Mesh size and collection characteristics of 50-cm diameter conical plankton nets

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Abstract

This paper compares collection characteristics of #2-(363 μm), #10-(156 μm), and #20-(76 μm) mesh conical plankton nets: dimensions were 50-cm diameter by 1.6-m long. The #2-mesh net severely underestimated the abundances of Lake Michigan copepods and cladocerans with the exception of the largest species (*Limnocalanus macrurus*). Zooplankton abundance estimates were more similar for the #10- and #20-mesh nets collections. Nauplii, however, were severely undersampled by the #10-mesh net with abundance estimates approximately 8 to 12 times lower than for the #20-mesh net collections. Most other larger zooplankton were 50% more abundant in the 20-mesh net collections than in the #10-mesh net collections: such consistent differences occurred despite large variations in taxa size. This indicates that a sampling bias occurred other than the loss of zooplankton through the meshes of the #10 net. We hypothesize that, by incorrectly locating the flowmeter in the mouth of the plankton net, we underestimated the volume of water filtered by the easily-clogged #20-mesh net and therefore overestimated taxa abundances. We conclude that the #10-mesh net provided accurate estimates of microcrustacean zooplankton abundances except for nauplii. The #10-mesh net used in our study had a filtration area ratio of 3.06 and operated at a calculated average filtration efficiency of 98%. The #20-mesh net had a filtration area ratio of 1.86 and operated at calculated average filtration efficiencies ranging from 64.7% (41.7 m station) to 79.6% (6.3 m station). Calculations are presented which show how the filtration efficiencies of the nets used in our study could be improved by net redesign.

Introduction

Selection of sampling gear for zooplankton studies involves consideration of animal abundance, size, and escape ability. In lakes, crustacean zooplankton are most frequently collected with conical or cylindrical-conical nets. Number 10-(156 μm) and #20-(76 μm) mesh nets are commonly used although coarser (#2, 363 μm; #5, 282 μm) and finer (#25, 64 μm) mesh nets also are used.

A #10-mesh net generally is used in waters where seston concentrations are sufficiently high to cause clogging and reduced filtration efficiency. While use of a #10-mesh net minimizes these concerns, such nets undersample smaller zooplankton. Conversely, while a finer #20-mesh net reduces losses of smaller microcrustacean zooplankton, such nets are especially prone to clogging which can create new biases.

There are few studies reporting the filtration efficiency of nets used in limnological investigations (Rawson, 1956; Schindler, 1969; Cummins *et al.*, 1969; Hall *et al.*, 1970; Gannon, 1972; Olenick, 1983) and which have investigated sampling biases associated with mesh construction (Likens & Gilbert, 1970). While marine research on net filtration characteristics has been more extensive (Saville, 1958; Barnes & Tranter, 1965; Smith *et al.*, 1968;

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Tranter & Smith, 1968; Tranter *et al.*, 1968; Vannuci, 1968), these studies were based on coarser-meshed nets than those used in most limnological zooplankton studies.

Here we report the results of an investigation which; (1) compares microcrustacean abundance estimates as determined by using plankton nets of different mesh sizes, and (2) compares the filtration efficiencies of plankton nets constructed of #10- or #20-mesh netting.

Methods

All collections were made in Lake Michigan (Fig. 1). Conical 50-cm diameter and 157-cm long (excluding bridle, codend, weights) nets equipped with a centrally-mounted, calibrated Rigosha flowmeter were used. Each collection was made by hauling the net from approximately one meter above the lake bottom to the surface.

The first study, conducted on June 16, 1977, was designed to provide information on selective loss of microcrustacean zooplankton through #2-(366 μm) and #10-(156 μm) mesh nets: a #20-(76 μm) mesh net was used as a standard of comparison. Duplicate vertical hauls (0–40 m) were performed at station DC-6 (Fig. 1), located 11 km from shore and in 42 m of water.

