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Gill-Net Mesh Selectivity Curve Developed from Length-Girth Relationship

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It is assumed here that body girth for each length of fish is distributed according to a normal distribution with a common standard deviation, and that all fish are held anywhere between the end of the opercle and the point of maximum girth by the mesh encircling the body. When a fish population encounters the gill-net, some fish will pass through the mesh because their maximum girth is smaller than the perimeter of the mesh. Some fish will alter their swimming course because they do not enter far enough to be held fast and the others will be retained. The probability that fish of length l do not pass through the mesh can be described by the following equation:

$$P_1 = \int_{\frac{Gmc-(p+ql)}{\sigma Gm}}^{\infty} \frac{1}{\sqrt{2\pi}} e^{-\frac{x^2}{2}} dx.$$

And the probability that fish which enter the mesh can be described by the following equation:

$$P_2 = \int_{-\infty}^{\frac{Goc-(v+wl)}{\sigma Go}} \frac{1}{\sqrt{2\pi}} e^{-\frac{x^2}{2}} dx.$$

The probability of fish which will be retained may be described by the area under both the cumulative distribution curves.

This theoretical mesh selectivity curve was applied to the herring gill-net. The length-girth relationships of herring were:

$$Gm = 0.659\,l - 3.106, \quad Go = 0.487\,l - 1.089.$$

The values of σGo were approximately common for various lengths, but the values of σGm showed increasing trends according to the increase of length. The averages were $\sigma Go=$ 3.57 mm and σGm=6.56 mm. Goc and Gmc were estimated from the relationship between the mesh-perimeter and girth at the net-mark. $Goc=2.15\phi$, $Gmc=2.22\phi$. From the above values, the mesh selectivity curves for each mesh-size were calculated, and the curves were compared with the length distribution of the herring-catch in the discussion.

McCombie and Fry,[1] and Ishida[2] developed the theory of mesh selectivity curve of gill-net by analysing the catch of gill-net of two or more mesh-sizes. Thereafter, their methods were made more developed by many investigators. Their methods are very prominent. On the other hand, as many investigators reported, there is a significant correlation between the mesh-size of gill-net and body girth of the fish held. And Konda[3] suggested that it was possible to predict the length-range of the fish held by a certain mesh, on the bases of the length-girth relationship. Although it is conceivable that gill-net mesh selectivity curve could be developed from length-girth relationship, no attempt has been taken hitherto. Here, the author attempts to estimate a theoretical gill-net mesh selectivity curve from the length-girth relationship.

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General Theory

Provided that all fish are held anywhere between the end of opercle and the point at the maximum girth by the mesh encircling the body, girth at the end of opercle determines the maximum size of fish held and the minimum size of fish held depends on the maximum body girth. Evidently, only fish of a limited range of size are to be held by the body between the end of opercle and the point at the maximum girth. Only fish thus meshed by the body are considered.

It is well known that length-girth relationship of the adult-form fish can be described by the equations:

$$Gm = p + ql,$$
$$Go = v + wl.$$

where p, q, v and w are constants, Go is the girth at the end of opercle, Gm is maximum body girth and l is fish length.

When Gm for each l is distributed according to a normal distribution with common standard deviation σGm, its distribution can be described as

$$N(p + ql, \sigma^2 Gm).$$

This distribution is shown in Fig. 1.

When the assumed fish population encountere the gill-net of mesh-size ϕ, some fish will pass through because their maximum body girth is smaller than the perimeter of the mesh. Some fish alter their swimming course because they do not enter the mesh far

