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A Theoretical Approach to the Selectivity of the Net Gears – III.*

On the Effects of Differences in Fish Shape

By
Akio FUJIISHI

There is an extensive literature relating to the gear selectivity research, which goes as far back as the late 19th Century [18]**. In the literature of the subject, we find useful references to the fact that the selection characteristics of a fishing gear are determined by the gear size and its design, the netting materials and the conditions under which it is fished, and that the selection properties differ with different species because of the marked differences in size, shape and ability to escape through the mesh. And most workers have studied the relations not only between the changes of composition of catches by the gear and its structural properties to device appropriate improvement, but also between the 50% selection point as a characteristic of the gear selectivity and the appropriate fish size at which a stock should be harvested [8]. The experimental results of some workers have been discussed in association with the length-girth relationships and the use of the ratio of body depth to breadth [8,11,12]. As referred to those results, the fact that the cross-sectional shape of fish body is one of the most important factor affecting escapement must be taken into account in examining the effects of the differences in fish shape. At present time the information about these shapes is conspicuously lacking in both quality and quantity, it needs, therefore, further investigations for the morphological characters by species.

The morphological measurements were made for six species of ground fishes and five species of Pacific salmon, including the measurements of cross-sectional shapes at two different positions. The purpose of this report is threefold:

(1) to determine whether the elliptical approximation for the fish shape used in the earlier report [10] will be good or not.

(2) to present the relations between the different measurements, for applying convenience of the theoretical methods [9,10].

(3) to describe the result of preliminary studies on how far the effects of the

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**The passage quoted from MYHRE

differences in fish shape extend to the mesh selectivity.

Materials and Methods

Present samples of the ground fishes except Alaska pollack were obtained among the commercial catches landed in the fish market in Shimonoseki and in the fishermen's

Table 1. The nomenclature used in this report regarding ground fishes and salmon. Japanese names appear in parentheses.

	No.	Species name		
Ground fish	1	Lizardfish	*Saurida tumbil*	(wani-eso)
	2	Japanese barracuda	*Sphyraena japonica*	(Yamato-kamasu)
	3	Horse mackerel	*Trachurus japonicus*	(Ma-aji)
	4	White croaker	*Argyrosomus argentatus*	(Shiro-guchi)
	5	Japanese sea bream	*Chrysophrys major*	(Ma-dai)
	6	Alaska pollack	*Teragra chalcogramma*	(Suketo-dara)
Pacific salmon	1	Sockeye salmon	*Oncorhynchus nerka*	(Beni-zake)
	2	Chum salmon	*Oncorhynchus keta*	(Shiro-zake)
	3	Pink salmon	*Oncorhynchus gorbuscha*	(Masu)
	4	Chinook salmon	*Oncorhynchus tschawytscha*	(Masu-no-suke)
	5	Coho salmon	*Oncorhynchus kisutch*	(Gin-zake)

Table 2. Number of fishes and range of body length.

Species	Total number	No. of the cross-sectional shapes measured		Range of body length (cm)
		at the body	at the head	
Lizardfish*	9	9	9	14.9 - 55.2
Japanese barracuda*	5	5	5	16.5 - 26.0
Horse mackerel*	12	12	12	15.5 - 24.5
White croaker**	10	4	0	15.6 - 19.3
Japanese sea bream*	13	13	9	12.4 - 24.9
Alaska pollack*	15	0	7	40.0 - 52.9
Sockeye salmon*	30	6	6	32.8 - 66.8
Chum salmon*	30	6	6	45.0 - 64.6
Pink salmon*	30	7	8	41.8 - 55.1
Chinook slamon*	30	7	7	37.3 - 104.0
Coho slamon*	14	1	1	50.9 - 60.0

*In the further analysis, the body length was used instead of the folk length.

**In the further analysis, the body length was used instead of the total length.

cooperative association of Yoshimi, Shimonoseki, by the coastal and pelagic trawlers. Alaska pollack and Pacific salmon were caught with the drifting gill-nets by the catcher boats belonging to the fleet of salmon factory vessel, Nojima-Maru. The former was collected in the period from September to November, 1970, and the latter was taken in different areas of the northwest Pacific Ocean and the Bering Sea during the period from May to July, 1971. Scientific names and Japanese names of fishes mentioned in this paper are listed in Table 1, number of fishes and ranges of body length in Table 2.

There are some possible dimensions for the morphological characters. The important dimensions for many fishes are probably the maximum girth or the girth at the base of first dorsal fin, the girth of some imcompressible part of the body such as the head and the cross-sectional shapes at those points[8]. For the purpose of advancing the study connected with fish shape affecting escapement, the following characters at different positions were measured besides general biological measurements on referring to the manual published by FAO[7] as shown in Fig. 1:

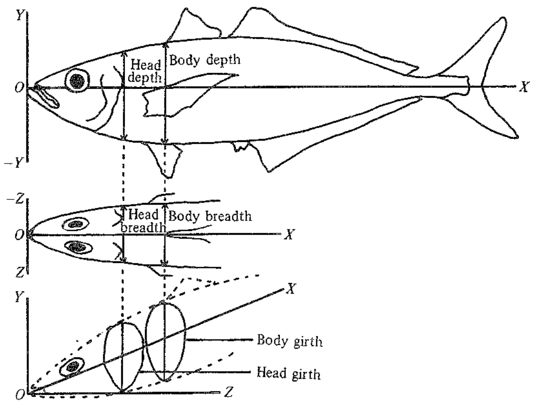

Fig. 1. Body measurements of fish.

Measured positions

(1) Posterior membranous edge gill cover,

(2) Insertion of anterior dorsal (intersection anterior margine first dorsal spine, fin held erect, with the contour of the back).

The author will call the above two positions "H-position for (1) and B-position for (2)" for convenience' sake in the further analysis.

Measurements

Longitudinal measurement

(1) Total length or fork length (B_L).

Vertical measurements

(2) Head depth at the H-position (H_D),

(3) Body depth at the B-position (B_D).

Lateral measurements

(4) Head breadth at the H-position (H_B),

(5) Body breadth at the B-position (B_B).

Other measurements

(6) Head girth at the H-position (H_G),

(7) Body girth at the B-position (B_G),

(8) Cross-sectional shapes at the above two positions,

(9) Body weight (B_W).

The length and the other linear dimensions of freshly caught ungutted fishes were measured with a measuring board or a slide caliper. The girth was measured with a flexible measure tape just closely around but not constricting the two positions. Some selected samples within the respective ranges of body length, including small size as well as large size, were their two (or one) positions cutted in three (or two) with a sharp edged tool after the above-mentioned dimensions had been measured to the centimeter below. On the occasion of measuring the complicated-shaped cross-sections, particular care was employed in keeping their original shapes because the more fresh the fish was, the larger the constriction of muscle became. In practice, a cutted cross-section in contact with paper took upright position against its lateral line, so that the external forms of the body and head shapes could be traced with a pencil along those edges. As there was a little doubt whether the obtained shapes would be true or not, the obtained shapes were corrected so that their maximum length and width were equal to the body depth (head depth) and body breadth (head breadth). The area of these cross-sections was measured with a planimeter in order to examine the adequacy of the elliptical approximation for the actual cross-section. The eccentricity of ellipse, which was used both as an index of sharpness of selection curves and as a degree of bodily thinness or flatness in the previous paper[10), was computed by the following formulae under the assumption that the fish shapes at two positions had an elliptical form.

$$\varepsilon = \sqrt{B_D{}^2 - B_B{}^2} \,/\, B_D \qquad \text{(at the } B\text{-position)} \quad \cdots\cdots \quad (1)$$

$$\varepsilon' = \sqrt{H_D{}^2 - H_B{}^2} \,/\, H_D \qquad \text{(at the } H\text{-position)} \quad \cdots\cdots \quad (2)$$

In case where the value of B_D (or H_D) is smaller than that of B_B (or H_B), the value of ε (or ε') was calculated by the substitution of B_B (or H_B) for B_D (or H_D) with each other in the formulae. By using the obtained eccentricity, the similarity between the shapes at two positions was tested in view of apparent importance of the head shape affecting escapement. Body weight was measured to the gram unit as a check upon the body length.

