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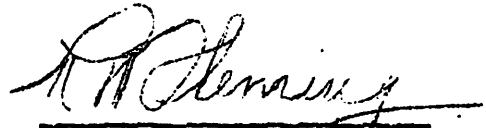
THE USE OF A LARGE CAPACITY PORTABLE PUMP FOR
PLANKTON SAMPLING, WITH NOTES ON PLANKTON
PATCHINESS

by

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ABSTRACT

A centrifugal pump with rated capacity of 400 gallons/minute was used for plankton sampling in Puget Sound. With the ship under way, 50 simultaneous paired hauls were made with the pump and a 0.5-meter nylon plankton net. The pumped water was passed through a special filtering unit and damage to the plankters was negligible. Data show remarkable agreement between catches of fish eggs captured by the pump and tow net. Large discrepancies between catches of motile organisms by the pump and tow net cannot be explained in terms of gear selectivity. Plankton patchiness--nonuniform distribution of planktonic organisms--is suggested as the explanation for the variations which occur between the two sampling devices on a paired haul. The use of large capacity pumps is recommended for further investigations of horizontal and vertical distribution of plankton.

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Introduction

During a recent fisheries research program in the North Pacific the Department of Oceanography of the University of Washington realized the need for a device capable of obtaining surface plankton samples from either a moving or a stationary vessel. Consequently, this study was undertaken to evaluate the pump as a means of sampling the plankton in the surface waters of the ocean.

In the work reported here a 0.5-meter plankton net is compared to a centrifugal pump with a rated capacity of 400 gallons/minute. A total of 50 paired hauls were made in Elliott Bay, Puget Sound, Washington (Figure 1) during the period of January 21 to 26, 1957. They were made in conjunction with a fish egg distribution study conducted by Dr. A. C. DeLacy, University of Washington College of Fisheries, and a group of his students. All of the hauls were made from the M. V. Commando, the research vessel of the College of Fisheries, and all hauls were made while the ship was under way. Samples collected from an anchored vessel will be the subject of a later report. An interpretation of the large variations encountered in the different sampling areas is beyond the scope of this paper, however such variations made it possible to compare the two sampling devices over a large range of plankton abundance.

History

The use of pumps as plankton sampling devices is not new to oceanographers and limnologists. Hensen's use of a steam pump in 1887 (Kofoid, 1897) for the collection of plankton marked the beginning of extensive but scattered attempts to provide a suitable method for pumping

