Distributions of Hooking Position in a Mouth for Sode Hooks Derived from the Stochastic Model of Hooking Mechanism

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Abstract

The distributions of hooking positions in a mouth for sode hooks were obtained with pole and line fishing experiments in a water tank in order to analyze hooking phenomena. The hooking positions of smaller hooks are almost distributed in a esophagus or near a fish snout, and those of larger hooks are almost distributed about the center of a mouth cavity back. The distributions of hooking position in a mouth derived from a stochastic model of hooking mechanism were fitted well on the observed distributions for smaller hooks. However, in the case of larger hooks, the estimated distributions were not fitted on the observed distributions. It appears that the estimated distributions for large hooks are different from observed ones because the entrance size of the esophagus is not included in the model.

1 Introduction

Theoretical models of the fishing mechanisms for a trawl [1] and a gillnet [2,3] include the cause and effect of size selection and show the typical size selections that occur for each net. Shimizu et al. [4] made a stochastic model of the hooking mechanism, which included the effects of fish size and hook size. The model fit well to the results of pole-and-line fishing experiments with “sode” hooks to masu salmon (*Oncorhynchus masou*). The multiple-regression of the moving coefficient (see Section

2.1) and the hooking coefficient to the fish and hook sizes was obtained then. The selectivity curves of sode hooks for masu salmon were calculated with the model, because those relations between fish and hook sizes and each coefficient were applied to the model, in addition to the movement limit of a hook [5-7]. These selectivity curves for different hook sizes that were plotted against total length were unimodal with a gentle long right slope. However the fitness of the stochastic model was not yet discussed in regard to the distribution of hooking positions and a hook movement in a mouth of fish.

In this paper, the distributions of hooking position in a mouth for sode hooks were obtained with pole and line fishing experiments in a water tank in order to analyze hooking phenomena. The estimated distributions of hooking position derived from the stochastic model of hooking mechanism were compared with the observed distributions. The modification of the stochastic model is discussed with regard to the characteristics of the estimated distributions and the hook movement.

2 Methods

2.1 Probability distribution of hooking position

The stochastic model of hooking mechanism [4] is described below. The hook movement in the mouth cavity is shown in Fig. 1. Let q be a distance from the snout to the position of a hook bend. The stop probability $S(q)$ represents the probability that a hook bitten by a fish stops moving inward in interval $[0,\ q]$ of the mouth cavity. The probability density function $s(q)$ of $S(q)$ is expressed as follows.

$$s(q) = a e^{-aq} \tag{1}$$

where a is the moving coefficient. The moving coefficient has been related to fish size and hook size.

Once the hook stops moving inward at q in the mouth cavity, the hook starts moving outward from q. While the hook moves outward, hooking occurs somewhere in the mouth cavity. Let L be the hook point height and x be the distance from the snout to the position of the point of the hook. The hooking probability $H(q - L - x)$ represents the probability that hooking occurs in interval $[x,\ q\text{-}L]$ after the hook has stopped moving inward at q. The probability density function $h(q-L-x)$ of $H(q-L-x)$ is expressed as follows:

$$h(q-L-x) = b e^{-b(q-L-x)} \tag{2}$$

where b is the hooking coefficient. The hooking coefficient also has been related to fish size and hook size.

Now let Q be the mouth cavity length, and D be the distance from the snout to a given position in the mouth cavity. The probability $P_c(D)$ represents the probability that hooking occurs in interval $[0, D]$ within the mouth cavity after the hook has stopped moving inward in interval $[D+L, Q+L]$.

$$\begin{aligned} P_c(D) &= \int_0^D \left(\int_{x+L}^{Q+L} s(q)\, h(q-L-x)\, dq \right) dx \\ &= \frac{be^{-aL} + ae^{-a(Q+L)-bQ}}{a+b} - \frac{be^{-a(D+L)} + ae^{-a(Q+L)-b(Q-D)}}{a+b} \end{aligned} \tag{3}$$

Then the probability $P_{dis}(D_1, D_2)$ represents the probability that hooking occurs in interval $[D_1, D_2]$ as follows.