Results

In selection studies the effects of differences in fish shape have to be considered. While a great deal of work has been carried out on the mesh selection of trawl and gill nets, comparatively little effort has been directed toward studying the morphological characters and related measurements of fish shape though the selectivity varied according to those sizes. For many species the measurement was made of length and in case of the special analysis of selection characteristics, girth was measured in place of length.

Many workers[1,3,4,8,11,14,15], therefore, discussed the mesh selection of trawl nets by using the relation between the body length and the mesh size, or between the body girth and the inner circumference of mesh. But whether or not fishes can pass through the meshes of cod-end depends significantly upon the cross-sectional shape at the maximum girth, as well as upon the size of mesh and degree to which it is open while fishing for the cod-end. In other words, the mesh selection seems to be decided mainly by the relation between the shape and size of fishes, and those of cod-end's meshes in operation. Accordingly, the theoretical methods[9,10] developed and described by the author were founded on the relative magnitude $2a/(T/4)$ that expressed the ratio of the body depth $2a$ of a fish to half length of mesh size $T/4$ (T corresponds to the inner circumference of a mesh) as a measure of foregoing relation. At the same time the possibility should not be overlooked that some better measure than the above magnitude could be applied. For example, the less body depth or breadth at the other part of the fish body in which to estimate the selection curves theoretically may be profitable rather than the depth or breadth at the maximum girth. For this, close examination on the various species is required for this sort of geometrical method.

Among the various morphological measurements, what is most necessary in applying the theoretical methods is to get the body depth or breadth in place of the body length or girth, though there is not enough information about them in these days. Further, in order to provide useful information as to the selection characteristics and the criterion for a mesh regulation of trawl fisheries by the theoretical method, it is particularly important to examine whether the various dimensions, as shown in Fig. 1, bear a constant relation to one another. If these constant relations can be generally used, the plausibility of theoretical methods which was checked up to some extent by the published data[1] in the preceding studies[9,10] may be easily tested and compared with many experimental results because the body depth required for the relative magnitude or, alternatively the body breadth can be calculated according to one of these relations. On the other hand, in discussing gill-net's selectivity, the girth and shape of the fishes subject to gill-netting are also of primary importance[12,16]. Therefore, similar relations were calculated for the Pacific salmon.

1. Relation between the measured characters

From the above standpoint, the following relationships were calculated between the measured characters by the usual way:

(1) Regression equation of the body depth (B_D) or body breadth (B_B) on the body length (B_L),

(2) Regression equation of the head depth (H_D) or head breadth (H_B) on the body length (B_L),

(3) Regression equation of the body girth (B_G) on the body length (B_L),

(4) Regression equation of the head girth (H_G) on the body length (B_L),

(5) Regression equation of the body girth (B_G) on the body depth (B_D) or body breadth (B_B),

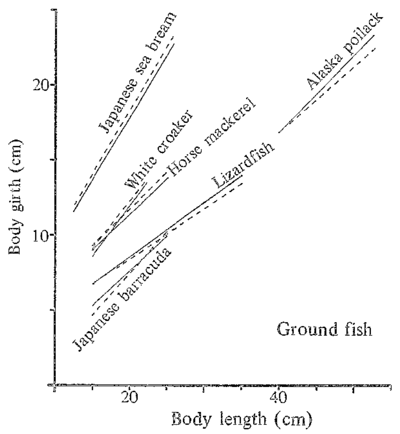

Fig. 2-1. The length-girth relationship in the present samples.
Solid line – Relation between the body girth calculated by the elliptical approximation and measured length.
Broken line – Relation between the measured body girth and length.

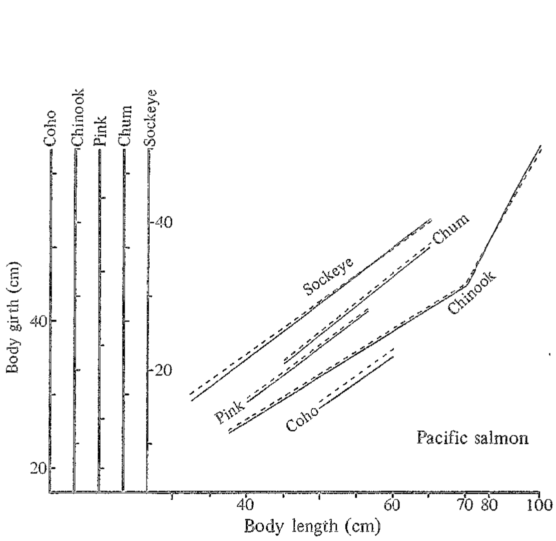

Fig. 2-3. The length-girth relationship in the present samples.
Solid line – Relation between the body girth calculated by the elliptical approximation and the measured length.
Broken line – Relation between the measured body girth and length.

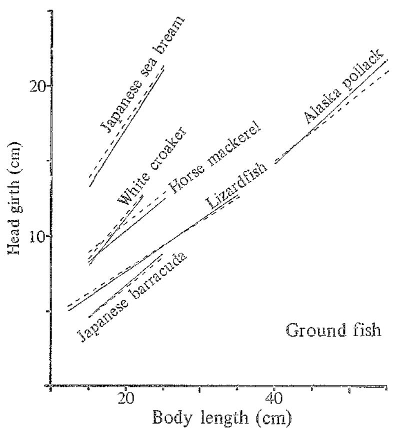

Fig. 2-2. The length-girth relationship in the present samples.
Solid line – Relation between the head girth calculated by the elliptical approximation and the measured length.
Broken line – Relation between the measured head girth and length.

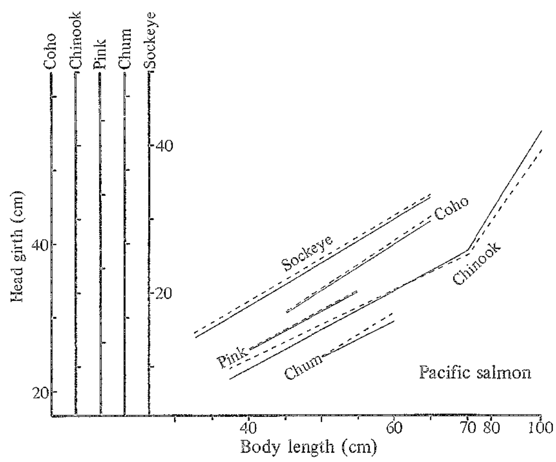

Fig. 2-4. The length-girth relationship in the present samples.
Solid line – Relation between the head girth calculated by the elliptical approximation and the measured length.
Broken line – Relation between the measured head girth and length.

(6) Regression equation of the head girth (H_G) on the head depth (H_D) or head breadth (H_B).

The equations of these fitted lines are summarized in Appendix Table A at the end of this chapter.

If a cross-section of fish body can be assumed as an ellipse and its major axis and eccentricity are $2a$ and ε, respectively, then the girth is

$$G = 4a\int_0^{\pi/2}\sqrt{1-\varepsilon^2\sin^2\phi}\,d\phi \quad \cdots\cdots (3)$$
$$\equiv 2\pi a\Phi$$

where : $\varepsilon^2 = 1-(2b)^2/(2a)^2$, $\Phi = 1-(\frac{1}{2})^2\varepsilon^2 - \cdots\cdots -\left\{\frac{1\cdot3\cdot\cdots\cdot(2n-1)}{2\cdot4\cdot\cdots\quad 2n}\right\}^2\cdot\frac{1}{(2n-1)}\varepsilon^{2n} - \cdots\cdots$

$2a$ and $2b$ correspond to the body depth and breadth, respectively.

