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Flume Experiments on the Hydrodynamics of Plankton Nets[1]

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Experiments on the dynamics of flow into conical plankton nets were conducted at the US Navy's David Taylor Model Basin. A pitot tube and a telemetering flowmeter were used to measure the distribution of flow across the mouths of three 1 m diameter nets with mesh apertures of 0.281 mm, 0.221 mm, and 0.111 mm. Velocity profiles at the mouth of bridled nets consistently showed maximum velocity near the margin of the mouth, and a distinct minimum at the centre. The velocity was uniform across the mouth of an unbridled net that was tested. The filtration efficiency of all nets was high at normal towing speeds and remained high up to speeds of 257 cm/sec. Sustained high efficiencies were due in part to stretching of the nylon material from which the nets were constructed.

Introduction

The necessity for quantitative measurements of the zooplankton community is well known, but flowmeter data from most commonly used samplers are difficult to interpret because of inability to determine the absolute volume of water filtered. Information on filtering efficiency and flow patterns derived from controlled flume experiments is necessary to establish the significance of flowmeter readings, and to suggest principles for the future design of plankton samplers.

Experiments to measure selected flow characteristics of conical plankton nets were conducted in the Circulating Water Channel at the US Navy's David Taylor Model Basin in October 1964 and April 1965. The objectives were to determine: (1) the relation between the total volume of water entering a plankton net and the volume measured by a meter mounted in the mouth of the net; and (2) how the filtering efficiency varied with changes in towing speed and mesh size.

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Table 1

Dimensions of three numbers of "Nitex" netting. Numbers 280 and 223 have single-strand, woven mesh. Number 110 has single strands in one direction, but alternating single and double strands in the other direction

	Mesh Aperture sizes (mm)				Thread sizes (mm)				
Nitex No.	Number of measurements	Min.	Mean	Max.	Number of measurements	Single weft	Single warp	Double warp	Percentage open area
280	250	0·256	0·281	0·306	50	0·171	0·171	–	39
223	100	0·188	0·221	0·244	100	0·122	0·122	–	42
110	100	0·094	0·111	0·125	50	0·045	0·057	0·088	43

Materials and Methods

Three plankton nets with the same dimensions, but different mesh sizes, were tested in the flume. Included was the ICITA net, used by all participants in the International Cooperative Investigations of the Tropical Atlantic (AUSTIN, 1963), and in continued use by the Bureau of Commercial Fisheries, Tropical Atlantic Biological Laboratory, Miami, Florida. To date, more than 1400 plankton samples have been collected with the ICITA net in regions of the tropical Atlantic Ocean.

The nets were conical and consisted of four longitudinal panels. Each net was 364 cm long, 100 cm in mouth diameter, and 10 cm in cod-end diameter. The mouth opening was laced to a brass ring fitted with a 3-wire towing bridle. The three wires of the towing bridle met at a common point 100 cm ahead of the mouth. The flowmeter normally mounted in the mouth of the ICITA net during field work was removed during the experiments. The filtering material of the ICITA net was Nitex[1] brand nylon, No. 280; the other two nets were constructed of Nitex Nos. 223 and 110 (see Table 1 for details). Disregarding the non-filtering portions of the three nets, the ratios of total area of netting aperture to mouth area were 3·09, 2·87, and 3·17, respectively.

The Circulating Water Channel is a straight flume about 15 m long and 7 m wide, with a 2·7 m water depth. Pumps at the downstream end continuously remove water and return it to the upstream end via a conduit beneath the channel. Water velocity in the channel can be controlled through a range of 51–488 cm/sec (1–9·5 knots), with a maximum variation of $\pm$ 3·5 cm/sec. Channel velocity was monitored continuously by a pitot tube permanently mounted in the middle of the channel, 1 m off the bottom.

During the October tests, the nets were rigged in the flume as they would be towed in the field, with a 3-wire towing bridle preceding the net mouth. In the April tests, the bridle was replaced with three diverging wires connecting the net ring to the channel walls and bottom. Flow of water was thus unobstructed forward of the net mouth.

In October the field of water velocity in and around the three nets was measured with a Prandtl-type pitot tube of 0·3 cm outside diameter. Fluid with a density of 2·94 g/ml was used in the manometer. Measurements were made at a series of points across the mouth diameters and inside the three nets at channel velocities of 51, 103, 154, 206, and 257 cm/sec (1–5 knots). Early tests indicated

[1] "Nitex" Tobler, Ernst and Traber, Inc., 71 Murray Street, New York, N.Y. 10007. (Trade names referred to in this manuscript do not imply endorsement of commercial products.)

