ON THE MECHANISM OF THE APPEARANCE OF THE SCALE STRUCTURE

IV. A Study on the Scale Structure of the Crucian Carp, *Carassius carassius* (L.)

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In general, the scale structure of fish has been considered ideally as the best representation of the ecological status of a species, group, or individual. However, it is noticeable that the scale structure differs quite with the different parts of the fish-body, and that it varies somewhat with the growth of the fish, but that in a certain body-portion there does exist a resemblance of the scales of fishes in the same group. On the other hand, the form of fish-body and the number of scales are nearly alike in a species or a group. Therefore, the growth of scale must be in accord with the growth of the fish-body. Therefore, the structure of the scales at a certain body-part may be influenced by the growth of that part. Having these points in mind, the writer studied the scales of the crucian carp and obtained some interesting results which may be useful in the ecological study of fish. Before going further, the writer wishes to express his hearty thanks to members of his laboratory for their help in the collection and handling of materials.

Material

The material of this study was collected by a drag-net for the collection of young fish from three small ponds near the buildings of the Faculty of Fisheries, Nanae-hama, Hakodate, in 1954 and 1955 (Table 1). In 1954 the collection was made twice at the three

Table 1. Material of this study

Date of Collection	May 18, 1954			August 2, 1954			May 7, 1955						
Sex[1]	Male	Female	Young	No Egg[2]	Spawn	Young	Largest Fish		2 nd Large		3 rd Large		Smallest
							Male	Female	Male	Female	Male	Female	Sex Ambiguous
Range of Body-length (mm)	45–109	45–106	16–36	40–91	54–132	10–35	97–105	95–117	75–91	75–90	50–73	49–73	21–49
Average Body-length (mm)	65	70	29	58	75	21	101	107.5	83.2	81.6	60.7	54.1	31.5
Number	32	53	39	80	16	35	2	9	9	11	23	65	263
Total	124			131			11		20		88		263
	637						382						

1) The female was recognized by the spawn, and the male by the sperm or the pearl organ.
2) This group probably includes males and the spawned females. The duration of this fish's spawning is so long that it continues from May to August.

ponds on the 18th May and the 2nd August. The fishes were used for such general studies as the scale arrangement on the body surface, the scale form or the general

scale structure at the different body-parts. The fishes of 1955 which were collected once at one pond on the 7th May, were employed for a study on the correlation of the scale structue with the stage of the growth of fish.

The ponds are artificial soak ponds laid out in 1927 for the ship wood materials of the Nichiro Fisheries Company[1]. Their dimensions are respectively 76 × 8, 50 × 8, 25 × 8 m; the water depth is about 1 meter, and the depth of mud about 15 cm; there is no outlet and no streams drain into them. The water is relatively clear, neutral in hydrogen-ion concentration. Found therein are the crucian carp, the loach (*Misgurnus anguillicaudatus* (CANTOR)), and the stickle-back (*Pygosteus sinensis* (GUICHENOT)) and such insects as *Anax parthenope*, *Kirkaldia deyrolli* VUILLEFROY, *Ranatra chinensis* MAYER, *Hydrophilus acumiratus* MOTSCHLSKY live. Plants growing there are the iris (*Acorus calamus*), the reed (*Phragmites* sp.), the willow (*Salix* sp.) at the margin, and the duckweed (*Potamogeton pusillus* L. and *Myriophyllum* sp.) at the bottom.

As above stated the ponds are small and not connected with the other waters, therefore there is no doubt that all specimens used in this study belong to a simple fish-group living under the same ecological conditions. The truth of this conjecture can be easily proved by the fact that the correlation curve of the body-depth to the standard body-length is nearly a straight line (Fig. 1). The body colour is reddish-brown or yellowish-brown irradiating goldish, and the ratio of body-depth to the body-length shows 25/67 in male and 12/35 in female in average. Thus the body-depth is relatively low, and so, the present material belongs to Kin-buna (goldish coloured fish) according to Y. Okada and M. Nakamura (1948)[2].

