The Rate of Overlapping of Fish Scales as an Index of Their Relative Growth Rate
I. A Preliminary Examination on Goldfish Scales

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Investigation into the relation of the length of the fish to the size of its scales plays an important part in population studies of fishes. Since such the relationship seems to show a straight line regression, it has generally been accepted that the scale increases in size proportionally with the increase in length of the fish. Strictly speaking, however, it should follow an exponential equation, $S=aL^b$ (S: scale length; L: body length; a,b: constant), when the growth of scales is considered from an allometric viewpoint. In fact, it has frequently been suggested that in many fishes the "scale size-body length" relationship shows a curvilinear character when traced throughout their lives (reviews by Kubo and Yoshihara, 1957, and by Nikolsky, 1963). Furthermore, one might expect that the relative growth rate of scales would vary according to seasons even within a year. The scale sizes plotted against a certain length of fish usually cover so wide a range that it is fairly difficult to discuss minute changes of the relative growth rate by scale size-body length analysis.

The growth of a fish is naturally accompanied by an extension in area of its body surface. Since the number of scales remains unchanged after they have fully developed, the growth rate of the scales in relation to the body growth should be reflected in their overlapping rates. The overlapping rate of a scale to the surrounding ones may be expressed by the ratio of the size of the exposed part to the size of the entire scale, because the exposed part literally means the area of the scale that is not covered by the neighbouring scales. A change, if any, in the overlapping rates of scales is therefore assumed to be more useful than the "scale size-body length" relationship as an index of the relative growth rate of scales. In an attempt to ascertain this assumption, an examination was carried out on the scales of goldfish.

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Material and Method

Three groups of the Wakin, the most common variety of goldfish (*Carassius auratus*), were introduced from a fish farm and reared in an outdoor pond of our laboratory. The fish groups were respectively called "S", "M", and "L" (small,

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Table 1. Number, body length, and body weight of the goldfish used as material

Group	May			August		
	Number of fish	Body Length in cm mean (range)	Body Weight in g mean (range)	Number of fish	Body Length in cm mean (range)	Body Weight in g mean (range)
S	42	5.4 (4.8– 5.9)	6.3 (4.6– 8.1)	32	7.0 (6.2– 8.4)	14.9 (10.4– 22.7)
M	35	7.7 (6.8– 9.2)	20.6 (14.7–31.1)	22	9.1 (8.2–10.0)	35.2 (26.0– 46.9)
L	8	11.9 (10.6–13.3)	65.1 (50.6–88.4)	5	13.4 (12.3–14.5)	107.0 (82.4–124.7)

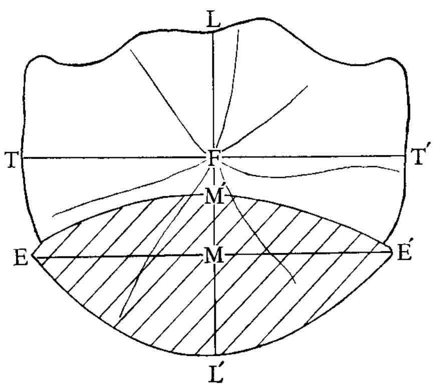

Fig. 1. Diagram of a goldfish scale showing the places measured. The hatched represents the exposed part of the scale.

EE′ : Width of the exposed part, connecting both lateral ends of the exposed part
TT′ : Width of the entire scale, parallel to EE′ and passing F (scale focus)
LL′ : Length of the entire scale, along the longitudinal axis passing M (mid-point of EE') and F
M′L′: Length of the exposed part, a part of LL′ corresponding only to the exposed part

medium, and large) according to size (Table 1). All fish of these three groups were in the second year of growth but they differed distinctly in size, probably because of differences of the length of the growth period in the preceding year due to different hatching dates.

The first examination took place in the middle of May on 85 goldfish and the second at the end of August on the same fish except for 26 which had died or were missing (Table 1). Five scales in sequence were removed from a definite portion on the left side of each fish in the first examination and the equivalent scales were removed from the right side in the second examination. The length and width of each scale and the length and width of the exposed part were measured under a shadowgraph. The places measured are indicated in Fig. 1. In order to measure the area of both the entire scale and of only the exposed part, an outline of an enlarged scale was traced on a piece of paper and it was weighed after cutting out the figure. A few regenerated scales, judged as such from their superficial patterns, were excluded from the measurements. The measurements of the normal scales were then averaged for each individual fish.

Results

During the examination period, the fish in each group showed good growth both in length and in weight (Tables 1, 2, and 3). The growth rate of the S-group appeared to be the highest and that of the L-group was the lowest in inverse order of size.