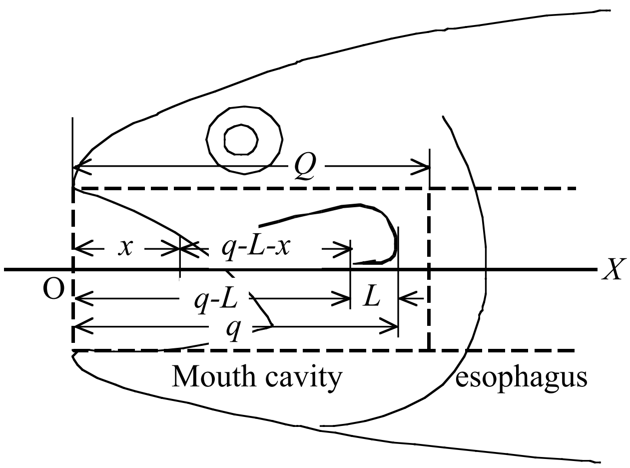

Fig. 1. Schematic drawing of the hook movement of the stochastic model in a mouth cavity on the *X* axis.
L, hook point height; O, origin, that is, the snout; *q*, distance from the snout to the position of the hook bend; *Q*, mouth cavity length; *x*, distance from the snout to the position of the hook point.

$$Pdis(D_1,D_2) = Pc(D_2) - Pc(D_1)$$
$$= \frac{be^{-a(D_1+L)} + ae^{-a(Q+L)-b(Q-D_1)}}{a+b} - \frac{be^{-a(D_2+L)} + ae^{-a(Q+L)-b(Q-D_2)}}{a+b}$$
$$= \frac{ae^{-a(Q+L)-bQ}\left(e^{bD_1} - e^{bD_2}\right)}{a+b} + \frac{be^{-aL}\left(e^{-aD_1} - e^{-aD_2}\right)}{a+b} \quad (4)$$
$$(0 \le D_1 \le D_2 \le Q + L)$$

The swallowing probability P_s is the probability that hooking occurs in the esophagus.

$$P_s = (1 - S(Q+L)) \cdot 1 = 1 - \int_0^{Q+L} s(q)dq = \int_{Q+L}^{\infty} s(q)dq$$
$$= e^{-a(Q+L)} \quad (5)$$

It is assumed that hooking always occurs when the point of the hook reaches the esophagus farther than Q. In this case, the hooking probability becomes 1.

The probability distribution of hooking position is calculated from the equations (4) and (5), in addition to the suitable value of coefficient a and b.

2.2 Data processing

The observed distributions of hooking position were obtained from the pole-and-line fishing experiments for masu salmon [4]. The conditions of the experiments are shown in Table 1. The hooking position of a capture fish was plotted on the simple figure of a mouth cavity back by hand. The x, y coordinates from the snout as origin were red by a digitizer, then those were converted in real size in proportion to

Table 1. Conditions of each experiment

Exp. No.	Hook No. (Gou)*1	Hook width W (mm)	Hook point height L (mm)	Leader No. (Gou)*1	Total length of fish (mm) Mean	Total length of fish (mm) S.D.	Number of fish	Mean mouth cavity length
1	0.3	2.0	2.3	0.4	145.5	6.2	100	25.2
2	0.8	2.6	2.4	0.4	134.9	5.8	100	23.3
3	2	3.2	2.6	0.4	133.5	5.9	100	23.1
4	3	3.7	3.2	0.4	129.9	5.9	100	22.5
5	5	4.7	4.1	0.8	145.1	6.0	100	25.1
6	9	7.0	5.8	1.5	145.8	6.7	99	25.2
7	13	10.0	7.2	2	132.9	5.2	98	23.0

*1 Gou number indicates the hook size or the leader size according to the Japanese numbering system (Larger hooks have higher Gou numbers than smaller hooks).

mean total length of fish used in the experiment. According to Shimizu et al. [4], the mouth cavity length Q of masu salmon was expressed as the following equation:

$$Q = 0.17TL \quad \text{(mm)}. \qquad (6)$$

Solver of Microsoft Excel was applied to the identification of the coefficient a and b with least squares. Chi-square was used assessing the goodness of fit between the observed distribution and the estimated distribution.

3 Results

The result of the fishing experiments is shown in Table 2. The estimated moving and hooking coefficients and the goodness of fit to the observed distribution are also shown in Table 2. The maximum number of capture fish was 62 individuals with the 5 Gou hook. The number of snagging was excluded from the capture fish. The number of trials was the number of snagging subtracted from the fishing trials equal to the initial number of fish. It was assumed that Drop took place out of hooking in the mouth cavity. Hooking positions plotted on the simple figure of a mouth cavity back are shown in Fig. 2. The hooking positions of a small 0.3 and 0.8 Gou hooks were plotted almost near the lip. Those of larger hooks spread around overall on the mouth cavity back. But those of the largest 13 Gou hook were plotted almost on the center of the mouth cavity near the eyeball.