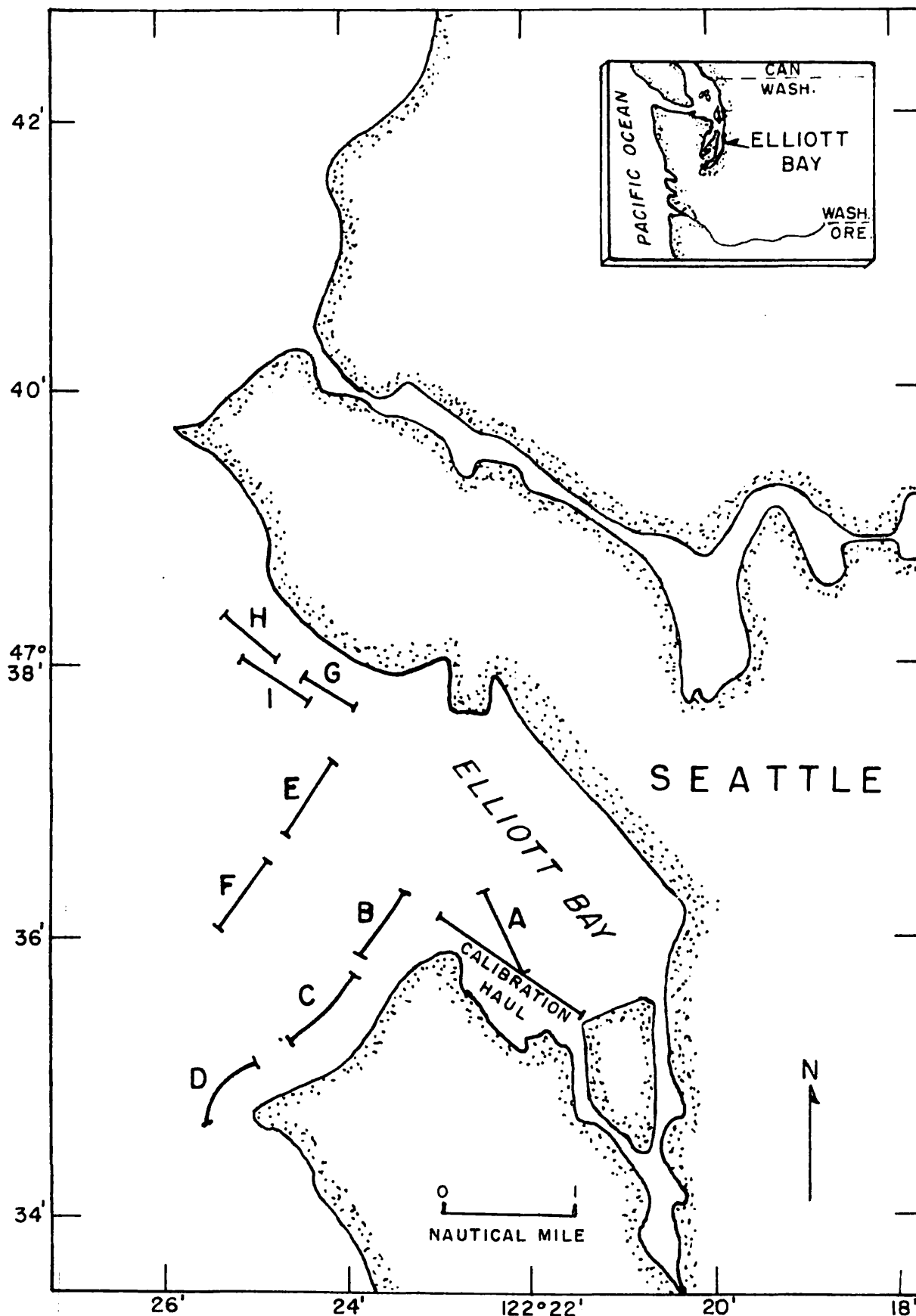


Figure 1. Location of stations in Elliott Bay, Puget Sound, Washington

plankton. The early researches are characterized by the use of makeshift equipment operating on a small scale, but even these studies were marked with some success, particularly in the study of phytoplankton. Later advances in the development of portable gasoline-operated centrifugal pumps allowed greater volumes of water to be filtered and made the gear a more satisfactory device for the sampling of zooplankton. Table 1 provides an historical summary of plankton-pump research. The paper by Gibbons and Fraser (1937) is especially useful as it covers the earlier studies and also provides references to related work not covered in this paper.

Methods and Results

The largest pump previously used for plankton studies delivered 270 liters of water per minute (Gibbons and Fraser, 1937). Tester and Stevenson (1949) used a 2-inch pump which was probably of greater capacity than that used by Gibbons and Fraser but the report does not cite the capacity. Other pumps yielded far less than the 200 liters per minute set by Wiborg (1948) as a minimum for reliable sampling. The gasoline-powered centrifugal pump used in the present study delivered 1533 liters per minute through a 3-inch outlet. To prevent excessive damage to plankters it was necessary to reduce the velocity by passing the water through a specially designed filtering drum. This device (Figure 2) was designed by Dr. Robert Paquette, with some help by the author. Water is passed from the pump into the bottom of a 54-gallon oil drum. Inside this drum is a pipe, 40 cm. in diameter and about two-thirds the height of the drum. The water which enters the drum passes out through the center pipe at about one twenty-fifth the original velocity. A filtering net is installed in the center pipe and,

Table 1. Historical summary of plankton pump research

Investigator and year	Type of pump	Capacity	How used	Where used
Hensen, 1887	Steam pump	not given	not given	Marine
Cleve, 1896	Ship's pump	not given	Attached silk net to pump when deck was washed	Marine
Giesbrecht, 1896 (Describes Kramer's work)	Ship's pump	not given	not given	Marine: delivered water to the bathtub of steamer
Peck, 1896	Steam pump	2-inch hose	not given	Marine: Buzzard's Bay, Massachusetts
Kofoed, 1897	Double-acting force pump, hand operated	1-cubic meter/600 strokes, 2-inch suction hose	20 feet of hose; 1-inch hose for outlet resulted in squeezing animals through No. 20 net. 1½-inch hose used as result	Lakes
Fordyce, 1898	Force pump, hand operated	347.5 cubic inches/stroke	Net made of fine wire gauze	Lakes
Bachmann, 1900	Intermittent pump?	10 liters in 15 minutes at 70 meters depth	No. 20 silk net, 54-70 microns mesh opening	Lakes
Juday, 1916	Vane pump, gas powered	300 rpm 30 liters/minute	30 meters of 2.5-cm hose	Lake Mendota
Robert, 1922	a. Wing pump	1/10 liter/stroke 1.5 cm.-hose	20-liter samples to depth of 50 meters	Lakes
	b. Many plankton pump	Size not indicated. Probably worked by compressed air	15-liter samples taken	Lakes

(continued)

Table 1 (cont.)

Investigator and year	Type of pump	Capacity	How used	Where used
Kokubo and Tamura 1931	Hand pump?	30 liters in $2\frac{1}{2}$ minutes	23 mm.-tubing 30 meters long	Aomori Bay, Japan
Kokubo, 1933	Wing pump	40 liters/6 minutes	15mm.-tubing to depth of 200 meters	not given
Gibbons and Fraser, 1937	Centrifugal pump	2.5-cubic meters/ 10 minutes	25 feet of 2-inch hose	Marine
Tester and Stevenson, 1949	Portable gasoline- motor pump	not given	2-inch iron pipe at depth of 3 feet	Marine: British Columbia
Barnes, 1949	Ex-National Fire Service	350 liters/minute	Pumped at 170 liters/ minute; net 200 mesh/inch	Marine
Tonolli, 1951	Suction pump	not given	Sucking out contents of tow nets	Lakes
Langford, 1953	a. Power pump, vane type b. Semi-rotary hand pump	30 liters/minute through 1-inch hose 5 liters/minute through $\frac{1}{2}$ -inch garden hose	All samples collected through No. 20 bolting cloth, all samples 10 liters each. Compared 2 pumps against Juday trap	Lakes
Collier, 1957	$\frac{1}{3}$ H.P. motor and pump	450 gallons/hour	8-hour continuous sample 10 feet below sea surface, $\frac{1}{4}$ of pump discharge sampled	Marine: Gulf of Mexico