Three frequency curves of the body-length present respectively two distinct modes (Fig. 2), and it is sure that each mode represents a fish-group hatched in the same period, but the conclusion that the mode corresponds to an year-group is hasty in such fish of a long spawn-period as this species. The similarity of the two curves of two groups in May of two separate years is axiomatic, representing two distinct modes at 20-40 mm and 45-75 mm. In May fishes have still not spawned, accordingly, even the first mode ought to mean the fishes hatched in the preceding year. However, two modes in the curve of a group collected in August 1954 are quite different in the meaning; the first mode of the smallest body-length probably shows the fishes hatched in the early spring of that year, accordingly, it is obvious that the second mode represents the

1) The history of ponds was examined carefully by Mr. Yasunosuke Inoue of this Faculty, to whom the author must express here his sincere thanks.

2) Y. Okada and M. Nakamura (1948) distinguished Kin-buna as an independent race from Gin-buna (silvery coloured fish), Gengorô-funa. According to them the sex-ratio of Kin-buna is 1, but in the present specimens the female is above the male in number; especially in the material of May 1955 the ratio was 34 to 85. T. Kafuku (1952) recognized also three forms within the species on the basis of digestive organs, treating the same material as Okada and Nakamura from a small lake, Jô-numa, in Gumma Prefecture.

