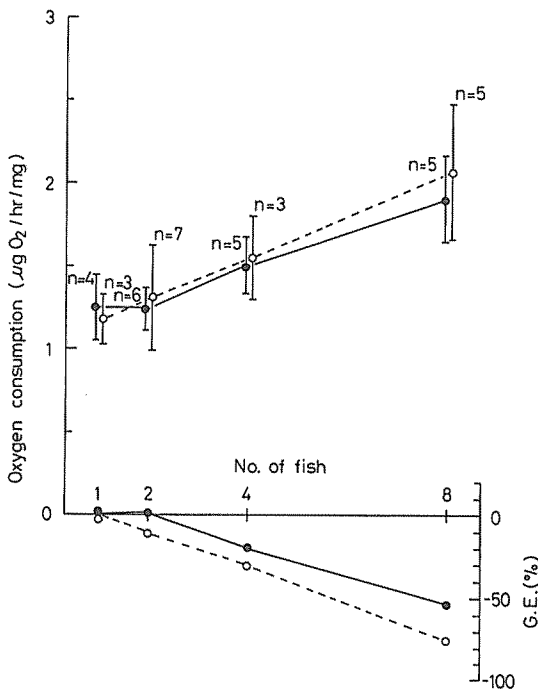


Fig. 8 Group effect on the oxygen consumption (mean $\pm$ S. D.) of young red sea bream. Solid and open circles denote the respiration chamber of 500 ml and 1000 ml, respectively.

with the number of fish. There was a significant difference between 1-2 and 4-8 individuals groups (U-test,  $P < 0.05$ ). Grouped 8 fish (2.72 g O<sub>2</sub>/hr/mg dry weight) had a 1.8-fold amount of respiration compared with solitary fish (1.52 g O<sub>2</sub>/hr/mg dry weight). Therefore, the latter exhibited a negatively large value of GE (-51%, -80%).

Similarly in young (Fig. 8), the oxygen consumption of grouped 8 fish (1.91-2.07 g O<sub>2</sub>/hr/mg dry weight) was significantly higher than that of solitary fish (1.18-1.25 g O<sub>2</sub>/hr/mg dry weight) (U-test,  $P < 0.05$ ). The GE value of the former was calculated at -51 to -75%. However, no or little difference was seen in the respiration amount between the small-sized (500 ml) and large-sized (1000 ml) chambers, as observed also in postlarvae (U-test,  $P < 0.05$ ).

## DISCUSSION

Group effect on the respiration of red sea bream has been demonstrated by IMABAYASHI and TAKAHASHI (1987), who are emphasizing that the settling juvenile of 9.2-17.5 mm in total length has a negative value of GE (Fig. 9). Grouped 4-8 fish averaged to be 1.3-fold time higher in oxygen consumption (U-test,  $P < 0.05$ ), and to be -31% lower in GE, when compared with solitary fish. In the present study, a negative group effect also occurred in the ben-

thic juveniles (GE -80%) and youngs (GE -64%). INOUE (1976) and ITAZAWA (1991) explains that such a negative group effect is usually caused by a stress.

By contrast, there is no occurrence of group effect in the postlarvae, even in grouped 16 fish, whose total length (7.3-10.6 mm) is only by 4.8 mm smaller than the settling juvenile with a negative group. It is, therefore, deduced that a sudden change in their group formation occurred at a transition from postlarval to juvenile stages.

Developmental change in the behavior of red sea bream, e.g., group formation and swimming speed, is depicted in Fig. 10. This is based both on the field surveys (TANAKA, 1985;

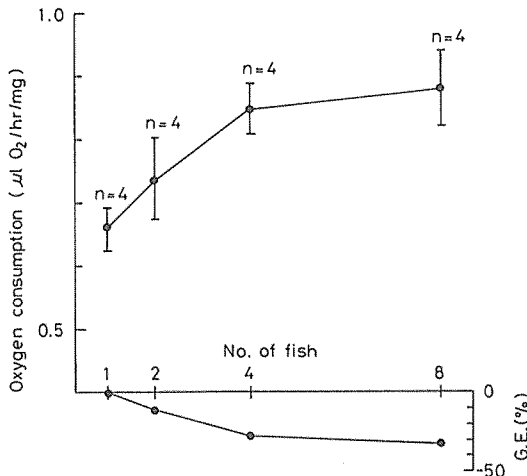


Fig. 9 Group effect on the oxygen consumption (mean±S. D.) of settling juveniles in red sea bream. These data are published by IMABAYASHI & TAKAHASHI (1987), who used the respiration chamber of 100 ml.

