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EXPERIMENTS ON THE PERFORMANCE OF PLANKTON SAMPLINGS WITH NET*

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I. Performance Test on Two Types of Plankton Net
Flow–Meter Manufactured in Japan

Flow–meters have been devised for use in making plankton net hauls in order to measure the volume of water that is actually filtered by the cloth of the net. In Japan two types of flow–meters have been manufactured and sold (fig. 1). The makers are:

Tsurumi Type: Tsurumi Seiki Kosakusho Co., Ltd.[1]

Rigosha Type: Rigosha Co., Ltd.[2]

Fig. 1. Plankton net flow–meters
A: Tsurumi type
B: Rigosha type

Both types were originally designed by Mr. Z. Nakai of the Tokai Regional Fisheries Research Laboratory in Tokyo under a principle similar to that of the Atlas Current Meter,[3] but smaller in size over–all. They are equipped with a propeller consisting of four blades to convert the force of water flow into revolutions of the shaft which is connected with the dial gauge by a rather complex assemblage of gears. The Atlas Current Meter has been used for oblique haul of a large plankton net, usually one meter in diameter at mouth, and is constructed so as to be very stout, while the instruments in Japan are designed for use in making vertical hauls with a comparatively small net, 45 cm in diameter at mouth. In vertical haul, as compared with oblique haul, the net usually passes through a relatively short distance in the water, hence certain additional revolutions of the propeller of the flow–meter, if they occur as a result of the apparatus being exposed to wind in the air above the sea surface, may result in a higher reading to certain extent on the dial of the flow–meter in relation to the total reading. In addition, in vertical haul a device to stop the counter revolution during descent of the net in the water is necessary. Under such circumstances instruments in Japan are not only small in size in order to correspond with the small size of the net, but also they are equipped with certain devices as stoppers.

The instrument of Tsurumi type is 8.3 cm in diameter and 7.5 cm in height of casing, weighing 0.65 kg in total assembly. It is equipped with two stoppers of very clever device (this part is patented); one stopper posteriorly prevents revolution of the

propeller during descent in the water by touching with the propeller as it is pressed upwards by water flow from below; the other stopper anteriorly which consists of balance weight and horizontal plate, acts to stop the revolution in the air by means of a stopping pin under the weight. The weight is lifted during ascent in the water because the water flow from above presses the horizontal plate which is set on a bar at the end opposite to the weight.

The instrument of Rigosha type is 6.3 cm in diameter and 5.5 cm in height of casing, weighing 0.4 kg in total assembly. The center hole of the propeller loosely fits to the shaft so as to make it possible for the propeller to slide up and down along the shaft. It has a ratchet on the upper portion of the shaft of the propeller which acts to stop the revolution while the instrument is going down into the depth. There is a weak spring around the shaft just below the propeller. The spring exerts force to lift the propeller up to touch the ratchet, so that the propeller do no longer revolve when the instrument is placed in the air, unless the instrument is faced against the wind of more than about 8 m/sec. But in ascending in the water the propeller is pressed by the water current, unless the hauling speed is less than about 40 cm/sec, and therefore, it is released from the ratchet.

The main purpose of the present experiments is to find out within what range of velocity of water flow these flow–meters show revolutions in constant ratio of the number of revolutions to the distance of tow. Nishizawa & Anraku (1956), when they made a performance test .on the flow–meter, Tsurumi type, experienced a certain variation in performance according to individual instruments; some instruments acted very well while others from the same maker did not do so. In the present experiments the best one of four available Tsurumi type instruments was used, but as to the Rigosha type instrument, there was only one available.

Tank Experiments

The experimental tank is 28 cm × 30 cm in section of the water channel, and the water flow driven by the propeller of an electric motor is regulated to keep the same velocity everywhere in the section with the aid of stream–lined plates. The velocity of water flow is recorded by means of a Pitot's tube, but in lower velocity than about 40 cm/sec it was also measured by observing the time required for the drift of a piece of wood for a definite distance. The velocity calculated from Pitot's tube is somewhat less than that calculated from drift of wood when the velocity is lower than about 30 cm/sec, while this is inversely changed at a velocity higher than about 30 cm/sec. It is unclear whether the measurement by Pitot's tube or by drift of a piece of wood shows more accurate value of the velocity, and so in plotting the revolution number of the flow–meters at various velocities of water flow both values of velocities were used. It was impossible to obtain a velocity of water flow higher than about 50 cm/sec.

Both types of instruments, Tsurumi and Rigosha, showed that, when they were placed against the counter water flow in the tank, the revolution of the propeller was immediately stopped by action of the stopper, even at a velocity of water flow as low as 30 cm/sec. This was made by supporting the instruments in horizontal situation; there may be, certainly, some different conditions from case of descending vertically at sea.

Tsurumi type (No. 101) and Rigosha type flow-meter were kept quite horizontal in the experimental tank at a distance just 20 cm below the water surface (from the upper side of casing of the instrument) and to face against the water flow. At various velocities of water flow the time required for 100 revolutions of propeller was recorded (fig. 2). Each experiment at the sa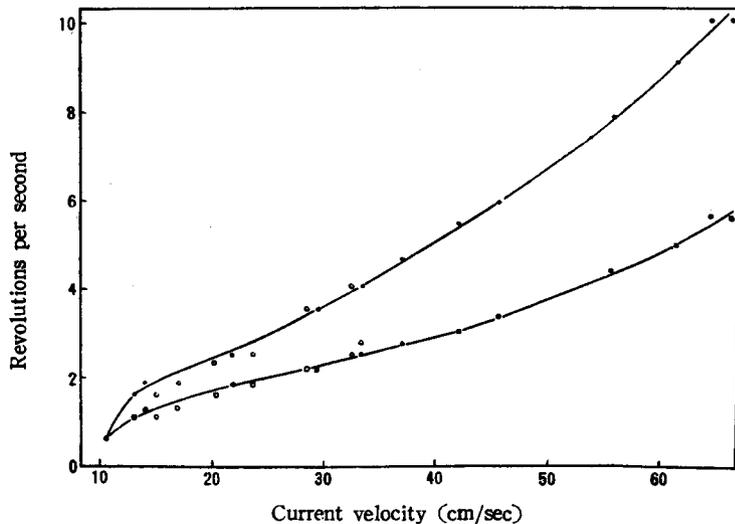me velocity of water flow was repeated three or four times, and in most cases the values of revolution showed almost no fluctuation.