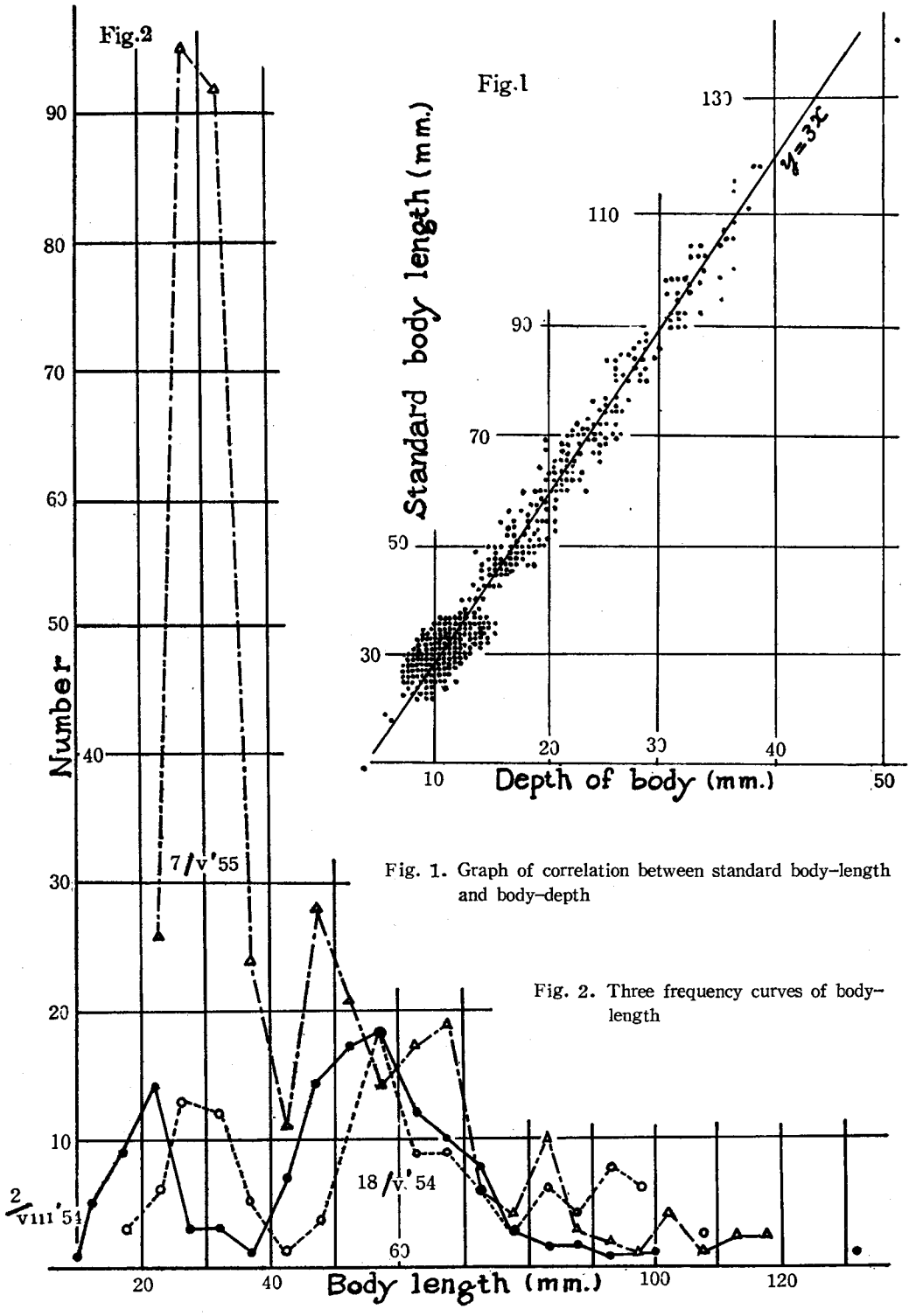

Fig. 1. Graph of correlation between standard body-length and body-depth

Fig. 2. Three frequency curves of body-length

growth of fishes in the first clear mode of collection in May. The individuals above 80 mm in body-length decreased rapidly in number in each collection in May and August. This fact suggests that there is a critical point of natural reduction in number of individuals at this body-length.

Method

The observations were made on specimens which were fixed with 10 per cent. formalin immediately after collection. Some fishes as the sample for the general study of scale were chosen arbitrarily, then all scales of each fish were arranged on a slide-glass. By this treatment the mutual position of each scale was not disturbed, and moreover, the lateral line, the perpendiculars to the lateral line from the anterior or the posterior ends of dorsal fin, and the positions of anal, pectoral, ventral, fins were marked distinctly. For the purpose of the comparative study of the corresponding scales at both sides of a fish, all scales of both body-sides were arranged in correspondence in two rows on a slide-glass.

For convenience of description, the scale row furnished with the lateral organ was treated as the basis or the middle row (M), and the rows above and below were called respectively the upper first, second etc. (U_1, U_2, ···) or the lower first, second etc. (L_1, L_2,···). Moreover, scales of each row were named the first, second etc. (S_1, S_2,···) from the front towards the back. With microscopical observation on such prepared slides, representations of all scales were drawn on a sheet of paper. In this manner, the scale-maps were completed, in which were noted the special form, the position and number of complete and incomplete radii, the longitudinal and transverse diameters[3] (LD, TD), the radius- and circulus-number of the anterior scale-part. The regenerated scale was measured for its longitudinal and transverse diameters, and besides, the longitudinal diameter of the central part lacking the circulus was also measured.

For the study of the changes of scales accompanying the growth of fish, all fishes in the largest and the second groups, 10 males and 10 females of the third group and 20 specimens of the smallest, sex ambiguous group, that is 71 fishes in total, were chosen by random sampling from the fishes collected in 1955. Then, the scales at four definite positions of these 71 fishes were prepared as the sample for detailed study ; one scale each from the upper first (U_1B) and third (U_3A) rows on a perpendicular from the anterior end of the dorsal fin to the lateral line, and one scale each at the lower first (L_1D) and the upper first (U_1C) rows on a perpendicular from the basal point of the anal fin (Fig. 3). To determine distinctly these four positions, at first the fish was put on a cross drawn on a sheet of paper so that the lateral line would agree with the

3) The longitudinal is a diameter corresponding to the fish-body axis through the nucleus, and the transverse is a perpendicular to the above through the nucleus. The measurements were made by the aid of a micrometer.

