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A new approach of determining gillnet selectivity based on the relationship between fish length and girth to estimate the length distribution of fish encountering a net

Yasuzumi FUJIMORI[1)]

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Abstract

A method of estimating the length distribution of fish that encounter a gillnet based on selectivity curve using the length–girth relationship of the target fish was proposed for use in fish surveys. This method was verified in a tank experiment using gillnets for rainbow trout (*Oncorhynchus mykiss*) of known size composition. Data from one body part of fish caught, near the dorsal fin, were used to estimate the selectivity curve. The curves, expressed as a normal curve, of each mesh size had the same shape, even though each was estimated individually. Additionally, there was a complete linear relationship between the mean of the curves regarded as the optimal girth and the mesh size. The estimated length distribution of the fish population corresponded to the length distribution of fish used in the tank experiment. These results confined the the efficacy of proposed method.

Key words : Gillnet, Selectivity curve, Fish girth, Survey

Introduction

Gillnets are used widely, both as commercial gear and as sampling gear for stock investigations. In stock investigations, they are used for biological sampling and estimating the size distribution of target species. However, researchers must consider mesh selectivity when estimating the size distribution of target species (Willis et al., 1985 ; Boy and Crivelli, 1988) and require precise estimates of the mesh selectivity of the gear used. Therefore, a method of estimating theoretical mesh selectivity curves based on the fish selection mechanism of gillnets is necessary.

There have been many studies of the mesh selectivity of gillnets and many reports about estimating selectivity curves (Hamley, 1975 ; Hovgård and Lassen, 2000). These methods can be divided into indirect and direct methods. In indirect estimates, mesh selectivity of gillnets is estimated as a relative value based on the numbers caught by more than one mesh size (Millar, 1992 ; Fujimori and Tokai, 2001). In direct estimates, a mesh selectivity curve is estimated based on pond or tank experiments with fishes of a known size composition (Koike, 1961 ; Fujimori et al., 1990) or tagging experiments (Hamley and Regier, 1973). The mesh selectivity curves estimated in most of the above-mentioned studies will be influenced by changes in the size distribution of fishes and seasonal differences of fish body condition. There are few studies in which the mesh selectivity curve has been estimated theoretically based on the fish-selection mechanism of gillnets. Sechin (1969) and Kawamura (1972) determined theoretical mesh-selectivity curves. Matsuoka et al. (1995) proposed a modified version of Kawamura's method. These methods are based on the rate of fish holding by mesh determined by the linear relationship between mesh and girth perimeter and its variance. A selectivity curve therefore can be estimated without being dependent on the catch if the length-girth relation of the target fish in each season is known. However, Reis and Pawson (1992) and Pet et al. (1995), who applied Sechin's method, report that this method is unsuitable for some species. This is conceivable assuming a mesh selects equally all parts of a fish's body. Actually, most fishes have protrusions such as operculums, pectoral fins, and dorsal fins that easily become entrapped in nets.

Nashimoto (1965) interpreted the selectivity of gillnets as a physical character determined by a balance between the stretch of thread and a fish body contraction by mesh. Accordingly, the factors of the dispersion that give a wide selection for gillnets must be clarified to accurately estimate the mesh selectivity as a physical characteristic. These factors can be classified into four kinds : 1) Multiple selection : Since a mesh does not always select only one part of the fish body, the length distribution of the fish caught consist of the distribution on several body parts (Pope et al. 1975 ; Hovgård, 1996). That length distribution will be wide if the girth of those parts is different. 2) Dispersion of the fish body condition : Relations between the girth and length of fishes can not be shown in one pair for an individual difference in growth. 3) Productive unevenness of mesh size : The mesh

[1)] *Laboratory of Marine Environment and Resource Sensing, Faculty of Fisheries Sciences*
(北海道大学大学院水産科学研究院海洋計測学講座)

size is not even, though the net is made in accordance with standards (Ferro and Xu, 1996). 4) Measurement error : An error in fish body measuring and duplication of the error by a second person. 1) and 2) are factors concerned with size selection by nets. This study describes a method for determining the selectivity curve of gillnets considering the influence of both factors and examines a method of estimating the length distribution of a population that encounter a net.