Using the equation (3), the following relationships were calculated between the calculated girth and the measured characters by the same way:

(7) Regression of the calculated body girth ($2\pi a\Phi$) on the body length (B_L),

(8) Regression of the calculated head girth($2\pi a'\Phi$)on the body length (B_L),

(9) Regression of the calculated body girth ($2\pi a\Phi$) on the body depth (B_D) or body breadth (B_B),

(10) Regression of the calculated head girth ($2\pi a'\Phi$) on the head depth (H_D) or head breadth (H_B).

The equations of the fitted lines are also shown in the Appendix Table A. As one way of testing the validity of the elliptical approximation for the cross-section, the regression equations obtained under (3), (4), (7) and (8) are shown graphically in Fig. 2, by species and by length. Fig. 3. shows the differences between the measured body girth and head girth. Those figures are based on the equations given in the Appendix Table A. As is obvious from Fig. 2, there was no essential differences between the calculated girth and measured girth within the respective length ranges of the samples.

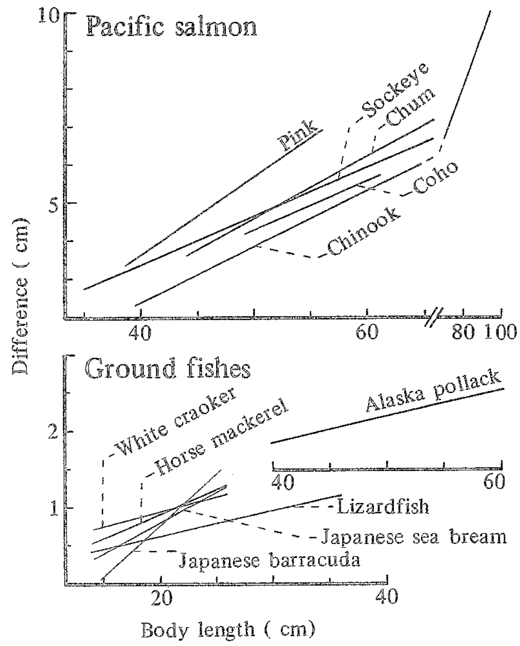

Fig. 3. The differences between the measured head girth and the measured body girth in the present samples.

2. The differences in the cross-sectional shape of fish body

The maximum girth or head girth, one of the good measure of the cross-section, has

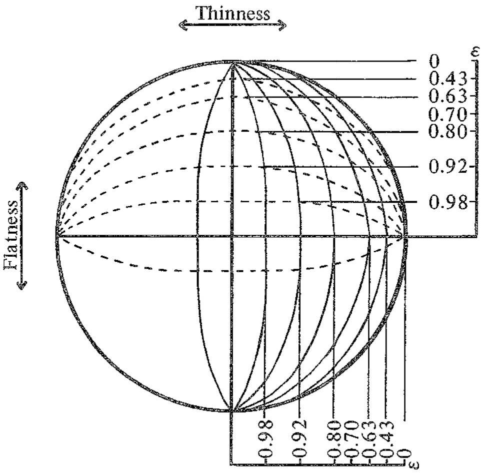

Fig. 4. Schematical representation of the thinness or flatness of fish body and the ε values of ellipse.

been frequently used in discussing how easy it was for a fish to slip through the given mesh, though the other profitable measure of cross-section should be examined in relation to the degree of thinness (or flatness) and the similarity between the shapes in question, in attempting to estimate the extent of the influence which any differences in fish shape within and between species have on the mesh selectivity. In this report, the ε and ε'values which correspond to the degree of thinness (or flatness) of fish body were calculated from the equations (1) and (2). As the value of ε increased, the shapes of round fishes become gradually thinner and those of flat fishes become flatter. Also, there is considerably large changes in thinness (or flatness) when the ε and ε' values are more than 0.7, as schemati-

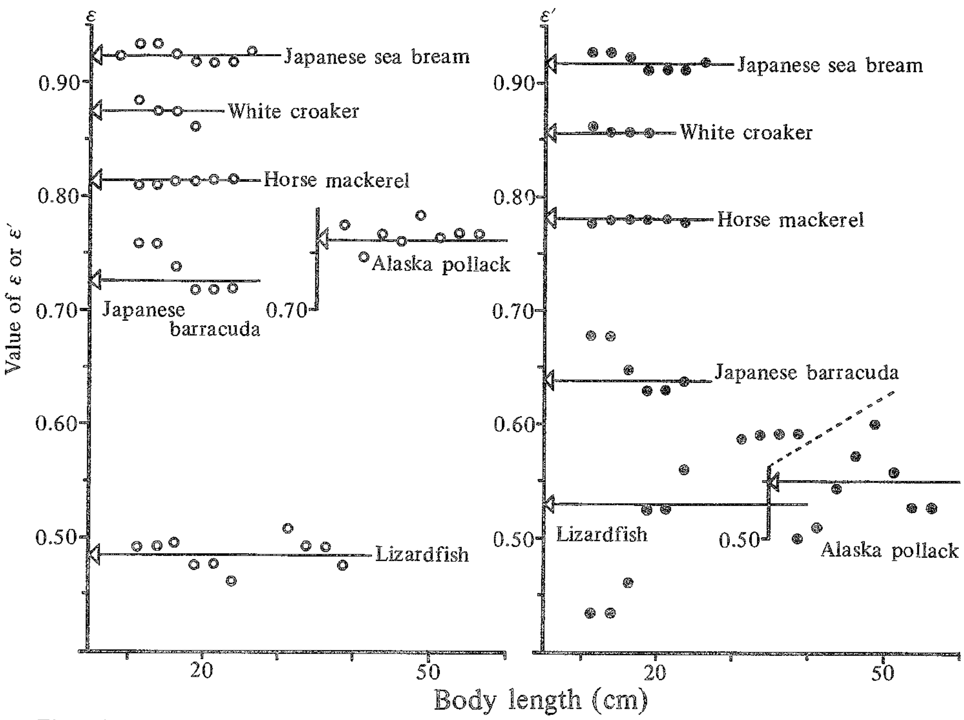

Fig. 5-1 The variation in the values of ε and ε' which were used as an index of the bodily thinness or flatness of individual fish.

cally shown in Fig. 4. The values derived from the different samples are shown in Fig. 5. Each plot in this figure was obtained from smoothing the ratios by a moving average of three at 2.5 cm intervals of body length. The following differences were detected from Figs. 4 and 5.

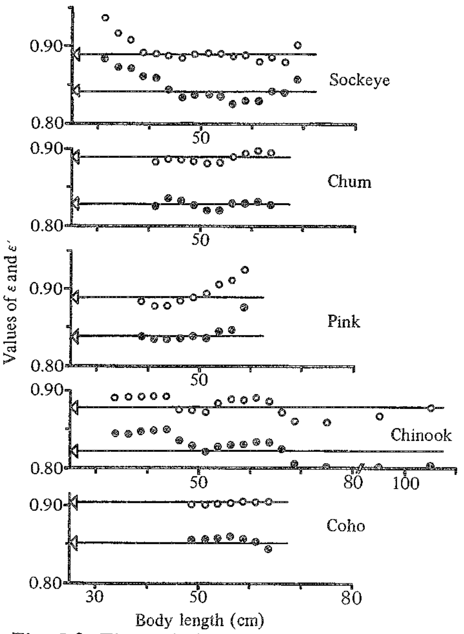

Fig. 5-2. The variation in the values of ε and ε' which were used as an index of the bodily thinness or flatness of individual fish.
Open circle – The values of ε at the B-position.
Solid circle – The values of ε' at the H-position.
Line with the triangle parallel to the abscissa – The averaged values of ε and ε'.