Fig.3

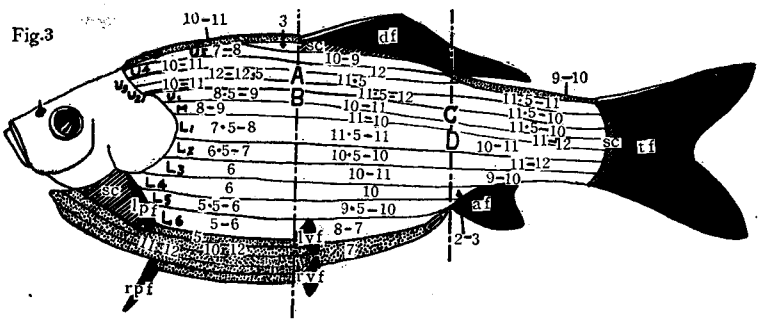

Fig. 3. Arrangement of scales on body surface
$L_1, _2, \cdots$, the lower first, second, ··· rows of scale; M, scale row of lateral line; $U_1, _2, \cdots$, the upper first, second, ··· rows of scale; af, anal fin; df, dorsal fin; lpf, rpf, left and right pectoral fins; lvf, rvf, left and right ventral fins; tf, tail fin; sc, small scales (part of oblique lines); A, B, C, D, scales which were used to secure data of correlation between diameters of scale, position of scale-nucleus and body-growth. Dotted part shows the upper edge and the under surface.

transverse line of the cross. Then, the fish was moved until the longitudinal line of the cross coincides with each perpendicular from the basal point of the dorsal or the anal fin to the lateral line. At last, the intersecting point of the scale row with a hair which coincided with the longitudinal line of the cross shows the definite position.

The slide of such chosen scales was magnified about 40 times by a magic-lantern apparatus for consideration to check any large error, and then the several portions of the scale measured. The diameter of the scale corresponding to the fish body axis is named the longitudinal diameter of the scale, and that corresponding to the body-depth is called the transverse.

Observation

I. Number and General Form of Scales

The body except the head is covered with cycloid scales which are nearly pentagonal in form, but such several small parts as the levator muscle of the pectoral fin, the neighborhood of the cloaca, and the bases of ventral and dorsal fins, are covered irregularly with small oval scales. Moreover, at the upper edge of body, namely from the supraoccipital bone to the dorsal fin and from the dorsal fin to the tail fin, there is a row of special shield-formed scales which are so long extraordinarily in their longitudinal diameters, and scales at the under surface so delicate that it is difficult to exfoliate them completely. The present report is confined to a study on the pentagonal scales covering the main body surface (Fig. 3).

In general, as to the pentagonal cycloid scale, the anterior margin in the young fish is straight, and the upper and lower margins are in parallel with each other, but as the fish grows the anterior margin comes to show jaggedness. The variation of scale

number is relatively narrow[4]. Though the average number of scale on each row in three portions is as fig. 3, the number of seven rows which succeed to the small scales at the base of tail fin is affected diversely with the small scales.

II. Longitudinal and Transverse Diameters of Pentagonal Scales

So far as the fishes of the same body-length are concerned the relation between the longitudinal and transverse diameters of scale at a given position is nearly definite. In general, in each scale row the anterior scale shows a shorter longitudinal than the transverse, and as the position follows posteriorly both of them increase gradually. For example, the two diameters of scales of specimens, 7 mm in standard body-length, attain the maximum at about the perpendicular from the anterior end of the dorsal fin to the lateral line, and then they decrease gradually. In this case, the transverse decreases sooner than the longitudinal, and so, in each row the longitudinal is greater without exception than the transverse in all scales positioned behind the perpendicular from the anterior end of anal fin to the lateral line. However, the maximum of transverse diameter appears more anteriorly in the lower scale-rows than in the upper scale-rows,

