GAS CONTENT OF THE BLOOD IN RESPONSE TO THAT OF MEDIUM WATER IN FISH—II. COMPARISON OF THE RESPONSES IN SEVERAL SPECIES

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In the previous work (ITAZAWA, 1957), the relationship between oxygen content of the arterial blood and oxygen tension in the medium water was investigated using carp, and the curve showing this relationship was found to be, to some extent, similar to the oxygen dissociation curve of blood. In the present paper, this relationship was also studied on five kinds of fish.

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Material and Method

The fish employed were rainbow trout, *Salmo irideus*, Japanese eel, *Anguilla japonica*, "Suzuki", *Lateolabrax japonicus*, striped mullet, *Mugil cephalus*, and brown-spotted grouper, *Epinephelus fario*. Furthermore, the data on the carp, *Cyprinus carpio* was quoted from the previous paper (ITAZAWA, 1957) for comparison. The size of the fish together with the experimental condition is shown in Table 1.

Table 1. Materials used and experimental conditions.

Species	Measurement of fish		Experimental conditions	
	Total length (cm.)	Body weight (g.)	Temperature of water (°C)	Chlorinity of water (‰)
<i>Salmo irideus</i>	30-35	271-387	2-9	0
<i>Anguilla japonica</i>	50-53	220-297	11-17	0
<i>Lateolabrax japonicus</i>	28-36	201-630	11-15	5.2-14.5
<i>Mugil cephalus</i>	28-31	186-275	12-19	5.0-10.0
<i>Epinephelus fario</i>	27-35	330-717	13-16	19.8

The method was similar to that described in the previous paper. The fish was kept in still water in a tank (ca. 35 l.) with a free surface exposed to air, and was bled a few times from the caudal artery. The temperature of the medium water was not controlled in the present experiment. Trout and eel were examined in freshwater, brown-spotted grouper in sea water, and the others in brackish water. The gas con-

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tent of the blood was determined by VAN SLIKE's manometric method. The oxygen capacity or the oxygen content of the blood equilibrated with air was determined in the following way. About 1-2 ml. of blood was equilibrated with air by shaking in the presence of a small quantity of heparin, and then 0.5 ml. of the blood was transferred into the extracting chamber of VAN SLIKE's manometric apparatus and analyzed by the routine procedure.

Results

The results of the experiment is summarized in Fig. 1, Fig. 2 and Table 2.

Fig. 1. The relationship between the oxygen content of arterial blood (ordinate) and the oxygen tension in medium water (abscissa). The same symbol on each curve shows the data from the same individual. The symbol with x (for example, $\times$, $\times$, etc.) means the data from the fish presenting manifest symptoms of dyspnoea.

Fig. 2. The relationship between the oxygen content of arterial blood (ordinate) and the oxygen tension in medium water (abscissa).

S.i. means *Salmo irideus*, *C.c.* *Cyprinus carpio*, *A.j.* *Anguilla japonica*, *L.j.* *Lateolabrax japonicus*, *M.c.* *Mugil cephalus*, *E.f.* *Epinephelus fario*.

Table 2. Oxygen capacity and percentage of oxygen saturation of the blood at the maximum level.

Species	Oxygen capacity (Vol. %)		Maximum level of oxygen in arterial blood. cf Fig. 2. (vol. %)	Percentage of oxygen saturation at the maximum level * (%)
		Mean		
<i>Salmo irideus</i>	11.0, 11.2	11.1	11	99
<i>Cyprinus carpio</i>	10.6, 10.4	10.5	8	76
<i>Anguilla japonica</i>	11.9, 12.4 9.3, 10.0 9.0	10.5	6.5	62
<i>Lateolabrax japonicus</i>	—	—	12	—
<i>Mugil cephalus</i>	13.7, 16.2 14.7	14.9	10	67
<i>Epinephelus fario</i>	11.4, 11.7	11.6	7.5	65

Discussion

As shown in Fig. 2, the maximum level of oxygen in the arterial blood was the highest (ca. 11 vol. %) in *Salmo irideus* among the three species examined in freshwater, the lowest (ca. 6.5 vol. %) in *Anguilla japonica*, and intermediate (ca. 8 vol. %) in *Cyprinus carpio*. Among the three species examined in brackish or sea water, the maximum level was the highest (ca. 12 vol. %) in *Lateolabrax japonicus*, the lowest (ca. 7.5 vol. %) in *Epinephelus fario*, and intermediate (ca. 10 vol. %) in *Mugil cephalus*. Thus the maximum level of oxygen in the arterial blood differed according to species. This finding seems to have some correlation with the activity of the fish. According

to the observations both in aquariums and in ponds, *Salmo irideus* is the most active species among the three freshwater ones, *Anguilla japonica* the most sluggish, and *Cyprinus carpio* intermediate. Among the three sea water species, *Lateolabrax japonicus* is the most active, *Epinephelus fario* the most sluggish, and *Mugil cephalus* intermediate.

As shown in Fig. 2, the critical tension of oxygen in the medium water to maintain the maximum level of oxygen in the arterial blood was the highest (ca. 100 mm. Hg) in *Salmo irideus* among the three freshwater species, the lowest (ca. 50 mm. Hg) in *Anguilla japonica*, and intermediate (ca. 80 mm. Hg) in *Cyprinus carpio*, indicating that it also differs according to species. This finding seems to have some correlation with the resistivity of the fish to lack of oxygen. According to the observations both in aquariums and in ponds, *Salmo irideus* seems to be the least resistant to lack of oxygen among the three freshwater species, *Anguilla japonica* the most resistant, and *Cyprinus carpio* intermediate. Among the three sea water species, *Lateolabrax japonicus* seems to be the least resistant to lack of oxygen, *Epinephelus fario* the most resistant, and *Mugil cephalus* intermediate. But these sea water species are left without discussion, because the critical tension of oxygen in the medium water to maintain the maximum level of oxygen in the arterial blood of these fish could not be decided in the present experiment.

