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Variations of Spinal Curvature and Vertebral Number in Goldfish

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Abstract The spinal curvature and the vertebral counts were investigated in fifteen races of the goldfish (*Carassius carassius auratus*), as compared with five forms of the crucian carps. On the basis of the spinal curvature, the examined fishes were roughly classified into the following three groups. The first group with Kin-buna type curvature, which includes all forms of the crucian carps is characterized by having the abdominal vertebrae always located above the base line and the majority of the caudal vertebrae are situated bellow the line (the degree of spinal curvature is generally small in its value). The second group with Wakin type curvature, which includes five races of the goldfish is closely related to the first group, but the degree of spinal curvature is comparatively large in its value. The third group with Ryukin type curvature, which includes other ten races of the goldfish is characterized by the vertebral column always situated above the base line (the degree of spinal curvature shows comparatively larger value). The total vertebral counts show relatively high values in the crucian carps, while the counts are somewhat reduced in most of the goldfish. And also it is presumed that there exists a negative correlation between the degree of spinal curvature and the total number of vertebrae.

The goldfish is commonly believed to be derived from the crucian carp, *Carassius carassius auratus* (Linnaeus), by artificial selection, originally in China. In Japan, about twenty or more races of the goldfish are established for a long time (Matsui, 1934). Those races of the goldfish have distinctive external features respectively, such as the body form, the eye shape, the fin form, the coloration, etc., although they show individual variations in some extent. With regard to the body form, they vary from the Wakin (Jap) with a moderately slender body to the Ranchu (Lionhead) with a short and round body. Such variations of the body form seem to be correlated with the curvation of vertebral column and the number of vertebrae.

From such points of view, we investigated the curvation of vertebral column and the vertebral number of fifteen races of the goldfish, comparing them with five forms of crucian carps.

Material and methods

The goldfish and the crucian carps examined in this investigation are as follows: the Wakin (Jap), Shubunkin, Comet, Jikin (Peacock-tail), Ryukin (Nymph), Tetsuonaga (Iron fringetail), Calico (Telescope nymph), Aka-demekin (Red telescope), Kuro-demekin (Black telescope), Chotengan (Celestail), Sanshiki-demekin (Calico telescope), Oranda-shishi-gashira (Oranda), Azumanishiki (Calico Oranda), Ranchu (Lionhead), Chinese Hana-fusa (Red velvetyball), Kin-buna (*Carassius auratus* subsp.), Nigoro-buna (*C. auratus grandoculis* Temminck and Schlegel), Gin-buna (*C. auratus langsdorfi* Temminck and Schlegel), Gengoro-buna (*C. auratus cuvieri* Temminck and Schlegel), and Kawachi-buna (the cultured form of the Gengoro-buna). Outline drawings of races of the goldfish and subspecies of the crucian carps (except for the Kawachi-buna) are shown in Fig. 1. For the present study, we used specimens of normal