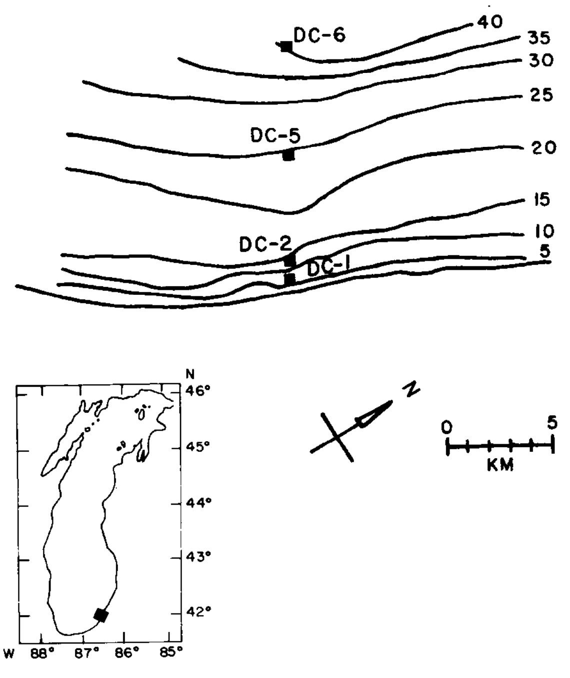

Fig. 1. Location of stations investigated during the study. Depth contours are in meters.

After the net was returned to the surface, the outside was washed down with water from a hose. Each sample was preserved with a sugar-formalin solution (Haney & Hall, 1973). In the laboratory, crustacean zooplankton were identified according to Evans *et al.* (1980).

Flowmeters were calibrated during the June 1977 study by mounting each flowmeter in an empty plankton ring and hauling it from 40 m to the surface three times. Lake conditions were calm and the wire angle was perpendicular to the lake surface. For each flowmeter, a regression of calibration flowmeter reading versus collection depth was calculated. The slope was estimated from the mean of the three calibration readings at the 42-m station (slope units = revolutions per meter) while the intercept was assumed to be zero, i.e. a zero flowmeter reading for a zero collection depth. This regression also provided for estimates of theoretical flowmeter reading for each net, assuming 100% filtration efficiency.

The second study, conducted over a several month period in 1979 as part of a larger monitoring study (Evans *et al.*, 1982), was designed to provide more detailed information on the loss of microcrustacean zooplankton through the meshes of a #10-net; a #20-mesh net was used as a standard for comparison. Duplicate #10-mesh net samples and a single #20-mesh net sample were collected monthly (May to November) at stations DC-1, DC-2, DC-5, and DC-6. The same flowmeter was used for the #10-net throughout the study, and a second flowmeter was used for the #20-mesh net.

Flowmeters were recalibrated in June 1979 at station DC-6. Calibrations changed little from the previous year. Calibrations were not performed during other cruises because lake conditions were not sufficiently calm to maintain a 0° wire angle during each calibration.

We estimated the average filtration efficiencies of the #10- and #20-mesh nets for collections made during the 1979 study. First, for each net, we calculated the linear regression of actual flowmeter reading versus collection depth: readings which were above the calibration line were discarded prior to calculating this regression. Since the error variance term was not constant, a weighed least square regression procedure was used. We then compared the flowmeter-with-net regression line to the calibration line to obtain the average filtration efficiency for each net at the four stations. The linear correlation coefficient between flowmeter reading and station depth also was calculated.

Only the 1979 study provided a sufficient number of observations to warrant statistical analysis. In order to determine whether or not zooplankton abundances were significantly different between the #10- and #20-mesh net collections, the nonparametric Wilcoxon rank sum test was used. Paired data collected in May at DC-2 were discarded because of an erroneous #20-mesh net flowmeter reading. This provided a total of 27 paired observations for the #10- (mean of two replicates) and #20-net collections.

All nets were constructed by the same manufacturer and were composed of Nitex monofilament in a simple locking weave. Mean (n = 20 or 21) aperture length and width, and mean filament diameter were measured for #10-mesh netting and #20-mesh netting using a compound microscope equipped with a calibrated micrometer. Porosity (p) was calculated according to Smith, *et al.* (1968):

$$p = a^2/(a^2 + b^2) \quad (1)$$

where a = pore size, and b = filament diameter.