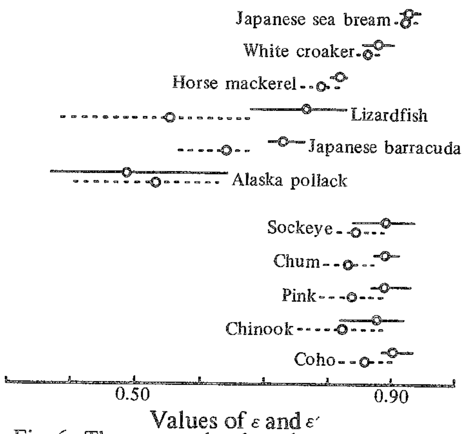

Fig. 6. The averaged values (open circle) of ε and ε' and the amount of scattering of ε and ε'.
Solid line with open circle – The values of ε.
Broken line with open circle – The values of ε'.

With the samples of six ground fishes, it is recognized that the values of ε and ε' differ according to species. These six species will be able to be divided into two sub-groups according to scattering of ε and ε' values. One is comprised of Japanese sea bream, white croaker and horse mackerel, and the other is of Japanese barracuda, lizadfish and Alaska pollack. A little difference between the average values of ε and those of ε' is found out among the former species, but relatively large difference is noted among the latter ones. Those differences are variable according to the body length amongst the former as well as the latter. In especial, there is extremely wider scattering of ε and ε' values for lizardfish and Alaska pollack. The ε' values of lizardfish are smaller in small specimens (body length under 15 cm) and larger in large ones (body length over 30 cm). On the contrary, the ε and ε' values of Japanese barracuda become smaller in large specimens as the body length increases. The ε-and-ε' differences by species are as follows:

Japanese sea bream	0.006,	Japanese barracuda	0.047,
white croaker	0.018,	lizardfish	0.049,
horse mackerel	0.029,	Alaska pollack	0.212.

In discussing whether or not the fish shape of a single species will hold similar form at different positions with each other, it will be more effective to investigate the limits of the ε and ε' values. As is obvious from Fig. 4, the ε and ε' differences of less than 0.03 are so slight as to be almost negligible when ε and ε' are larger than 0.70. It may be said, therefore, that the fish shapes at two different positions hold similar form with each other as for the species of the former group. Such a small difference is probably due to the fact that the *H*-positions of the former group were situated at a very little distance from their *B*-positions. While there is a large difference in ε and ε' values for the latter group, but even if ε or ε' is smaller than 0.70, fish shape hardly changes so long as the ε-and-ε' differences do not exceed 0.05. Accordingly, the difference between the fish shapes at two positions in Japanese barracuda and lizardfish are little, if any, but large in Alaska pollack.

With the samples of five species of Pacific salmon, when compared with the values of ε and ε' by species, considerably large difference is observed. In especial, it is apparent that those values increase both in the lower limits of length ranges for sockeye salmon and in the upper limits of length ranges for pink salmon. But there is a little difference of ε and ε' values in the length ranging from 40 cm to 60 cm (40 cm to 55 cm for pink salmon). The difference between the average value of ε and those of ε' cannot be ignored even in the above ranges, which are the available population size for salmon fishery. That is, the ε values by species were, on average, 0.05 or so larger than the ε' values at any given length. If the sample with body length of 50 cm varies in the value of ε or ε' from 0.85 to 0.90, the change which appeared in a cross-section having a constant body depth or

Table 3. The rate of similarity in the fish shapes derived from the ε and ε' values by species.

Speices	The values of ε and ε'				Rate of similarity
	ε		ε'		$R = (\varepsilon - \varepsilon')/\varepsilon$ (%)
	(Mean	σ)	(Mean	σ)	
Lizardfish	0.483	0.063	0.532	0.068	-10.14
Japanese barracuda	0.725	0.024	0.638	0.048	12.00
Horse mackerel	0.813	0.009	0.784	0.018	3.57
White croaker	0.784	0.017	0.860	0.010	2.06
Japanese sea bream	0.922	0.011	0.916	0.012	0.65
Alaska pollack	0.761	0.042	0.549	0.087	27.86
Sockeye slamon	0.889	0.023	0.841	0.021	5.40
Chum salmon	0.888	0.012	0.827	0.019	6.87
Pink salmon	0.888	0.020	0.835	0.024	5.97
Chinook salmon	0.876	0.024	0.822	0.031	6.16
Coho salmon	0.903	0.014	0.857	0.021	5.09

Note: Minus sign given in the "rate" column indicates that the cross-section of body is more circular than that of head.

head depth is exactly equivalent to the decrease of 1.1 cm in body breadth or 0.9 cm in head breadth for the same fish body. When the body breadth with the same length decreases from 6.5 cm for the ε value of 0.85 to 5.4 cm for the ε values of 0.90, the difference in girth reaches about 1.5 cm in case of the same body depth. There is no remarkable difference in the average value of ε among the five species. This is also the case of the average value of ε'. From the foregoing, it may be considered as the fish shape at different positions with dissimilar form and different size. However, the fish shapes at *B*-positions and *H*-positions for Pacific salmon are considered to be closely similar to one another. To indicate the amount of scatter in calculated values of ε and ε', the maximum and minimum values are shown in Fig. 6, together with the average values. Table 3 shows the rate of similarity between the fish shapes at the two positions.

3. The actual fish shape and area of cross-section

Fundamentally, in the mechanism of selectivity, there are many factors which are influenced by the probability. Accordingly, the theoretical methods described in the preceding reports[9,10] are based on the fact that whether fishes having the same value of relative magnitude can make those escapes or not can be considered as the problem of the probability. That fishes are selected at the "rate" corresponding to body length, have already observed in many experiments, especially, by means of the cover-nets and alternate hauls methods, and BUCHANAN-WOLLASTON[2] suggested trially the definition of "chance selection" to it. And this probability or "rate" of retention must be generated

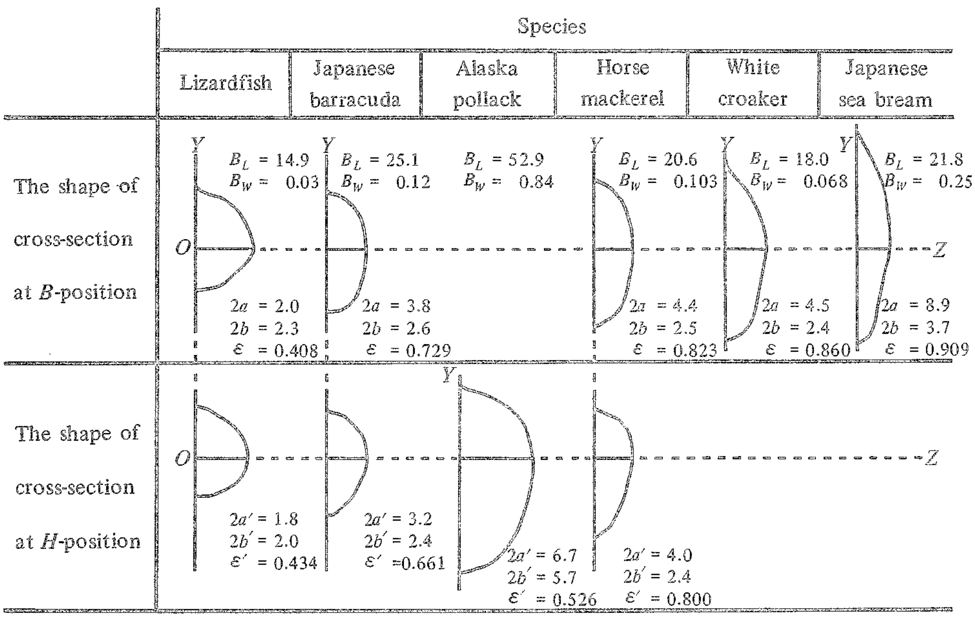

Fig. 7-1. The detailed measurements of the cross-sectional shapes at different positions by species. The letter symbols, *Y*, *Z* and *O* are the same in Fig. 1.