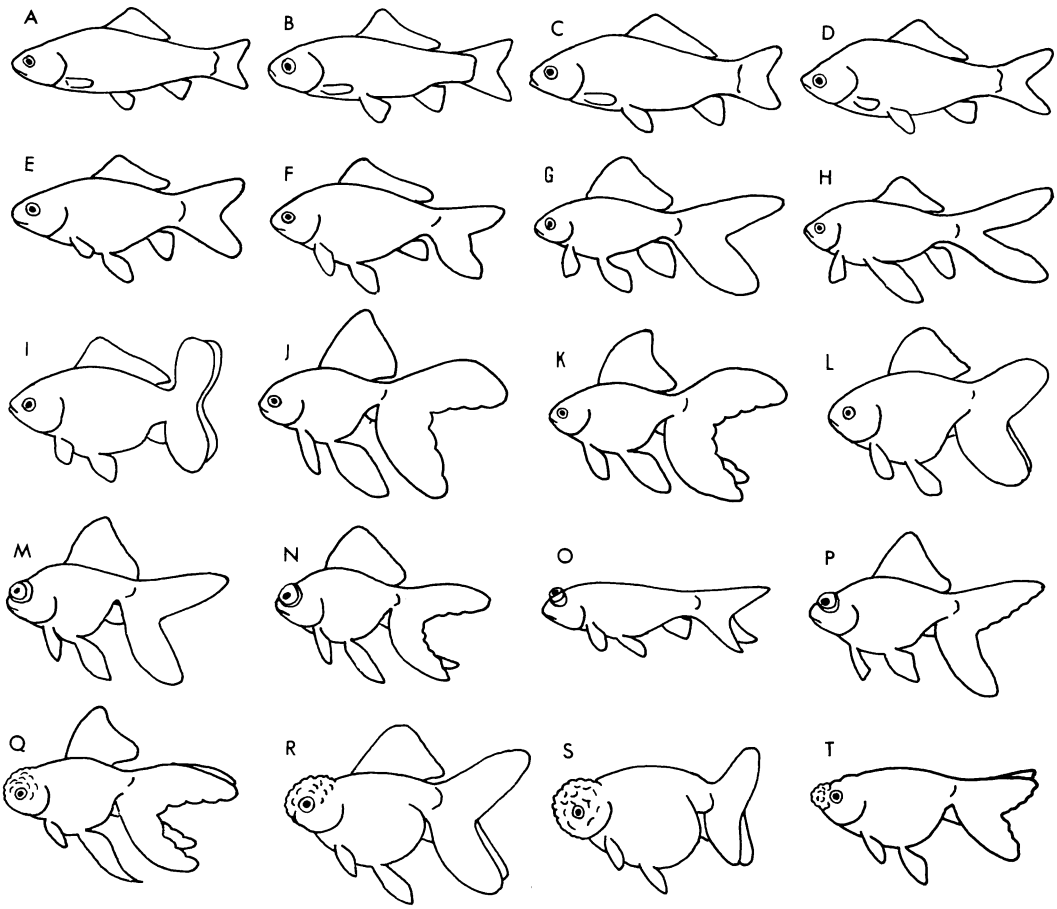

Fig. 1. The outline drawings of the examined races of the goldfish and subspecies of the crucian carps (except for Kawachi-buna). A, Kin-buna; B, Nigoro-buna; C, Gin-buna; D, Gengoro-buna; E, Wakin (with simple caudal fin); F, Wakin (with tri-lobed caudal fin); G, Shubunkin; H, Comet; I, Jikin; J, Ryukin; K, Tetsuonaga; L, Calico; M, Aka-demekin; N, Kuro-demekin; O, Chotengan; P, Sanshiki-demekin; Q, Oranda-shishigashira; R, Azumanishiki; S, Ranchu; T, Chinese Hanafusa.

external appearance for each form, and those with extremely deformed vertebral column were avoided. The localities where samples were obtained were as follows: the Gin-buna from the Ichigi River, Mie Pref.; the Gengoro-buna and the Kawachi-buna from the fishponds of the Osaka Prefectural Freshwater Fish Experiment Station in Neyagawa, Osaka Pref.; the Kin-buna from Jonuma, Gunma Pref.; the Nigoro-buna from Lake Biwa, Shiga Pref.; the Jikin from a fish culturist in Ise, Mie Pref.; and other races of goldfish from several fish-culturists in Koriyama, Nara Pref.

Vertebral number and degree of the curvation of the vertebral column were examined on X-ray photographs in lateral view. The vertebral counts include the Weberian vertebrae, counted as four, and the urostylar vertebra, counted as one. Hereafter, instead of "the curvation of the vertebral column," we shall use "the spinal curvature," the term used by Ford (1937 : 14). In the present investigation, the spinal curvature was indicated by a curve traced on the X-ray photograph by joining the center of each centrum. The specimens were preserved in 10% formalin in

Table 1. The list of crucian carps and goldfish, with the number of samples, counts, and measurements of specimens.