YANO *et al.*, 1969) and on the rearing observations (FUKUHARA, 1976, 1985; FUKUHARA & KISHIDA, 1980; YAMASHITA, 1963; YANO & OGAWA, 1981). Postlarvae of 3.5-10.5 mm spend a pelagic life with a low speed of swimming, and mostly aggregate. There is not a definite interaction among the aggregating individuals. The swimming speed begins to increase remarkably at the later postlarval stage. The settlement from pelagic to benthic lives occurs in the early juveniles of 12-15 mm, which are collected abundantly in the shallow waters of 20 m in

Life history

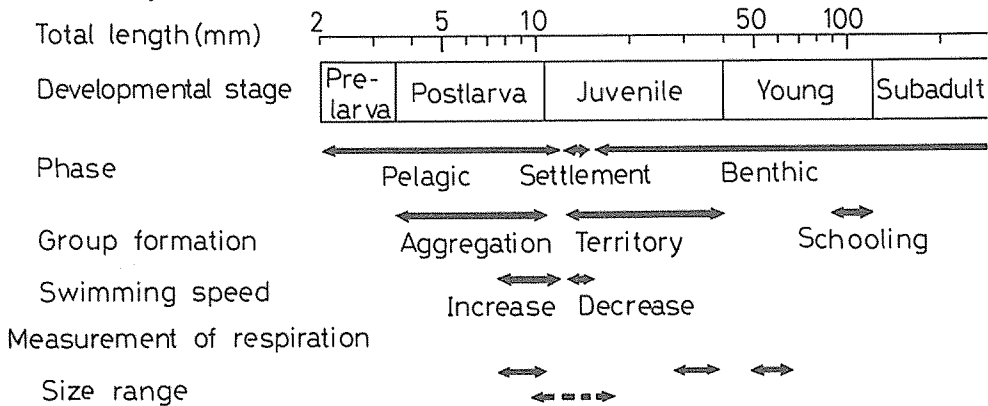


Fig. 10 Change in behavior of red sea bream after hatching, based mainly on the data of several reports (FUKUHARA, 1976, 1985; FUKUHARA & KISHIDA, 1980; TANAKA, 1985; YAMASHITA, 1963; YANO *et al.*, 1969; YANO & OGAWA, 1981). The size of fish examined on group effect is shown.



depth. Immediately after the settlement, most of the juveniles tend to form various sizes of territory in rearing tanks, and temporarily drop the swimming speed. In young fish of 40-120 mm, the territory disappears completely and in turn schooling is formed. The natural population migrates offshore in a tight schooling at the later young stage.

These developmental changes in the behavior of the fish seem to be closely connected with its respiration. At juvenile stage, enhancement of respiration with increase of number of individuals seems to be mainly due to a competition among the fish for space such as territory-defending behavior. The territory is considered to be established immediately above the bottom, because the value of GE is more negative in the benthic juveniles than in the settling ones. In the case of forcibly grouped fish, the territory-defending behavior increases its movement as well as a stress, and probably results in increasing amount of the respiration.

Simultaneously with the disappearance of territory, the negative group effect is expected to disappear at the young stage. However, its oxygen consumption is significantly higher in grouped 8 fish. The present study seems to indicate that behavior and respiration does not correlate to each other at the young stage. Even in grouped 2-4 fish with no group effect, oxygen consumption increases with the space per fish, i.e., less than 125 l/fish. This small space was observed in grouped 8 fish enclosed in the respiration chamber of 50 ml (63 ml /fish) and 1000 ml (125 ml/fish). It is, therefore, considered that a remarkably small space itself increases the respiration amount of young fish as well as a stress.

Similarly at aggregating postlarval stage, behavior is not obviously reflected in respiration. The oxygen consumption is not significantly lower in a group than solitariness, although aggregation is generally expected to have a positive group effect. This fact suggests the two followings. First, the aggregation formed by postlarvae has a weak interaction among the individuals. Secondly, the formation of group would enhance their activity, especially at the later postlarval stage with a remarkable increase of swimming speed, whereas most of the active postlarvae would be psychologically stable.

It is, therefore, considered in red sea bream that amount of the movement is able to accounts for change of the oxygen consumption, and are not closely correlated with the sychological stability.

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## マダイ幼魚の酸素消費量に及ぼす群効果

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マダイの酸素消費量が群形成によって影響されるかを明らかにするため，着底前の後期仔魚（全長 7.3-10.6 mm），それに着底後の稚魚（27.1-37.6 mm）と若魚（52.0-65.8 mm）を対象として，室内実験を行った。酸素消費量の測定は，各発育段階の魚を単独と 2-16 個体の群に分離して呼吸室に収容し， $17 \pm 0.6^\circ\text{C}$ ・明状態（4500 lx）で行った。後期仔魚期では，個体数が増加しても酸素消費量に変化がみられなかった。稚魚期では負の群効果がみられ，単独と 8 個体群の間での酸素消費量の平均増加率は 1.8 倍（ $1.51 \rightarrow 2.71 \mu\text{g/hr/mg dry weight}$ ）を示した。若魚期では，単独と 8 個体群の間で酸素消費量に有意な差がみられたが（ $1.22 \rightarrow 1.99 \mu\text{g/hr/mg dry weight}$ ），これは個体当たりの生活空間が著しく減少したためと考えられる。このような酸素消費量の変化はいずれも，各発育段階のマダイ自身の行動様式と良く対応していた。

キーワード：群，酸素消費量，単独，縄張り，発育段階，マダイ