Materials and Methods

Distinctions of data by catch part

To reduce the influence of the dispersion by multiple selection in the mesh selectivity curve estimation, data must be separated based on the body part that is most often wedged or entangled in the net. Because this part has a certain range on fish body, it is desirable to use data on the part that has no change in the girth inside the range, such as the trunk of Pacific saury. Accordingly, a part is appropriate to selectivity estimation when the length–girth relationships at both ends of the range do not differ.

Estimation of mesh selectivity curve and length distribution of encountered population

Kawamura (1972) supposed the dispersion of the girth that corresponds to a certain length to become a normal distribution. In present study, the dispersion of the length that corresponds to the girth G_p is supposed to follow a normal distribution with mean length $\overline{l}_p$ and variance σ as $N\left(\overline{l}_p,\sigma\right)$. Moreover, the variance σ is constant for all G_p. The term p shows the class of the girth that $\overline{l}$ corresponds to. The relationship between the length l and girth G is shown as follows :

$$l = aG + b \tag{1}$$

The density distribution of the length d_j is shown as

$$N\left(aG_p + b,\sigma\right) = \frac{1}{\sqrt{2\pi}\,\sigma} e^{-\frac{1}{2}\left(\frac{l_j-(aG_p+b)}{\sigma}\right)^2} \tag{2}$$

Here, l_j is the j–th class length and G_p is the p–th class girth.

The catch per unit effort, C_{ij}, by the mesh size m_i to the length l_j is assumed in the following equation, which was expanded from the equation used by Kitahara (1968).

$$C_{ij}=S_{ij} \cdot q \cdot d_j \cdot A \tag{3}$$

Where S_{ij} is the mesh selectivity by mesh size m_i to length l_j, d_j is the relative density of fish at l_j expressed in Eq. (2) and A is the number of fish in the population. The catching efficiency q is assumed to be constant for all fish sizes and mesh sizes. When the selective target of the mesh is the girth, that is, when S_{ij} is substituted for S_{ip}, the length distributions shown in Eq. (2) must be taken into consideration. That distribution continues with the girth in accordance with the length–girth relationship of Eq. (1), as shown in Fig. 1. Therefore, the numbers caught (C_{ij}) in this case is the total number at length l_j of each girth G_p.

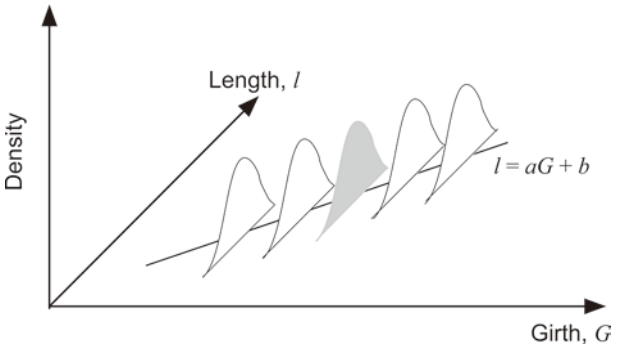

Fig. 1. Schematic of length distribution continued toward the girth with linear relationship.

$$C_{ij} = \sum_p S_{ip} \cdot q \cdot n_p \cdot \frac{1}{\sqrt{2\pi}\,\sigma} e^{-\frac{1}{2}\left(\frac{l_j-(aG_p+b)}{\sigma}\right)^2} \tag{4}$$

The catching efficiency q is influenced by the behavior character of each fish species and its diurnal activity (Fujimori et al., 1994), and the net material (Collins, 1992 ; Machiels et al., 1994). In the present study, the value q is assumed to be constant because the nets were made of the same material, and used with the same fish species. n_p is the number of fish at girth G_p in the fish population $\left(A = \sum_p n_p\right)$. The mesh selectivity S_{ip} of mesh size m_i to girth G_p is assumed in the follow equation to be a function of girth :

$$S_{ip} = S_i\left(G\right) = e^{-\frac{1}{2}\left(\frac{G_p-\lambda_i}{\omega_i}\right)^2} \tag{5}$$

Here, λ_i is the optimal girth with maximum selectivity, and ω_i is the parameter which determines the width of the selectivity curve.