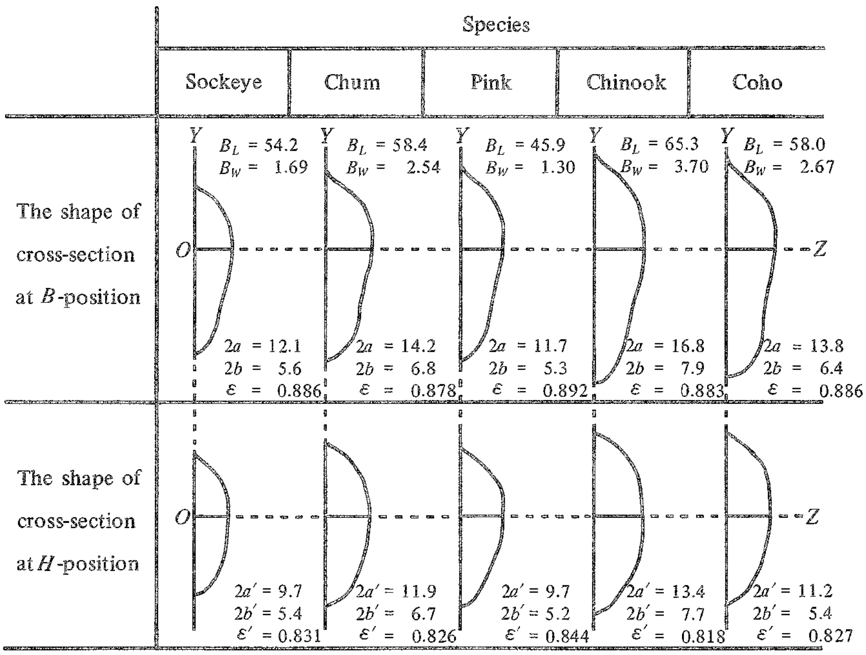

Fig. 7-2. The detailed measurements of the cross-sectional shapes at different positions by species.
B_L.,B_W., $2a$., $2b$., $2a'$ and $2b'$ are abbreviations for Body length, Body weight, Body depth, Body breadth, Head depth and Head breadth, respectively.
The values of ε were calculated from $2a$ and $2b$.
The values of ε' were calculate from $2a'$and $2b'$.

from a measrue related to the realtive magnitude. At this point the author adopted the ratio of area of cross-section of fish body to that of mesh as this measure. In so far as the theoretical methods are founded on the above-mentioned ratio, account should be taken of the areal differences in fish shapes. In general, it is often seen that the fishes will have entirely different shapes even if their girth are equal to one another. Namely, the girth is necessary to make a test of the validity of the elliptical approximation for the actual fish shapes but not enough. Accordingly, this part deals with the comparison of the measured area with the calculated area. And this comparison are used as a supporting method of the test.

With a view to testing the validity, several samples per a single species were examined in association with the areal measurements of cross-sections. The examples of detailed measurements at two positions and associated data are shown in Fig. 7, by species. Any of those shapes seem to be all right to consider as approximately elliptical forms with different eccentricities. On the understanding that the cross-sectional shape of fish body is deemed as an ellipse, the areas of cross-sections at two positions for all the samples are calculated by using the following equation from the measured body depth (head depth) and body breadth (head breadth). Area (S) *of* ellipse having the major axis $2a$

and minor axis $2b$ can be expressed as follows:

$$S = \pi ab \quad \cdots\cdots (4)$$

This can be written as

$$S = \pi a^2 \sqrt{1-\varepsilon^2} \quad \cdots\cdots (4)'$$

As being pointed out in the preceding section, the cross-sectional shapes at the specific positions are almost similar to each other in the same species. Accordingly the equation $(4)'$ is considered a quadratic equation of body depth (head depth) when ε is constant. Moreover, for many species, it has been expressed by a linear relationship between the body depth or breadth and body length, within certain limited ranges. Therefore, the area of cross-section can be given in the second order equation of body length. A graphical analysis indicated a parabolic association between the two variates, the calculated areas and the body depth (head depth) or body length for all the species examined. The same statements are true of the measured areas of cross-section. The equations for the fitted parabolae are shown in Appendix Table B.

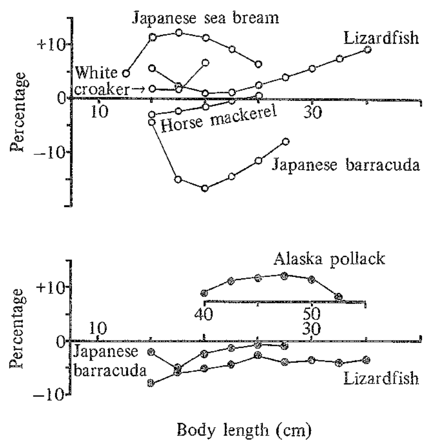

Fig. 8-1. The differences showing percentage $(S_E - S_M) / S_M$ between the measured crossectional area (S_M) and the area calculated by the elliptical approximation (S_E).

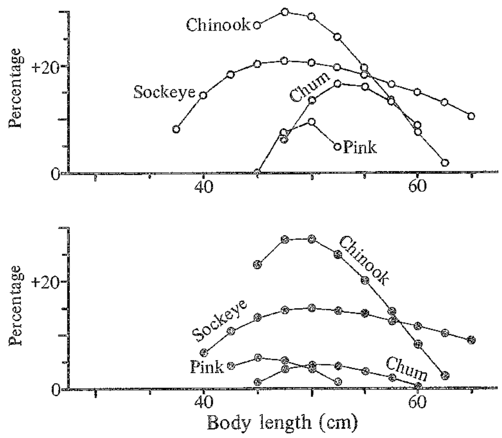

Fig. 8-2. The differences showing percentage $(S_E - S_M) / S_M$ between the measured cross-sectional area (S_M) and the calcuiated area by the elliptical approximation (S_E).
Open circle – The difference at B-position.
Solid circle – The difference at H-position.

The extent of the bias in the areas was estimated according to the parabolae derived so far; and in Fig. 8. The percentages of the areal differences were poltted against the body length. From this figure it is readily apparent that the calculated and measured areas were essentially dissimilar to each other. If we compare and contrast the actual shapes as shown in Fig. 7 with their corresponding ellipse, we will be but poorly able to make out the cause for these differences.

Discussion

Since the early 1950's a great deal of gear selectivity research has been carried out in the countries belonging to ICNAF or ICES or both, for the purpose of securing the optimum fishing rate on a given population of fish. In 1957, the factors in a situation where selective action is operating are stated in part in the Summary Report[13] of the Joint Scientific Meeting of ICNAF, ICES and FAO, p. 7 to 8.

> "It was recognized that escape by a fish or its retention by the gear were determined in the case of the mesh by the fit of the minimum value to which the greatest cross-section of the fish shape could be compressed (by its own efforts or by non-lethal other forces) to the maximum diameter to which the lumen of the net could be stretched by the efforts of the fish or by the dynamics of the gear.
>
> Fish shape: It was recognized that differences in shape might have effects that would make simple measurements of some one cross-sectional dimension unreliable as a guide to the selective relation between fish and mesh size.
>
> Mesh shape: This discussion related to the variations in the dimensions of the effective lumen of a mesh under different conditions of strain, and to similar variations as between meshes in different parts of the net. It was noted that little work had been done to determine these variations although efforts had been made to measure the consequences thought to flow from them, that is differences in selection."

It was further reported that account must be taken of the differences in fish size, behaviour patterns of fish, mesh size and mesh location.

