A 160-cm Opening-Closing Plankton Net*

II. Some Notes on the Towing Behavior of the Net

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Abstract: The towing behavior of three Ocean Research Institute nets, ORI-200, ORI-33, and ORI-C, is considered from the results of their performance tests and the routine samplings. The following facts are observed:

1. It seems very difficult to tow the net straightly in oblique tow. The experiment shows that the net speed and the volume of water filtered can be kept almost constantly in descent, while they are increased and greatly varied in ascent.
2. In horizontal tow, the net depth is decreased rapidly at a moment when the net is opened on a throttling system. The time required for the stabilization of the net and the vertical thickness of the towing layer increase with increasing of the length of wire out.
3. The determination of the towing depth by the measurement of wire angle is only reliable for samplings in the water shallower than 500 m.
4. The filtration ratio for each of the ORI nets is approximately 0.95.
5. When catches taken by the three nets are compared, the catches do not greatly depend upon the mesh size for the animals whose maximum width is larger than the coarsest mesh aperture.
6. The effective cross-section all area of the ORI-C net in regard to small euphausiids which pass through the coarse-mesh portion of the net is 0.63 m^2 .

1. Introduction

One of the authors (OMORI, 1965) has described an opening-closing plankton net, 160 cm in mouth diameter and 750 cm in length, three kinds of which are named ORI-C, ORI-200, and ORI-33 after their difference in mesh size, and several accessories which are being used successfully in the Ocean Research Institute. The present paper deals with some of the results obtained with these apparatus during the performance tests and routine plankton samplings, especially in regard to the towing characteristics of the net.

The filtering section of the ORI-200 is made solely of vinylon fabric netting, $1.97 \times 1.97 \text{ mm}$ mesh apertures, while that of the ORI-33 is made of silk netting GG 54, $0.33 \times 0.33 \text{ mm}$ mesh apertures. That of the ORI-C consists of the said two materials.

2. Operation of the net

The net is connected to a wire cable, 9 mm in diameter, with a double release gear or net holder (OMORI, 1965). At the end of the cable, a sinker, 100-kg in weight, is shackled by means of eyes. The net was generally towed from the stern obliquely or horizontally while the ship sailed at a speed of 2 or 4 knots. To determine the actual towing depth and the volume of water filtered, direct measurements were made by attaching a TS depth distance recorder (hereafter referred to as DDR) and an RGS flowmeter to the inside of the net ring.

3. Observations

(1) *Movement of the net in oblique tow*

In the oblique tow, the following simple method was employed for some 90 towings. An open net was released from the stern at a speed of approximately 1 m/sec, while the ship sailed at a speed of 2 knots (1 m/sec). When a requisite amount of wire had been paid out, the net was recovered immediately with the same speed as when released. The speed of the ship was not reduced until the net was lifted up to

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Table 1. Variation of the towing time, distance, speed, volume of water filtered, and wire load for each 100-m depth in the ORI-C net oblique tow.

	Depth (m)	Time (sec)	Distance (m)	Speed (m/sec)	Volume of water filtered (m ³)	Wire load (kg)
Wire out	0-100	150	110	0.7	200	93
	100-200	150	110	0.7	200	—
	200-300	150	110	0.7	200	—
	300-400	150	110	0.7	200	—
	400-500	150	110	0.7	190	—
	500-580	160	100	0.6	190	253
Recovery	580-500	40	120	3.0	220	603
	500-400	110	230	2.1	440	—
	400-300	160	290	1.8	530	—
	300-200	170	310	1.8	530	—
	200-100	190	320	1.7	580	333
	100-0	410	490	1.2	960	—

Fig. 1. Movement of the ORI net in oblique tow. (Redrawn from AIZAWA *et al.*, 1965)

the surface.