The propeller of neither instrument started to revolve at velocity less than 10 cm/sec, and their performance was very irregular at about that velocity.

Figure 2 shows that the propeller of Rigosha type instrument revolves faster than Tsurumi type, but fast revolution itself does not always

Fig. 2. Performancce of two types of flow-meter in experimental tank
     Upper line: Flow-meter, Rigosha Type
     Lower line: Flow-meter, Tsurumi Type
     ● : Current velocity is calculated from Pitot's tube.
     ○ : Current velocity is calculated from drift of wood piece.

mean good performance of the instrument. The two lines in respect of both types drawn for points plotted for the obtained values respectively are both considerably curved (fig. 2). Thus it is indicated that the number of revolutions of two instruments against a definite distance somewhat varies with change of towing velocity, at least in such low velocity as adopted in tank experiments. It must be noticed, however, that the above results might involve the misreading of velocity of water flow in the tank because of inaccurate methods of measurement by Pitot's tube or by drift of wood piece.

Experiments at Sea

Experiments were carried out aboard the "Hokusei Maru" off Hakodate on July 3, 1956, when the sea was rather smooth. The two types of flow–meters were set at the two ends of a plate respectively, which was supported horizontally by an iron bar (fig. 6). This assemblage was lowered into the sea until the wire was run out by 50 meters. Immediately after having been lowered it was hauled up above the sea surface, and the number of revolutions of both flow–meters was recorded. Such experiments were repeated with progressive increase of hauling velocity from 30 cm/sec to 227 cm/sec. The angle of wire suspended to this depth varied from 5 to 15.
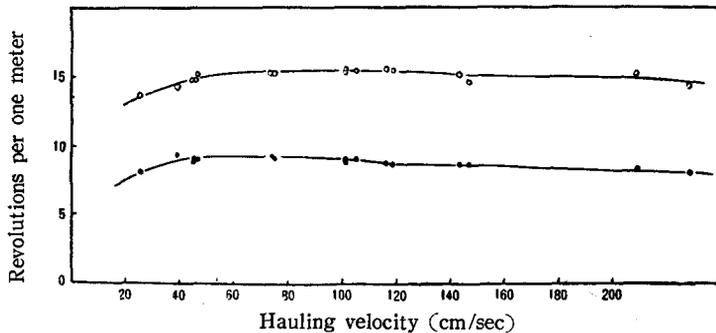

Fig. 3. Performance of two types of flow–meter at sea

• : Tsurumi Type   o : Rigosha Type

Figure 3 is a graph of the number of revolutions of · flow–meters for each meter at various velocities of haul. It is shown that the revolutions of both types of instrument were kept nearly cons–tant at any velocity except at one less than about 40 cm/sec.

In vertical haul with standard net (45 cm in diameter at mouth) the hauling velocity is usually kept as nearly as possible at one meter per second. In this case the velocity of flow of water that passes through the mouth ring of the net may be less than the above velocity because of resistance offered by the cloth of the net. Although this resistance may be variable with the degree of clogging of the samples on the mesh openings of the cloth, experiments with 45 cm standard net made at sea by vertical haul from 150 meter depth in comparatively clean water showed that revolutions of the flow–meter, Tsurumi type, which was held at the center of the mouth ring of the net, were decreased by about 30–40% as compared with the case of the flow–meter without net (cf. p. 9). It is calculated that the revolution of the flow–meter at the center of the mouth ring of the net occurs as fast as about five times per meter at 120 cm/sec of hauling velocity. These values of revolution correspond to about 60 cm/sec of velocity of water flow; that is, the values are within the limit of performance of the instrument.

II. Estimation of Increase in Hauling Distance in Vertical Haul with Net due to Drift of the Ship

In vertical haul with plankton net, when the ship is not well equipped to adjust her situation against the wind and current, the actual distance of haul would be increased due to the drift of the ship caused by wind (as well as by undersurface current). In such cases the net which is lowered to the desired depth (the length of wire run out is known) would be hauled at some distance from the point at which the net was lowered to the sea surface apart from the original location of the ship, so that the net would pass through a larger distance than the length of wire run out. This increase is included in the reading of flow–meter kept at the center of the mouth ring of the net, and the total amount of water filtered by the net may be simply calculated. However, in the hauls, if flow–meter is not employed, it would yield an error to a certain extent in estimating the volume of plankton in samples. For such reason, usefulness of flow–meter in vertical haul (exactly non–vertical) in bad weather is emphasized (Cushing, 1955).

During the voyage in the Bering Sea in the summer of 1955, a flow–meter Tsurumi type was kept on the special casing on the wire apart from the mouth ring of the net (45 cm × 165cm net) in order to register only the distance of haul irrespective of variation of filtration of the net. Notwithstanding the fact that the length of wire run out was always kept to just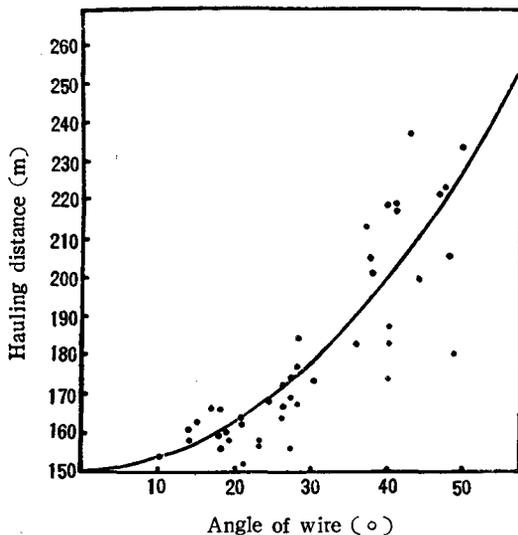 150 meters, the revolutions of the flow–meter held at a such position greatly varied. The variation must have resulted from the changing drifting–rate of the ship, and, therefore, the variation is supposed to have a correlation with the angle of wire when suspended. On more than 70 times of hauls the revolutions of flow–meter are plotted against the angle of wire at the corresponding haul (fig. 4). The curve drawn for distribution of such plottings fits to the formula: $y = 0.0275 x^2$, where y is increase of hauling distance and x is angle of wire. From this formula the distance of haul is obtained for each round number of degrees of wire (table 1). The present data is

Fig. 4. Relation between hauling distance and wire angle

based on the hauls of 45 cm × 165 cm net with 10 kg of weight using steel wire of 2.7 mm diameter. The ship "Oshoro Maru" (617 gross ton) is liable to be drifted by wind from the side because of her considerably high free board. The present experiments merely show the necessity of such considerations as increase of hauling distance when the ship is drifted by wind. Investigators should estimate constants of

Table 1. Relationship between wire angle and hauling distance

Length of wire run out (m)	Angle of wire when suspended	Hauling distance calculated (m)
150	0	150
150	5	151
150	10	153
150	15	156
150	20	161
150	25	167
150	30	175
150	35	184
150	40	194
150	45	206
150	50	219
150	55	233

the above formula with their own gears on board their own ships.