Names	Number of samples	Body length (cm)	Degree of spinal curvature* (cm^2)	Vertebrae**		
				Abdominal	Caudal	Total
1 Gin-buna	10	6.9–15.9	7.53+1.77=9.30	17–18(17.60)	13–14(13.70)	30–32(31.30)
2 Gengoro-buna	8	6.0–8.4	7.97+1.77=9.74	17–18(17.67)	11–14(13.38)	28–32(31.00)
3 Kin-buna	3	8.6–11.0	8.13+1.77=9.90	17–18(17.33)	13(13.00)	30–31(30.33)
4 Nigoro-buna	3	10.4–15.2	6.97+3.90=10.87	16–17(16.67)	15(15.00)	31–32(31.67)
5 Kawachi-buna	9	5.8–8.8	9.63+1.70=11.33	17–18(17.89)	13–14(13.56)	31–32(31.44)
6 Wakin(Funao-shaped)	8	7.2–8.4	9.50+3.83=13.33	17–18(17.25)	12–14(13.00)	29–31(30.25)
7 Jikin	10	3.5–12.8	13.50+2.03=15.53	15–18(16.50)	9–12(11.00)	25–29(27.50)
8 Shubunkin	8	3.6–9.5	13.60+2.07=15.67	17(17.00)	12–14(13.13)	29–31(30.13)
9 Comet	3	7.6–9.5	14.27+2.17=16.44	16–18(17.00)	13(13.00)	29–31(30.00)
10 Wakin(Mitsuo-shaped)	8	4.8–5.5	18.80+0.90=19.70	15–18(16.50)	12–14(13.00)	29–31(29.50)
11 Azumanishiki	3	4.9–6.9	23.33+0.20=23.53	10–14(12.00)	9–11(9.67)	19–23(21.67)
12 Chotengan	4	3.7–4.4	15.17+0 =15.17	15–16(15.50)	12–14(13.00)	27–30(28.50)
13 Chinese Hanafusa	5	5.5–6.3	18.07+0 =18.07	13–14(13.40)	13–15(13.80)	26–29(27.20)
14 Sanshiki-demekin	6	3.2–3.6	20.27+0 =20.27	13–15(13.83)	11–14(12.33)	24–28(26.16)
15 Tetsuonaga	1	9.2	20.30+0 =20.30	13	15	28
16 Calico	6	3.9–5.2	22.50+0 =22.50	12–15(13.50)	11–14(12.38)	23–29(25.88)
17 Oranda-shishigashira	3	6.7–7.3	25.07+0 =25.07	13(13.00)	10–12(10.67)	23–25(23.67)
18 Aka-demekin	6	3.6–4.4	26.40+0 =26.40	15(15.00)	13–15(13.85)	28–30(28.83)
19 Kuro-demekin	10	2.9–4.3	26.40+0 =26.40	12–15(13.80)	11–14(12.60)	24–28(26.40)
20 Ryukin	9	3.1–9.4	30.53+0 =30.53	12–17(13.56)	11–15(12.89)	25–29(26.44)
21 Ranchu	16	3.2–6.9	38.10+0 =38.10	12–14(12.38)	7–11(9.31)	19–23(21.69)

* The value of the area restricted above the base line + the area restricted below the line=the sum of these two value.

** The values in parentheses indicate the mean.

their most natural posture so as to prevent twisting or bending.

For the study of the spinal curvature, the body axis (the tip of the snout to the center of the penultimate vertebra) was found unsuitable. The line drawn from the anterior end of the first vertebra to the posterior end of the penultimate vertebra was mainly used as the base line for comparison of the spinal curvature. To evaluate the degree of spinal curvature, we measured with the planimeter the area enclosed between the standardized base line of 20 cm and the mean curve of spinal curvature. The mean curve in each race of the goldfish and subspecies of the crucian carps was drawn through connecting representative five points, each of which was a mean of the intersecting points of curves of individual specimen on each of five vertical lines spaced at regular intervals on the base line.

Results

Spinal curvature: Fig. 2 indicates individual variations of the spinal curvature in 4 specimens of the Jikin, against the body axis. In the case of the Jikin, the position of the first vertebra that is at the left end of each curve varies considerably against the body axis.