The observed distributions of the hooking positions onto the X axis as origin at

Table 2. Results of the estimation of coefficients a and b, and χ^2 fitness test

Exp.	Hook No.	Coefficient		Significant provability of χ^2 test: Hooking distribution in the mouth cavity		Significant provability of χ^2 test: Inclusive of swallowing		Trial	Fish	Catch	Hooking	Swal-	Drop	Snag-
No.	(Gou)	a	b	P	d.f.	P	d.f.				in Mouth	lowing		ging
1	0.3	7.61E-02	4.97E-02	0.435	1	0.736	2	98	100	38	17	12	7	2
2	0.8	8.46E-02	1.35E-01	0.037	3	0.075	4	99	100	50	25	11	13	1
3	2	1.16E-01	1.45E-01	0.277	2	0.436	3	96	100	44	26	4	10	4
4	3	8.43E-02	3.00E-01	0.145	4	0.208	5	96	100	58	37	13	4	4
5	5	9.81E-02	6.04E-01	0.001	4	0.001	5	96	100	62	50	3	5	4
6	9	1.07E-01	2.53E+00	0.018	4	0.008	4	98	99	52	48	0	3	1
7	13	1.08E-01	3.44E-01	0.000	2	0.000	2	86	98	53	30	0	11	12

a snout are shown in Fig. 3 and Fig. 4. In addition, the swallowing rate, the swallowing probability and the probability $P_{dis}(D_1, D_2)$ also are shown in these figures. In the case of the small hooks shown in Fig. 3, all the goodness of fit between the observed distribution of hooking positions and the estimated one were fine. But those distributions for relative large hooks were significantly different between the observed and the estimated ones shown in Fig. 4. Then, the swallowing probability was larger than the observed swallowing rate for relative large hooks.

4 Discussion

The estimated distributions of hooking positions calculated with the stochastic model were good fit to the observed ones for the relative small hooks less than 3 Gou sode hook. Although a masu salmon has the deep rent of a mouth, the assumptions of a cylinder with same diameter as a mouth cavity shape and a hook movement in the