On the other hand, if the distance of drift of the ship caused by wind at any velocity can be known by bearing on shore or by direct measurement of current, otherwise empirically, the distance of haul of the net is simply calculated by a formula:

$$x = \sqrt{a^2 + 2dl \sin \alpha + l^2},$$

where x is the distance of haul of the net, α is the angle of wire, d is the distance of drift, and l is the length of wire cast.

III. Estimation of Filtration Coefficient of Various Types of Plankton Net

Most of the works for estimation of filtration coefficient of plankton net have adopted such methods as making comparison of the individual number or volume of plankton organisms between those collected by net haul and those collected quite quantitatively by pumping method or other ways (Kokubo & Tamura, 1931 and many other works). As has been shown, the plankton animals themselves are not always distributed at random even in a limited area at sea (Barnes & Marshall, 1951; Motoda & Anraku, 1955b; Anraku, 1956) and this fact commonly results in a rather wide variation of amount of zooplankton samples in replicate hauls. It seems to be desirable to estimate filtration coefficient of the net more directly, *i. e.*, by physical technique, when zooplankton samples are considered. The present experiments were undertaken for estmation of filtration coefficient of plankton net by reading revolutions of the flow–meter kept on the net.

In vertical haul with net the variation of revolutions of flow–meter which is kept at the center of the mouth ring is supposed to occur because of the varying rate of clogging of the organisms and other suspended materials on the mesh opening of cloth of the net as well as the increasing rate of hauling distance due to the drift of the ship (p. 4). The clogging of the net varies with the abundance and nature of suspended organic and inorganic materials existing at the time of the collection, and the drift of the ship results from the wind pressure against the ship together with the current of water. It is supposed so far as usual ocean collections are concerned, that the variation of

flowmeter readings which is caused by the rate of drift of the ship is exceedingly large compared with that caused by the difference of abundance and nature of materials collected. Clogging of plankton organisms and other suspended materials on the cloth of the net of course may cause a decrease of filtering efficiency of the net, but in the second series of the present experiments successive replicate hauls were made without removing the materials collected in the net. Notwithstanding, the flow-meter readings in replicate hauls with 45 cm net or 20 cm fine mesh net did not yield regular decrease in flow-meter readings. The first haul did not always yield larger number of revolutions of flow-meter than the last hauls (up to ninth). These facts indicate, so far as the case of the second series of the present experiments is concerned, that concentration of materials in the net does not apparently affect the filtering efficiency of the net. The volume of plankton organisms and other materials collected in this sampling was comparatively small; less than 1 cc for the vertical haul from about 40 meter depth with 45 cm net and also similarly with 20 cm fine mesh net. Accordingly the present data may not be widely adoptod to other cases.

First Series of Experiments

The first series of experiments was made in the same work as the experiments on the variabilities of catches (p. 15), off Cape Esan, southern Hokkaido, on April 30, 1956. The sea bottom is so deep that the ship was not able to drop her anchor. She was drifted by wind, resulting in a certain extent of inclination of wire when suspended.

Calibration of flow-meter (Exp. 1)

For calibration of flow-meter they were held at the center of a ring of 45 cm diameter, and raised up to sea surface after the wire was paid out by 150 meters. Two flow-meters were hauled simultaneously by assembly in pair (fig. 5, cf. Motoda & Anraku, 1955b). Exact distance of haul was unknown due to the drift of the ship, but supposed increase of hauilng distance was calculated adopting the data on the relationship between the increase of hauling distance and wire angle (p. 5).

Fig. 5. Assembly of two
flow-meters

On this assumption the revolutions of flow-meter for a definite distance of haul at about 1 m/sec of hauling speed were calculated (table 2). The three bridles of the ring as well as horizontal iron rod might have interfered the revolutions of flow-meters to some extent, but the possible error due to this interference
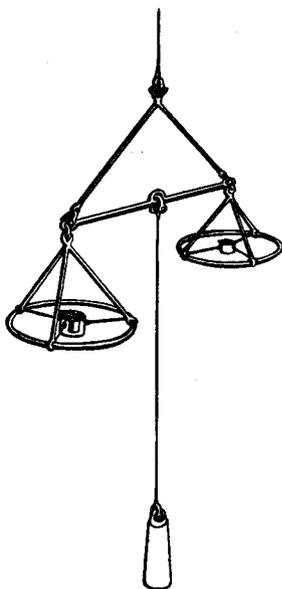
Table 2. Calibration of flow–meter (I)
April 30, 1956, off Cape Esan; "Oshoro Maru", without anchoring

No. of experiments	1	1
Type of flow–meter	Tsurumi 101	Tsurumi 102
Number of hauls repeated	5	6
Mean wire angle (°)	33.5	33.5
Deviation of wire angle (°)	28–38	28–38
Length of wire run out (m)	150	150
Hauling speed (m/sec)	1.1–1.2	1.1–1.2
Hauling distance corrected by increase due to drift of ship (assumed from wire angle) (m)	186	186
Mean revolutions for 186 m	1724	1494
Deviation of revolutions	1425–2086	1268–1865
Revolutions per 100 m	927	803

Table 3. Filtration coefficient of three types of net (I)
April 30, 1956, off Cape Esan; "Oshoro Maru", without anchoring