Movement of the net in water was determined by an analysis of records obtained by the DDR (AIZAWA *et al.*, 1965). Fig. 1 presents a characteristic curve for the ORI-C tow with 1,000 m of wire out. The net reached the 580-m depth at the moment when all of the wire had been paid out. It took 15 minutes for the wire release (1.1 m/sec) and 18 minutes for the recovery (0.9 m/sec). As the ship was travelling at a constant speed during the tow, the net speed naturally varied greatly. The variations in the towing time, distance, speed, and in the volume of water filtered for each 100-m depth are shown in Table 1. It was observed that the actual towing speed was almost constantly 0.7 m/sec while the net was lowered, whereas the speed greatly increased during the recovery. Particularly, at the beginning of the recovery the net rose very rapidly at a speed of more than 3.0 m/sec (6 knots). The speed was then lowered gradually with

approaching the net to the surface. But at last the change of the mean towing speed from 0.7 m/sec to 1.7 m/sec was observed in the course of descent and ascent. The gradient of the path followed by the net became smaller with decreasing the depth of the net. The towing distance, and hence the volume of water filtered, was increased with decreasing the depth. The maximum wire load, 603 kg, was recorded at the moment when the wire recovery was started.

(2) Movement of the net in horizontal tow

In this tow a closed net was lowered to the requisite depth while the ship was sailing at a speed of 2 knots. When all of the wire had been paid out, the net was opened on a throttling system by means of the double release gear. After 30 or 60 minutes of fishing, the net was closed again. Then it was recovered while the speed of the ship was reduced gradually from 2 knots to dead slow.

The typical paths followed by the nets in four horizontal tows show that the depth of the net rapidly decreased at the moment when the net was opened (Fig. 2). Then the net fished a stabilized towing depth in a stable condition. It was observed that the time required for the stabilization of the net and the vertical thickness of the towing layer were increased with increasing the length of wire out.

Fig. 2. Movement of the ORI net in horizontal tow. Arrow directing downwards on each curve indicates a point when the net was opened. Arrow directing upwards indicates when the net was closed.

During the tow, the wire cable strain measured with a tension meter changed from 143 kg to 248 kg when the net was opened at 100 m of wire length. The stress increased to 333 kg when the wire was paid out by 1,500 m.

Fig. 3. Depth determined by DDR plotted against depth determined by wire angle measurement. Measurements were carried out in the bays (•) and in the open sea (○).

(3) The wire angle and actual towing depth

During the above series of tow, the wire angle was measured just when all the requisite amount of wire had been paid out. When the net was towed at a speed of 1 m/sec, the wire angle was varying between 50° and 70° under ideal weather condition. Angles of 70° – 80° were measured when the speed of the ship increased to 2 m/sec. Fig. 3 shows a comparison of the equilibrium depth determined by the wire angle measurement with that obtained by the DDR. The difference in depths determined by the two measurements was considerably small until the net reached a depth of about 500 m. However, the variance became great in deeper layers. Thus, the determination of the net depth by the surface angle should be employed only for samplings in the shallow layers, otherwise it may invite a serious error in net operation. On the other hand, when the net was towed in the water shallower than 1,000 m, most of the DDR depths showed a slightly deeper level than that determined by the wire angle measurement. It seems to indicate that because of the heavy sinker, 100-kg in weight, the wire cable draws an arched curve during such tows, just like the curve for depressing net. Among the experiments, several ones

Table 2. Change of the wire angle with the length of wire out.

Length of wire paid out (m)	Number of tows	Wire angle in deck	Mean depth determined by wire angle (m)	Mean depth determined by DDR (m)
300	6	57° (52° – 63°)	163	172
1000	7	56° (48° – 65°)	559	600
2000	23	60° (51° – 71°)	1000	1020
4000	5	69° (66° – 74°)	1434	1360

were carried out in the open sea under rather bad weather conditions, but the tendency did not differ.