Since then information[3,4,6,16,17,19] concerning the shape of mesh and its flexibility and escape patterns of fish has been being accumulated slowly, principally as a result of direct observation by the SCUBA divers using cameras or the underwater television. Taking the result of these observations into consideration, the theoretical methods of estimating selectivity curves were based upon the following assumptions:

(1) In the first report of this series, the meshes in the cod-end are quite rigid and in diamond shape during the whole hauling period. In the second report the meshes hold diamond shape and wide hexagonal shape in addition. Namely, there are instances where the mesh may be changed from the diamond shape into the hexagon as a slightly flexible mesh, at the condition under which a fish is in a midist of passing through the diamond-like mesh.

(2) The cross-secitonal shapes at the specific positions are similar each other in case of the same species and the body depth (or breadth) at this position is proportional to the body length of that fish. Those shapes have an elliptical form.

(3) When fishes try to pass through the mesh, they dash perpendicularly their heads against the vicinity of the center of mesh surface.

The author applied his analytical procedure to AOYAMA's experimental results[1] from the East China and the Yellow Seas, and obtained consistent selectivity curves for the species of commercial importance, including round fishes and flat fishes. The calculated curves derived from the theory did not extend very far beyond the limits of experimental error in the selection ranges and the other selection characteristics. However, it was found that some parts of these curves were not necessarily the same with the experimental curves for ten species examined[10]. These differences were a few centimeter in body length in most cases. But in the case of the upper part of the obtained curves corresponding to hair tail, *Trichiurus lepturus*, the discrepancies between two curves were at most 5 cm in snout-anus length. This anomaly probably arises because the hair tail had particular morphological features in comparison with the other nine species. In addition to the features, such a large anomaly may be due to the multiplying error in underlying the assumptions.

From the practical point of view, the assumptions, especially in respect to those of working shapes of meshes throughout the cod-end and behaviour patterns of fish species in relation to selection process, may involve some problems which must be revised and brought up to real conditions. In order to minimize the discrepancies as much as possible, it is necessary to check whether such discrepancies were traced to the assumptions. Furthermore, to what extent the assumption under (2) applies to data from the commercial fisheries is not known. The more reliable estimate for this open question here is a subjective one. As a tentative step in the close examination of the above, the adjusted selectivity curves were determined according to the same procedure[10] by using the measured areas of fish shapes at *B*-position. The findings from this test are in general accord with their original curves. In other words, the difference in cross-sectional area as shown in Fig. 8 have produced very little effect on the form of selectivity curves. This suggests that the elliptical approximation for the cross-section of fish body is still valid in a series of the sort the author has derived, and consequently the effects of differences in fish shape can be estimated to some extent from the size of ε or ε' values. The properties of ε values have been described in detail by the author.[9,10].

It should be noted, however, that there are other sources of bias in such an analysis which cannot at present be investigated. And the author concerns himself in this paper only with certain aspects of the fish shapes' problem about several specimens of round fishes. A discussion about some flat fishes will be reported at another opportunity.

Summary

One of the major objectives of gear selectivity research is to establish an adequate method of fisheries managements by the legal restrictions on mesh size. It is, however, very difficult to decide a criterion of mesh size in the complex trawl fisheries where various species are taken simultaneously because each species has its own selectivity curve[1]. The enacted mesh size to date, which is suitable only for the several fishes of

commercial size, has been decided after the consideration of the characteristics such as the 50 % selection points corresponding to those fishes. In order to keep level the latest catch and to secure a good catch in the future, it is advisable to investigate simultaneously the selection characteristics of many other fishes as well, but quite difficult. In the preceding papers the author presented the theoretical methods more favorable for the estimation of these characteristics from the data of mesh size and general biological measurements of fishes, without recourse to the experiments, though there are some problems awaiting solution in the theoretical methods that are based upon the assumptions. This paper dealt with the results of detailed and precise measurements of fish body as a first necessary step in examining the assumption regarding fish shape. And the results obtained were summarized as follows:

(1) Judging from the results of investigating the girth and the area of the cross-sectional shape of fish, the elliptical approximation for the actual cross-section might be applied to other species.

(2) To measure the girth of fishes is relatively tedious compared with the other measurements having linear dimensions, though the body girth and head girth can be calculated approximately from the data of body (head) depth and body (head) breadth. When the measured girth is compared with the calculated ones from formula (3), it may be quite all right to consider that the calculated girth is accurate enough for practical usage in the selection study.

(3) It is probable that the effects of differences in fish shape will be able to be estimated from the size of eccentricity.

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Appendix Table A. The regression equations between the various characters.

Appendix Table A–1. Between the body depth (B_D) or body breadth (B_B) and the body length (B_L).

Species		Regression equations	F
Ground fish	Lizardfish	$B_B = 0.1256\ B_L + 0.3680$	224.527**
	Japanese barracuda	$B_D = 0.1683\ B_L - 0.5221$	129.180**
	Horse mackerel	$B_D = 0.1930\ B_L + 0.6750$	269.283**
	White croaker	$B_D = 0.2394\ B_L + 0.1282$	7.247*
	Japanese sea bream	$B_D = 0.3621\ B_L + 0.6629$	221.184**
	Alaska pollack	$B_D = 0.1924\ B_L - 1.1803$	16.998**
Pacific salmon	Sockeye	$B_D = 0.3142\ B_L - 3.2924$	492.400**
	Chum	$B_D = 0.3144\ B_L - 5.9927$	300.578**
	Pink	$B_D = 0.3565\ B_L - 5.0367$	171.642**
	Chinook	$B_D = 0.2528\ B_L - 0.2781$	184.886**
	Coho	$B_D = 0.2986\ B_L - 2.6645$	28.140**

Appendix Table A–2. Between the head depth (H_D) or head breadth (H_B) and the body length (B_L).

Species		Regression equations	F
Ground fish	Lizardfish	$H_B = 0.1254\ B_L + 0.1064$	194.383**
	Japanese barracuda	$H_D = 0.1533\ B_L - 0.6544$	78.2382**
	Horse mackerel	$H_D = 0.1541\ B_L + 0.9538$	293.411**
	White croaker	$H_D = 0.2494\ B_L - 0.3695$	20.224**
	Japanese sea bream	$H_D = 0.3366\ B_L + 0.8105$	125.443**
	Alaska pollack	$H_D = 0.1681\ B_L - 1.6076$	42.041**
Pacific salmon	Sockeye	$H_D = 0.2368\ B_L - 2.0074$	687.670**
	Chum	$H_D = 0.2566\ B_L - 3.2670$	232.551**
	Pink	$H_D = 0.2285\ B_L - 1.4321$	171.642**
	Chinook	$H_D = 0.2033\ B_L - 0.0244$	283.455**
	Coho	$H_D = 0.2083\ B_L - 0.2709$	14.453**

Appendix Table A–3. Between the body girth (B_G) and the body length (B_L).

Species		Regression eqautions	F
Ground fish	Lizardfish	$B_G = 0.3481\ B_L + 1.4162$	158.232**
	Japanese barracuda	$B_G = 0.5471\ B_L - 3.6113$	562.076**
	Horse mackerel	$B_G = 0.4751\ B_L + 2.1886$	191.403**
	White croaker	$B_G = 0.6223\ B_L - 0.0867$	19.773**
	Japanese sea bream	$B_G = 0.8384\ B_L + 1.6790$	224.214**
	Alaska pollack	$B_G = 0.4318\ B_L - 0.4037$	14.430**
Pacific salmon	Sockeye	$B_G = 0.7138\ B_L - 6.3465$	578.540**
	Chum	$B_G = 0.8019\ B_L - 11.4661$	458.773**
	Pink	$B_G = 0.7352\ B_L - 6.5903$	162.648**
	Chinook	$B_G = 0.6126\ B_L - 1.1444$	209.015**
	Coho	$B_G = 0.7188\ B_L - 6.8884$	27.578**

Appendix Table A–4. Between the head girth (H_G) and the body length (B_L).