We also calculated mesh area (total area (m) of the net in square meters), filtration area (f), and filtration area ratio (r) where

$$f = m \times p \quad (2)$$

$$r = f \,/\, \text{mouth area} \quad (3)$$

Results

During the June 1977 study, total zooplankton density estimates averaged 2 580 m^{-3} with the #2-mesh net, 62 530 m^{-3} with the #10-mesh net, and 85 610 m^{-3} with the #20-mesh net (Table 1). The #2-mesh net severely undersampled all but the largest zooplankton (*Limnocalanus macrurus*). Abundance estimates more were similar for the #10- and the #20-mesh net.

The 1979 study provided a more detailed data base for comparing sampling characteristics of the #10- and a #20-mesh nets. Actual flowmeter readings for the #10-mesh net at the four stations and the flowmeter calibration line are shown in Figure 2a. Several flowmeter readings were above the calibration line suggesting that filtration efficiency occasionally exceeded 100%. This artifact probably occurred when the net was hauled over a greater distance than station depth. Oblique wire angles occurred most frequently in the deeper and less

Table 1. Mean (n = 2) abundances and percent composition of zooplankton collected on June 16, 1977, at the same 42-m station in southeastern Lake Michigan using vertically hauled (0–40 m) 50-cm diameter plankton nets equipped with different mesh sizes. Also given is the abundance ratios between nets.

	#2 mesh		#10 mesh		#20 mesh		Abundance ratio		
	#/m³	%	#/m³	%	#/m³	%	20:2	20:10	10:2
Nauplii	5	0.2	15 528	24.8	41 815	48.8	8 363.0	2.7	3 105.6
Cyclops spp. C1–C5	21	0.8	6 280	10.0	5 172	6.0	246.3	0.8	299.1
Cyclops spp. C6	216	8.4	1 617	2.6	3 628	3.1	16.8	2.2	7.5
Diaptomus spp. C1–C5	1 096	42.5	11 514	18.4	12 694	14.8	11.6	1.6	10.5
Diaptomus spp. C6	275	10.7	1 352	2.2	1 449	1.7	5.3	1.1	4.9
Epischura lacustris C1–C6	13	0.5	24	0.0	106	0.1	8.2	4.4	1.9
Eurytemora affinis C1–C6	13	0.5	48	0.1	104	0.1	8.0	2.2	3.7
Limnocalanus macrurus C1–C6	218	8.5	286	0.5	290	0.3	1.3	1.0	1.3
Bosmina longirostris	584	22.6	25 364	40.6	20 645	24.1	35.4	0.8	43.4
Daphnia spp.	29	1.2	59	0.1	27	0.0	0.9	0.5	2.0
Eubosmina coregoni	6	0.2	35	0.1	54	0.1	9.0	1.5	5.8
Minor cladocerans	51	2.0	85	0.1	52	0.1	1.0	0.6	1.7
Asplanchna spp.	53	2.0	337	0.5	654	0.8	12.3	1.9	6.4
Total	2 580		62 530		85 610		33.2	1.4	24.2