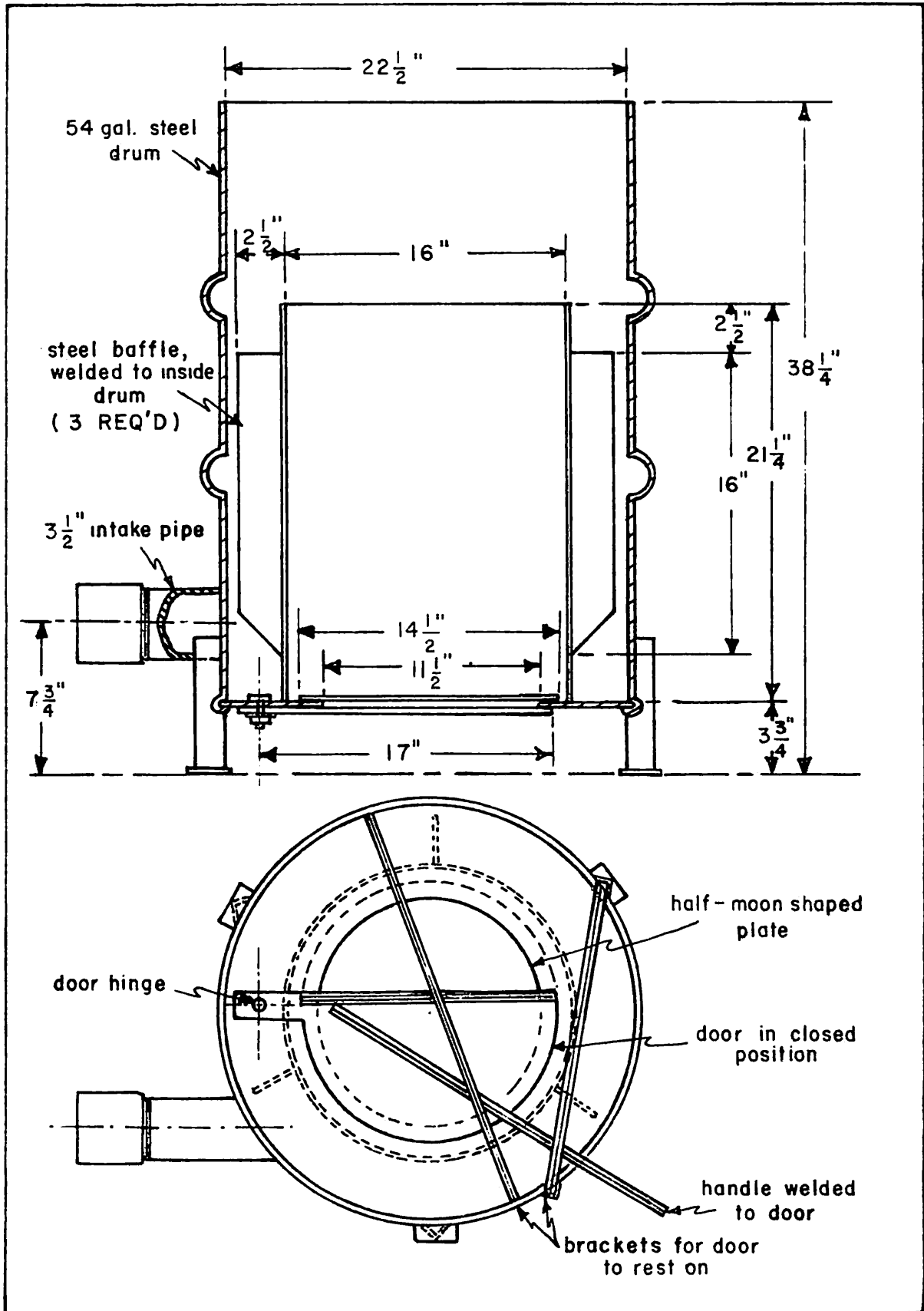


Figure 2. Filtering drum used during experiment.

at the reduced flow, the water is filtered efficiently. Figure 3 is a schematic diagram of the filtering system. For the present work a 0.5-meter plankton net was used in the center pipe for filtering the water passed through the pump. This net was made of silk, with a mesh opening of 0.514 mm. At the beginning of the study the net was fastened to the center pipe by means of large rubber bands. Later, for convenience in handling, the net was held tightly between the pipe and a metal hoop made with an inside diameter slightly larger than the outside diameter of the pipe.

With the exception of the jellyfish and ctenophores, which were badly damaged, the pump catches were in excellent condition, and the one attempt to hatch fish eggs caught with the pump was successful.

The pump was calibrated by determining the length of time required to fill a 54-gallon oil drum. With 6.1 meters of 3-inch suction hose it took 8 seconds to fill the drum.

The plankton tows were made with a 0.5-meter net equipped with an Atlas meter. This net was made of monofilament nylon, with a mesh opening of 0.476 mm. The net was calibrated by towing it over a known distance and recording the revolutions made by the Atlas meter. It was assumed that the net fished at 100 per cent efficiency--that all of the water column through which the net passed was strained. On this basis, the number of liters strained per revolution of the Atlas meter was determined. The volume of water strained by all tow-net hauls was then based on the number of meter revolutions for the haul. Because of the large mesh size and because of the relatively low plankton abundance no clogging of the net ever occurred.