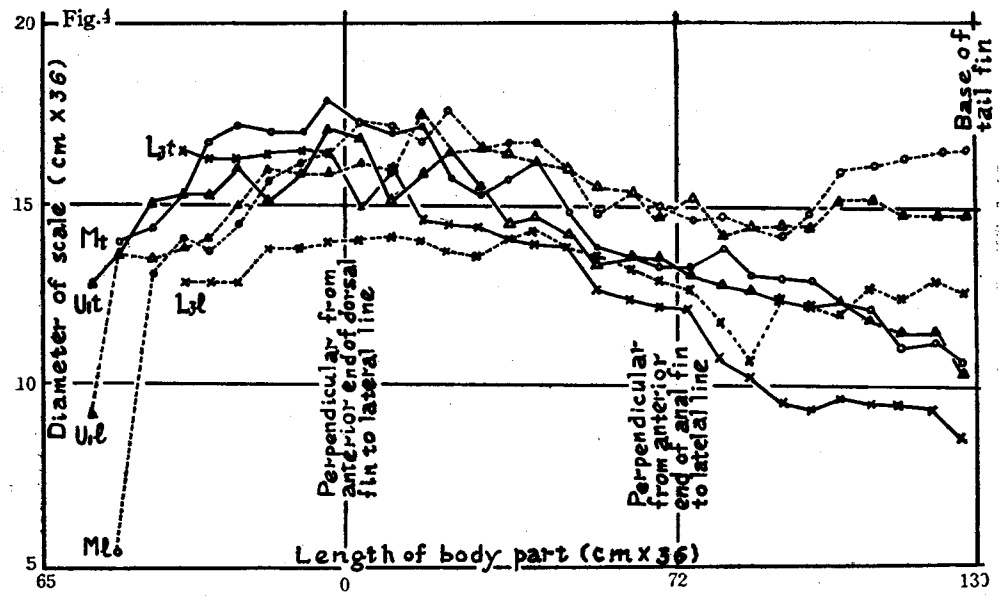

Fig. 4. Graph of average diameter of scales from five specimens of 7 cm in standard body-length

M, scales with lateral organ; L_3, the lower third scale-row; U_1, the upper first scale-row; l, longitudinal diameter; t, transverse diameter.

4) The scales constituting the lateral line in the present material numbered 29 to 32. This is a narrower variation than the observation, 27 to 35, published by T. Kafuku (1952) on Kin-buna from Jô-numa.

and in each row the maximum of the longitudinal has a tendency to appear more posteriorly than the maximum of the transverse (Fig. 4).

The relation between the two diameters somewhat varies with the growth of the body-length, and the increments of the diameters differ from each other by the different body-parts. Accordingly, any scale of a large fish differs from that at the correspondent position of a small fish in the relation between the two diameters.

The scales at four positions (U_1B, U_3A, L_1D, U_1C) of 71 samples which were chosen from the fishes collected in 1955 by the above mentioned method show the following tendency : the difference of the two diameters of scales at the anterior part (U_1B, U_3A) diminishes according to the growth of the fish, namely, in the small fish the longitudinal is obviously shorter than the transverse, but when the fish grow to about 10 cm length the two diameters come to be the same. On the contrary, at the posterior part (L_1D, U_1C) the difference between the two diameters becomes more divergent