The "scale length-body length" relationships obtained respectively in May and in August are shown in Fig. 2. It may apparently be concluded that the scales grew at the same rate as the fish bodies from May to August, because no clear difference can be observed between the two regressions. A different conclusion

Table 2. Changes in the body length composition of the three fish groups from May to August

		Body Length in mm																			
		45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140
S	May	2	25	15																	
	Aug.				4	13	12	1	2												
M	May					2	8	18	4	2	1										
	Aug.								2	8	7	5									
L	May													2	2		1	2	1		
	Aug.																1	1		1	2

Table 3. Changes in the body weight composition of the three fish groups from May to August

		Body Weight in gram																							
		5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120
S	May	4	38																						
	Aug.			18	12	2																			
M	May			1	18	11	4	2																	
	Aug.						4	7	8	2	1														
L	May											3	1		1	1	1		1						
	Aug.																	1				2	1		1

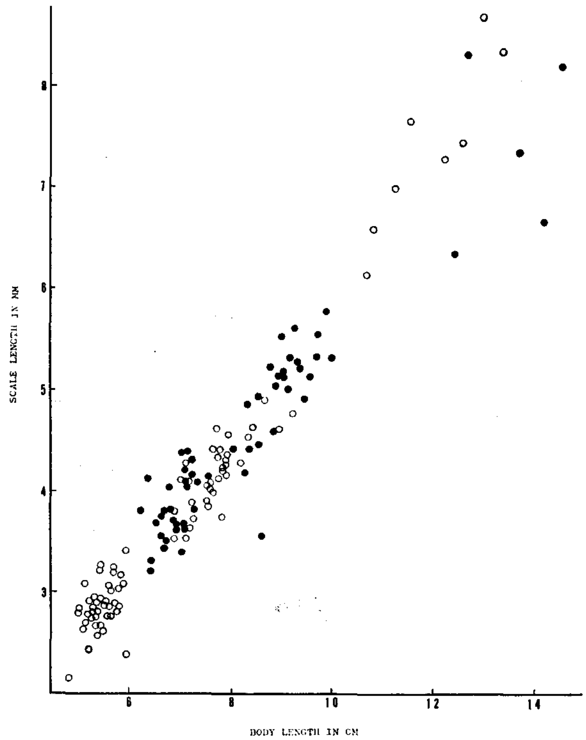

Fig. 2. Comparison of the relationships between the body length and the mean scale length of the same goldfish measured in May (∘) and in August (•)

can be drawn, however, when the length of the scale is plotted against the length of the exposed part of the scale, rather than against the length of the body (Fig. 3). The length of the exposed part (1) relative to the length of the entire scale (L) was lower in August than in May. This is also evident from Table 4 in which the frequency of the ratio 1/L within each group is shown for both May and August. A similar but more obvious result was obtained from the relation between the area of the entire scale (S) and the area of the exposed part (s) (Fig. 4), and by computing the ratio s/S (Table 5). The fact that the majority of the dots for August lie below those for May (Figs. 3 and 4) and that both the ratios 1/L and s/S clearly decrease between May and August (Tables 4 and 5) proves that the overlapping rate of the scale increased during this period. In other words, the growth rate of the scale exceeded that of the body in the period between May and August. It should be noted that this was not possible to show by the comparison of the length of the scale to the length of the body (Fig. 2). In a similar comparison of the width of the scale to the width of the exposed part, the difference is also noticeable between May and August though it is somewhat indistinct (Fig. 5, Table 6).

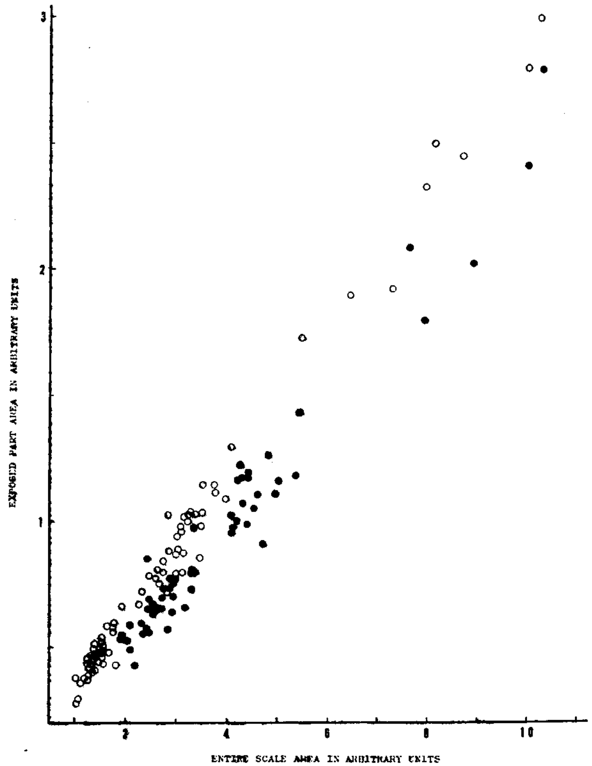

Fig. 4. Comparison of the relationships between the area of the entire scale and of the exposed part in May (∘) and in August (•)