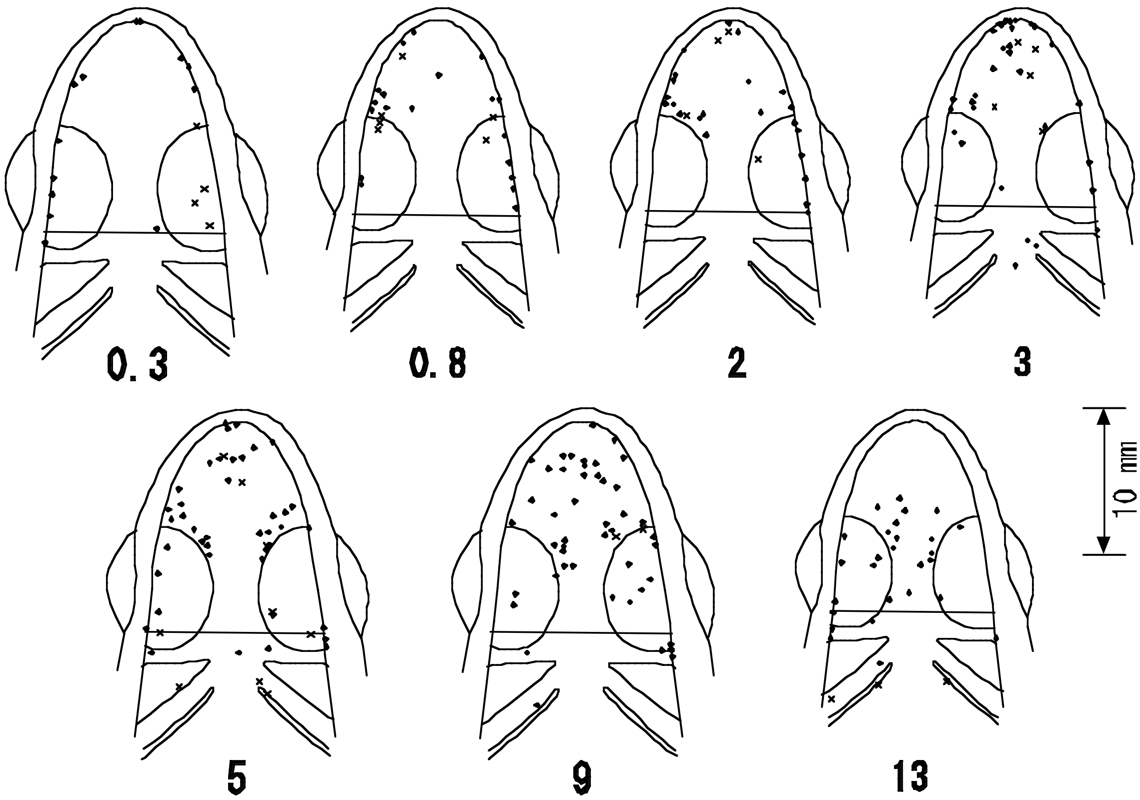

Fig. 2. Distributions of hooking positions for the different size of a sode hook in the mouth cavity back of masu salmon. Numbers show the hook number used in the experiment.
●, hooking position on the mouth cavity back; ×, corresponding hooking position on the lower jaw.

mouth cavity with a hook point parallel to a body axis are appropriate. In the case of a large hook relative to fish size, the stochastic model cannot represented well the detailed hooking phenomenon like the distribution of hooking positions in a mouth, although the capture probability and the swallowing probability, which is a cumulative probability, has the adequate goodness of fit to the observed value.

Swallowing did not take place at all with a relative large hook, probably a given size hook between 5 Gou and 9 Gou used in the experiments. In the case of a large hook moreover, it appears that hooking does not take place in the process of going out of the mouth cavity, but hooking takes place on the mouth cavity back when the hook enters with a point upward and then the mouth closes. Therefore hooking positions for 13 Gou hook close about the center of the mouth cavity back.

The swallowing probability does not become zero even for the 13 Gou hook. Shimizu et al. [7] added the movement limit to the stochastic model obtaining the size selectivity curve. The movement limit was calculated with the multiple-regression to the