Among 10 examined specimens of the Jikin, 5 had their first vertebra located above the body axis, 1 just on the line, and remaining 4 below the axis. In all specimens of this race, however, the posterior segment of the spinal curvature was located below the axis, varying in its length from individual to individual. Except for the Jikin, in all of the examined goldfish and crucian carps their anterior segments of the spinal curvatures are usually located above the axis and also their posterior segments are located above or, at

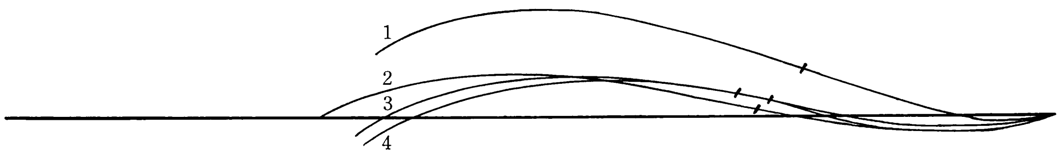

Fig. 2. Individual variations of the spinal curvature of the Jikin, against the body axis. An oblique dash on each curve indicates the boundary between abdominal and caudal vertebrae. The body length of four specimens are: 1, 10.4 cm, 2, 12.8 cm; 3, 10.1 cm; 4, 7.0 cm.

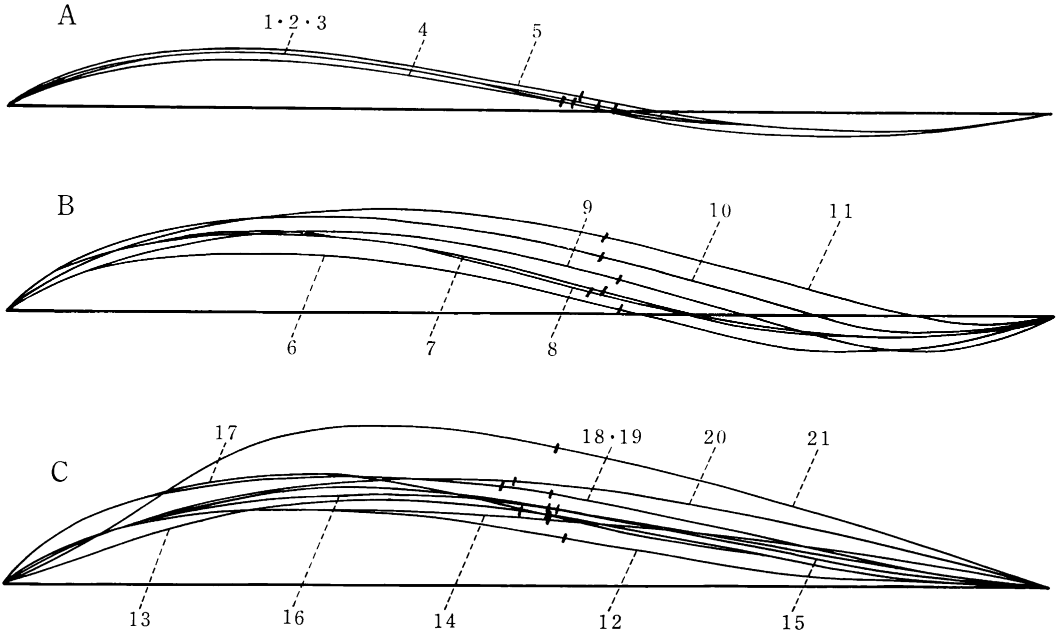

Fig. 3. Variations of the spinal curvature (against the base line) of the examined fishes which are classified into three groups. A, Kin-buna type; B, Wakin type; C, Ryukin type. The numbers labeled to each curve corresponds to the number at the first column in Table 1. An oblique dash on each curve indicates the end of the abdominal vertebrae.

most, on the axis. Thus, in the correlation between the spinal curvature and the body axis, the Jikin alone is distinguished from other forms.

The body axis, however, is unsuitable for comparison of the spinal curvature, because the length of the vertebral column varies from individual to individual as shown in Fig. 2.