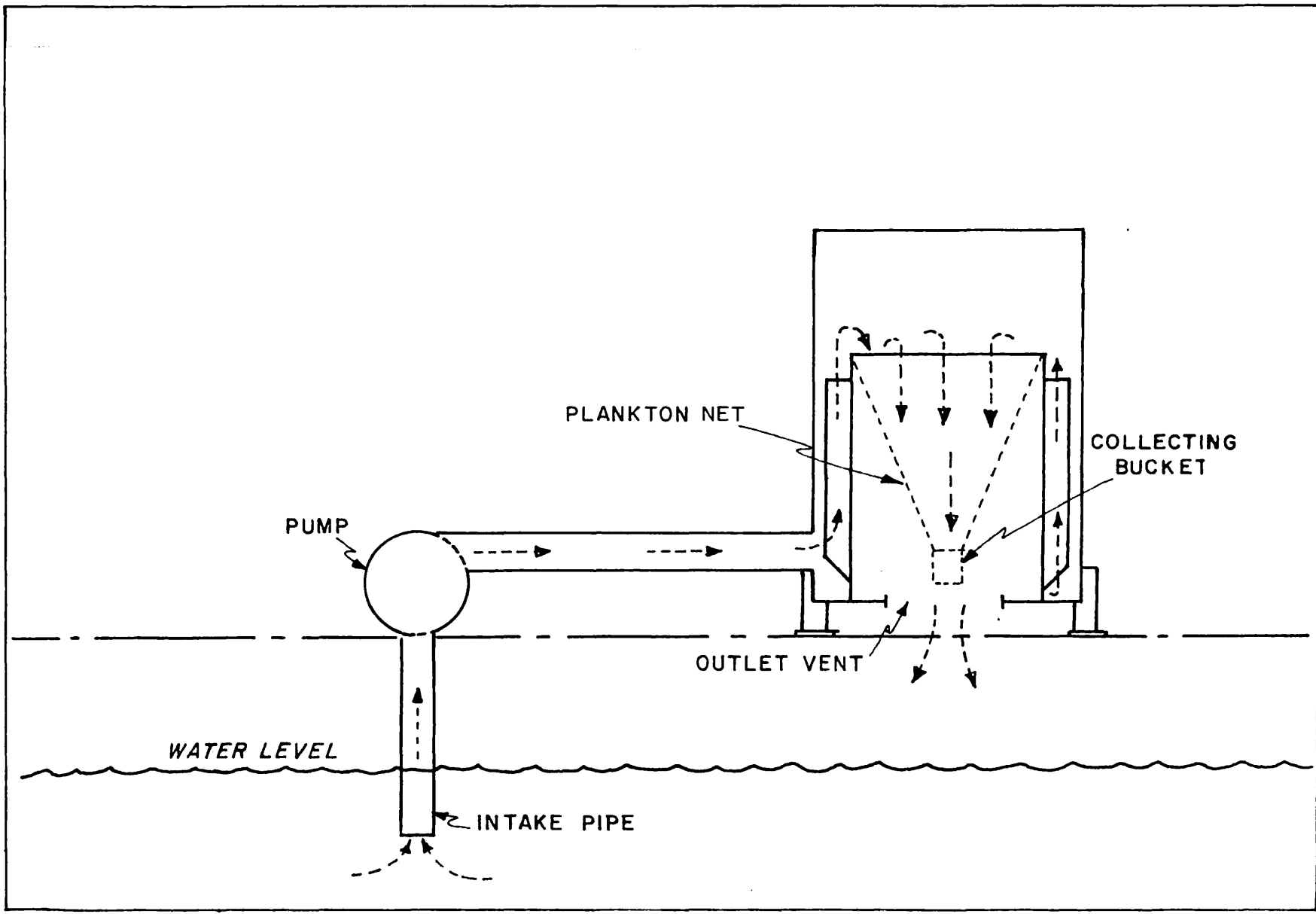


Figure 3. Schematic diagram of filtering equipment.

The paired hauls were made as follows: the suction hose was suspended on the port side, close to the ship. The plankton net was towed from an outrigger on the port side and slightly behind the ship. Both samplers were fished close to the surface, their mouth openings about 7 meters apart. At first the mouth of the hose was directed towards the stern but during most of the study the suction hose opened forward, in the direction of the ship's motion. No difference in the catches could be detected between the two positions. The pump was kept running between hauls, but without the net installed in the center pipe. The filtering net for the pump system was placed in the center pipe at the same time the towing net was placed in the water. The hauls were made for 10 minutes, then the towing net was removed from the water and the pump net was lifted off the center pipe. At the end of each haul, the sides of the nets were rinsed and the contents were collected in metal cups at the cod ends. The collecting cups for both nets were identical. The collections were preserved in 5 per cent formalin and stored in 8-ounce jars.

In the operations outlined above, the 0.5-meter net filtered approximately 200 cubic meters and the pump delivered about 15 cubic meters. Table 2 presents the number of fish eggs, the number of copepods, the total number of motile organisms, and the total number of motile organisms minus copepods caught in each haul and adjusted to the number per 100 cubic meters. The fish eggs are mostly the pleuronectid, Paraphrys vetulus, probably mixed with some eggs of another pleuronectid, Platichthys stellatus, and the eggs of the gadid, Gadus macrocephalus. All of these eggs are about 1.0 mm. in diameter and are practically indistinguishable. Of the total

Table 2. Adjusted counts of plankton catches

Date 1957	Haul and station	Time	Organisms/100m ³							
			Eggs		Copepods		Total motile organisms		Total motile organisms minus copepods	
			Net	Pump	Net	Pump	Net	Pump	Net	Pump
1-21	1-A	1322	1749	1083	130	422	147	436	17	14
	2-B	1350	139	77	78	102	107	102	29	0
	3-D	1437	40	27	177	7373	229	7411	52	38
	4-F	1503	46	45	184	4266	220	4311	36	45
	5-E	1520	52	13	178	7840	190	8870	12	1030
1-22	6-C	0943	271	96	137	723	170	755	33	32
	7-D	1000	53	77	429	500	454	545	26	45
	8-F	1020	62	91	109	307	149	327	40	20
	9-E	1041	1431	564	410	199	578	282	168	83
	10-C	1149	112	218	362	122	392	243	30	121
	11-A	1258	471	436	235	141	254	153	19	12
	12-B	1318	122	134	123	58	150	70	27	12
	13-C	1335	173	121	208	141	232	218	34	123
	14-D	1352	37	45	662	410	719	429	57	19
	15-F	1411	54	77	232	64	267	122	35	58
	16-E	1429	110	173	191	153	225	211	34	58
	17-H	1453	2769	4842	221	224	294	320	73	96
	18-G	1511	2979	4265	212	211	268	237	56	26
19-I	1535	1619	3642	846	1531	899	1543	53	12	
1-23	20-A	0915	874	1051	111	352	144	461	33	109
	21-B	0935	381	372	212	167	252	250	40	83
	22-C	0953	377	359	108	340	150	404	42	64
	23-D	1010	208	141	110	135	149	160	39	25
	24-A	1303	1529	1827	138	58	156	122	18	64
	25-B	1321	476	526	111	128	137	173	26	55
	26-C	1337	205	160	113	70	150	77	33	7
	27-F	1403	266	295	112	340	138	365	26	25
	28-E	1420	386	115	112	6	130	6	18	0

(continued)

Table 2 (cont.)