The wire angle increased with the increase of wire length. That is, the effect of paying-out the wire in lowering the net decreases greatly as the wire length increases. When the net was towed at a speed of 2 knots, any significant change of the wire angle was not observed until the wire length of 1,000 m was reached. But the angle was then gradually increased, and was about 70° when the wire was paid out to 4,000 m (Table 2).

(4) Filtering efficiency of the net

When the sea was very calm, both with and without the net, net ring with a sinker of 50-kg suspended by three bridle ropes was towed vertically through a column of water of 200-m in length at a constant speed of 1 m/sec, and the numbers of the flowmeter revolutions were compared. The measurement was repeated at least three times for each series.

As shown in Table 3, a surprisingly high filtration ratio, around 0.95, was obtained for the three ORI nets. It is apparently higher than those previously reported for several plankton nets of similar type, e.g. 0.7–0.9 for the Indian Ocean standard net (MOTODA and OSAWA, 1964) and 0.76 for the North Pacific standard net (MOTODA *et al.*, 1957). This is probably due to the fact that the present net was designed for increasing the filtering area in order to raise its filtration capacity. The ratio of the diameter to the length of the filtering section of the ORI net is 1:3.75, whereas it is 1:2.65 for the Indian Ocean standard net (CURRIE, 1963), and 1:3.20 for the Discovery N 100 net (KEMP *et al.*, 1929).

In the vinylon netting, 53% of the total fabric

Table 3. Filtration ratio of the three ORI nets.

	Without net		ORI-200	ORI-C	ORI-33
Date and time	1330-1430 Dec. 13, 1964		1140-1205 Dec. 13, 1964	1250-1315 Dec. 13, 1964	1210-1230 Dec. 13, 1964
Reeling speed	1 m/sec		1 m/sec	1 m/sec	1 m/sec
Length of wire	200 m		200 m	200 m	200 m
Flowmeter	RGS 428	RGS 429	RGS 428	RGS 429	RGS 429
Number of trials	4	4	3	3	3
Wire angle	0°	0°	3°	2°	3°
Mean revolutions per 200 m	2058	2175	1960	2070	2090
Ratio	1		0.95	0.95	0.96

area is open, while 46% of that is open in the silk netting. The close coincidence with the filtration ratio of the ORI-200 to the ORI-33 seems to indicate that the filtering efficiencies in these two different mesh portions of the ORI-C are almost the same.

The ORI-C can theoretically strain about 114 m³ of water when it is towed for 1 minute at a speed of exactly 1 m/sec. In the surface horizontal tows from the stern at a speed of about 2 knots, however, the net filtered an average 129 m³ of water per minute (Table 4).

Table 4. Volume of water filtered by the ORI-C net in surface horizontal tows.

	Duration of tows (minutes)	Depth (m)	Volume of water filtered (m ³)	Volume of water filtered per minute (m ³)
a	5	3-7	636	128
b	5	3-7	646	129
c	29	3-7	4009	138
d	30	3-7	3573	119
				Mean 129

This might have occurred because of the strong stream produced by the ship's propeller, resulting in an actual towing speed faster than 2 knots. To collect strictly only the surface plankton, the net should naturally be towed in the water which is not influenced by the ship. Towing of the net in such agitated water will involve several difficult factors, such as, not only the mixing of plankton by samplings in certain thickness of the water, but also the increases in the towing speed and in the volume of water

filtered.

On the other hand, the variation of the volume of water filtered per minute was examined for 45 oblique tows using five different lengths of the wire out (Table 5). The mean values calculated for each series of the tows did not greatly differ from each other.

(5) *Comparison of the catches of the three ORI nets, and the effective cross-sectional area of the ORI-C*

To obtain strict quantitative collection, the net should be constructed of a single mesh size, chosen according to the interests of the investigator. The ORI-200, 1.97-mm mesh aperture, and the ORI-33, 0.33-mm mesh aperture, were made for that purpose. Meanwhile, the ORI-C was constructed with two portions of these different mesh apertures, so as to catch animals of a wide range in size simultaneously with minimum degree of effort. The filtering area of the ORI-C, that is the cross-sectional area of the mouth opening, is 2.01 m² for the coarse-mesh portion and 0.18 m² for the fine-mesh portion. The former portion will reliably retain animals of about 2-mm cross-section, and the latter will fish those of about 0.35-mm cross-section. However, percentages of animals of intermediate size caught by each portion are not known.