Fig. 3 indicates the mean spinal curvatures of goldfish and crucian carps, in relation to the base line defined above. Each form had its characteristic spinal curvature, as shown in Fig. 3 A–C. The degree of spinal curvature of each form is also indicated in Table 1.

The first group, which has the Kin-buna type curvature, includes all examined crucian carps (Fig. 3A). They are characteristic in having the abdominal vertebrae always located above the base line, while the majority of the caudal vertebrae are situated below the line. Moreover, the maximum distance of each curve from the base line is smaller than that of the other two groups. Therefore, the degree of spinal curvature is usually smaller in its value and is not so much different among five members of this group (Table 1).

The second group, which has the Wakin type curvature, includes the Wakin, Jikin, Shubunkin, Comet, and Azumanishiki (Fig. 3B). As to the Wakin, we treated two subforms separately, the Funao-shaped Wakin with a simple caudal fin and the Mitsuo-shaped Wakin with a tri-lobed caudal fin. This type is closely related to the above-mentioned Kin-buna type. In this group of fishes, the anterior segment of the spinal curvature located above the base line is relatively longer and the maximum distance between each curve and the base line is usually much larger than that of the Kin-buna type. Considerable variations were observed among the races of the second group. The spinal curvature of the Funao-shaped Wakin is very similar to that of Kin-buna type. On the contrary, in the Azumanishiki the spinal curvature is rather similar to the Ryukin type which will be mentioned later. Between the Funao-shaped Wakin and Mitsuo-shaped Wakin, there exists a considerable difference: the latter has its own curve which is rather similar to that of the Azumanishiki. In the Jikin and the Shubunkin, the spinal curvature resembles each other, and the curve is relatively similar to that of the Funao-shaped Wakin. The Comet has its own curve intermediate between the above-mentioned two extremities. As shown in Table 1, the fish of this group had the higher values of the degree of spinal curvature than the fish of the Kin-buna type. Among the members of this group, the Azumanishiki has the largest value, while the Funao-shaped Wakin has the smallest value, and the Mitsuo-shaped Wakin has its value much larger than that of the Funao-shaped Wakin.

The third group, which had the Ryukin type curvature, includes other ten goldfish, two-thirds of the examined races of the goldfish (Fig. 3C). The most remarkable feature of this type is that the whole vertebral column is situated above the base line. Among the members of this group, the chotengan has the curve with the smallest maximum distance and the Ranchu with the largest maximum distance from the base line. In the remainders the curves are similar and difficult to distinguish from each other. The races of the third group had comparatively larger values of the degree of spinal curvature, as compared with forms of the above-mentioned two groups (Table 1). The Chotengan has the smallest value in this group, while the Ranchu has the largest value. The Chinese Hanafusa, Sanshiki-demekin, Tetsuonaga, and Calico have the smaller value for the members of this group. Even in these races, the degrees of spinal curvature are subequal to those of the Mitsuo-shaped Wakin and Azumanishiki of the Wakin type. The Ryukin has a large value which is next to the Ranchu. And other three races, the Oranda-shishigashira, Kuro-demekin, and Aka-demekin, had moderately large value, and intermediate between the above-mentioned two extremities of the third group.

Vertebral counts: As shown in Table 1, the number of vertebrae considerably varies among the examined fishes and also individually to some extent. Fig. 4 indicates the variation of the total vertebral counts and those of the abdominal and caudal vertebrae. Here those counts are expressed as the mean values for each race and form.

In the case of the crucian carps (Fig. 4 : 1–5), the total vertebrae are about 30–32 and comparatively numerous. They are similar in their constitution of vertebral counts, having about 17–18 abdominal and about 13–14 caudal vertebrae. The Nigoro-buna was a exception in having about 1 less abdominal and about 1 or 2 more caudal vertebrae than the other crucian carps. Among the Wakin type goldfish, two subforms of the Wakin, Shubunkin, and Comet (Fig. 4, 6 and 8 to 10) had about 30 vertebrae in total. And also they had the abdominal and caudal vertebral counts similar to the crucian carps. The Mitsuo-shaped Wakin slightly differs from the Funao-shaped Wakin in having about 1 less abdonimal vertebra. Most of the remaining goldfish have comparatively fewer vertebrae,