No. of experiments	2	2,3	3
Type of net	Marutoku Net	North Pacific Standard Silk Net	North Pacific Standard Nylon Net
Flow–meter used	Tsurumi 101	Tsurumi 102	Tsurumi 101
Number of hauls repeated	5	12	5
Mean wire angle (°)	38.4	39.8	39.2
Deviation of wire angle (°)	35–40	30–50	30–50
Length of wire run out (m)	150	150	150
Hauling speed (m/sec)	1.2	1.2	1.2
Hauling distance corrected by increase due to drift of ship (assumed from wire angle) (m)	197	201	199
Mean revolutions of flow–meter	969.8	1056.3	1188.0
Deviation of revolutions	948–1014	982–1145	1125–1240
Revolutions per 100 m	492	525	597
Revolutions in per cent for standard calibration (=filtration coefficient) (%)	53	65	64
Deviation of filtration coefficient (%)	51–55	61–70	61–67

was neglected in consideration. The last line of table 2 gives the number of revolutions of each flow–meter for 100 meter haul. Maximum deviation of revolutions in five or six replicate hauls reached to 21% in Tsurumi 101, and 25% in Tsurumi 102.
Estimation of filtration coefficient of 45 cm net (Exp. 2-3)

Three kinds of nets were used, viz., (1) Marutoku Net, (2) North Pacific Standard Silk Net and (3) North Pacific Standard Nylon Net (p.12). These nets were made of cloth of the same mesh size, approximately 0.33 mm. Assembly of two nets was hauled at the same time. As is shown in table 3, the filtration coefficient of Marutoku Net is 0.53, that of North Pacific Standard Silk Net is 0.65 and that of North Pacific Standard Nylon Net is 0.64.

Second Series of Experiments

The second series of experiments was made in Mutsu Bay from October 29 to November 1, 1956. In most cases the ship dropped anchor, and in the experiments while the ship was drifting the wind was fortunately weak, making it possible to lower the wire almost vertically; thus the increase of hauling distance due to drift of the ship could be neglected.
Calibration of flow–meters (Exp. 4-6)

In this experiment an assembly composed of two flow–meters was hauled without any interference of bridles or wire itself above the meter (fig. 6). Table 4 gives

revolutions of four types of flow–meters for 100 meter haul. The largest deviation of revolutions for replicate hauls reached to 3.7% (Rigosha 114), 7.7% (Rigosha, no number), 7.1% (Tsurumi 61), 0.7% (Tsurumi 65), and 9.9% (Tsurumi 102) respectively.
Estimation of filtration coefficient of 45 cm and 20 cm nets (Exp. 7-10)

The nets were equipped respectively with a flow–meter at the center of mouth ring, and replicate hauls were made separately for each net. Each observed number of revolutions on the net was converted to the number of revolutions for 100 meter haul.

Fig. 6. Assembly of flow–meters for calibration

From this series of experiments filtration coefficient was estimated to be 0.62 for Marutoku Net and 0.87 for North Pacific Standard both Silk and Nylon Nets (table 5).

Kobayashi and Igarashi (1956) give the following theoretical formula for the filtering–rate of conical plankton net:

$$\sin \varphi_o = \frac{\mu}{\sqrt{1 + \mu^2}}$$

Where $\sin \varphi_o$ is filtering–rate and μ is $\frac{c\alpha}{\sin\theta}$; where c is *Vena Contracta*, α is the ratio of the area of total mesh openings to the total area of net, and 2θ is the angle

Table 4. Calibration of flow-meter (II)
Oct. 30-31, 1956, Mutsu Bay; "Oshoro Maru," anchored

No. of experiments	4	4	5,6	6	5
Type of flow-meter	Rigosha 114	Rigosha no number	Tsurumi 61	Tsurumi 65	Tsurumi 102*
Number of hauls repeated	7	7	8	2	2
Hauling depth (m)	35 or 40	35 or 40	35 or 40	35 or 40	35 or 40
Hauling speed (m/sec)	0.7-1.2	0.7-1.2	0.7-1.2	0.7-1.2	0.7-1.2
Mean revolutions per 100 m	1244	1578	766	690	710
Deviation of revolutions per 100 m	1200-1290	1538-1700	740-820	685-695	640-780

*Instrument, Tsurumi 102, was reconstructed after the experiments in April 1956.

Table 5. Filtration coefficient of four types of net (II)
Oct. 30 – Nov. 1, 1956, Mutsu Bay; "Oshoro Maru," anchored or without
anchoring, but wire was suspended nearly in vertical.

No. of experiments	7	8	9	10
Type of net	Marutoku Net	North Pacific Standard Silk Net	North Pacific Standard Nylon Net	20cm × 70cm fine mesh net
Flow-meter used	Tsurumi 61	Tsurumi 61	Tsurumi 61	Tsurumi 61
Number of hauls repeated	9	9	5	5
Hauling depth (m)	28	28 or 40	40	40
Hauling speed (m/sec)	1.1-1.2	1.1-1.2	1.1-1.2	1.5-1.6
Mean revolutions per 100 m	429.7	656.7	670.2	193.5
Deviation of revolutions per 100 m	429-537	550-713	655-690	188-200
Revolutions in per cent for standard calibration (=filtration coefficient) (%)	62	87	87	25
Deviation of filtration coefficient (%)	56-70	72-93	86-88	25-26

of terminal apex of the net. Putting the figures estimated on the materials of the nets used in the present experiments into the above formula the filtering-rate is calculated as 0.8 for Marutoku Net and 0.9 for North Pacific Standard Net. These values are somewhat higher than those obtained in the present experiments to some extent.

Fujita (1956) made a discussion on physical problem of the collection efficiency of a plankton net. Adopting the data, 0.58 and 0.76 of filtration coefficient of Marutoku Net and North Pacific Standard Net obtained by the present experiments, values of constant "α" in his formula (the constant inversely proportional to the viscosity of

water and directly proportional to the magnitude of mesh openings) are calculated with results of 0.86 and 0.94 respectively.

The filtration coefficient of 20 cm × 70 cm fine mesh net (bolting cloth XX 16, 157 meshes per linear inch, approximately 0.086 mm of mesh opening) was 0.25 (table 5).

Nishizawa & Anraku (1956) found that the flow-meter attached at the center of the ring of 20 cm net, and even flow-meter set at the center of 20 cm ring only, revolves faster than the case of flow-meter without ring at the towing speed of 40–80 cm/sec, but the present experiments made at about 1.5 m/sec show only 25% of revolutions of flow-meter on the net for the calibration.