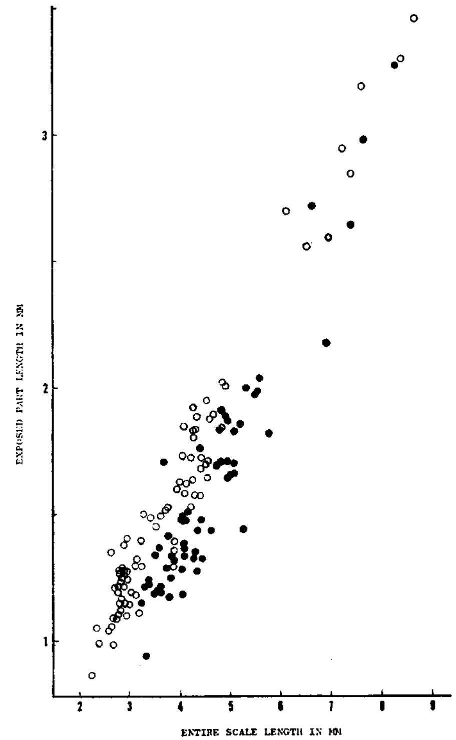

Fig. 3. Comparison of the relationships between the length of the entire scale and the length of the exposed part in May (∘) and in August (•)

Table 4. Changes in the frequencies of the ratio "exposed part length : entire scale length" (l/L) from May to August in each group

l/L		0.26	0.28	0.30	0.32	0.34	0.36	0.38	0.40	0.42	0.44	0.46
S	May					1	4	8	8	8	9	3
	Aug.		4	4	7	6	9	2				
M	May				1	3	6	5	11	7	2	
	Aug.	1		2	5	7	4	2	1			
L	May						1	3	3		1	
	Aug.			1		1		2	1			

Table 5. Changes in the frequencies of the ratio "exposed part area: entire scale area" (s/S) from May to August in each group

s/S		0.18	0.20	0.22	0.24	0.26	0.28	0.30	0.32	0.34	0.36
S	May			1			8	8	14	6	5
	Aug.	1	2	6	11	8	3				
M	May				4	4	9	14	2	1	1
	Aug.	1		9	4	6	2				
L	May					3	3	2			
	Aug.			2	1	2					

Table 6. Changes in the frequencies of the ratio "exposed part width: entire scale width" (w/W) from May to August in each group

w/W		0.72	0.74	0.76	0.78	0.80	0.82	0.84	0.86	0.88	0.90	0.92
S	May	1		2		3	8	12	13	1	2	
	Aug.	1	3	3	8	7	7	3				
M	May				2	4	7	7	6	7	1	1
	Aug.			4	4	4	8		1	1		
L	May						2	1	2	1	2	
	Aug.				1	1	1	1	1			

Comparing groups at the same month, May or August, both the ratios l/L and s/S seem to show a little decrease from the S- to the L-group. But if the comparison is made in connection with the body growth from May to August (compare Tables 4 and 5 with Tables 2 and 3), the following facts are to be noted. 1) The fish of the S-group in August are still smaller than those of the M-group in May. Nevertheless both the ratios l/L and s/S are smaller in the former than in

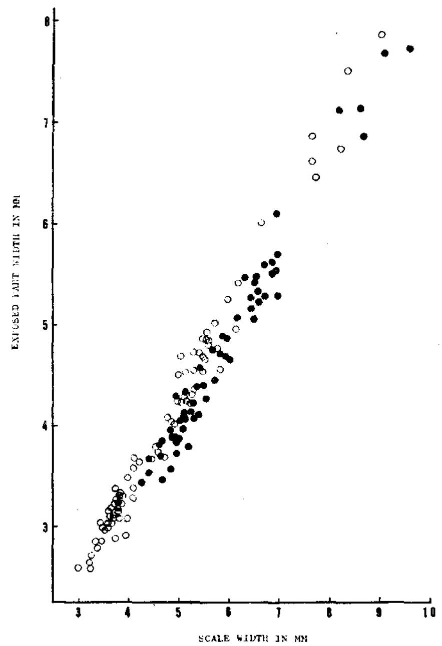

Fig. 5. Comparison of the relationships between the width of the entire scale and of the exposed part in May (o) and in August (•)