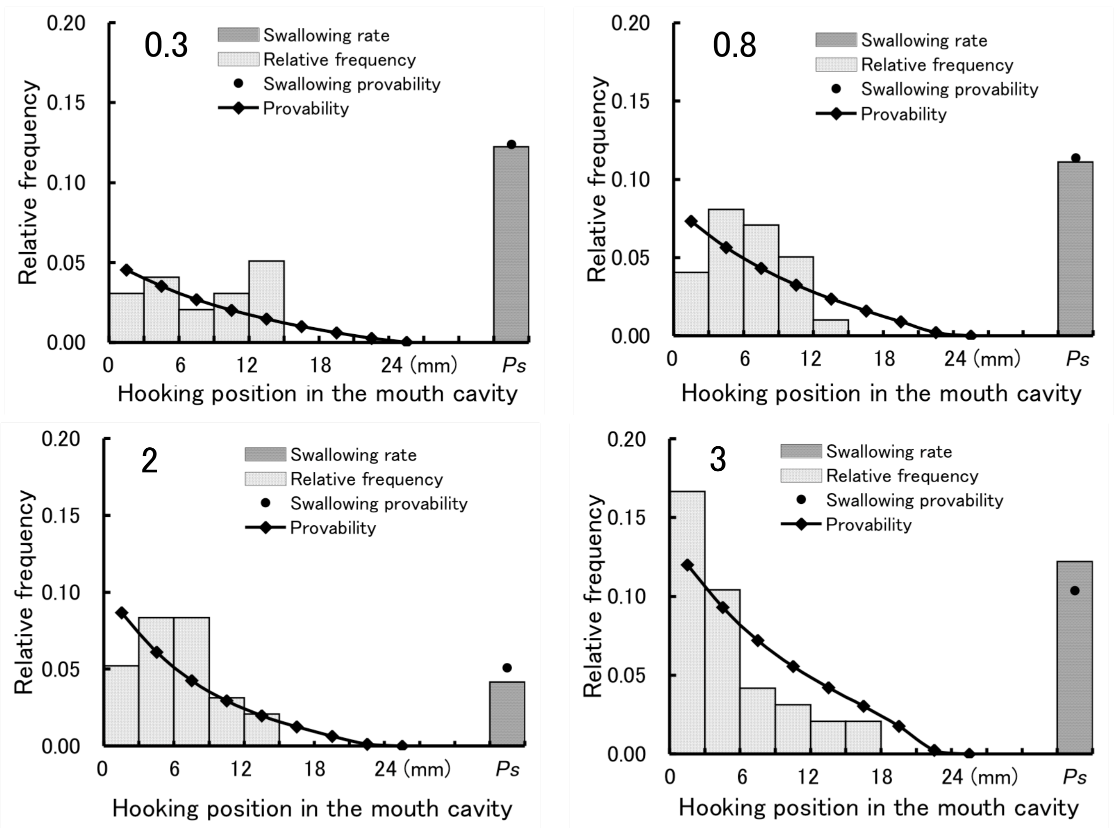

Fig. 3. Comparison between observed and estimated distributions of hooking position for the different size (0.3 - 3) of a sode hook. *Ps*, swallowing provability.

total length of fish and the hook width like the moving and hooking coefficients. It appears that the movement limit is influenced by the factors of the shape of the mouth cavity and the entrance diameter of the esophagus. The relation between the movement limit and those factors is required in order to introduce the movement limit to the stochastic model. It will be developed that our stochastic model includes the factor of a mouth cavity shape and a hook shape in future. An identification method of parameters in the stochastic model of the hooking mechanism will be established to get more reliable selectivity curves of angling gears.

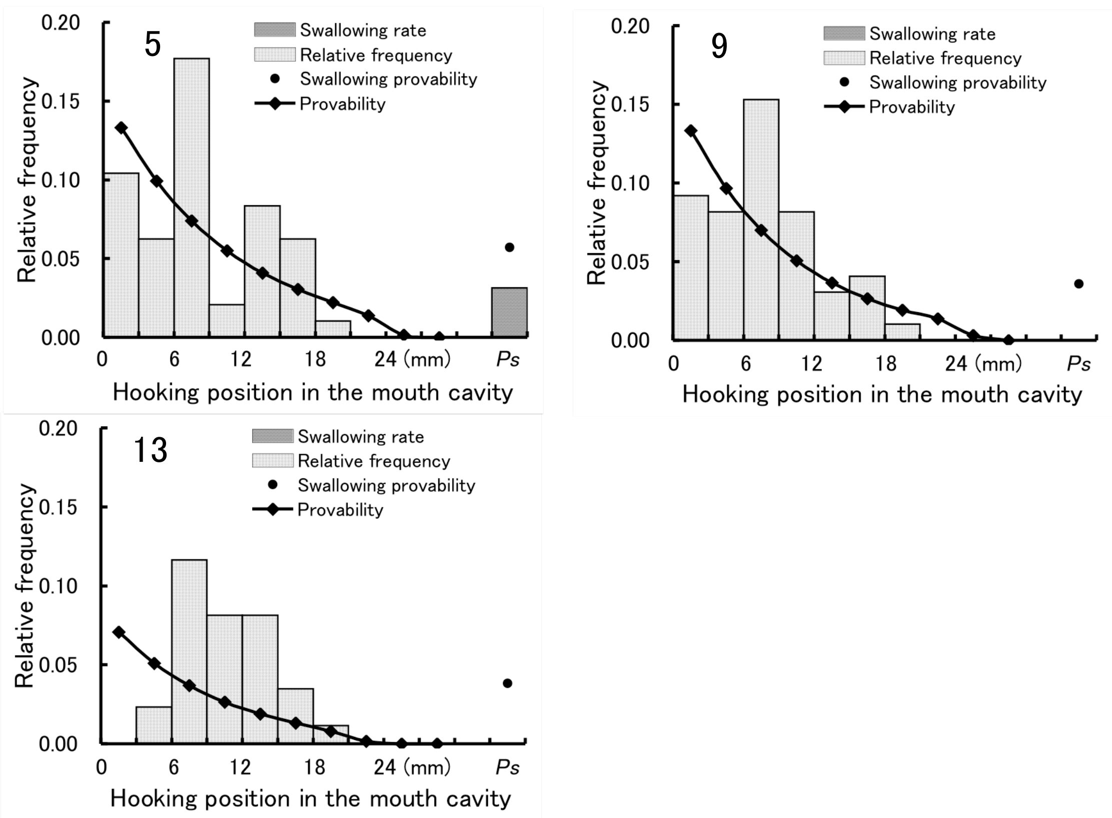

Fig. 4. Comparison between observed and estimated distributions of hooking position for the different size (5 -13) of a sode hook. *Ps*, swallowing provability.

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