Date 1957	Haul and station	Time	Organisms/100m ³							
			Eggs		Copepods		Total motile organisms		Total motile organisms minus copepods	
			Net	Pump	Net	Pump	Net	Pump	Net	Pump
1-24	29-A	1644	19	26	92	51	113	51	21	0
	30-B	1706	348	122	103	743	196	775	93	32
	31-C	1722	83	38	117	173	165	224	48	51
	32-D	1739	43	26	346	800	387	839	41	39
	33-F	1756	39	6	285	19	335	19	50	0
	34-C	1814	103	71	407	1229	447	1255	40	26
	35-A	2003	170	64	261	647	285	672	24	25
	36-B	2020	910	475	300	992	362	1024	62	32
	37-C	2036	118	173	351	890	391	903	40	13
38-D	2052	88	64	613	211	613	211	0	0	
1-25	39-A	1700	2600	2135	70	1184	87	1299	17	15
	40-B	1719	524	519	137	704	193	813	56	109
	41-C	1737	320	430	164	525	202	596	38	71
	42-D	1752	80	83	284	800	326	973	42	173
	43-F	1812	34	13	333	992	413	1037	80	45
	44-E	1828	256	231	414	986	502	1037	88	51
	45-Cal	1858	149	29	105	384	120	409	15	25
1-26	46-Cal	1923	84	195	144	921	180	1114	36	193
	47*-B	0701	1692	1417	152	366	178	384	26	18
	48-C	0715	53	51	139	211	163	243	24	32
	49-D	0733	49	77	174	173	206	211	32	38
	50-E	1818	3475	4200	65	211	72	231	7	20

* Pumped only 7 minutes

organisms caught, other than fish eggs, copepods were the most important group. Copepods were 84.7 per cent of the tow net catches and 92.0 per cent of the pump catches. Amphipods, crustacean larvae, annelids, chaetognaths, medusae, tunicates, fish larvae, euphausiids, ostracods, and cladocerans also were caught.

The counts for fish eggs, total organisms, and total copepods are of the whole sample. In eight pairs of hauls, the six dominant copepod species (Calanus finmarchicus, Tortanus discaudatus, Aetidius armatus, Acartia longiremis, Metridia lucens, Corycaeus affinis) were counted. For ten of these hauls the whole catch was counted, and for six hauls aliquot samples were counted. The aliquots were taken according to the method described by Frolander (1955).

Measurements were made to determine the maximum and minimum body length of the six copepod species which were counted. The measurements are based on the largest and smallest copepods encountered of each species.

Table 3 gives the counts and measurements of the six dominant copepod species in eight paired hauls. These counts are presented as the number of individuals per 100 cubic meters.

Discussion

Table 2 shows that the concentration of eggs caught by both tow net and pump are closely alike for most pairs of hauls. This similarity becomes more apparent when the egg catches of the pump and the tow net are plotted against each other (Figure 4). In only 12 pairs of hauls did the catches of eggs vary by more than a factor of 2 between the tow net and the pump. If all hauls are considered, the tow net gave the higher concentration of eggs in 29 pairs of hauls, and the pump was higher in 21 pairs of hauls.

Table 3. Counts of selected copepod species
(Number per 100 cubic meters of water, and size range of each species)

Haul		<u>Calanus</u> <u>finmarchicus</u> 2.6-4.2 mm	<u>Tortanus</u> <u>discaugatus</u> 1.3-1.7 mm	<u>Aetidius</u> <u>armatus</u> 1.5-2.3 mm	<u>Acartia</u> <u>longiremis</u> 0.9-1.5 mm	<u>Metridia</u> <u>lucens</u> 1.9-2.8 mm	<u>Corycaeus</u> <u>affinis</u> 0.75-1.1 mm
5	Net	0.5	75	0	96	0	4
	*Pump	64	512	0	1024	0	5632
14	*Net	134	158	462	0	0	12
	Pump	13	13	301	51	0	6
19	*Net	150	0	582	75	0	19
	Pump	38	0	1286	0	13	19
22	Net	24	41	15	19	0	0
	Pump	26	122	13	115	0	0
39	*Net	5	14	28	0	32	0
	Pump	96	307	141	141	96	64
43	*Net	72	124	165	0	41	0
	Pump	45	179	224	26	51	0
44	*Net	145	114	103	41	41	0
	Pump	77	102	141	58	32	0
48	Net	18	43	45	12	1	0
	Pump	51	6	45	38	0	0