The experiment was made to evaluate the gross selectivity of the sizes and groups of animals for the different sizes of mesh. The three ORI nets were towed continuously for a period of 50-51 minutes each, and samples

Table 5. Variations in the maximum depth attained and in the volume of water filtered by the ORI-C net in oblique tows. (*Maximum depth was estimated from the wire angle.)

Wire length (m)	Maximum depth attained by net (m)	Duration of tows (min)	Vol. of water filtered per minute (m ³)	Mean (m ³)
200	94*	9	100	121
	94*	7	118	
	97*	7	138	
	106*	7	119	
	108*	7	130	
	112*	7	142	
	112*	7	123	
	112*	6	141	
	114*	9	111	
	114*	8	98	
	118*	7	132	
	126*	8	119	
	146*	7	108	
300	150	12	143	133
	150	12	132	
	160	12	138	
	160	12	135	
	160	11	132	
	200	12	126	
	200	11	125	
1000	400	37	142	128
	500	36	140	
	580	33	119	
	580	35	123	
	740	33	118	
2000	850	77	130	128
	900	76	145	
	920	77	134	
	930	77	126	
	950	76	136	
	1000	78	117	
	1000	76	135	
	1000	79	120	
	1100	81	122	
	1260	67	140	
	1300	76	127	
	1300	79	125	
	1440	84	110	
4000	1430	174	145	138
	1560	178	131	
	1800*	162	136	
	1868*	172	145	
	2000*	174	134	
	2300*	153	136	
Mean 129				

obtained were examined and compared. The oblique tows by open nets with 850-m wire out were carried out off the Cape Kinkazan, eastern part of Honshu Island, from 2157 to 0050 on April 25 and 26, 1964. During the experiments, the wind speed were in a range of 12-20 m/sec, and so the nets were towed in a straight line along the cruise track, without getting back to the start position. The ship kept her speed at about 2 knots during the tows, but actually she moved only about 3,000 m horizontally throughout the experiment. Unfortunately, neither DDR nor flowmeter was equipped with at that time, however, from the wire angle measurement, all the nets were supposed to have lowered to the 490-m layer and to have filtered about the same amount of water. In the laboratory, the catches were allowed to stand in graduated cylinders for 24 hours before the settling volume was determined. After that the samples were divided with Motoda's splitting box and organisms in aliquots were counted for each group and their wet weights were determined.

The composition of animals caught in the samplings is shown on Table 6. In the samplings with the nets ORI-33 and ORI-C, copepods smaller than 5 mm, chiefly composed of *Pseudocalanus minutus*, occupied a large part of the total animals in number, amounting to 93.2% and 83.8%, respectively. On the other hand in the ORI-200 sampling, numerous groups were euphausiids (32.7%) and larger copepods (26.4%). *Euphausia pacifica* was a main constituent of the former, and *Calanus cristatus* and *Eucalanus bungii bungii* were predominant species in the latter. The difference of catches among three nets was more significant in total number than in total wet weight.

The relation between mesh size and size of animal was determined for euphausiids which were consisted largely of *E. pacifica* (Fig. 4). It was observed that most of the euphausiids whose body length was smaller than 12.5 mm passed through the coarse mesh net. Above this body length, dependance of catches on the mesh size was not great. The mean maximum width of the thorax of 43 individuals of *E. pacifica*, whose body length of between 12.6-15.0 mm,

Table 6. Comparison of catches taken by the three ORI nets.