Species		Regression equations	F
Ground fish	Lizardfish	$H_G = 0.3153\ B_L + 1.4537$	64.876**
	Japanese barracuda	$H_G = 0.4125\ B_L - 1.6659$	151.976**
	Horse mackerel	$H_G = 0.4094\ B_L + 2.5919$	256.032**
	White croaker	$H_G = 0.5877\ B_L - 0.3199$	31.748**
	Japanese sea bream	$H_G = 0.7504\ B_L + 2.6358$	111.1852**
	Alaska pollack	$H_G = 0.3985\ B_L - 0.9279$	71.279**
Pacific salmon	Sockeye	$H_G = 0.5865\ B_L - 4.6063$	671.560**
	Chum	$H_G = 0.6378\ B_L - 7.8250$	257.143**
	Pink	$H_G = 0.5311\ B_L - 2.0446$	110.506**
	Chinook	$H_G = 0.4697\ B_L + 2.1879$	299.905**
	Coho	$H_G = 0.5928\ B_L - 4.8652$	33.380**

Appendix Table A–5. Between the body girth (B_G) and the body depth (B_D) or body breadth (B_B).

Species		Regression equations	F
Ground fish	Lizardfish	$B_G = 2.7731\ B_B + 0.3902$	621.723**
	Japanese barracuda	$B_G = 3.2104\ B_D - 1.7849$	393.072**
	Horse mackerel	$B_G = 2.4264\ B_D + 0.6835$	227.806**
	White croaker	$B_G = 2.0249\ B_D + 2.0242$	79.443**
	Japanese sea bream	$B_G = 2.3188\ B_D + 0.1176$	1254.052**
	Alaska pollack	$B_G = 2.2094\ B_D + 2.5090$	116.869**
Pacific salmon	Sockeye	$B_G = 2.2426\ B_D + 1.5728$	1789.100**
	Chum	$B_G = 2.2070\ B_D + 2.3686$	795.321**
	Pink	$B_G = 2.1048\ B_D + 3.3336$	955.956**
	Chinnok	$B_G = 2.3956\ B_D - 0.0377$	3366.324**
	Coho	$B_G = 2.2054\ B_D + 2.3070$	61.736**

Appendix Table A–6. Between the head girth (H_G) and the head depth (H_D) or head breadth (H_B).

Species		Regression equations	F
Ground fish	Lizardfish	$H_G = 2.4750\ H_B + 1.3007$	370.520**
	Japanese barracuda	$H_G = 2.6676\ H_H + 0.2108$	267.323**
	Horse mackerel	$H_G = 2.5990\ H_H + 0.2841$	207.347**
	White croaker	$H_G = 2.1900\ H_H + 1.2590$	157.314**
	Japanese sea bream	$H_G = 2.2211\ H_H + 0.8950$	482.895**
	Alaska pollack	$H_G = 2.1859\ H_H + 3.9984$	208.609**
Pacific salmon	Sockeye	$H_G = 2.4447\ H_H + 0.6977$	1192.392**
	Chum	$H_G = 2.4226\ H_H + 0.9858$	701.261**
	Pink	$H_G = 2.0389\ H_H + 4.1707$	244.845**
	Chinook	$H_G = 2.4512\ H_H + 0.5755$	2697.772**
	Coho	$H_G = 2.1131\ H_H + 4.2544$	34.553**

Appendix Table A–7. Between the calculated body girth ($2\pi a\Phi$) and the body length (B_L).

Species		Regression equations	F
Gorund fish	Lizardfish	$2\pi a\Phi = 0.3648\ B_L + 1.2572$	169.769^{**}
	Japanese barracuda	$2\pi a\Phi = 0.4682\ B_L - 1.8095$	330.344^{**}
	Horse mackerel	$2\pi a\Phi = 0.4846\ B_L + 1.6919$	253.860^{**}
	White croaker	$2\pi a\Phi = 0.6851\ B_L - 1.7064$	14.245^{**}
	Japanese sea bream	$2\pi a\Phi = 0.8329\ B_L + 1.1383$	193.236^{**}
	Alaska pollack	$2\pi a\Phi = 0.5009\ B_L - 3.0876$	24.368^{**}
Pacific salmon	Sockeye	$2\pi a\Phi = 0.7450\ B_L - 8.2343$	561.799^{**}
	Chum	$2\pi a\Phi = 0.7795\ B_L - 10.8437$	363.854^{**}
	Pink	$2\pi a\Phi = 0.7491\ B_L - 7.7481$	188.478^{**}
	Chinook	$2\pi a\Phi = 0.6230\ B_L - 2.0587$	254.378^{**}
	Coho	$2\pi a\Phi = 0.6273\ B_L - 2.7793$	37.446^{**}

Appendix Table A–8. Between the calculated head girth ($2\pi a'\Phi$) and the body length (B_L).

Species		Regression equations	F
Ground fish	Lizardfish	$2\pi a'\Phi = 0.3384\ B_L + 0.9374$	174.630^{**}
	Japanese barracuda	$2\pi a'\Phi = 0.4317\ B_L - 1.9774$	214.617^{**}
	Horse mackerel	$2\pi a'\Phi = 0.4039\ B_L + 2.2759$	352.960^{**}
	White croaker	$2\pi a'\Phi = 0.6292\ B_L - 1.4339$	22.200^{**}
	Japanese sea bream	$2\pi a'\Phi = 0.7685\ B_L + 1.7162$	101.101^{**}
	Alaska pollack	$2\pi a'\Phi = 0.4511\ B_L - 3.1609$	65.598^{**}
Pacific salmon	Sockeye	$2\pi a'\Phi = 0.5923\ B_L - 5.5649$	720.466^{**}
	Chum	$2\pi a'\Phi = 0.6195\ B_L - 7.2475$	358.246^{**}
	Pink	$2\pi a'\Phi = 0.5313\ B_L - 2.0579$	148.695^{**}
	Chinook	$2\pi a'\Phi = 0.5399\ B_L - 1.9826$	343.858^{**}
	Coho	$2\pi a'\Phi = 0.4829\ B_L + 0.4830$	23.508^{**}

Appendix Table A–9. Between the calculated body girth ($2\pi a\Phi$) and the body depth (B_D) or body breadth (B_B).

Species		Regression equations	F
Ground fish	Lizardfish	$2\pi a\Phi = 2.9085\ B_B + 0.1731$	1101.003^{**}
	Japanese barracuda	$2\pi a\Phi = 2.7581\ B_D - 0.2819$	929.110^{**}
	Horse mackerel	$2\pi a\Phi = 2.5088\ B_D + 0.0034$	2826.212^{**}
	White croaker	$2\pi a\Phi = 2.4267\ B_D - 0.2229$	239.924^{**}
	Japanese sea bream	$2\pi a\Phi = 2.2035\ B_D - 0.4129$	2630.269^{**}
	Alaska pollack	$2\pi a\Phi = 2.3762\ B_D + 1.7045$	298.967^{**}
Pacific salmon	Sockeye	$2\pi a\Phi = 2.3498\ B_D - 0.0977$	1251.083^{**}
	Chum	$2\pi a\Phi = 2.2273\ B_D + 1.5347$	2215.230^{**}
	Pink	$2\pi a\Phi = 2.0643\ B_D + 3.3001$	293.550^{**}
	Chinook	$2\pi a\Phi = 2.4086\ B_D - 0.5563$	2263.340^{**}
	Coho	$2\pi a\Phi = 1.9631\ B_D + 4.7481$	156.998^{**}

Appendix Table A–10. Between the calculated head girth ($2\pi a'\Phi$) and the head depth (H_D) or head breadth (H_B).