The length distribution of fish that encounter a net with mesh size m_i, E_{ij}, is shown as follows from Eq. (4) :

$$E_{ij} = q\sum_p n_p \cdot \frac{1}{\sqrt{2\pi}\,\sigma} e^{-\frac{1}{2}\left(\frac{l_j-(aG_p+b)}{\sigma}\right)^2} \tag{6}$$

If the girth range of the target population is covered by the series of mesh sizes used, the number of j–th class fish in population n_j is estimated by summing up the j–th class number of fish encountered for each mesh size using an inverse of the catching efficiency as follows :

$$n_j = 1 / q\sum_i E_{ij} \tag{7}$$

The values λ_i, ω_i, and n_p are estimated by minimizing the MSE (mean square error) between the experimental catch and

the estimates from Eq. (4) with the simplex method (Nelder and Mead, 1965).

Tank Experiment

A tank experiment was conducted at the Ohizumi Freshwater Experimental Station of Tokyo University of Marine Science and Technology using short (500 × 80 cm) gillnets with different mesh sizes (4.1, 4.6, 5.1 cm, stretched mesh size). The nets were made of brown multi-filament nylon with twine size 210D/2. The nets had a hanging ratio of 60%. The experimental fish consisted of about 3,000 one-year-old rainbow trout (*Oncorhyncus mykiss*). A total of 150-200 fish was released into a concrete tank (400 × 600 × 100 cm) after their fork length were measured. The fishing experiments commenced after sunset (20 : 00 p.m.). Four replicates were conducted at 30-minute intervals using a different mesh size everyday. The duration between net setting and hauling was 30 minutes, as described by Losanes et al. (1992). Catch was removed from the net after each replicate. Fork length and distance between proboscis and catch position were recorded. The catch position was judged by the net mark, which was a wound caused who snagged by a mesh. The same number of fish caught were replaced in the tank for the next replicate to keep the number of fish constant. Fish that were not caught at the end of a day were replaced with new individuals on the following day.

An analysis was conducted for the total catch data of each mesh size. The catch position was expressed as a value relative to the fork length. A total of 200 fish were sampled at random from the group of experiment fish, and their bodies were measured to examine the relationship between length and girth. The fork length and the distance between the proboscis and several protruding parts (a : maxilla ; b : pre-operculum ; c : operculum ; d : pectoral fin ; and e : dorsal fin) are shown in Fig. 2, and their girths were recorded. The relationship between the girth and the distance stated above is shown in Fig. 3, expressed as the relative value to fork length.

Results

Frequencies of catch part

Table 1 shows the length distribution of the fish in the tank and fish caught for each mesh size. The 4.1 cm-mesh net had the highest catch. The distribution of catch positions on the fish is shown in Fig. 4. For the 4.1 cm-mesh net, the highest frequency of catch position occured at 0.15-0.2 in relative length, decreased gradually after that, and showed a mode again at 0.4-0.45. There are modes near 0.2 and 0.4-0.45 for the other mesh sizes as well. The position of the first mode around 0.2 clearly corresponds with the range that contains the pre-operculum, operculum, and pectoral fins from Fig. 2. Furthermore, the position of the second mode (0.4-0.45) occurred near the front base of the dorsal fin. These results show that the catch of rainbow trout occurred at these two parts. These parts can be divided into two ranges of 0.15-0.3 and 0.3-0.45 relative length. There were not many differences in girth in the range to the dorsal fin after the pectoral fin (Fig. 3). It is therefore considered that the catch data in the range of 0.3-0.45 were suitable for estimating the mesh selectivity curve.

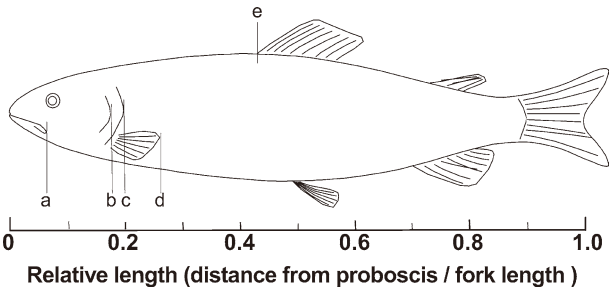

Fig. 2. Drawing of a rainbow trout used in the experiment. Each abbreviation from a to e shows a measuring position : a, end of maxilla ; b, pre-operculum ; c, operculum ; d, pectoral fin ; e, dorsal fin.