Net		ORI-200		ORI-C		ORI-33	
Station		38-3		38-2		38-4	
Position		38°28.9'N 142°33.8'E		38°28.4'N 142°32.8'E		38°29.3'N 142°34.3'E	
Date		April 25, 1964		April 25, 1964		April 25-26, 1964	
Time		2300-2350		2157-2247		2359-0050	
Wire length		850 m		850 m		850 m	
Wire angle		52°		52°		52°	
Settled volume		200 cc		680 cc		2325 cc	
Animals smaller than 50 mm		No. of individuals	Wet weight (g)	No. of individuals	Wet weight (g)	No. of individuals	Wet weight (g)
	Coelenterata	75	+	101	+	96	+
	Chaetognatha	324	2.6	3048	16.2	15600	19.2
	Polychaeta	9	+	64	+	480	+
	Copepoda (> 5 mm)	436	3.1	3104	13.4	3639	17.0
	(< 5 mm)	24	+	53096	50.9	403720	363.2
	Euphausiacea (> 10 mm)	536	41.1	1481	41.9	1798	44.3
	(< 10 mm)	28	+	1907	3.8	5882	3.6
	Mysidacea	5	+	8	+	6	+
	Amphipoda	64	1.0	256	+	320	+
	Decapoda Crustacea	45	1.3	85	+	250	1.0
	Decapoda Mollusca	16	1.0	66	2.3	140	3.0
	Pisces	40	1.9	53	2.3	205	2.6
	Others	50	1.0	120	1.2	880	3.0
Animals larger than 50 mm	Decapoda Crustacea	3	4.1	1	2.1	6	1.0
	Pisces	1	5.4	1	0.8	4	23.4
Total		1656	62.4	63391	141.7	433025	497.4

was 2.02 mm. This width is closely approximate to the coarse mesh aperture (1.97 mm).

The effective cross-section of the ORI-C for the catch of euphausiids was then examined. The cross-sectional area, and hence the maximum filtering capacity, of mouth opening of the silk netting portion of the ORI-33 is about 11 times as large as the corresponding portion of the ORI-C. However, the number of small euphausiids, less than 12.5 mm, captured by the ORI-33 was only 3.2 times as many as that by the ORI-C. From these values, the effective cross-sectional area of the ORI-C for these animals was obtained to be about 0.63 m², while the actual mouth opening area for its silk mesh portion is 0.18 m². It indicates that the front portion, coarse-mesh netting, serves to catch greatly to large part of the smaller euphausiids.

That is, there might be a funneling effect towards the codend, so that more of these animals were taken by the net than was to be expected from the opening area of the portion, as suggested by ARON (1962) in the Isaacs-Kidd midwater trawl studies. The maximum width of almost all the copepods caught was less than 2.00 mm. The effective cross-section of the ORI-C for this group was 0.28 m². The funneling effect of the net was also seen for these animals, although it was smaller than that for the euphausiids. The considerably large change of the values between copepods and euphausiids might be caused by the difference of size composition and behavior of the animals.

4. Discussion

Practically, in spite of several good characteri-

Fig. 4. Variation of size of euphausiids caught by the three ORI nets.

sticks of the ORI net for adequate collection of agile plankton, the use of the weight in towing the net has seriously limited the display of performance of the net. A large amount of wire had to be paid out to keep the net at the requisite depth during the tows. For instance, using the sinker of 100k-g in weight, if one desired to tow the net in the 1500-m layer at a speed of 2 knots, generally about 4,000 m of wire cable had to be released. Paying-out of the wire caused an inefficiency in lowering of the net as the wire length increased, and, at the same time, a greater part of the time must be spent on lowering and recovering the net. The vertical thickness where the net can fish efficiently was limited greatly when the net was towed faster than 2 knots. In the present investigation, therefore, tows of the net at the ship's speed faster than 2 knots were carried out

only for samplings in shallow layers, although the net and its accessories proved to be strong enough for the tows at speeds up to 7 knots. During earlier experiments, several types of depressors were tried. Unfortunately, however, none of them showed a great deal of course stability when the towing speed became faster than 3 knots. In spite of many works on the design of new plankton nets, an effective way for lowering and towing of the net without releasing a great amount of wire cable has been scarcely studied. It should be strongly emphasized to make great efforts for the development of a suitable depressor or other instrument to solve this problem.