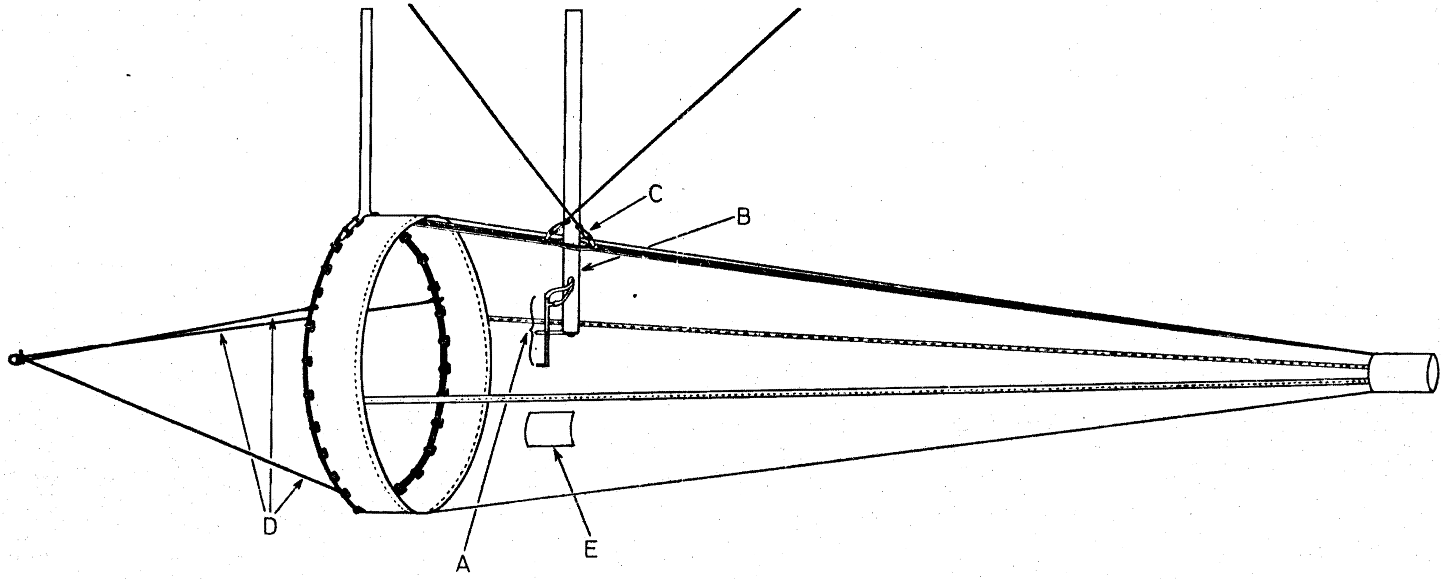

Figure 1. Method of measuring water velocity in a conical plankton net under flow conditions in the David Taylor Model Basin Circulating Water Channel. A) pitot tube B) instrument strut C) double-tabbed zipper D) towing bridle E) portion of net photographed to determine stretching.

that flow was symmetrical about the centre of the net mouth; consequently, subsequent measurements were made only along the radius from the centre to the bottom edge of the net. In April only the ICITA net was tested. Velocity measurements on the ICITA net mouth and forward of the net were made with two instruments, a pitot tube of 0·6 cm outside diameter, with a 1·75 g/ml density manometer fluid, and a telemetering Marine Advisors[1] flowmeter. The impeller housing of the flowmeter is 7·6 cm in diameter and 15·2 cm long. Electrical impulses, caused by magnets in the five rotating fibre-glass impeller blades, are telemetered to the surface via an electrical cable. Both the pitot tube and the flowmeter could be mounted on the lower end of a strut for positioning in and around the nets. A racking device for the strut provided precise vertical and horizontal positioning of the instruments at all channel velocities. Channel velocities were the same as those used in October.

Velocity measurements inside the net were made by inserting the instruments through a double-tabbed zipper extending from the mouth to the cod-end along the uppermost longitudinal seam of the net (Figure 1). Results of the internal measurements are not reported in the present paper.

Telephotographs of the No. 110 Nitex net under flow conditions were taken through a window in the Circulating Water Channel at velocities of 31, 62, 124, 185, and 247 cm/sec. A millimetre rule was sewed loosely on the portion of the net to be photographed to provide an absolute scale for measurement. The number of apertures was counted in a 15 × 15 mm area of mesh in each photograph.