Mesh selectivity curve

Table 2 shows the parameter and AIC value (Akaike, 1974) of the linear regression for the relations between length and girth. The calculation was done using the data from the pectoral fins and dorsal fin, which were at both ends of the 0.3-0.45 range, and the data of both were combined. It is thought that no difference occurred in the length-girth relations at the pectoral fins and the dorsal fin, because the AIC value in the estimation for the data combined was less than that for the data separately. Therefore, the parameter when

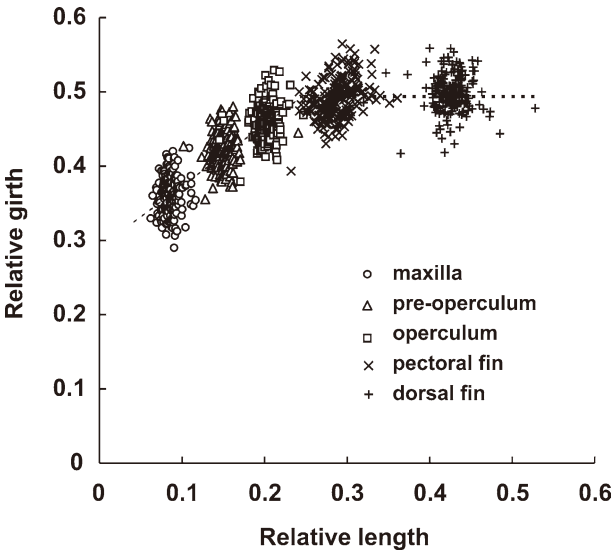

Fig. 3. Relationship between the length and the girth of each measuring position : maxilla, pre-operculum, operculum, pectoral fin, and dorsal fin. Both the length and the girth are standardized by the fork length.

Table 1. Length distributions[1] of fish in the tank and fish caught at the two body parts distinguished by net marks.

	Mesh size (cm)								
	4.1			4.6			5.1		
Length class (cm)	Fish in tank	maxilla–pectoral fin (0.10<0.25)[2]	trunk (0.25≦0.45)	Fish in tank	maxilla–pectoral fin (0.10<0.25)	trunk (0.25≦0.45)	Fish in tank	maxilla–pectoral fin (0.10<0.25)	trunk (0.25≦0.45)
15 - 15.9	23	0	2	12	0	0	4	0	0
16 - 16.9	86	0	13	46	0	0	44	0	0
17 - 17.9	160	12	27	134	0	2	128	0	0
18 - 18.9	185	18	25	220	0	12	197	0	1
19 - 19.9	183	19	8	125	5	26	169	1	9
20 - 20.9	121	11	0	50	2	8	42	1	11
21 - 21.9	33	0	0	13	2	3	15	0	2
22 - 22.9	9	0	0	0	0	0	1	0	0
23 - 23.9	0	0	0	0	0	0	0	0	0

[1] Numbers are the total of four replicates at each mesh size.

[2] The parentheses shows the captured position in relative length shown in Fig. 2.

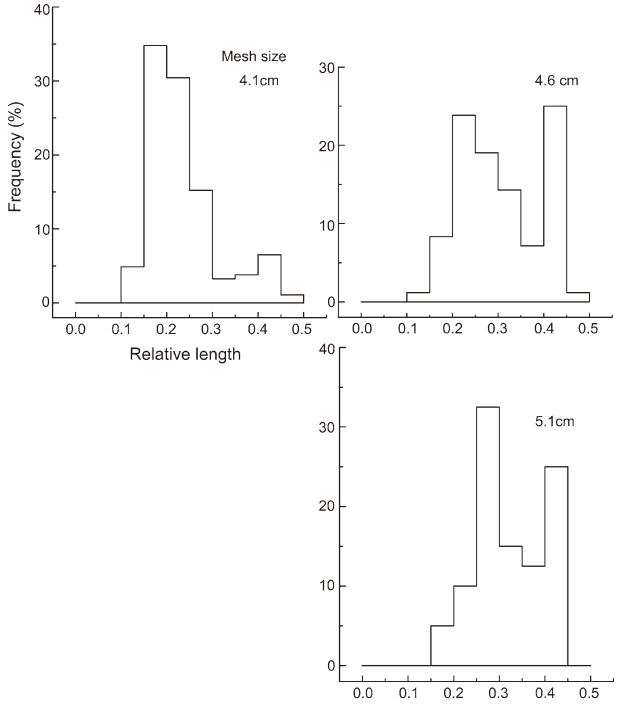

Fig. 4. Frequency of the net mark position on fish body in relative length.