In the face of this inevitable fact, the oblique tow seems to be the most useful sampling method. In this way, if the ship's speed is the same, the net can filter more water than the horizontal tow in a limited distance, and also can be towed faster than the horizontal tow during its recovery. The increase of the towing speed serves greatly to increase the ability of capturing the larger active animals. During our studies made chiefly in the Bays of Sagami and Suruga, it was often observed that macroplanktonic and small nektonic animals, such as adult euphausiids, all- or half-red decapod crustaceans, and fish, were found in considerable numbers in the samples taken by oblique tows, while they were caught infrequently and in small numbers by the horizontal tows.

In the present investigation, open nets of the ORI-C have been more frequently towed obliquely with 1,000 or 2,000 m of wire out. With this method we could save the sampling time greatly and also could obtain a general idea of the macroplanktonic and micronektonic faunas living in the investigated area. The most numerous animals regularly captured by the ORI-C oblique tows made at depths ranging from the surface to about 1,000 m were copepods and chaetognaths, respectively about 3 mm long and 12 mm long. Meanwhile, all- or half-red decapod crustaceans and fish exceeding 20 mm in length were usually taken by about 20-40% in wet weight of the samples. The largest fish ever taken was a specimen of *Photonetes albipinnis* (DÖDERLEIN), 267 mm in

total length.

The ORI-C type combination net is generally strong and durable, because the fine-mesh portion occupies only a small part of the net. Moreover, by the funneling effect towards the codend, the fine-mesh portion usually catches more organisms than is to be expected from the cross-sectional area of its mouth opening. Finding of some useful conversion factor by a series of experiments concerning the effective cross-section of the net would make a rough estimation of the biomass possible. It is considered, however, that the conversion factor becomes useless if dense organisms caused the clogging in the fine-mesh portion of the net. At that time, it is easily supposed that the escapement of smaller organisms through the coarse-mesh portion must be increased.

On the other hand, it was found from the comparison of three nets of different mesh sizes that the dependance of catches on the mesh size is almost negligible for the animals whose maximum width is larger than the coarsest mesh aperture. This might indicate that, if filtering efficiency of the nets is similar and the clogging of the net is not occurred, the finest net will be the most useful in order to sample animals of a wide range in sizes quantitatively.

Actually, it seems impossible to tow the net straightly in the oblique tow. The present study confirms that the volume of water filtered and the speed of the net are increased greatly at a certain depth and also decreased at another depth. Such great variations of course make it difficult to execute a strict quantitative analysis of the samples. To prevent this as much as possible, the net should be towed in a limited range of vertical thickness of water, probably less than 200 m.

There are still many problems to be solved in quantitative sampling zooplankton, especially of larger forms. In the oblique tow, particularly, it is very difficult to control the towing depth from the ship (Table 5). The depth of the net is greatly changed especially when the net fishes through the water which flows in different speed compared to the upper layers. If the resistance of water is larger than that at the surface, the maximum depth to be reached

by the net will be decreased, and at the same time the actual towing speed of the net in that depth will be increased. To obtain micronektonic organisms, the towing speed of the net should be increased up to above 4 knots at least. We have observed that, when the net was towed at the ship's speed of 4 knots, the catch of a sergestid shrimp, *Sergestes lucens*, increased usually to more than four times of that with the 2 knots tow. Using the ORI net, a high-speed oblique tow in a certain layer with opening-closing mechanism has been attempted and now several performance tests are being done at the Ocean Research Institute.

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