Results

Measurements of the three bridled nets revealed non-uniform flow across the mouth openings. Velocities were maximum near the peripheries and minimum at the centres (Figure 2-A). Flow near the peripheries actually exceeded channel velocity in some observations. The difference between peripheral and central velocities increased with channel velocity. Measurements of the unbridled ICITA net showed uniform velocity across the mouth (Figure 2-B).

Filtering efficiency was determined by comparing the experimentally measured flux of water through the mouth of each net with the flux through a netless ring. The filtering efficiency of the No. 280 Nitex net at 51 cm/sec, as measured the October experiments, was somewhat lower than the value obtained in April (Figure 3). Slow response of the manometer fluid due to the small diameter of the pitot tube used in October is believed to be responsible for these low readings. Subsequent flume tests by the Bureau of Commercial Fisheries and the National Academy of Sciences yielded data which substantiated the higher flowmeter efficiencies. At 103 cm/sec, the efficiencies of the three nets were greater than 97 per cent. The efficiency of the ICITA net in October decreased above 103 cm/sec, but leveled off between 206 and 257 cm/sec. The April data for the ICITA net and the October data for the Nos. 223 and 110 nets showed that the efficiencies did not consistently decrease with increased channel velocity above 103 cm/sec, but tended to level off or even rise above that point. Filtering efficiencies of the unbridled ICITA net were not significantly lower than those of the bridled net. The high filtering efficiencies of the

[1] Marine Advisors, Inc., P. O. Box 1963, 7440 Girard Ave., La Jolla, California 92038.