There were found rather high values of filtration coefficients on both Marutoku Net and North Pacific Standard Net in the second series of experiments compared with the values observed in the first series. The difference of values would be caused by non-random samplings whether resulted from technical treatment or from non-random distribution of plankton organisms. At present, the filtration coefficient of Marutoku Net is tentatively supposed to be 0.58 and that of North Pacific Standard Net to be 0.76, taking means of the two series of experiments. This figure is a tentative one, but may be considered as an approximate value in usual case, and may be applied for approximate estimation of zooplankton volumes on the samples collected by non-flowmeter samplings. However, there is a failure in the present experiments, namely, the authors became aware after the experiments that the mesh opening of Marutoku Net used had been decreased from 0.33 mm of original size to approximately 0.21 mm possibly because of clogging during long employment (p.17). The filtration coefficient of new Marutoku Net, therefore, must be larger than the observed data to some extent.

Some of the plankton samplers, e. g., High Speed Plankton Sampler, Gulf I, III (Arnold, 1952; Gehringer, 1952) are equipped with current meter behind the filtering portion; that is, the amount of water filtered by the filtering portion is estimated on the water flow before it runs out from the posterior opening of metal casing of the instrument. It seems more plausible to estimate the water flow at the portion of the flow out because there may be a turbulence of water around the mouth opening to some extent (cf. Currie & Foxton, 1957). How about such estimation on the ordinary conical net in vertical haul ? The following experiments were rather tentative tests on the readings of flow-meters which are attached to the posterior ring of long canvas cylinder containing net.

The revolutions of flow-meters when they are kept at the center of both upper and lower rings of 45 cm × 290 cm canvas cylinder (supposed to be non-filtering) are given in table 6. The lower flow-meter revolves faster than the upper flow-meter by about 1.6. The readings of revolutions (108%) of the lower flow-meter even exceeded the calibrated value. When Marutoku Net is set in this canvas cylinder (fig. 7) the lower flow-meter revolves faster than upper flow-meter by about 2.8 (table 7). In the case of

Table 6. Revolutions of flow-meters kept at the both ends of 45 cm × 290 cm canvas cylinder

No. of experiments	11	12
Position of flow-meter	Center of upper ring	Center of lower ring
Flow-meter used	Tsurumi 61	Tsurumi 61
Number of hauls repeated	3	3
Hauling depth (m)	40	40
Hauling speed (m/sec)	1.5	1.3-1.4
Mean revolutions in per cent for standard calibration (%)	70	108
Deviation in per cent (%)	69-72	100-109

Table 7. Revolutions of flow-meters kept at the both ends of canvas cylinder installed with Marutoku Net inside

No. of experiments	13	14
Position of flow-meter	Center of upper ring	Center of lower ring
Flow-meter used	Tsurumi 61	Tsurumi 61
Number of hauls repeated	4	3
Hauling depth (m)	40	40
Hauling speed (m/sec)	1.1	1.1
Mean revolutions in per cent for standard calibration (%)	32	90
Deviation in per cent (%)	28-38	88-93

Table 8. Revolutions of flow-meter kept at both ends of canvas cylinder installed with North Pacific Standard Silk Net inside

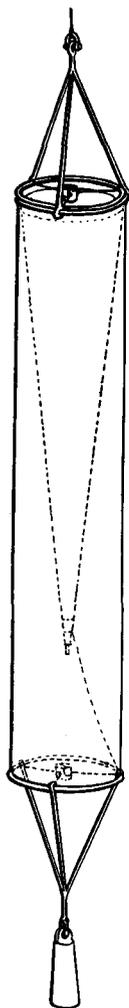| No. of experiments	15	16	17
Position of flow-meter	Center of upper ring	Center of lower ring	Inner side of lower ring
Flow-meter used	Tsurumi 61	Tsurumi 61	Tsurumi 61
Number of hauls repeated	3	3	3
Hauling depth (m)	40	40	40
Hauling speed (m/sec)	1.1-1.2	1.1-1.2	1.1-1.2
Mean revolutions in per cent for standard calibration (%)	46	88	69
Deviation in per cent (%)	46-46	85-91	64-74

North Pacific Standard Net flow-meter set on the lower ring revolves faster than the upper flow-meter by about 1.9 (table 8). The flow-meter set at the center of lower ring of canvas cylinder containing Norpac Net revolves faster than the flow-meter attached on the inside periphery of lower ring by about 1.3, indicating that the water flow in the canvas cylinder is interferred with along the side of cylinder possibly due to the friction of canvas cloth at the side (table 8). When fine mesh net (20 cm × 70 cm) is set inside the 20 cm × 121 cm canvas cylinder, the flow-meter at the center of the lower ring of canvas cylinder revolves faster than the flow-meter at the center of the upper ring by about 1.2 in the case of the smaller Rigosha flow-meter, and by about 2.1 in the case of the larger Tsurumi instrument (table 9).

It is always found that the flow-meter revolves faster at the lower portion than at the upper portion of the canvas cylinder, and, in addition, the flow-meter at the center of the lower ring revolves faster than at the periphery. The revolutions of the flow-meter at the mouth of the net become less when net is covered with canvas cylinder (except the case of 20 cm net) compared with the case of net only. The decrease of water flow due to friction on the inner surface of canvas cylinder might have occurred in this case. The usefulness of canvas cover to obtain more accurate estimation on filtering-rate of the net than usual method cannot be claimed. More detailed experiments and criticism on this problem are expected to be made by physicists.

IV. Specification of "North Pacific Standard Net" and Variabilities of Catches with It

Specification of standard net suggested by Norpac Meeting

Fig. 7. Canvas cylinder installed with net

Oceanographers and marine biologists from Canada, United States, New Caledonia and Japan had a meeting on North Pacific Oceanography (NORPAC Meeting) in Honolulu in February 1956. The subcommittee on biology of this meeting proposed a recommendation for the standardization of plankton net, depth of collection and quantitative treatment of zooplankton samples in hopes of making truly comparable the data on standing crops of zooplankton from various areas of the Pacific. But it is not suggested that the standard method should necessarily replace the methods now in use which are designed to meet the needs of particular investigations; the standard method may be adopted in addition to those used for special purposes.