data were combined was adopted for determining the mesh selectivity curve. The mean of the length variance in every girth class (d = 0.5 cm) at the pectoral fins and the dorsal fin as shown in Fig. 3 was used as σ in Eq. (2), in which the variance was calculated for the mean length $l = aG + b$ (σ = 0.80, min : 0.65, max : 0.95). Fig. 5 shows the numbers caught in the experiment estimated by the calculation in Eq. (4). The range and form of the distribution by the calculation corresponded well with the experimental data (Kolmogorov–Smirnov test, P<0.05).

The determined mesh selectivity curve for fish girth is shown in Fig. 6. All curves have the same shape. The differences in the parameter ω_i, width of curve, and selection range (Pope et al., 1975) for all mesh sizes were small (Table 3). The interval of the optimal girth of each mesh size was nearly constant. The correlation coefficient approached 1.0 in the linear regression related to the mesh size and the optimal girth ($\lambda = 1.86\ m + 1.11$).

Length distribution of the population encountering net

The length distribution was calculated from the Eq. (6) and (7) as shown in Fig. 7. The total number of fish of the estimates was made equal to the fish population, total value of the experimental fish (n = 2,000), with a rate corresponded to the catching efficiency q (=0.18) to compare them both. The modal length and the length range of estimates agreed with those of the population used in the experiment (Kolmogorov–Smirnov test, P<0.05).

Discussion

The mesh selectivity curves of each mesh size have the same shape, even though the curves were estimated individually for each mesh size. In addition, the linear relationship between the optimal girth and the mesh size had a high correlation. These results support the theory of Baranov (1914), which explained the geometric similarity between mesh size and fish-body size. Thus, it is considered that dividing the catch parts is important when estimating mesh selectivity curve as filter characteristics of the net used. Based on the result of this study, it is easy to explain the reason why most of the selectivity could not be expressed as unimodal curve. If the difference of the girth of some catch parts with high frequency is large, selectivity will be shown as a skewed or bimodal curve by combination of each part (Hovgård, 1996). This phenomenon make it difficult to estimate the length distribution of the target population on gillnet survey. However, the girth selectivity curve in this study can be expressed by a simple curve as normal function, and is robust to growing and seasonal condition of fish body. Once the

Table 2. Linear regression parameter of the length–girth relationship and AIC value. Upper rows show separately the results from the pectoral fin and dorsal fin data, while the lower are the result when the data were combined.

	Pectoral fin	95% Confidence interval (+/−)	Dorsal fin	95% Confidence interval (+/−)
a	1.61	0.14	1.57	0.12
b	3.86	1.27	3.99	1.10
MSE	165.79		134.92	
Sum of MSE			300.71	
AIC			1,001.26	
			Combined	
a			1.58	0.09
b			4.02	0.84
MSE			305.79	
AIC			1,000.17	

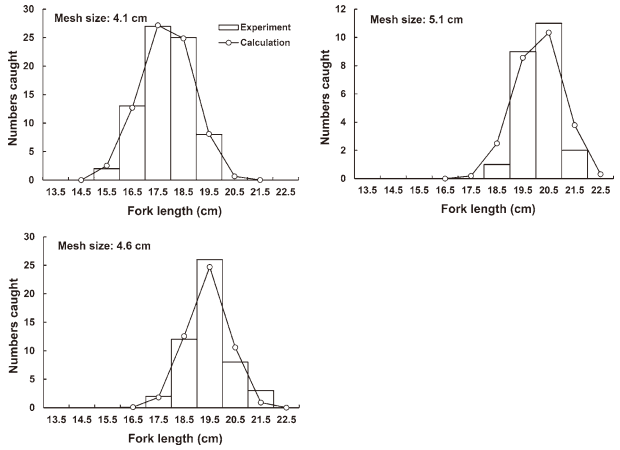

Fig. 5. Length distribution of fish caught in the experiment and from the mesh selectivity calculation for each mesh size.