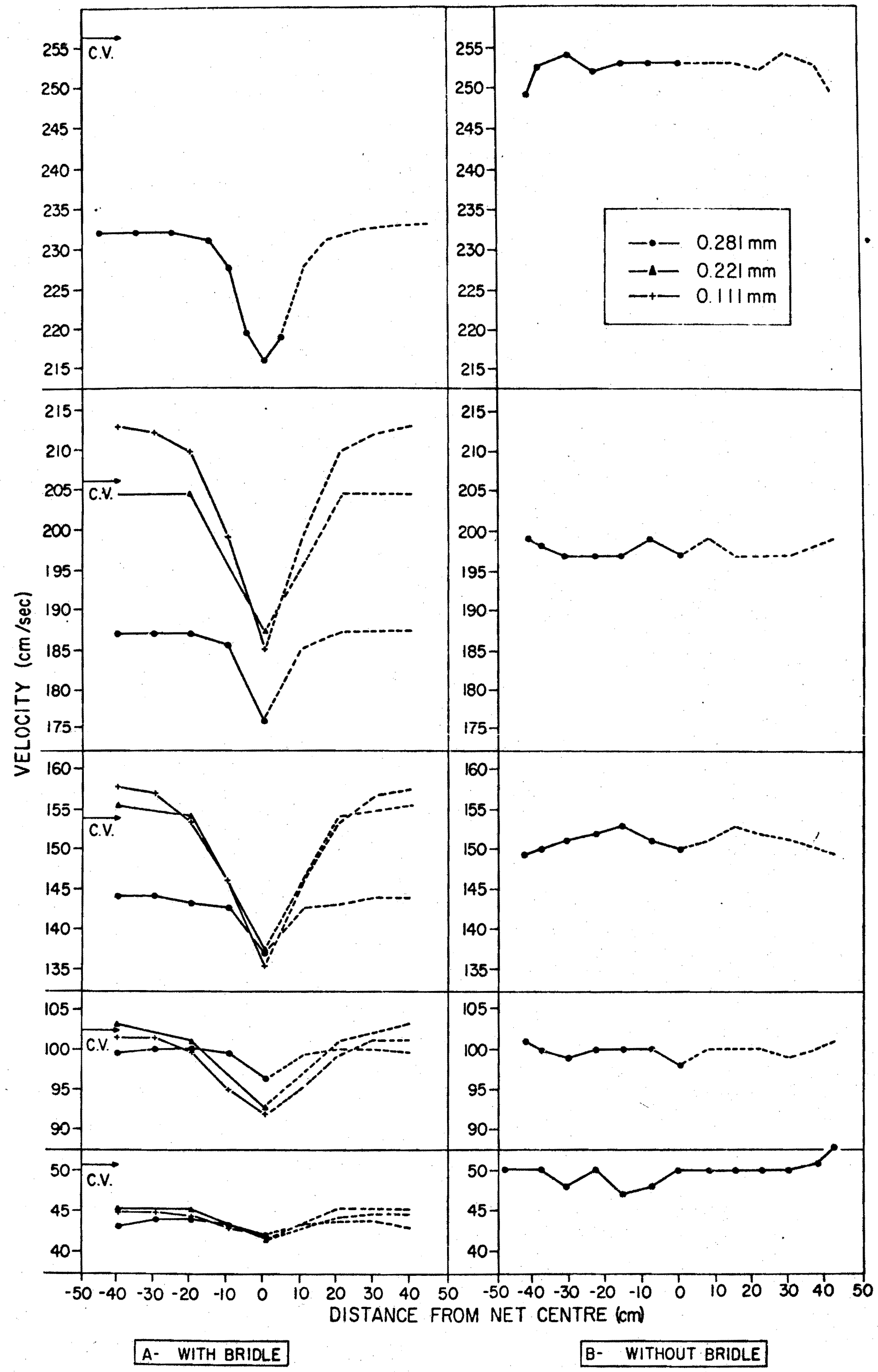

Figure 2. Velocity profiles in the mouths of three conical plankton nets at different channel velocities (C. V.), (A) with towing bridle and (B) without towing bridle. Symbols in the upper right panel indicate mesh sizes of the nets. The solid lines show velocities measured along the radius of the mouth of the net; broken lines are mirror images of the solid lines.

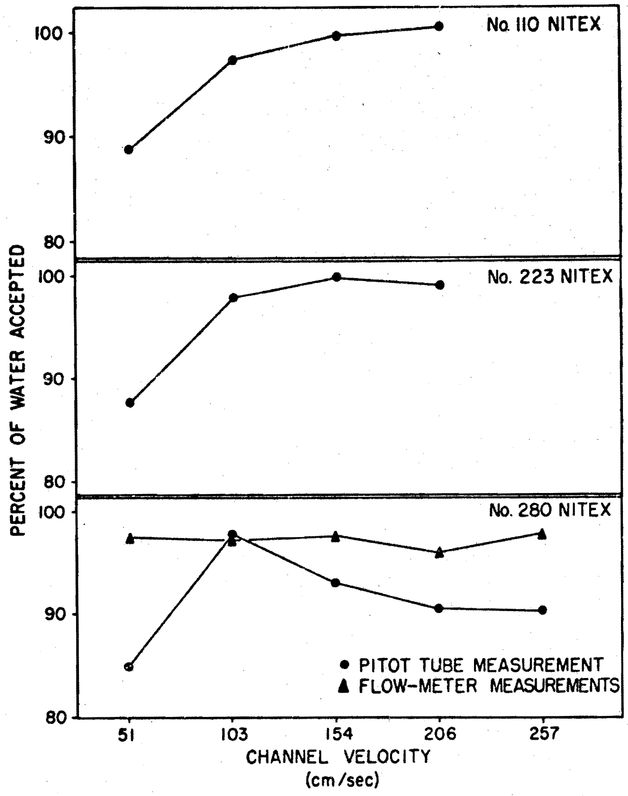

Figure 3. Filtering efficiencies for three conical plankton nets of different mesh sizes at different channel velocities.

nets at the higher channel velocities may have resulted from stretching of the mesh material.

Figure 4 illustrates the change in the number of mesh apertures in a 15 × 15 mm area of netting as channel velocity increased. The greatest amount of stretching occurred between 103 and 206 cm/sec, but the material continued to stretch up to speeds of 247 cm/sec, the highest speed at which photographs were made. The amount of stretching indicated in Figure 4 cannot be used to quantify the change in filtering efficiency, because it represents only one spot on the net, approximately 1 m from the mouth.

Discussion

The effect of the bridle on flow distribution can be demonstrated by comparing the velocity profiles of the bridled nets with those of the unbridled net. The net without a bridle had a relatively uniform distribution of velocity across the net mouth at all channel velocities tested. The non-uniform distribution of flow of the bridled nets is attributed to the presence of the towing bridle.