Table 9. Revolutions of flow-meter kept at both ends of 20cm × 121cm
canvas cylinder installed with 20cm × 70cm fine mesh net

| No. of experiments	18	18	19	20
Position of flow-meter	Center of upper ring	Center of lower ring	Center of upper ring	Center of lower ring
Flow-meter used	Rigosha 114	Rigosha no number	Tsurumi 61	Tsurumi 61
Number of hauls repeated	5	5	3	3
Hauling depth (m)	33 or 34	33 or 34	33	40
Hauling speed (m/sec)	0.9-1.1	0.9-1.1	0.7-0.9	1.4-1.5
Mean revolutions in per cent for standard calibration (%)	37	46	24	51
Deviation in per cent (%)	33-42	40-48	23-26	44-55
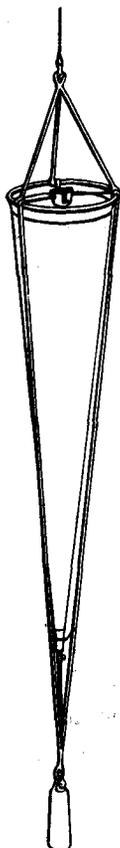
Fig. 8. North Pacific
Standard Net
rigged for
vertical use

Proposed specifications for a standard plankton net (fig. 8) and procedure are as follows:

Net:
Diameter: 45 cm at mouth
Shape: Conical
Length of filtering cloth: 180 cm
Material: 0.33 mm aperture with grit gauze, bolting silk or nylon
Bucket: Not specified

Flow-meter:
A simple, inexpensive meter of small type shall be mounted in the center of the mouth of the net.

Hauling procedure:
The hauls shall be whether vertical or oblique, from an estimated depth of 150 meters. Hauling speed shall be kept 1 m/sec, in maximum 2 m/sec.

Laboratory procedure:
Wet weight determination is suggested. The samples may be weighed after removing water from the organisms by rolling them repeatedly on blotting paper or by any other convenient way. This does not preclude the displacement volume method as well. Exceptionally larger organisms than usual constituents in the samples shall be removed before the measurement.

Reporting of data:
Data on zooplankton concentrations shall be reported as mg or gr wet weight per 1000 cubic meters of water filtered, or as cc in wet displacement volume per 1000 cubic meters.

In the Scripps Institution of Oceanography at La Jolla, California, and the Pacific Oceanic Fishery Investigations in Honolulu customary zooplankton collection have been made by oblique haul with large-sized and coarse-meshed net. They will help to obtain data comparable with those from western Pacific areas mostly operated by Japanese ships by adjusting the sampling in such way that the North Pacific Standard Net is attached on the wire above the customary large net so as to let the standard net sample the plankton through upper 150 meter layer by oblique haul.

In Japan since 1949 most of the plankton investigations supervised by the Fisheries Agency have adopted the method which was standardized by Mr. Z. Nakai for the Cooperative Sardine Research Program. The method is that a conical net, so-called "Marutoku Net", 45 cm in diameter at mouth, 100 cm in length including canvas band, with materials of bolting silk cloth GG 54, 52.5 meshes per linear inch, having approximately 0.33 mm mesh opening, is hauled from the depth of 150 meters as indicated by the length of wire run out, to the sea surface at a speed of 1 m/sec. A small type of flow-meter may be held at the center of the mouth ring of the net to register the amount of water that has been filtered by the net. The modification from this customary net to the "North Pacific Standard Net" is only concerned with the lengthening of the filtering portion.

Japanese ships have usually made collections without concern for the exact depth of haul; the haul has been made for a definite length of wire run out. Although such work is very easy, for comparison of abundance of zooplankton in upper 150 meter layer in various areas the haul should be made from an estimated depth of 150 meters as assumed from the angle of wire. It is desirable, however, when distinct discontinuity of water masses exists within this range of depth that the haul may be made only through that portion of the sea above the depth of such discontinuity, because the principal aim is the comparison of standing crop of zooplankton in the upper water mass.

Diurnal change in zooplankton volume in the upper 150 meters may result in complexity in comparison of abundance of samples over wide area when the samples are collected at different times of the day with each other (cf. King & Hida, 1954; Motoda & Anraku, 1954, 1955a); frequent observations covering day and night, as well as desirably at dawn and twilight, in a comparatively limited area may be able to offer the correction curve.

Analyses of variance of catches by replicate vertical hauls at sea

Because of necessity for comparison of the data obtained hitherto with "Marutoku Net" to those with new standard net in future, the present experiments were undertaken to affirm variabilities of catches with the two types of net and to show the difference between them in amount of total catches. Materials of this experiment are the same collections as used in first series of experiments on filtration coefficient of the nets

(p. 7), made off Cape Esan, Southern Hokkaido, on April 30, 1956. The following three patterns of conical nets were used.

  1) 45 cm in diameter at mouth, 100 cm in length, with bolting silk, GG 54 (Marutoku Net)
  2) 45 cm in diameter at mouth, 180 cm in length, with bolting silk, GG 54 (North Pacific Standard Net)
  3) 45 cm in diameter at mouth, 180 cm in length, with nylon cloth, NGG 54 (North Pacific Standard Net)

Table 10. Replicate hauls with three patterns of net
Ss: Standard Silk Net
Sn: Standard Nylon Net
M: Marutoku Net

No. of haul	Time	Net	Calculated amount of water filtered(m^3)
1	12:46–12:50	Ss	21.3
		M	17.0 *
2	13:03–13:05	Ss	21.1
		M	17.6
3	13:16–13:18	Ss	19.6
		M	16.4
4	13:38–18:40	Ss	21.7
		Sn	21.5
5	13:48–13:50	Ss	21.3
		Sn	20.8
6	13:59–14:02	Ss	20.6
		Sn	21.5 *
7	14:13–14:15	Ss	20.7
		M	16.6
8	14:30–14:32	Ss	20.9
		M	16.9
9	14:42–14:44	Ss	20.3
		M	16.5
10	14:54–14:57	Ss	20.9
		Sn	19.5
11	15:08–15:11	Ss	22.9
		Sn	20.3
12	15:18–15:21	Ss	22.3
		Sn	20.7

*Flow–meter reading failed; assumed from the data of similar wire angle.

The hauls at sea were made according to the procedure shown in table 10; the first three hauls with altogether standard silk net and Marutoku net, the second three hauls with altogether standard silk net and standard nylon net, the third three hauls again with altogether standard silk net and Marutoku net, and the fourth three hauls with altogether standard silk net and standard nylon net.