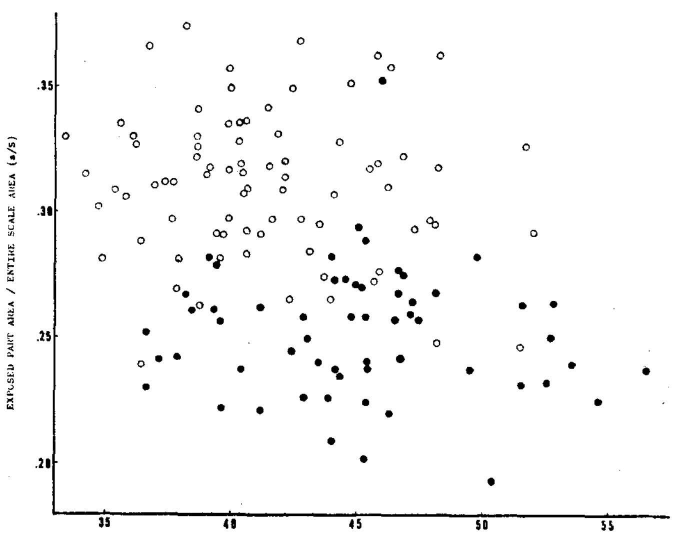

Fig. 6. The relation between the fatness and the ratio "exposed part area: entire scale area" (s/S) in May (o) and in August (•)

the latter. 2) The same relation exists between the fish of the M-group in August and those of the L-group in May. Thus it is obvious that a certain rate of overlapping of the scales is not correlated to a definite length or weight of the fish.

Since the relative area of the body surface is naturally considered to be correlated to the fatness of the fish, it is possible to suppose that there exists some relation between the overlapping rate of scales and the fatness of fish. The relation between the fatness and the ratio s/S is shown in Fig. 6. No appreciable correlation was found between the two either in May or in August.

Discussion

It was reported by Kobayashi (1961) that the "scale size-body length" relationship of salmon fry in seaward migration differed remarkably from that of the fry being reared in freshwater. This suggests that the scale growth rate relative to the body growth may vary according to environmental factors. Considerable difference in the relative size of the exposed part would have been observed among the three goldfish groups if it were possible to compare the ratios 1/L or s/S when their bodies were the same size. The reason for such difference is presumed to be different periods of growth in the preceding year due to different hatching dates. Environmental conditions may also have had an effect on the ratios.

Kubo and Yamahira (1955) attempted to find differences in the "scale size-body length" relationship among Pacific salmon populations. It has been shown in this study that the growth rate of the goldfish scales exceeded that of their bodies during the four months from May to August. This conclusion was obtained by examining changes in the ratio of the size of the exposed part to the size of the entire scale and not by examining changes in the ratio of the scale length to the body length. It seems to suggest that the method employed in this study would apply to population analyses of fishes better than the comparison of the "scale size-body length" relationships. The problem awaits further research.

Concerning the relation between the fatness of fish and the growth of the scales, Saito (1955) reported that the scales of crucian carp kept in a starved condition increased their overlapping rate visually along the dorso-ventral body axis. A correlation between the fatness of fish and the rate of overlapping of the scales was not noticed in this study. Though the fish appeared to be somewhat fatter in August than in May, it is unlikely that the lower ratios of 1/L and s/S in August are correlated with this increase in fatness. Possibly the situation in normally growing fish would be different from that of starving ones.

Summary

Changes in the relative growth rate of fish scales was assumed to be reflected

in the rate of the overlapping of the scales. This can be expressed by the ratio l/L (length of the exposed part of scale/length of the entire scale) or s/S (area of the exposed part/area of the entire scale). The scales of goldfish which were reared for four months from May to August were measured. The rate of the overlapping of the scales appeared to increase during that period because both the ratios l/L and s/S were shown to be smaller in August than in May. This suggests that the growth rate of the scales exceeded that of the body. An examination of the "scale length-body length" relationships failed to suggest the above fact. Changes in the rate of overlapping of scales expressed by the relative size of their exposed parts are presumed to be a possible index of their relative growth rate.

References

Kobayashi, T. (1961). Biology of chum salmon, *Oncorhynchus keta* (Walbaum), by th growth formula of scale. *Sci. Rep. Hokkaido Salmon Hat.* **16**, 1–102.

Kubo, I. and Yoshihara, T. (1957). Suisan Shigen-gaku. 345p. Tokyo; Kyoritsu-Shuppan.

Kubo, T. and Yamahira, K. (1955). Seibutsu Chosa Hokoku No. 3, Suisan-cho (*Rep. Biol. Invest. No. 3, Fish. Agency*) 1–36.

Nikolsky, G.V. (1963). The ecology of fishes. (Translated into English by L. Birkett). 352p. London; Acad. Pr.

Saito, S. (1955). On the mechanism of the appearance of the scale structure. III. On the regeneration of the scales of the crucian carp. *Carassius carassius* (L.), when they are reared with the different food. *Bull. Fac. Fish., Hokkaido Univ.* **5** (4), 332–335.