The velocity profiles provide a basis for determining the optimum location

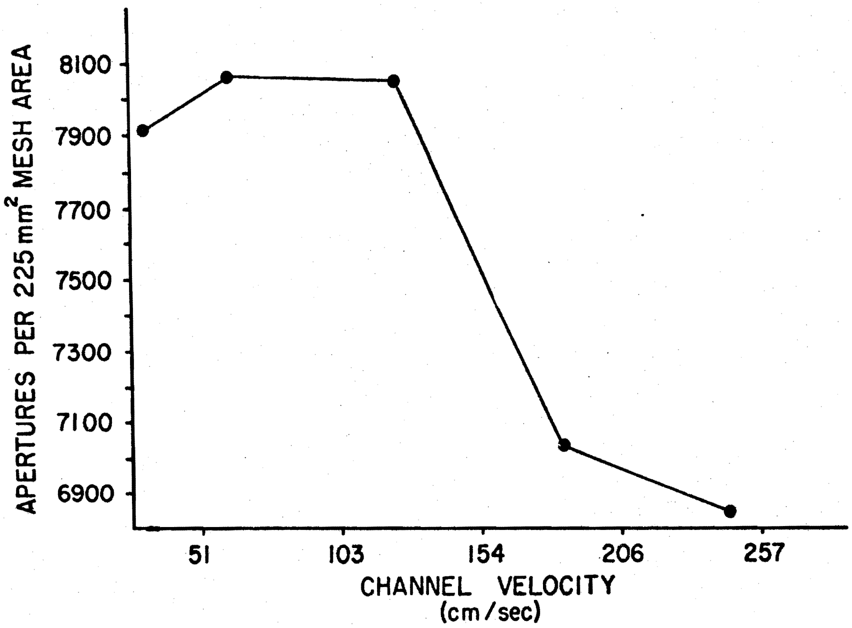

Figure 4. Changes in the number of mesh apertures per 15 × 15 mm area of netting with increasing channel velocity. A decrease in aperture count indicates stretching of the net material.

of a meter in the mouths of bridled nets to monitor flow most accurately. A meter mounted in the low-velocity central core would give low values for the total volume of water entering the net. Correction factors would have to be applied to readings of a central meter to determine the amount of water filtered by the net. The flow at a distance of 25–40 cm from the centre is more representative of mean flow through the entire mouth, and the range of velocity between these two points is small. A meter mounted in this relatively steady velocity "plateau" would give more accurate values for the total volume of water entering the net.

Nishizawa and Anraku (1956) conducted field tests on a similar conical plankton net with flowmeters mounted centrally and peripherally. They found that the velocity at the centre of the mouth was always 20–30 per cent lower than at the periphery at hauling speeds of 90–130 cm/sec. This difference is roughly equivalent to the 6–36 per cent difference observed by us in similar field tests. An alternative solution to an off-centre mounting of the flowmeter would be to eliminate the bridle completely, as described by Nakae (1962), thus removing the source of discontinuous flow. Elimination of the bridle would not only solve the problem of meter placement, but would negate any effect the bridle might have of forewarning organisms of the approach of the net.

All three nets changed shape with varying channel velocities. At low velocities, the net assumed the shape of a cone preceded by a loose, billowy, cylindrical section, approximately 1 m long. As channel velocities increased from 51 to 154 cm/sec, the length of the cylindrical section decreased, and above 154 cm/sec, the net assumed precisely the configuration of a cone. We believe that the point of inflection between cylinder and cone represents the boundary between netting of low filtering rate in the cylindrical section and high filtrating rate in the conical section. It is reasonable to suppose that a channel velocity exists beyond which a net can no longer filter all the water encountered. When maximum capacity is reached, all other variables remaining constant, it follows that a further increase in channel velocity would result in a rejection of water and a decrease in filtering efficiency. In the present study, either this maximum capacity was not reached or some other variable (e.g., stretching of the Nitex material) acted to sustain the filtering efficiency.

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Summary

A discontinuity in flow across the mouths of three conical, bridled plankton nets was observed when the nets were tested in a circulating water channel. Maximum flow occurred at the periphery and a distinct minimum occurred at the centre of the nets. The discontinuity was due to interference by the towing bridles. Effect of this discontinuity were:

(1) To reduce the amount of water passing through a centrally-mounted flowmeter as compared with the mean amount passing through the entire mouth. Low estimates for the volume of water filtered would be obtained from these meter readings.

(2) To reduce slightly the filtration efficiency of the net.

(3) Possibly, to forewarn organisms of the approaching net. It is recommended that the flowmeter be mounted in an off-centre position, or that the bridle be eliminated.

Filtration efficiencies of the three nets were high at all channel velocities tested; and are explained in part by the stretching of the material from which the nets were constructed.

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