Species		Regression equations	F
Gournd fish	Lizardfish	$2\pi a'\Phi = 2.7013\ H_B + 0.5417$	3979.671**
	Japanese barracuda	$2\pi a'\Phi = 2.7897\ H_D - 0.0074$	423.290**
	Horse mackerel	$2\pi a'\Phi = 2.5909\ H_D - 0.1029$	569.643**
	White croaker	$2\pi a'\Phi = 2.4905\ H_D - 0.3113$	640.255**
	Japanese sea bream	$2\pi a'\Phi = 2.2886\ H_D - 0.1751$	864.861**
	Alaska pollack	$2\pi a'\Phi = 2.4961\ H_D + 2.2848$	225.688**
Pacific salmon	Sockeye	$2\pi a'\Phi = 2.4664\ H_D - 0.2154$	2330.989**
	Chum	$2\pi a'\Phi = 2.3552\ H_D + 1.3629$	899.789**
	Pink	$2\pi a'\Phi = 2.2758\ H_D + 1.6997$	358.444**
	Chinook	$2\pi a'\Phi = 2.6303\ H_D - 1.7294$	3094.287**
	Coho	$2\pi a'\Phi = 2.0300\ H_D + 4.3948$	156.998**

In all the tables, * significant 0.05 level,
** significant 0.01 level.

Appendix Table B. The parabolic equations between the areas of cross-sections at different positions and the body length.

Appendix Table B–1. Between the measured area at the B-position (S_B) and the body length (B_L).

Species		Regression equations	F
Ground fish	Lizardfish	$S_B = 0.0136\ (B_L)^2 - 0.1440\ (B_L) + 3.1530$	49.172**
	Japanese barracuda	$S_B = 0.0074\ (B_L)^2 + 0.3263\ (B_L) - 4.3438$	868.358**
	Horse mackerel	$S_B = 0.0497\ (B_L)^2 - 1.2065\ (B_L) + 13.5365$	149.125**
	White croaker	$S_B = 0.1697\ (B_L)^2 + 6.8648\ (B_L) - 61.1091$	12.933**
	Japanese sea bream	$S_B = 0.0021\ (B_L)^2 + 1.4697\ (B_L) - 12.2733$	38.261**
	Alasak pollack	————	————
Pacific salmon	Sockeye	$S_B = 0.0519\ (B_L)^2 - 2.7458\ (B_L) + 53.3438$	38.180**
	Chum	$S_B = 0.1349\ (B_L)^2 - 11.6736\ (B_L) + 292.3139$	1885.424**
	Pink	$S_B = 0.2712\ (B_L)^2 - 24.2533\ (B_L) + 586.6290$	11.964*
	Chinook	$S_B = 0.1327\ (B_L)^2 - 11.6119\ (B_L) + 292.0419$	131.905**
	Coho	————	————

Appendix Table B−2. Between the measured area at the *H*-position (S_H) and the body length (B_L).

Species		Regression equations	F
Ground fish	Lizardfish	$S_H = 0.0150\ (B_L)^2 - 0.2465\ (B_L) + 3.5711$	82.350^{**}
	Japanese barracuda	$S_H = 0.0191\ (B_L)^2 - 0.3363\ (B_L) + 2.5516$	63.630^{**}
	Horse mackerel	$S_H = 0.0178\ (B_L)^2 - 0.1203\ (B_L) + 3.3667$	99.331^{**}
	White croaker	———	———
	Japanese sea bream	———	———
	Alaska pollack	$S_H = -0.0450\ (B_L)^2 + 5.1827\ (B_L) - 120.8388$	70.721^{**}
Pacific salmon	Sockeye	$S_H = 0.0377\ (B_L)^2 - 1.9767\ (B_L) + 40.2893$	80.731^{**}
	Chum	$S_H = 0.0433\ (B_L)^2 - 2.2655\ (B_L) + 44.0390$	63.109^{**}
	Pink	$S_H = 0.0627\ (B_L)^2 - 4.2359\ (B_L) + 95.9494$	14.580^{**}
	Chinook	$S_H = 0.1056\ (B_L)^2 - 9.2098\ (B_L) + 231.1785$	157.493^{**}
	Coho	———	———

Appendix Table B−3. Between the calculated area at the *B*-position (S_{B-C}) and the body length (B_L).

Species		Regression equations	F
Ground fish	Lizardfish	$S_{B-C} = 0.0196\ (B_L)^2 - 0.3883\ (B_L) + 5.6835$	87.319^{**}
	Japanese barracuda	$S_{B-C} = 0.0203\ (B_L)^2 - 0.2779\ (B_L) + 1.7394$	139.986^{**}
	Horse mackerel	$S_{B-C} = 0.0531\ (B_L)^2 - 1.3130\ (B_L) + 14.1840$	145.714^{**}
	White croaker	$S_{B-C} = -0.1395\ (B_L)^2 + 5.9103\ (B_L) - 53.5166$	14.991^{**}
	Japanese sea bream	$S_{B-C} = -0.0214\ (B_L)^2 + 2.4583\ (B_L) - 20.6258$	43.893^{**}
	Alaska pollack	$S_{B-C} = -0.0335\ (B_L)^2 + 4.5542\ (B_L) - 108.1210$	11.245^{**}
Pacific salmon	Sockeye	$S_{B-C} = 0.0337\ (B_L)^2 - 0.5510\ (B_L) - 1.3143$	120.475^{**}
	Chum	$S_{B-C} = 0.0208\ (B_L)^2 + 0.9358\ (B_L) - 46.5496$	104.447^{**}
	Pink	$S_{B-C} = 0.0787\ (B_L)^2 - 5.1143\ (B_L) + 115.4754$	97.503^{**}
	Chinook	$S_{B-C} = 0.0588\ (B_L)^2 - 4.1912\ (B_L) + 118.1732$	112.135^{**}
	Coho	$S_{B-C} = 0.0450\ (B_L)^2 - 2.5602\ (B_L) + 68.4343$	17.531^{**}

Appendix Table B−4. Between the calculated area at the *H*-position (S_{H-C}) and the body length (B_L).

Species		Regression equations	F
Ground fish	Lizardfish	$S_{H-C} = 0.0142\ (B_L)^2 - 0.2171\ (B_L) + 3.0675$	121.299^{**}
	Japanese barracuda	$S_{H-C} = 00.174\ (B_L)^2 - 0.2552\ (B_L) + 1.5435$	95.560^{**}
	Horse mackerel	$S_{H-C} = 0.0369\ (B_L)^2 - 0.8352\ (B_L) + 9.7236$	198.330^{**}
	White croaker	$S_{H-C} = -0.1347\ (B_L)^2 + 5.4895\ (B_L) - 48.4570$	13.387^{**}
	Japanese sea beram	$S_{H-C} = -0.0488\ (B_L)^2 + 3.3127\ (B_L) - 27.2911$	27.731^{**}
	Alaska pollack	$S_{H-C} = -0.0608\ (B_L)^2 + 6.7763\ (B_L) - 157.9600$	45.185^{**}
Pacific salmon	Sockeye	$S_{H-C} = 0.0254\ (B_L)^2 - 0.4962\ (B_L) + 2.1511$	198.298^{**}
	Chum	$S_{H-C} = 0.0158\ (B_L)^2 + 0.6154\ (B_L) - 29.5313$	153.109^{**}
	Pink	$S_{H-C} = 0.0240\ (B_L)^2 - 0.6179\ (B_L) + 13.3663$	135.999^{**}
	Chinook	$S_{H-C} = 0.0399\ (B_L)^2 - 2.4624\ (B_L) + 67.5069$	99.451^{**}
	Coho	$S_{H-C} = 0.0509\ (B_L)^2 - 4.2362\ (B_L) + 130.7374$	13.335^{**}

In all the tables, *significant 0.05 level, ** significant 0.01 level.