In conclusion, it may be considered that the maximum level of oxygen in the arterial blood is higher in active fish than in sluggish ones, and that the critical tension of oxygen in the medium water to maintain the maximum level of oxygen in the arterial blood is lower in resistant fish to lack of oxygen than in less resistant ones. However, it must be noted that the present experiment possesses the following defects.

The tension of carbon dioxide in the medium water was neither controlled nor determined in the present experiment. The effect of carbon dioxide on the oxygen affinity is considerable in fish blood. Root (1931) showed that the hemoglobin of fish blood never became completely saturated with oxygen at higher levels of carbon dioxide. But according to pH value, the tension of carbon dioxide is considered to have been fairly low when the oxygen tension in the medium water was high (the right part of each curve in the present paper).

One of the reasons why the maximum level of oxygen in the arterial blood did not reach the oxygen capacity (cf. Table 2.) may be due to the effect of confinement in a small tank. HALL (1930) showed that the mackerel could not obtain sufficient oxygen unless swimming freely. In the present experiment, the fish was kept in a tank (50 cm. × 28 cm., depth of water 25 cm.), so they could not swim so freely. But the effect of the confinement is not considered to have been so extreme in the present case, because the disparity between the maximum level of oxygen in the arterial blood and the oxygen capacity was larger in sluggish species than in active ones.

KAWAMOTO (1929), DILL *et al.* (1932) and IRVING *et al.* (1941) demonstrated the sig-

nificance of the temperature effect on the oxygen affinity of fish blood. However, the fluctuation of temperature during the experiment in each species may not be considered to affect seriously on the results. (cf. Table 1.)

BLACK (1955, 1957a, 1957b, 1957c) demonstrated increase of lactic acid in fish blood unless extreme care is taken to prevent the fish from being excited, and the produced acid may reduce the affinity of blood for oxygen. However the excitement of fish was not so intense in the present experiment, although the minimum excitement during bleeding was inevitable.

As each individual of the fish was repeatedly bled a few times, the loss of blood may have changed the physiological conditions of the fish. But the author confirmed in the previous report that the effect of the repeated bleeding upon the physiological conditions of fish was not so serious as to change of oxygen content of the blood unless the bleeding was repeated too many times (ITAZAWA, 1957).

All the defects described above which may be included in the present experiment are considered not to have been serious, so it may be concluded that the maximum level of oxygen in the arterial blood and the critical tension of oxygen in the medium water to maintain this level associate with the habit and habitat of the fish.

Summary

1. The relationship between oxygen content of the arterial blood and oxygen tension in the medium water was compared among six kinds of fish. The figure showing this relationship was, to some extent, similar to the oxygen dissociation curve of blood.

2. The maximum level of oxygen in the arteriolar blood was higher in the following order: *Salmo irideus* > *Cyprinus carpio* > *Anguilla japonica* among the species examined in freshwater; *Lateolabrax japonicus* > *Mugil cephalus* > *Epinephelus fario* among the species examined in brackish or sea water. These orders seem to have a positive correlation with the activity of the fish.

3. The critical tension of oxygen in the medium water to maintain the maximum level of oxygen in the arterial blood was higher in the following order: *S. irideus* > *C. carpio* > *A. japonica* among the freshwater fish. This order seems to have a negative correlation with the resistivity of the fish to lack of oxygen.

References

- 1) BLACK, E. C.: Blood levels of hemoglobin and lactic acid in some freshwater fishes following exercise. *J. Fish. Res. Bd. Canada*, **12**, 917-929 (1955).
- 2) BLACK, E. C.: Alterations in the blood level of lactic acid in certain salmonoid fishes following muscular activity. I. Kamloops trout, *Salmo gairdneri*. *Ibid.*, **14**, 117-134 (1957a).
- 3) BLACK, E. C.: *Ditto*. II. Lake trout, *Salvelinus namaycush*. *Ibid.*, **14**, 645-649 (1957b).
- 4) BLACK, E. C.: *Ditto*. III. Sockeye salmon, *Oncorhynchus nerka*. *Ibid.*, **14**, 807-814 (1957c).
- 5) DILL, D. B., EDWARDS, H. T. and FLORKIN, M.: Properties of the blood of the skate (*Raia*

- oscillata*). *Biol. Bull.*, **62**, 23-36 (1932).
- 6) HALL, F. G.: The ability of the common mackerel and certain other marine fishes to remove dissolved oxygen from sea water. *American J. Physiol.*, **93**, 417-421 (1930).
 - 7) IRVING, L., BLACK, E. C. and SAFFORD, V.: The influence of temperature upon the combination of oxygen with the blood of trout. *Biol. Bull.*, **80**, 1-17 (1941).
 - 8) ITAZAWA, Y.: Gas content of the blood in response to that of medium water in fish. *Bull. Japanese Soc. Sci. Fish.*, **23**, 71-80 (1957).
 - 9) KAWAMOTO, N.: Physiological studies on the eel. II. The influence of temperature and of the relative volume of the red corpuscles and plasma upon the hemoglobin dissociation curve. *Sci. Rep. Tohoku Imp. Univ.*, 4th ser., **4**, 643-659 (1929).
 - 10) ROOT, R. W.: The respiratory function of the blood of marine fishes. *Biol. Bull.*, **61**, 427-456 (1931).