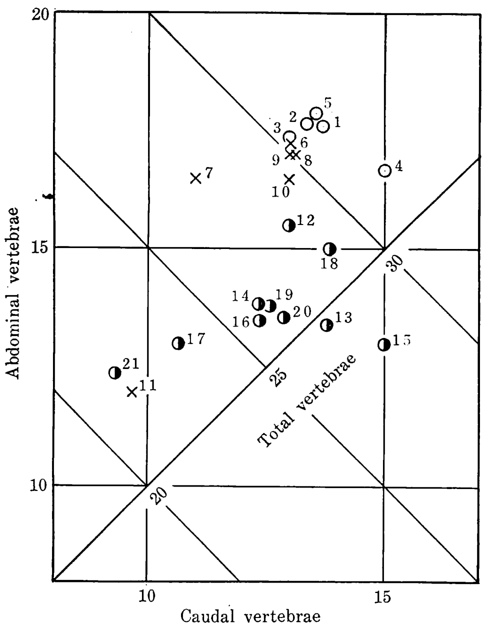

Fig. 4. Variations of the total vertebral counts and the constitution of abdominal and caudal vertebrae. Open circles, the Kin-buna type; crosses, the Wakin type; semi-open circles, the Ryukin type. The numbers labeled to each mark correspond to the numbers at the first column in Table 1.

which is due to the diminution of the abdominal and/or the caudal vertebral number. The constitution of abdominal and caudal vertebral counts largely varies from race to race. Of the second group (with Wakin type curvature), the Jikin and Azumanishiki (Fig. 4 : 7 and 11) are different from each other in the total vertebral counts and the vertebral constitution, and also from other members. In the case of the Jikin, the abdominal vertebral counts were same with that of the Mitsuo-shaped Wakin, but the caudal vertebral counts were about 2 fewer than that of the Mitsuo-shaped Wakin; accordingly the total vertebral counts were about 28. The Azumanishiki had the lowest total vertebral counts of about 22, in the group of this type, which was composed of 12 abdominal and about 10 caudal vertebrae.

In the third group with Ryukin type curvature, the Chotengan and Aka-demekin (Fig. 4, 12 and 18) had higher counts of vertebrae, totaling about 29. They are composed of about 16 abdominal and 13 caudal vertebrae in the former, and 15 abdominal and about 14 caudal ones in the latter. The Sanshiki-demekin, Calico, Kuro-demekin, and Ryukin had a similar constitution of vertebral counts, namely about 14 abdominal and 12–13 caudal vertebrae (Fig. 4 : 14, 16, 19 and 20). Accordingly, their total vertebral counts are reduced to about 26. In the Oranda-shishigashira, the vertebrae were reduced to about 24 in total, and composed of 13 abdominal and about 11 caudal vertebrae (Fig. 4 : 17). The Ranchu had the fewest total vertebrae with about 12 abdominal and about 10 caudal vertebrae (Fig. 4 : 21). In two remaining races, the Chinese Hanafusa and Tetsuonaga (Fig. 4, 13 and 15), number of caudal vertebrae was equal to or more than that of abdominal vertebrae, and unique among examined fishes. Especially in the specimen of the Tetsuonaga, the abdominal vertebrae were reduced to 13, while the caudal ones were 15.

Discussion

As already mentioned above, the spinal curvature and vertebral counts of the goldfish considerably vary among the examined races. The races of goldfish are, however, different from crucian carps in the following points: (1) the spinal curvature is either the Wakin type or Ryukin type; (2) the degree of spinal curvature is comparatively large in its value; and (3) the vertebral counts are somewhat reduced in most of the examined races.

