FIELD EXPERIMENT ON PAIR-TRAWL*

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In the preceding papers,^{1~10)} the method of the theoretical analysis about the behaviour of sweep line has been developed on a number of practical problems in ground trawling. An application of the theory, however, has been limited to a series of model experiments and the validity of the theory for a practical gear has remained unverified.

The present paper deals with the verification of the theory by field experiment, on respective cases of ordinary sweep line and chain fitted sweep line in pair-trawling. It is rather difficult to investigate the behaviour of sweep line during the actual fishing process. In the present experiment a model pair-trawl net was operated in a different way from the usual fashion adapted by Japanese pair-trawlers.

Description of Model Gear

A model net was constructed, reducing the linear scale of standard one employed by 50 tons type commercial boats to 1/3. The design of this model net is not in accordance with TAUTI's law of similarity. The principal dimensions of the different parts of the net are as follows:

Length of head-line	15 m.
Length of foot-line	16 m.
Length of bag	7 m.

Two manila ropes of diameter 2 cm. and equal length 200 m. were attached to the dan-lenos on each sides of wing. These ropes were used as sweep lines and towing warps.

Experimental

For the present investigation was adapted a similar method of operation as in the case of beach seine. In the first place, ten mark buoys with distinct coloured flags were fastened to the ropes of port and starboard sides by thin twines at the points distant from each dan-lene by 0, 20, 40, 80 and 120 m. From the locations of these mark buoys, were obtained the informations concerning the form of sweep line laying on the sea ground. Parts of both ropes having length 40 m. from each dan-leno were laid on a sandy bottom of depth 4 m. almost linearly, with net at

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its midpoint, parallel to the coast line. The remaining parts of both ropes having length 160 m. were laid along the direction normal to the coast line in such a manner that the ends of both ropes just reach to the sea side. Twists of net and ropes laid out were unravelled by skin divers. Then, the ropes of port and starboard sides were pulled simultaneously from the land keeping the distance between ropes to be 100 m., as far as the net start to move: while a diver was watching the net to tell the moment at which it starts to move. The tension acting on rope was measured by the use of tension meter at the instant when the net started to move. Then pulling was stopped, and two observer at the land determined the positions of mark buoys by triangulation.

The value of K_t , tangential component of frictional force per unit length of rope, was measured by pulling one end of the sweep line of length 200 m. laid initially linearly on the bottom. In order to determine the normal component of frictional force of rope, K_n , similar procedures as described in the reference⁴⁾ were applied; a rope graduated at every 5 m. interval was laid at first on the sea ground in such a form that two parts of it are bent perpendicularly. The sweep line was laid in contact with the graduated rope in a similar form. Then, one end of this sweep line was pulled leaving the graduated rope at its initial position. At a regular interval of towing, the linear sizes of deformed curve of rope projected to both parts of the graduated rope were eye-measured by divers. The resistance of net was independently measured by towing only the net. Throughout the whole course of experiment, the gear was towed manually. The hydrodynamic resistance acting on the net may be neglected as compared with its frictional resistance, because of the slow speed of towing.

In the experiment of chain fitted sweep line, were employed the same net and ropes as in the case of ordinary sweep line. At each point on the port and starboard ropes distant 80 m. from the respective dan-lenos were attached chains having length 1 m. and weight 8 kg. In a similar manner as in the case of ordinary sweep line, ropes and net were laid at first on the sandy bottom. Here, eight mark buoys were connected to both sides of ropes by thin twines at every interval 40 m. from each dan-leno, including the positions of dan-leno. Then, the both ends of ropes were pulled simultaneously, keeping the distance between two ropes to be 100 m. At each instance when the ropes were hauled by 20 m. and by 80 m., the tension acting on warp was measured. Moreover, at these moments, hauling was stopped once and the positions of mark buoys were determined by triangulation.

Results and Discussion

i) Behaviour of ordinary sweep line

The positions of each mark buoy after and before towing are shown in Fig. 1-

Fig. 1. Positions of mark buoys attached to sweep line of pair-trawl. Broken lines show approximated form of sweep line. A-A': Shoreline; B, B': Positions of observers (Length B-B' is 80 m.); x: Positions of buoy before towing; x: Positions of buoy after towing.

As seen in the figure, the positions of buoys in both stages are deviated to the port side of net; this may be due to wind blowing. The form of rope can be determined approximately by taking into consideration the leeway of mark buoys. This approximated form of rope after the net has moved is also illustrated as a broken line in Fig. 1. The tension acting on a warp at the moment when the net starts to move is measured to be 9~10 kg.