* Count based on aliquot sample

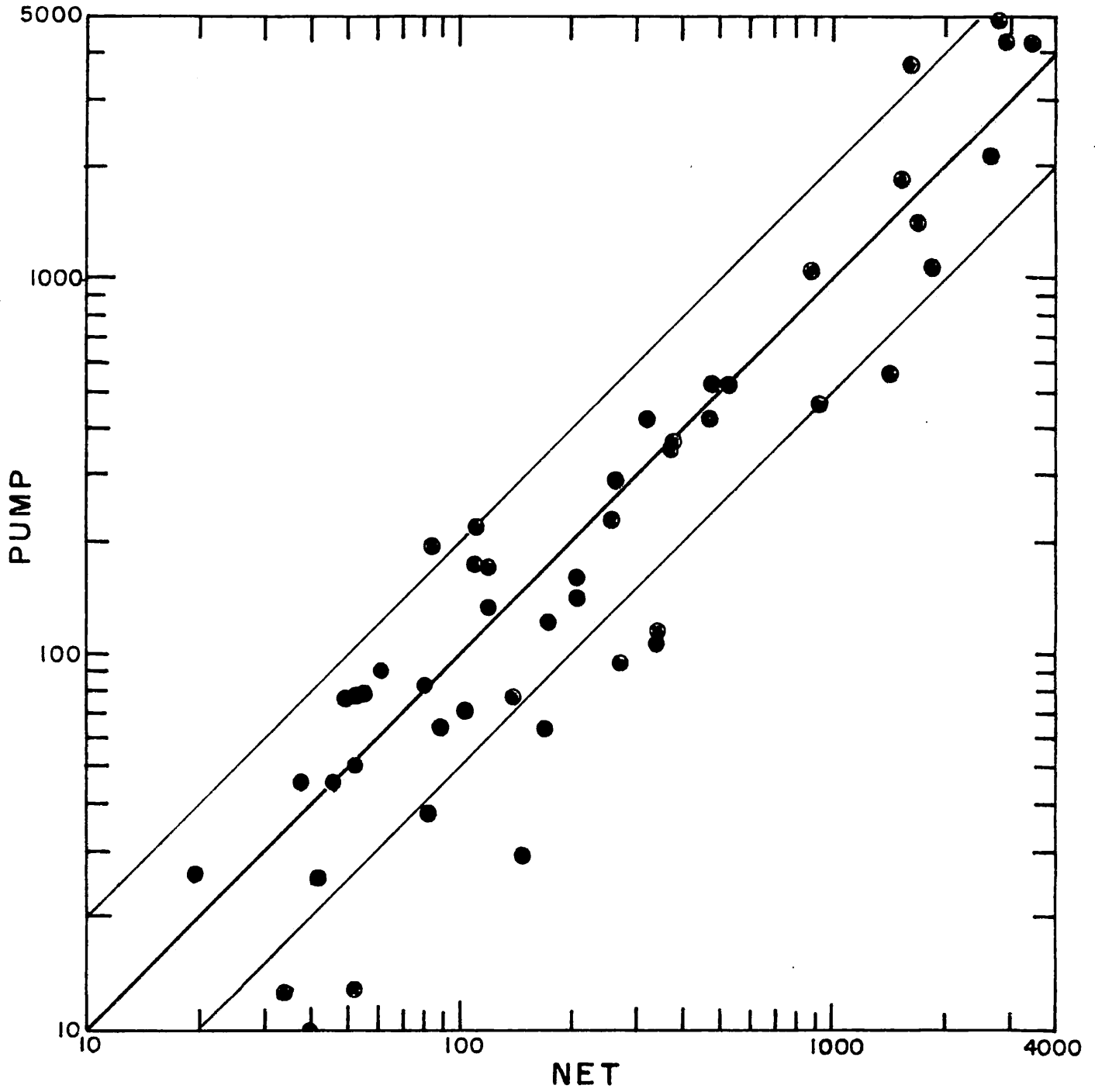


Figure 4. Catch of eggs per 100 cubic meters of water.

Nearly all of the fish eggs were from demersal species. Spawning by these fish apparently takes place close to the bottom and the eggs float to the surface, where they are distributed by the currents. It is reasonable to believe that the distribution of eggs is random over a small area (let us say a square having sides 7 meters in length) unless an oceanographic boundary condition such as a convergence line exists within the square. If the fish eggs are randomly distributed in this square it would also be reasonable to believe that two sampling devices operating within the area at the same time would catch, on an average, the same number of fish eggs per unit volume of water.

The mesh sizes in the towing net (mesh opening 0.476 mm.) and the pump net (mesh opening 0.544 mm.) are slightly different; however, the mesh openings in both nets are sufficiently small to prevent the escape of the types of eggs used in this study. The close approximation of the fish egg counts from the paired tow net and pump catches is, therefore, a good indication of the validity of the assumption that the tow net fishes at 100 per cent efficiency.

Table 2 shows that for both total motile organisms and copepods there are discrepancies between the catches of the pump and the tow net, the pump outfishing the net in 33 of the 50 paired hauls. The total of motile organisms is strongly dependent upon the catch of copepods, therefore the total catch of motile organisms minus copepods is also presented in Table 2. Here again, although the tow net outfishes the pump in only 26 of the 50 paired hauls, there are large discrepancies between the catches. In 21 pairs of hauls the catch of motile organisms other than copepods varies by

more than a factor of 2 between the two types of gear. The tow-net and pump catches of both copepods and total motile organisms exclusive of copepods are plotted in Figures 5 and 6.

There are two possible explanations for the wide variations found in the counts of the motile organisms: gear selectivity and/or plankton patchiness. Motile organisms may have different avoidance-attraction reactions to different sampling devices, or the slight variations in the type of mesh and in mesh size may be sufficient to enable animals to pass through one net but not through the other. The importance of gear selectivity can be partially evaluated by examining the available data.