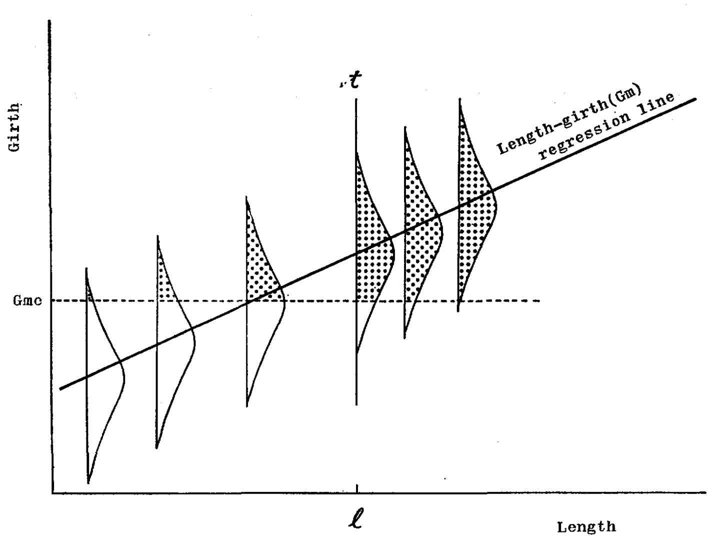

Fig. 1. Distribution of maximum body girth (Gm) for each length (l) when σGm is common for various lengths. The shaded area shows the range of the girth of the fish that do not pass through the mesh when the truncation by girth occurs at Gmc.

enough to be held fast and the others will be retained.

Truncation by girth will occur at *Goc* and *Gmc*, which are some critical values of *Go* and *Gm* respectively. The fish that do not pass through the mesh have larger maximum girth than *Gmc*. Therefore the probability that the fish of length l do not pass through the mesh is to be represented by the shaded area shown in Fig. 1. P_1, the probability, can be described:

$$P_1 = \int_{Gmc}^{\infty} \frac{1}{\sqrt{2\pi}\ \sigma Gm} e^{-\frac{[t-(p+ql)]^2}{2\sigma^2 Gm}} dt.$$

Setting
$$\frac{t-(p+ql)}{\sigma Gm} = x,$$

and so
$$dt = \sigma Gm\, dx,$$

we have
$$P_1 = \int_{\frac{Gmc-(p+ql)}{\sigma Gm}}^{\infty} \frac{1}{\sqrt{2\pi}} e^{-\frac{x^2}{2}} dx.$$

Hence, the probability that the fish of length l do not pass through the mesh is to be the cumulative distribution of the probability density function:

$$f(x) = \frac{1}{\sqrt{2\pi}} e^{-\frac{x^2}{2}}$$

(*cf.* Fig. 2). And as l is continuous, P_1 for various l is distributed as shown in Fog. 3.

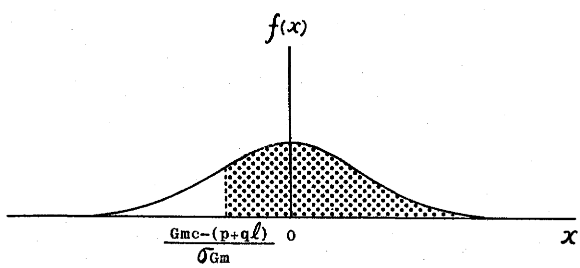

Fig. 2. Probability that the fish do not pass through the mesh.

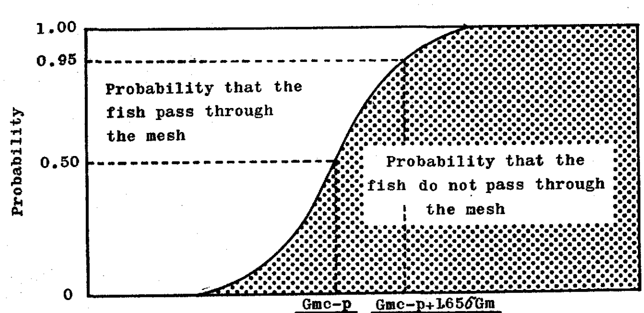

Fig. 3. Distribution of P_1 for various l.

On the other hand, some fish do not enter the mesh because their girth at the end of opercle are larger than the mesh-perimeter. And so, under the same consideration as in the previous, when truncation by girth occours at *Goc*, the probability that the fish of length *l* enter the mesh is to be represented by the shaded area shown in Fig. 4. P_2, the probability, is described as follows:

$$P_2 = \int_{-\infty}^{Goc} \frac{1}{\sqrt{2\pi}\ \sigma Go} e^{-\frac{[t-(v+wl)]^2}{2\sigma^2 Go}} dt,$$

where σ *Go* is the standard deviation of the distribution of *Go*.