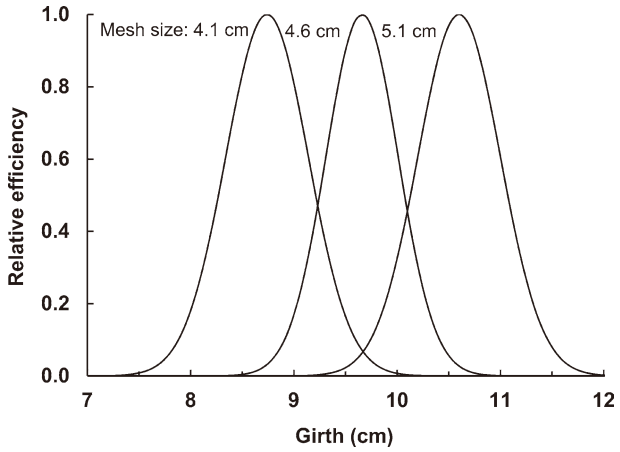

Fig. 6. Estimated mesh selectivity curve of each mesh size.

Table 3. The parameters of the selectivity curve and estimated selection girth range.

	Mesh size (cm)		
	4.1	4.6	5.1
Optimal girth, λ_i (cm)	8.74	9.66	10.60
Width, w_i	0.40	0.35	0.40
Selection girth (cm)			
Upper	9.39	10.22	11.25
Lower	8.09	9.10	9.95
Range*	1.29	1.13	1.31

* : The difference between the upper and the lower values of the 5% selection girth.

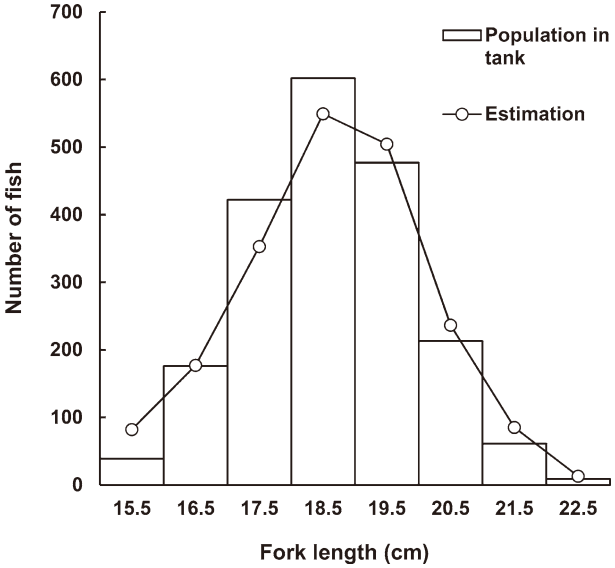

Fig. 7. Comparison of length distribution of the fishes between the experiment and the estimation from the method in this study.

girth selectivity curve is obtained by a certain gillnet to the target species, the length distribution of the fish encountered with net can be estimated using the relationship between length and girth using the method in this study though the length-girth relationship must be given from the other work. Still, the catch part used for selectivity analysis must be selected with care to precisely estimate the mesh selectivity curve for fish girth. It is possible that the catch part can be determined from the observation for net mark on fish body in the case of single netting gillnet.

In this study, the proposed method was validated since the estimated length distribution fit the length distribution of the population in the water tank. Henceforth, an examination of the model in consideration of the productive unevenness of mesh size and measurement error will be necessary to further improve the precision of the selectivity curve.

The variance σ of length to girth in Eq. (2) was determined from the data sampled by a scoop net to prevent the effect of mesh selectivity in this study. Therefore, a sample from selection-less fishing gear becomes necessary to attain the same condition in sea investigations. For example, the data from trawl survey should be employed to calculate σ. If the gillnet's own catch is used as this sample, the idea of the arrangement of the mesh size to draw a gillnet to the selection-less fishing gear becomes necessary.

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