Table 3--which gives the counts of the major copepod species in eight pairs of hauls, as well as the size range of the copepods examined-- indicates that gear selectivity is not a sufficient explanation of the discrepancies encountered. If one sampling device was more selective than the other, the results obtained by sampling a random population with the two devices would, on the average, be consistently different. If Calanus, for example, was randomly distributed and the pump was more selective for this species than the tow net, the pump on the average would outfish the tow net by a factor directly related to the selectivity. The wide variations in the counts of Calanus and all of the other copepods counted, with the possible exception of Aetidius, strongly point to the probability that a factor other than gear selectivity is involved. While for Hauls 5, 39, and 48 the pump markedly outfished the net for Calanus, the exact opposite happened in Hauls 14 and 19. The pump and net yielded similar values for the remaining three pairs of hauls which were examined. For Acartia, the

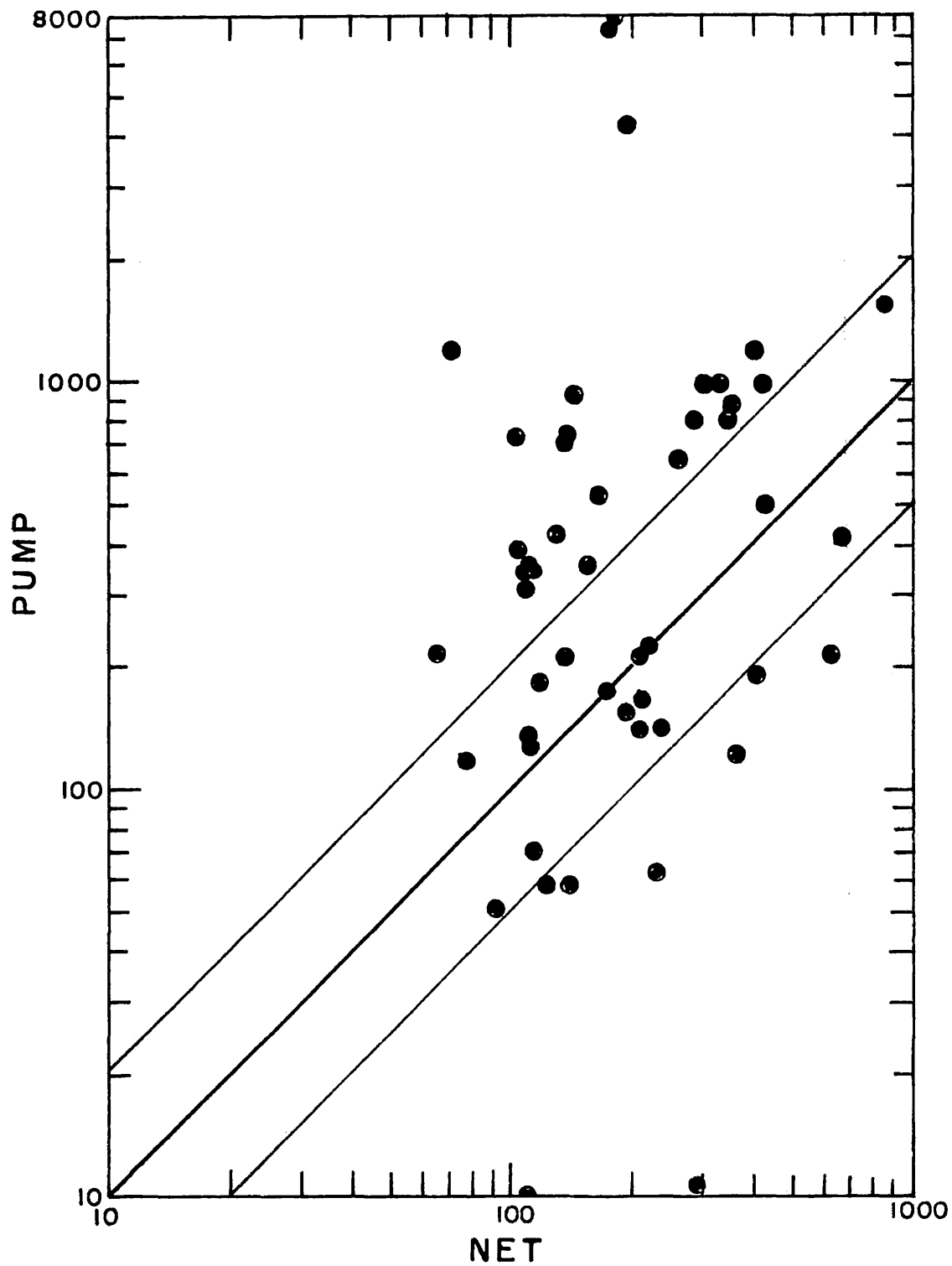


Figure 5. Catch of copepods per 100 cubic meters of water.