Setting $$\frac{t-(v+wl)}{\sigma Go} = x,$$

and so $$dt = \sigma Go\ dx,$$

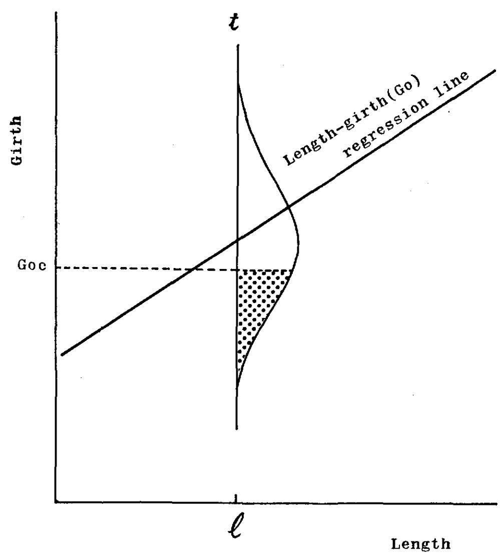

Fig. 4. Distribution of girth at the end of opercle (*Go*) for length (*l*), and truncation by girth at *Goc*.

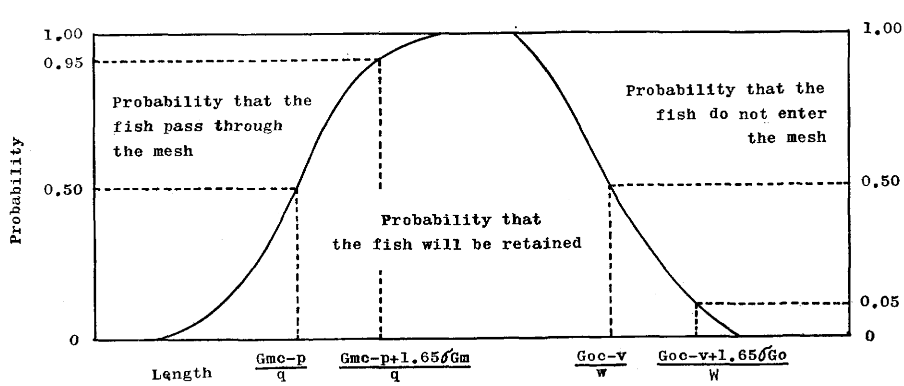

Fig. 5. Mesh selectivity curve of gill-net.

we have $$P_2 = \int_{-\infty}^{\frac{Goo-(v+wl)}{\sigma Go}} \frac{1}{\sqrt{2\pi}} e^{-\frac{x^2}{2}} dx,$$

Therefore the probability that the fish will be retained is to be represented by the area under the both cumulative distribution curves shown in Fig. 5. And both of these cumulative distribution curves are those showing the mesh selectivity curve of gill-net of mesh-size ϕ.

An application of the theory of the mesh selectivity curve to herring gill-net

Materials

The materials were sampled at random from the herring caught by a train gill-net of various mesh sizes. The mesh-sizes were 30, 35, 42, 50, 61, 68 and 76 mm. The thread of net was of nylon mono-filament. The herring samples were caught in August and September of 1969 in the Okhotsk Sea. Girth and fork length of hering were measured. Girth were measured at four points—at the ends of opercle and of preopercle, at the maximum girth and at the net mark.

Results

Relation between the length and girth of herring is shown in Fig. 6. Length of

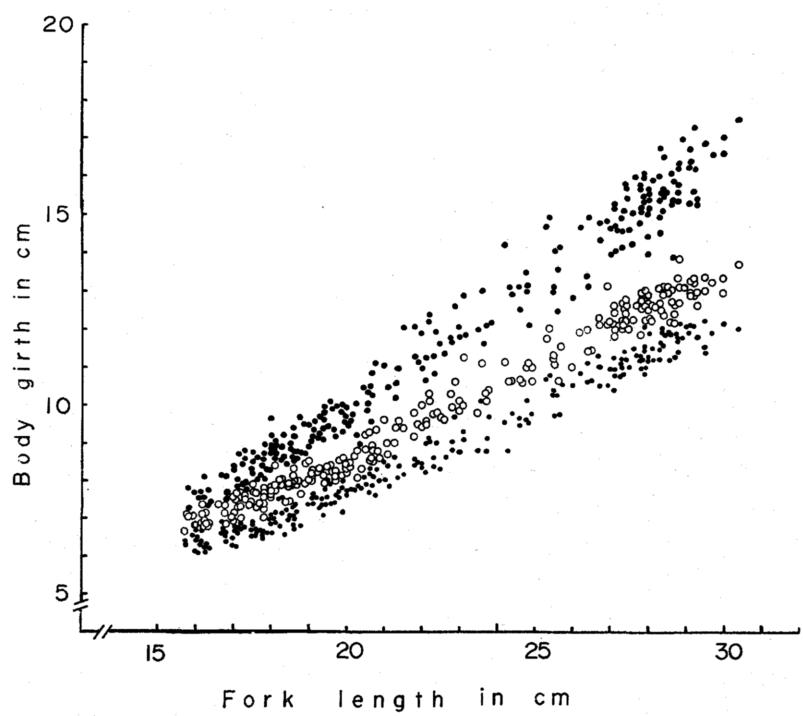

Fig. 6. Relation between the length and girth of herring, large closed circle: maximum girth, small closed circle: girth at the end of preopercle, open circle:,girth at tne end of opercle.