The value of K_t is calculated to be 0.40 gr./cm., by using the data for the frictional force of rope, 8 kg., which was obtained by pulling the rope of length 200 m, originally laid linearly. The value of K_n can be obtained by the method mentioned in the reference;⁴⁾ denote by $x_t]_{\theta=\pi/2}$ and $y_t]_{\theta=\pi/2}$ the respective linear sizes of the deformation of rope, which appears by towing the one end of rope originally laid in L-shape, projected to the towing direction and its normal direction. The ratio $y_t/x_t]_{\theta=\pi/2}$ is expressed as a function of $\kappa(=K_t/K_n)$ by the equation

$$\frac{y_t}{x_t}]_{\theta=\pi/2} = \frac{e^{\kappa\pi/2} - \kappa}{\kappa e^{\kappa\pi/2} + 1}. \quad (1)$$

The plots of $y_t]_{\theta=\pi/2}$ against $x_t]_{\theta=\pi/2}$ are given in Fig. 2, from which the slope

Fig. 2. Plots of $y_t]_{\theta=\pi/2}$ against $x_t]_{\theta=\pi/2}$, obtained experimentally.

$y_t/x_t]_{\theta=\pi/2}$ gives 0.74. Moreover, from the equation (1) the corresponding value of κ is determined to be 0.70. Substituting $\kappa=0.70$ together with the half distance between port and starboard ropes $Y_r=50$ m. into the equation (4) of the reference⁵⁾

$$\frac{K_n}{T_n} Y_r = \frac{1}{\kappa^2 + 1} [e^{\kappa(\pi/2 - \theta_n)} - (\kappa \cos \theta_n + \sin \theta_n)], \quad (2)$$

the tension T_n acting on sweep line at dan-leno can be obtained as a function of the angle θ_n between the direction of T_n and the direction normal to that of towing. This T_n is shown in a tabular form:

$\theta_n(^{\circ})$	$T_n(\text{kg.})$	$\theta_n(^{\circ})$	$T_n(\text{kg.})$
0	1.84	30	4.35
10	2.37	40	6.40
20	3.15	50	10.18

The tension T_n acting on rope at dan-leno is measured to be about 4 kg. by towing only the net, keeping the distance between dan-lenos to be the range of 10 to 3 m. Accordingly, the value of θ_n is seen to be nearly 30° when the net is in action. Putting $\theta_n=30^{\circ}$ the arc length S_r of the curve assumed by rope and its projection X_r to the towing direction are obtained in terms of the equations (2) and (3) of the reference:⁵⁾

$$S_r = 120 \text{ m.}, \quad X_r = 100 \text{ m.}$$

This calculated values of S_r and X_r are favourably compared with the observed ones as shown in Fig. 1. The mark buoys at the distance 120 m. measured along each rope from the dan-lenos just reach to sea sides, as seen Fig. 1. It is seen that

the measured value of tension on rope ($=9\sim 10$ kg.) should coincide with the tension T_t , which can be obtained theoretically, at the terminal point of the curve. The equation (1) of the reference⁵⁾ gives the value of T_t :

$$T_t = 4.4 \text{ kg.} \times 2.08 = 9.15 \text{ kg.}$$

The value of T_t theoretically determined agrees with the observed one within experimental error.

ii) Behaviour of chain fitted sweep line

The observed positions of mark buoys in the respective stages of towing are illustrated in Fig. 3. In the present case, the positions of mark buoys are deviated

Fig. 3. Positions of mark buoys attached to chain fitted sweep line. Broken lines show approximated form of sweep line. A-A': Shoreline; B, B': Positions of observers (Length B-B' is 80 m.); x: Position of buoy before towing; x: Position of buoy, towed by 20 m.; x: Position of buoy, towed by 80 m.

to the starboard side of net, because of wind blowing. In the figure is shown the approximated form of rope when the ropes were hauled by 80 m. as a broken line. The measured tension of rope are as follows:

Towed distance	(Port)	Tension	(Starboard)
20 m.	30 kg.		18 kg.
80 m.	24 kg.		16 kg.

Now the values of K_t and K_n , the tangential and normal components of frictional force of rope, are available from the preceding section.

Substituting $\kappa=0.70$ and $\alpha=90^\circ$ into the equations (3), (7), (8) and (9) of the reference,¹⁰⁾ the dimensionless values, R_n/T_p , R_s/R_n , $K_n Y/R_n$ and Y/S , characteristic for the rope employed are expressed as functions of θ_p and θ_n . In Fig. 4 are shown the isopleths of them. The frictional resistance R_s of chain was measured independently and is about 8.0 kg. Moreover, the resistance R_n of net may be approximated to

Fig. 4. Isopleths of R_n/T_p , $K_n Y/R_n$, Y/S and R_s/R_n for $\kappa=0.70$ and $\alpha=90^\circ$.

$$R_n = 2T_n = 8.0 \text{ kg.}$$

Then we have the ratios $R_s/R_n=1.0$ and $K_n Y/R_n=0.35$, since Y the half distance between both ropes is 50 m. from experimental condition. From Fig. 4, the corresponding values of Y/S , R_n/T_p and θ_p become 0.68, 0.80 and 60° , respectively.

Accordingly, the value of T_p is obtained to be 10 kg. From $T_p=10$ kg. and $\theta_p=60^\circ$ the value of T_i becomes 14 kg. The value of T_i theoretically determined is compared with the observed one of starboard rope. The measured T_i of port rope shows larger values, which may be due to the irregularity of pulling as seen in Fig. 3.

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