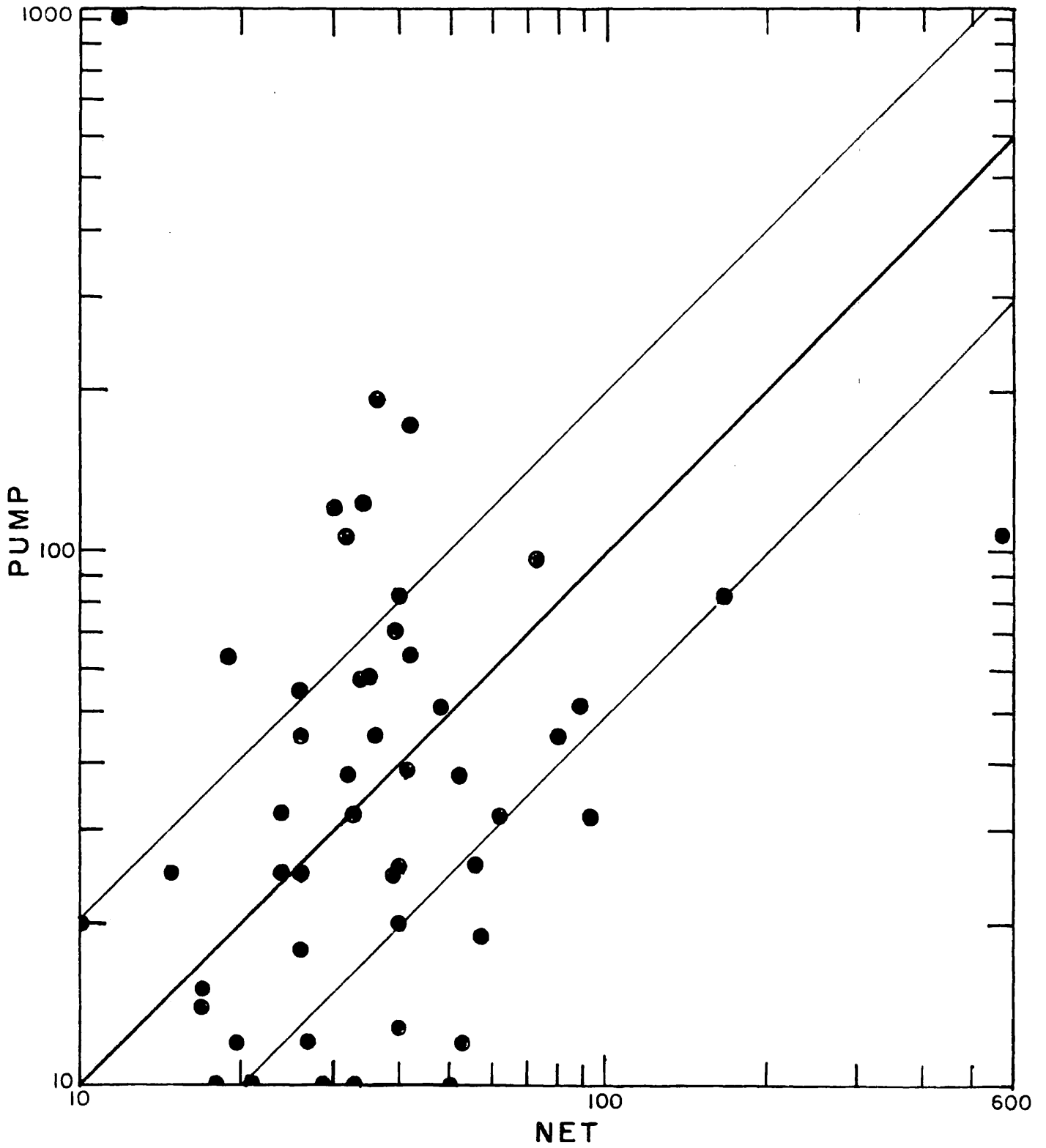


Figure 6. Catch of motile organisms minus copepods per 100 cubic meters of water.

pump outfished the net in Hauls 5, 14, 22, 39, 43, and 48, the reverse holding true for only one haul (19), and very similar counts were obtained for the other haul examined (44). For Corycaeus, where the widest discrepancies occurred, the pump outfished the tow net by a factor greater than 1000 in Haul 5; however, similar counts for this species are made in Haul 14.

Although the data show that, on the average, the pump caught more copepods per unit volume of water than the tow net, the greater efficiency of the pump is not sufficient to account for the wide variations which occur between the two sampling devices in a paired haul.

The alternative explanation for the large differences is plankton patchiness--the nonuniform distribution of planktonic organisms. These patches would be of a small scale, much like the mating swarms of aerial insects. The plankton of a particular species or group of species would occur in relatively dense concentrations spread over too small an area for both sampling devices to encounter during a haul. The gear passing through such a patch or group of patches would provide the higher catch. All factors being equal each sampling device would have an equal chance to pass through a patch; it would then be expected that the counts would vary considerably between the two devices for each paired haul, but that for many paired hauls there would be no trend of one net outfishing the other. Such a trend would indicate that the sampling devices have different powers of selectivity. The Chi-square values for the hypothesis that the tow net and pump are equally selective (one device will outfish the other 50 per cent of the time) is 1.28 when applied to the fish egg counts; 0.08 when applied to the counts

of motile organisms excluding copepods; and 5.12 for the copepods counts. If the hypothesis is true, Chi-square (with one degree of freedom) has only a 5 per cent chance of being greater than 3.84. It is therefore probable that although the pump and net have about equal selectivities for fish eggs and total motile organisms other than copepods, the pump outfishes the tow net for copepods.

The wide variations encountered in examining the counts of specific copepods, therefore, are probably related to a highly non-uniform distribution of these species--in other words, plankton patchiness.

The concept of plankton patchiness is important, particularly in the study of feeding behavior of fishes. Allen and Aron (1957) have shown that in some salmon stomachs the contents were highly stratified, indicating that for some reason the fish suddenly changed their food supply. One stomach, for example, contained both amphipods and euphausiids in almost pure cultures, with a sharp division between the two groups. This might be accounted for by the fish actually selecting individual euphausiids from among the plankton and then, after a period of time, selecting only amphipods. It is easier to believe that the stomach contents represent actual pure cultures as they occur in nature: the salmon changed its food supply by swimming from a swarm of amphipods to a swarm of euphausiids.

A problem posed by the data in this report is the evaluation of the size of the plankton patches. The pump appears to be an ideal tool for investigating the horizontal extent of the patches, and can probably be used successfully from a moving vessel to a depth of about 20 meters. Several pumps, operating simultaneously with intakes at different depths

and at different distances apart, could provide a three-dimensional picture of plankton distribution.

The concept of patchiness posed in this paper is micro-environmental. The concept does not exclude the fact that large areas will vary considerably in their productivity; however, only by understanding of the parts can we understand the whole.

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