herring sample ranged from 15.5 to 30.5 cm. With a fork length of 20.5 cm as the dividing point between small and large herring, the length-girth relationship of small herring was different from that of large herring. So the data from large herring were used in the subsequence, because the herring were considered to become adult-form and the length-girth relationship become linear when their bodily length reaches 20.5 cm.

The length-girth relationships of herring can be described by the quqations (unit: cm):

$$Gm = 0.659\,l - 3.106,$$

$$Go = 0.487\,l - 1.089.$$

KIPLING[4)] showed that the weight-length relationships of char and perch caught by the gill-net of two or more mesh-sizes did not differ significantly from those of true population. From the same reason as his, it is considered that the length-girth relationships obtained here do not differ significantly from those of true population in the fishing ground.

Values of standard deviation, σGo and σGm, were obtained at the intervals of each 10 mm length on the probability sheet (Table 1).

Table 1. Values of standard deviation of the distribution of body girth.

Fish length	Standard deviation	
	σGo	σGm
210–219 mm	3.7 mm	5.6 mm
220–229	3.6	5.9
230–239	3.6	5.8
240–249	–	-
250–259	3.7	6.2
260–269	–	–
270–279	3.8	7.0
280–289	3.3	7.1
290–299	3.3	8.3
Average	3.57	6.56

Although the values of σGo were approximately common for various lengths, the values of σGm showed the increasing trend according to the increase of the length. Though this does not agree with the above assumption, the averages were used in the calculation—σGo=3.57 mm, σGm=6.56 mm.

The extention of the net thread was ignored because it was comparatively small.[5)] At the moment when fish held, the rate of body contraction k is given by

$$k = 2\phi/Gn,$$

where 2ϕ is mesh perimeter and Gn is the girth where fish was held by a mesh. When the holding position is near to the position at the end of opercle, k is approximately equal to the rate of body contraction at the end of opercle ko, and when it is near to the position at maximum girth, k is approximately equal to the rate of body contraction at maximum girth km. Hence

$$Gmc = 2\phi/km,$$
$$Goc = 2\phi/ko.$$

As the position at the net mark is considered to be the holding position, Gn is the girth at the net mark. The distribution of $1/k$ was shown in Fig. 7. Although $1/ko$ and $1/km$ ranged widely, averages were used in the subsequence; $1/ko=1.076$ and $1/km=1.108$. And so $Goc=2.15\phi$ and $Gmc=2.22\phi$.

From above values, the length of fish selected by each mesh-size was calculated (Table 2). And the mesh selectivity curves for each mesh-size were compared with the fork length distribution of herring caught in 20, August at 55°16′N–142°36′W in Fig. 8.

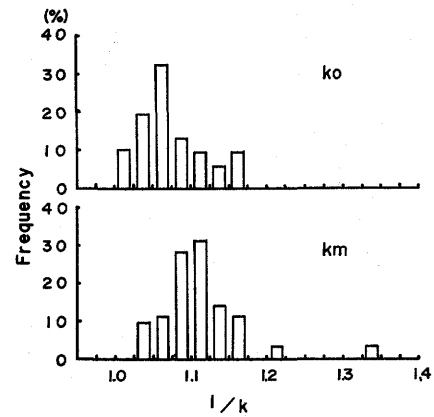

Fig. 7. Distribution of $1/k$.