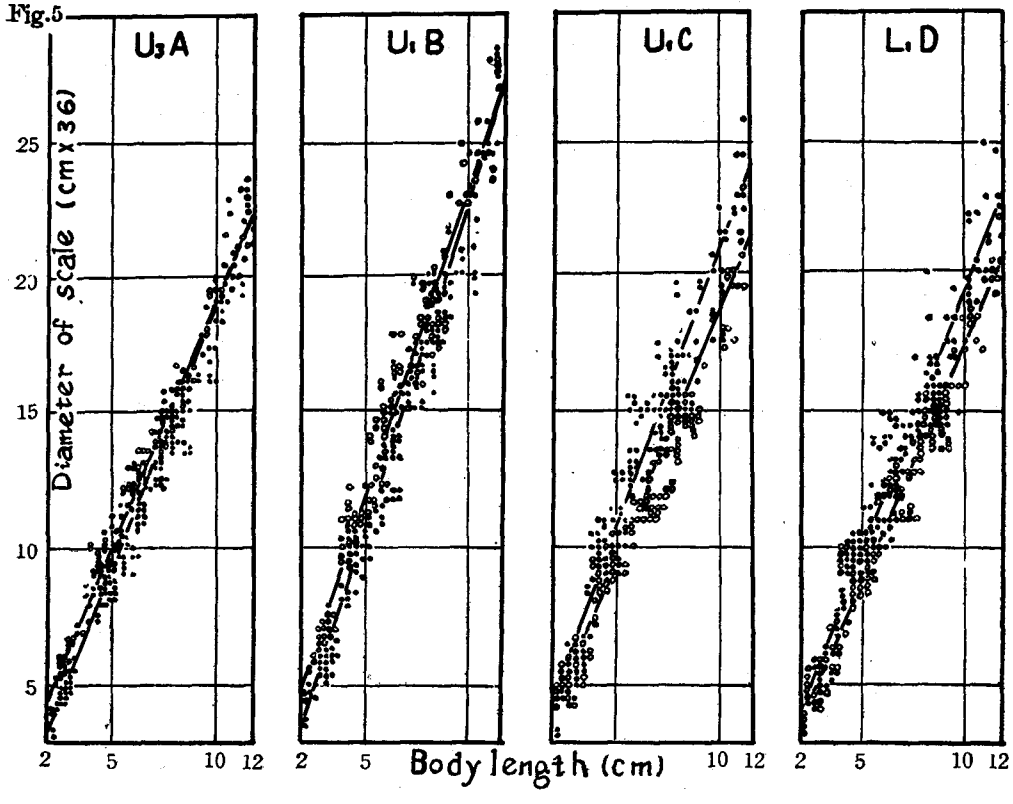

Fig. 5. Correlation curves between fish-growth and diameters of scale
Black spot, longitudinal diameter ; white spot, transverse diameter ; U_3A, U_1B, scales of the third and the first upper rows on a perpendicular from anterior end of dorsal fin to lateral line; U_1C, L_1D, scales of the first upper and lower rows on a perpendicular from anterior end of anal fin to lateral line (see fig. 3).

with the growth, that is, in the large fish the rate of the longitudinal to the transverse becomes superior to that in the small fish. In other words, in the growth of the fish every scale grows more rapidly longitudinally than transversely, namely, the ratio of the longitudinal to the transverse increases with the growth of the fish (Fig. 5).

III. Position of Scale-nucleus

The writer reported in brief on this problem in a previous paper (1953). He has now had further opportunity to make more detailed researches. The scale grows sooner in a forward direction, accordingly it results that the relative position of the nucleus moves backward with the growth of the fish.

In general, the ratio of the anterior radius to the longitudinal diameter of a scale increases with the body-growth of the fish, but the difference of increase of this ratio is obviously recognizable between the both sexes. Namely, the increment of male is slow, but the female shows a rapid increasement. Consequently, in the third fish-group, 49–73 mm in body-length, the ratio is smaller in the female than in the male, while in the second group, 75–91 mm in body-length, it becomes nearly alike in the two sexes ; in the largest group, 95–117 mm in body-length, the ratio of the female contrarily becomes superior to that of the male. The increment of ratio differs also with the different positions. In the female, by the growth from the third group, 54.1 mm in average body-length, into the largest group, 107.5 mm in average, the increases of the ratios at the four positions, U_3A, U_1B, U_1C and L_1D, show respectively as follows: 0.039, 0.024, 0.031 and 0.042.