The amount of water filtered by the nets in each collection is calculated by the revolutions of flow-meters on the net calibrated with non-net flow-meter hauls.

Examining samples in the laboratory the authors became aware of the fact that there happened apparently large number of small-sized copepods and a few other similar sized animals in the samples of Marutoku Net compared with the contents of the samples of North Pacific Standard Net. Such small-sized animals included in the samples of Marutoku Net were 0.8–1.7 gr in a haul, while in the samples of North Pacific Standard Net were only 0.2–0.9 gr. Marutoku Net used in this experiment is that which has long been employed at sea, and later close microscopic examination shows that the mesh openings are clogged with dried adhering materials to some extent, making the mesh opening about 0.21 mm. On the other hand, North Pacific Standard Nets both of silk and nylon used in the experiments were new and the mesh openings of them were about 0.33 mm. These facts might possibly resulted in the finding of the larger number of small-sized animals in Marutoku Net than in North Pacific Standard Net.

Such carelessness in conducting the experiments may much decrease the value of data; in the statistical treatment of the present data small-sized copepods and a few other animals were removed from the analyses. In the five groups of animals individual number and wet weight were estimated separately by groups (tables 11, 12). Analyses of variance were made for the following four series of experiments as to the individual counting only.

    Series 1. Three times replicate paired hauls with 45 cm × 100 cm Marutoku Net
          and 45 cm × 180 cm North Pacific Standard Silk Net

    Series 2. Ditto

    Series 3. Three times replicate paired hauls with 45 cm × 180 cm North Pacific
          Standard Silk Net and Nylon Net

    Series 4. Ditto

In analyzing the variances, logarithmic values for the number of animals were used instead of the actual number. In the first place, calculation was made as to the logarithms of individual number of main five groups without making correction concerning the filtered amount of water, and eight analyses were made independently. Secondly, the analyses were made regarding the logarithms of individual number after making correction by flow-meter readings, $i. e.$, correction for an estimated amount of water filtered, and similarly eight separate analyses were made.

The percentage standard deviation and its 95% fiducial limits calculated from each table of analyses of variances are given in table 13, A and B. Rather wide variation of catches is found in each case. In most cases opposite to expectation North Pacific Standard Net does not yield narrow limits of variation compared with Marutoku Net. The previous report (Motoda & Anraku, 1955b) gives an account of variability of

Table 11. Individual number of five groups of animals in the sample of each haul
(Correction by flow-meter readings is not made)

Series of experiments	1						2						3						4					
Net	45cm×180cm Silk Net			45cm×100cm Silk Net			45cm×180cm Silk Net			45cm×100cm Silk Net			45cm×180cm Silk Net			45cm×180cm Nylon Net			45cm×180cm Silk Net			45cm×180cm Nylon Net		
No. of haul	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Calanus plumchrus	1673	1058	723	1409	603	701	739	349	418	544	314	423	408	391	210	546	431	209	222	247	1140	249	244	988
Calanus cristatus	6	4	3	10	4	2	15	1	7	10	5	8	14	6	4	12	1	1	6	7	3	4	10	1
Euphausiids	54	35	20	73	35	15	7	10	34	8	12	45	9	5	3	8	4	2	40	86	75	58	57	81
Themisto	24	11	15	81	54	43	27	18	56	55	30	97	15	66	31	15	24	49	42	61	22	31	16	55
Sagitta	222	99	122	147	71	55	64	72	112	35	84	117	63	94	62	56	92	53	124	117	143	123	106	136
Total	1979	1207	883	1720	767	816	852	450	627	652	445	690	509	562	310	637	552	314	434	518	1383	465	433	1261

Table 12. Wet weight in gr of five groups of animals in the sample of each haul
(Correction by flow-meter readings is not made)

Series of experiments	1						2						3						4					
Net	45cm×180cm Silk Net			45cm×100cm Silk Net			45cm×180cm Silk Net			45cm×100cm Silk Net			45cm×180cm Silk Net			45cm×180cm Nylon Net			45cm×180cm Silk Net			45cm×180cm Nylon Net		
No. of haul	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Calanus plumchrus	3.0	2.4	1.8	2.6	2.4	1.7	1.5	0.6	0.7	1.1	0.6	0.7	0.7	0.8	0.3	0.6	0.9	0.3	0.4	0.4	2.7	0.5	0.5	2.4
Calanus cristatus	0.1	0.05	0.05	0.2	0.1	0.05	0.2	0.05	0.1	0.1	0.1	0.1	0.2	0.1	0.05	0.1	0.05	0	0.1	0.1	0.05	0.05	0.1	0.05
Euphausiids	0.1	0.1	0.1	0.1	0.1	0.05	0.05	0.05	0.1	0.05	0.05	0.2	0.05	0.05	0.05	0.05	0.05	0.05	0.1	0.1	0.1	0.1	0.1	0.5
Themisto	0.1	0.1	0.1	0.4	0.3	0.5	0.1	0.1	0.3	0.3	0.3	0.5	0.1	0.5	0.2	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.1	0.3
Sagitta	0.8	0.3	0.6	0.7	0.3	0.3	0.4	0.3	0.5	0.2	0.4	0.4	0.4	0.5	0.3	0.4	0.4	0.4	0.5	0.4	0.7	0.5	0.4	0.6
Total	4.1	2.95	2.65	4.0	3.2	2.6	2.25	1.1	1.7	1.75	1.45	1.9	1.45	1.95	0.9	1.25	1.5	0.95	1.3	1.2	3.65	1.25	1.2	3.85

Table 13. Percentage standard deviations and their 95% fiducial limits
(in parenthes) of catches by replicate hauls with 45 cm net

A. Without correction by flow-meter readings

Series of Experiments	45 cm × 100 cm Marutoku Net	45 cm × 180 cm North Pacific Standard Silk Net
1	83 (30-336)	45 (47-212)
2	80 (31-327)	120 (21-487)

Series of Experiments	45 cm × 180 cm North Pacific Standard Nylon Net	45 cm × 180 cm North Pacific Standard Silk Net
3	123 (20-449)	71 (34-294)
4	113 (22-453)	97 (28-362)

B. After correction by flow-meter readings

Series of Experiments	45 cm × 100 cm Marutoku Net	45 cm × 180 cm North Pacific Standard Silk Net
1	81 (31-328)	51 (46-217)
2	82 (30-331)	122 (20-493)