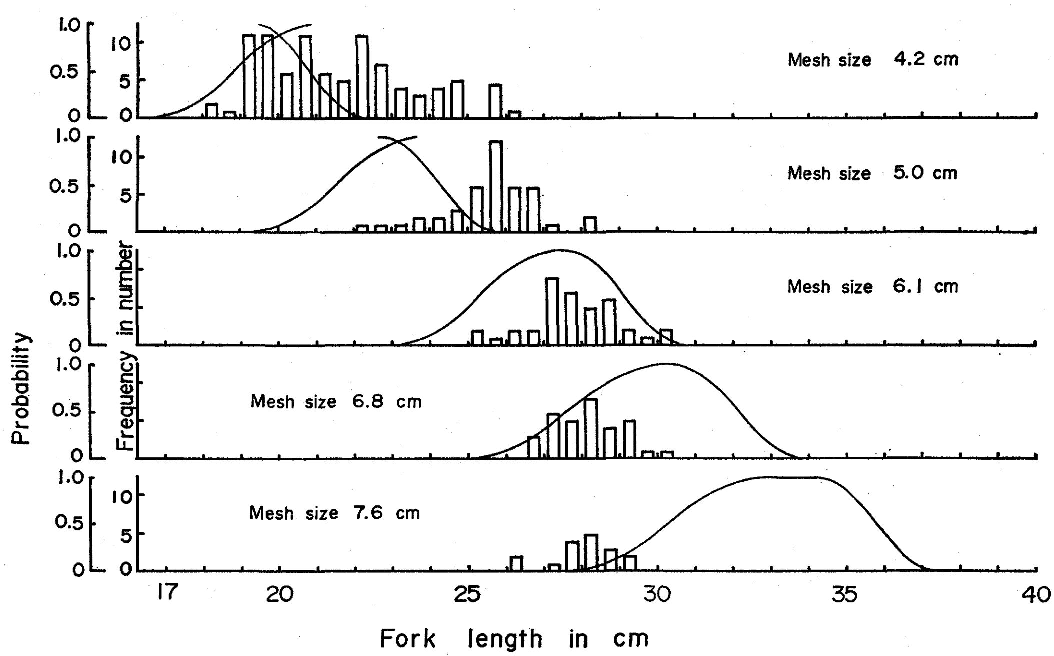

Fig. 8. Fork length distribution of herring-catch and the calculated mesh selectivity curve for each mesh size.

Table. 2. Calculated length of fish selected by each mesh-size.

Mesh size	Fish length			
	Truncation at *Gmc*		Truncation at *Goc*	
	50% point	95% point	50% point	5% point
42 mm	189 mm	205 mm	208 mm	220 mm
50	216	232	243	255
61	253	269	292	304
68	276	293	322	335
76	303	320	358	370

Discussion

The mesh selectivity curve obtained here shows negative skew, and it is different from the ISHIDA's[6] and FARRAN's[7] mesh selectivity curves showing positive skew. This difference between the two might be caused by that the author took no account of the fish held at the fore part of opercle but ISHIDA and FARRAN took account of them.

The mesh selectivity curves show that the range of length of fish held varies in proportion to the mesh-size, that is, the selectivity of smaller mesh-size is sharper than that of larger one.

In this paper, it could not be showed whether the theoretical mesh selectivity curve was fit to the practical length distribution of fish caught by a gill-net, because according to the day or position of fishing the catch of the gill-net of one mesh-size varied widely in length distribution. This variability might be caused by the difference of length distribution of fish population in the fishing ground.

Compared the author's mesh selectivity curve with the fork length distribution of herring caught in one fishing operation, the latter is ascertained to be bigger than the former of mesh size of 42 and 50 mm. It was very difficult to find out the net-marked fish in the catch of gill-net of those mesh-sizes. Hence, the fish caught by the gill-net of those mesh-sizes might be held at the fore part of opercle, such as at the end of pre-opercle or other bony parts. It might be considered that this would occur when the mesh-size of the gill-net is too small compared with the fish length of the fish school in the fishing ground.

In the mesh-sizes of 61 and 68 mm, the size distribution fitted well to the selectivity curve. These mesh-sizes might be suitable to catch the herring. And most of the fishermen used the herring gill-net of those mesh-sizes.

In the mesh-size of 76 mm, the size distribution is smaller than the selectivity curve. This phenomenon could not be explained well. MCCOMBIE and BERST[8] reported that fish were held at girth/perimeter ratios smaller than 0.8 or 0.9. The mechanic of this holding should be researched more further in the future.

In this paper the materials of net and thread were not taken into consideration. But it is known that those materials affect the catch.[9] Moreover, length-girth (*Gm*) relationship and the rate of contraction may change with the season because the development of gonad, the volume of the stomach contents and the adipose deposit of body change with the season.[10] In the further study these items should be considered.

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