The correlation between the number of circuli[5] at the anterior part of a scale and the longitudinal diameter of that scale shows a direct proportion. In fishes below 70 mm in body-length, the scale at U_3A is specially inferior in circulus number to the scales at U_1B, U_1C and L_1D. The three latter are nearly the same in circulus number and in length of longitudinal diameter (Fig. 4). However, with the subsequent body-growth the scale at U_1B comes to surpass the others in increment of circulus. There is an indistinct tendency for the increment of circulus to be more great in the central body-part than in the periphery.

IV. Regeneration of Scales

The regeneration scales vary in number with each individual, but the positions are scattered in a manner to display a certain tendency. According to the examination on twenty fishes, 53–65 mm in body-length, the body surface can be divided into three areas by the degree of density of the regenerated scales. The wedge-formed area extending from the anterior M–L_5 to the posterior U_1 is the most compact, where the

5) The "number of circulus" was decided by the method of enumerating the circuli crossing with the anterior radius.

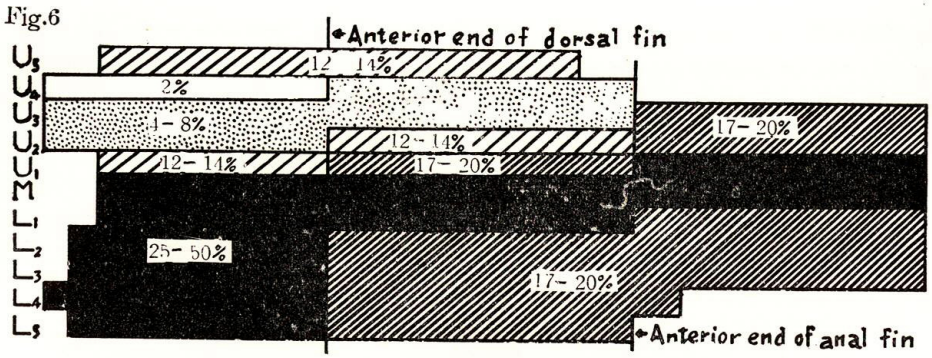

Fig. 6. Dispersion-map of regenerated scales, showing that regenerated scales are most likely to occur on the belly

regenerated scale reaches a value of 25–50 per cent. In the remaining part of the belly and the part from median U_1 to posterior U_2–U_3, regenerated scales amount to about 17–20 per cent. The greater part of the back shows decrease to a value of 2–14 per cent. (Fig. 6).

The small fish has a few regenerated scales, but with the growth of the fish they increase rapidly. Four groups of specimens collected in 1955 show respectively 9, 27, 45, 53 in number of regenerated scales. Moreover, in the third group there is no recognizable difference between the two sexes in number of regenerated scales. However, increase in body-length accompanies the rapid increase in number in female, while in the male it is nearly inchangeable, and consequently the relative number of regenerated scales of male and female in the largest fish-group diverges 15 to 29.

Among the regenerated scales of the large fishes, two different types of the regeneration-process are noticed. The first type (Fig. 7b) showing the structure of the

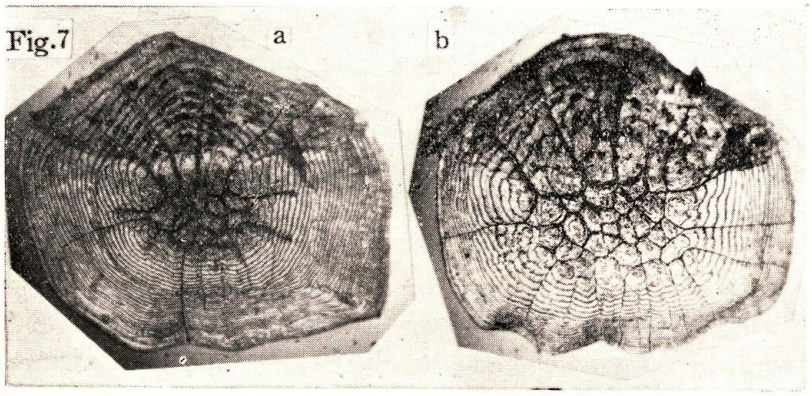

Fig. 7. Two types of regenerated scale on right side of a fish, 76 mm in body-length, collected on May 18th, '54
a, L_2S_{18} regenerated in the second preceding year; b, L_3S_7 regenerated in the preceding