Series of Experiments	45 cm × 180 cm North Pacific Standard Nylon Net	45 cm × 180 cm North Pacific Standard Silk Net
3	120 (21-428)	68 (35-284)
4	98 (25-393)	72 (34-295)

catches by replicate hauls with Marutoku Net to be 47% of percentage standard deviation and 46-217% of 95% fiducial limits, based on the experiments made off Otaru on August 7, 1953. The difference of variation of catches with 45 cm net between the previous and the present experiments is rather large. Difference in population as well as technical inconstancy might have caused this difference of variation of catches. It would be safe to consider that such variation by vertical haul with 45 cm net whether 100 cm long or 180 cm long, has the possibility of reaching the largest values observed, *i. e.*, about 122% of percentage standard deviation ···about 20-493% of 95% fiducial limits. If so, one catch should not be considered as more abundant or less than other catch unless it exceeds the another catch by about five times or reaches one-fifth of other catch in comparison with the mean.

Ratio of catches between 100-cm-long net and 180-cm-long net

For calculating the ratio of catches between both types of the net, the data of the three hauls of the first and second series of the above experiments are grouped together. The calculation gives 1.15 of mean ratio of catches in individual number of 180 cm long North Pacific Standard Net to those of 100 cm long Marutoku Net. Its 95% fiducial limits are 83 and 164%. When the catches are corrected by flow-meter readings (amount of water filtered) these values become 0.92 and 65-152% of 95% fiducial

limits. In wet weight, ratio of catches between the two types of the nets is 0.99 and 71–126% of 95% fiducial limits when the catches are not corrected by flow–meter readings. They become 0.81 and 75–87% of 95% fiducial limits when correction by flow–meter readings is made.
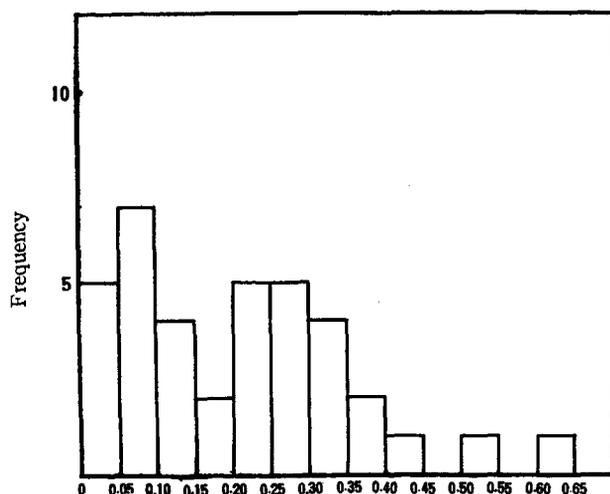
The above results show that the ratio of amount of catches is approximately 1 between 100 cm long Marutoku Net and 180 cm long North Pacific Standard Net, though this ratio varies within considerably wide variation.

It is remembered that the filtration coefficient assumed from flow–meter readings is apparently larger in 180 cm long net than in 100 cm long net (p. 11). Notwithstanding, 180 cm long net does not yield apparently nor statistically larger catch than 100 cm long net. However, such ratio and its variations between two types of the nets are included within the limits of variation of catches in replicate hauls (p. 19).

Duplicate vertical hauls at sea

Our laboratory has used a net of 45 cm × 165 cm, GG 54, 1954. In the Norpac observations to the Bering Sea in the summer of 1955 such net was hauled from approximately 150 meter depth twice at each station (Motoda & Fujii, 1956). The first haul was made before beginning the hydrographic cast and the second haul after finishing that cast. These two samplings for each station very commonly yielded amounts of plankton samples differing from each other to a certain extent.

It is seemingly proven that the frequency of the ratio of half the difference between duplicate samples to the mean of them in displacement volume is distributed normally with the mean value zero (fig. 9), so that the standard deviation of this ratio is calculated with result of 0.250; twice is 0.500, and therefore, 95% fiducial limits are 50% and 150%. In this case volume of one catch should not be considered to differ from that of other catch unless the difference is not larger than the mean of them. The calculation in this case is based on many hauls which were made at various localities covering a wide area, and the materials treated

Ratio of difference between duplicate hauls to the mean of them (wet displacement volume)

Fig. 9. Histogram showing frequency distribution of ratio of difference to mean of duplicate hauls (half is taken on the abcissa, because a mean is related against lower and upper deviations.)

might have included various different populations.

V. Acknowledgement

VI. Summary

(1) Two types of flow-meters manufactured in Japan for use of plankton net haul are tested on their performance. In both types of instruments the propeller revolves at constant rate against the unit distance of tow at a speed more than 40 cm/sec. Devices for stopping the revolutions in the air as well as against the reversed flow of water are effectively operated.

(2) Increase of hauling distance in vertical haul of the plankton net occurs when the ship is drifted by the wind. Basing on the experiments at sea for 0–150 meter haul the relation between the angle of suspended wire and distance through which the net has actually passed is given in the formula, $y = 0.0275x^2$, where y is increase of hauling distance and x is wire angle. The constants will vary with the net and weight used.

(3) The filtration coefficient of two types of conical nets, i. e., 45 cm × 100 cm Marutoku Net and 45 cm × 180 cm North Pacific Standard Net, both made of filtering cloth having approximately 0.33 mm of mesh opening, is estimated by reading the revolutions of flow-meter which is attached at the center of the mouth ring, with results of 0.58 in Marutoku Net and 0.76 in North Pacific Standard Net.

(4) Specifications of North Pacific Standard Net recommended at the oceanographic meeting in Honolulu in February 1956 are described.

(5) The variabilities of catches by vertical haul from about 150 meter depth with Marutoku Net and North Pacific Standard Net are calculated on the samples of replicate hauls (table 13). The largest values among the data obtained, 122% of percentage standard deviation with 20–493% of 95% fiducial limits, may be suggested to be adopted on the samples collected with such 45 cm net.

(6) The amount of catches with Marutoku Net and with North Pacific Standard Net is compared statistically; there is no significant difference between them.

(7) Duplicate hauls with 45 cm × 165 cm net made at 37 stations in the Bering Sea show the 0.500 of standard deviation (50 - 150% of 95% fiducial limits) of ratio of half the difference to mean of duplicate catches.

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