The degree of spinal curvature and the vertebral counts have a negative correlation as a whole (the correlation coefficient:-0.8147), as shown in Fig. 5. Nevertheless, in the correlation between these features, the Jinkin and the Azumanishiki (Fig. 5, 7 and 11) of the second group with Wakin type spinal curvature seem to be different from the rest of the members of this group. In the Azumanishiki, emphasis was put on the situation of the posterior segments of vertebral column,

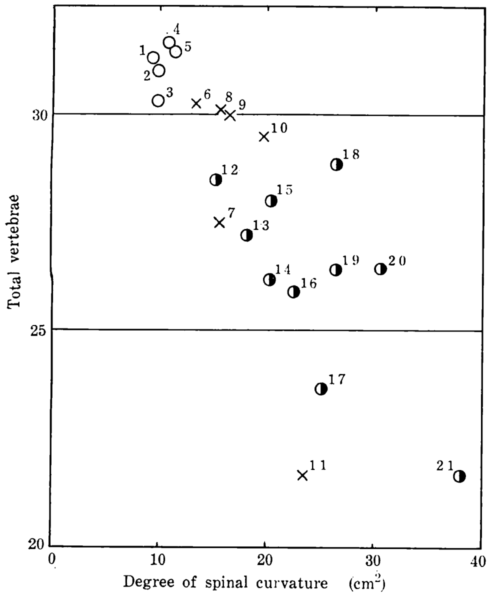

Fig. 5. Correlation between the number of total vertebrae and the degree of spinal curvature. Three kinds of marks and the numbers labeled to each mark, are same as in Fig. 4 and Table 1.

when the race was grouped in the second group on the basis of the status of the spinal curvature (Fig. 3 : 11). However, when we regarded the degree of the spinal curvature (Table 1), the number of vertebrae (Table 1) and the constitution of vertebral counts (Fig. 4 :11), the race was adequate to be included in the third group (Ryukin type). The Jikin which belongs to the second group showed a distinct constitution of vertebral counts (Fig. 4 : 7). The race was distinguished from all of other examined forms in having the curvations particularly correlated with the body axis (Fig. 2). Furthermore, the race is provided with a characteristic tetra-lobed caudal fin: each lobe is separated from others and is situated vertically against the body axis (Fig. 1 : I).

Kawamoto (1960) observed that in the slender bodied goldfish (Wakin and Shubunkin) the body cavity is narrow and the swimbladder is situated almost horizontally, and that in the short bodied goldfish (Ryukin), the swimbladder is inclined downward posteriorly and the body cavity is much larger and shorter than the slender bodied goldfish. In our examination of goldfish, the short bodied goldfish included all of the races of the Ryukin type (except for the Chotengan) and the Azumanishiki of the Wakin type. Their body cavity is larger and shorter than the slender bodied goldfish which includes the rest of the members examined. And the degree of spinal curvature of the former is comparatively large in the value as compared with the latter.

In the goldfish, the form and size of the caudal fin largely vary from race to race (Fig. 1). Fraser-Brunner (1931) reported that the proportion of the two lobes of the swimbladder is correlating with the size of the caudal fin in the common goldfish, for the adjustment of the altered center of gravity. However, Kawamoto (1960) stated that the lobes of the swimbladder of the Ryukin are not always correlated with the altered center of the body gravity. In our examination, it may be roughly said that the races of the goldfish with the simple caudal fin, such as the Funao-shaped Wakin, Shubunkin, and Comet, had the smaller values of the degree of spinal curvature and the larger number of vertebrae, as compared with other races of the goldfish with the complex tails, which will be discussed later in relation to the genealogy. Among the goldfish, the structure of the caudal skeleton that is specialized to support and operate the caudal fin, varies not only from race to race but also individually (Matsui, 1935).

In many races of the examined goldfish, the number of vertebrae largely varied from individual to individual. It has been experimentally proved that the change of temperature has effects on the number of vertebrae in fishes, such as the Medaka, *Oryzias latipes* (Temminck and Schlegel) (Lindsey and Ali, 1951) and the ninespine stickleback, *Pungitius pungitius* (Linnaeus) (Lindsey, 1962). Unfortunately, we do not know the temperature in which our examined specimens were raised. It is remarkable, however, that the extreme variations of the vartebral number can be observed in all of the hybrid races with the complex tails, such as the Azumanishiki, Calico, and Ranchu (Table 1).