early regeneration, can be guessed to have occurred in the previous year. The other type (Fig. 7a) shows a more advanced structure. There is no doubt that it was regenerated in the second preceding year because the central net-worked figure is constricted to a small area. The regenerated scales are unexpectedly numerous, and as above mentioned they are found specially at each side of the belly. The writer thinks that these numerous regenerated scales are chiefly a result of the falling off from abrasion due to sexual acts during the spawning season. If he guesses right, two types of regenerated degree may represent two times of the spawnings.

Conclusion

The scales at the different parts of a fish differ in structure; there is resemblance between the structure of the corresponding scales of different fishes. Moreover, with the growth of fish-body, the scale at a certain position may grow under a general rule that is definite in the species. The writer attempted to determine clearly whether or no such rule may exist, using 637 specimens of *Carassius carassius* (L.) collected from three small ponds at Nanae-hama, Hakodate City.

The pentagonal cycloid scales covering the best part of fish-body are simple at the margins in the young fish, but they come to have jaggedness at the anterior margin with growth. This was also reported by H. Kobayasi (1938). The jaggedness appears at about the time when the growth of body length has reached about 4.5 cm. It is interesting that H. Kobayasi (1954) pointed out that the ctenoid scale at the stage of early development represented the structure of the cycloid scale.

The nucleus changes in relative position because the growth of scale is more rapid anteriorly than posteriorly. Accordingly, at the young stage the nucleus exists rather at the anterior part, but with the growth it moves towards the posterior part.

The number of scales furnished with the lateral organ in the material of this study is narrow in variation, 29 to 32, comparing with 27 to 33 (mode, 29) of Kin-buna reported by Y. Okada and M. Nakamura (1948)[6], and is many more than about 27 according to Y. Okada, K. Uchida and K. Matsubara (1935). In fact, this fish so varies greatly that several varieties and races are admitted, and so, not only the number of scales but also the other characteristics are different according to the life-envirommment.

The increments of both diameters of scales from the different body-parts are different. This fact shows a rhythmic growth of the different body-parts. In specimens under 10 mm in body-length, the depth of anterior body-part is relatively large, but marked growth in the length of body as a whole follows. Accordingly, with the growth of body, the scale grows with greater rapidity longitudinally than transversely. The backward growth of scale is minute, and the longitudinal growth is due mainly to the

6) According to their study, Gin-buna and Gengorô-funa show respectively 28 to 31 (mode, 29), 29 to 33 (mode, 32) in number of scales furnished with lateral organ.

forward growth. This results in the shifting of the scale-nucleus towards the posterior in relative position. The speed of growth of scale or of the body-length is faster in the female than in the male.

The regeneration scales of the present material are many more in number than those of *Abramis brama* L. and *Carassius carpio* L. reported by W. Wunder (1949). According to him, the regenerated scales are especially recognizable in the anterior one fourth body-part and in the tail stalk. The present results corroborate his conclusion guessing that these parts are easy to remove by the rubbing and the damage.

The number of types of the degree of regeneration may be connected with the conjectured spawning-times. However, if the scales can be regenerated completely as was reported on the gold-fish by R. Suzuki (1952), this view is nonsensical. R. Suzuki observed the complete regeneration within only 180 days, but on the contrary on the same fish, W. Wunder (1949) reported that the regenerated scale after four years differs still from the normal scale; the subject fairly begs for further investigations.

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