Gosline (1971) stated that "the progressively increasing emphasis on caudal locomotion in teleostean evolution is associated with the general trend toward reduction in the number of vertebrae. . . . the relatively stiff bodied, tail-swinging higher teleosts often have 24 or fewer." The crucian carps have fewer number of vertebrae among the Japanese cyprinid fishes, (Nakamura, 1969). In the goldfish, though the matters are not quite similar to the case of higher teleosts, the reduction of the number of vertebrae seems to be favorable to the fish with the complex tail for tail-swinging.

Referring to the Matsui's diagram (1934) of the genealogical relationship among the Japanese goldfish, we regarded the status of spinal curvature and the variation of the vertebral number in the examined races about half of total races of the Japanese goldfish. Firstly, the Funao-shaped Wakin and Shubunkin are provided with the simple caudal fin which is genetically dominant character against the complex tail. The former is considered to be the prototype of the goldfish and the latter to be the hybrid between the crucian carp and the Sanshiki-demekin. In these two races, the spinal curvature and the constitution of vertebral counts are similar to the crusian carps. In the Comet which can be produced by crossing the crucian carp with the Ryukin (Matsui, 1935), these features can be also observed. Secondly, the Calico (Sanshiki-demekin × Ryukin) and the Azumanishiki (Sanshiki-demekin × Oranda-shishigashira) are the hybrid between two different races to the goldfish. In these two races, the degree of spinal curvature is intermediate of those of their parents, and the vertebral counts are somewhat fewer in the mean value than those of their parents. Thirdly, the following races are considered to be the matants: the Wakin to be a mutant derived from the Hibuna (red crucian carp); the Ryukin, Jikin, and Aka-demekin, from the Wakin; the Oranda-shishigashira and Tetsuonaga, from the Ryukin; the Sanshiki-demekin, Kuro-demekin, and Chotengan, from the Aka-demekin; and the Ranchu, from the Maruko. Excepting the Tetsuonaga, all races examined are characteristic in having fewer vertebral number in the mean value than their respective ancestral forms, though the relation between the Ranchu and the Maruko is uncertain because of the lack of data. In the Chinese Hanafusa, the geneological relationship between the race and the Japanese goldfish is unknown, and it has not been possible to prove the point discussed above.

Thus, the variations of the spinal curvature and the vertebral number of the goldfish seem to be correlated, in relation to their functions, with the change of the body form of the races which were artificially selected from a number of hybrids and mutants. However, as stated by Ford (1937), if a vertebral character is to be of any use in taxonomy or phylogeny, it must show a reasonable degree of intraspecific constancy. In our examined goldfish, either the spinal curvature or the vertebral number somewhat varied from individual to individual, and their extent of variation was different from race to race. Therefore, it may be unable to overrate these features in taxonomic and phylogenetic importance. A general trend of variations in these features, however, among the examined fish could be traced. In the present investigation, we have not examined the size and form of the vertebral elements, which were left for future investigations.

Acknowledgments

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キンギョの品種間における脊柱の彎曲状況と脊椎骨数の変異について

浅野 博利・久保 喜計

キンギョ 15 品種とフナ 5 型について，第 1 脊椎骨と尾端部より第 2 番目の脊椎骨とを結ぶ直線を基準とし，各椎体中央部を通るように描いた脊柱の彎曲状況を比較した．また脊柱の彎曲状況と脊椎骨数との関係も調べた．

脊柱の彎曲状況はキンブナ型(フナ 5 型)では基準線に対して腹椎骨部は上方に，尾椎骨部は下方に位置し，全般に脊柱彎曲度(基準線と曲線で囲まれる部分の面積)が小さい．キンギョでは，ワキン型(5 品種)とリュウキン型 (10 品種) に大別され，前者はキンブナ型に近いが，脊柱彎曲度が幾分大きい．リュウキン型は脊椎骨がすべて基準線より上方に位置し，脊柱彎曲度もさらに大きい．ランチュウではその傾向が特に著しい．

平均脊椎骨数はフナでは全般的に多く，キンギョでは一般に脊柱彎曲度が大きくなるに従って，次第に減少する傾向がみられる．

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