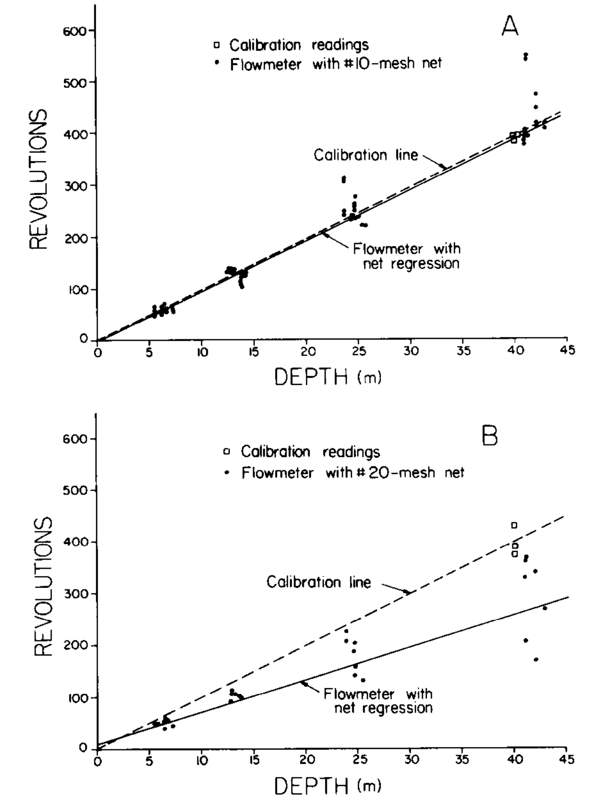

Fig. 2. Flowmeter reading versus collection depth for (a) the #10-mesh net, and (b) the #20-mesh net, May to November 1979. Also shown is the calibration line (dotted) and the flowmeter (with net) weighted least squares regression (solid line). For the #10-mesh net, flowmeter readings which lay above the calibration line were not used in the regression analysis. Observations collected at the same time and location using the #20-mesh net also were discarded. See text for further explanation.

protected offshore waters. Twenty points (i.e. 10 paired observations) which lay above the 100% filtration efficiency (calibration) line were discarded and the weighted least squares linear regression calculated for the remaining points ($n = 36$). The regression was:

revolutions = 9.69 depth(m) − 0.66, where $r = +0.99$ and $p < 0.01$.

For the #20-mesh net, all flowmeter readings were below the calibration line (Fig. 2b) indicating that this fine-mesh net had a lower filtration efficiency than the #10-mesh net. A similar series of calculations were performed with the #20-mesh net data set as were performed for the #10-mesh net data. Ten #20-mesh net observations, made at the same locations and times as the 10 discarded paired #10-mesh net observations, were excluded from the regression analysis. This provided a total of 17 observations for the #20-mesh net collections. The calculated weighted least squares linear regression was:

revolutions = 6.16 depth(m) + 10.98,

where $r = +0.82$ and $p < 0.01$.

Filtration efficiency of the #10-mesh net ranged from 97.6% to 98.5% increasing slightly with depth (Table 2): estimated filtration efficiency exceeded 100% when the 20 extraneously high flowmeter readings were included in the regression analysis. The estimated filtration efficiency was lower for the #20-mesh net decreasing from 79.6% at the shallowest station to 64.7% at the deepest station. Seston concentrations, as indicated by Secchi disc depth, decreased with station depth (Table 2). For each net and station, we calculated the correlation between Secchi disc and flowmeter readings. The small number of observations and variations in distance of tow prevented the detection of any meaningful relationship between water clarity and

Table 2. The mean collection depth (m), Secchi disc depth (m), and estimated average filtering efficiencies for #10-mesh net and #20-mesh net collections at four stations in southeastern Lake Michigan, May to November 1979. Standard deviation is given in parenthesis.

Station	Mean collection depth	Mean Secchi disc depth	Average filtering efficiency (%)	
			#10 mesh net	#20 mesh net
DC-1	6.3 (0.6)	3.2 (1.2)	97.6	79.6
DC-2	13.2 (0.5)	3.6 (0.8)	98.1	70.4
DC-5	24.6 (0.6)	4.9 (2.1)	98.4	66.5
DC-6	41.7 (0.7)	6.7 (1.9)	98.5	64.7

Table 3. Measured and calculated specifications for the 50-cm diameter, 157-cm long, #10-mesh and #20-mesh cone nets used in the 1979 study. Standard deviation is given in parenthesis.

Parameter	#10 mesh net	#20 mesh net
Aperture length (μ)	142.5 (<.0)	69.1 (3.4)
Aperture width (μ)	152.5 (6.1)	69.4 (2.2)
Diagonal length (μ) (calculated)	210.5	98.0
Monofilament strand width (μ)	66.0 (6.3)	50.7 (0.9)
Locking strands (2) width (μ)	85.9 (3.8)	91.9 (9.7)
Porosity	0.46	0.28
Filtering area (m^2)	0.53	0.32
Filtering area ratio	3.06	1.86

flowmeter reading at each of the four stations.

Aperture width (Table 3) for the #10- and #20-mesh nets was slightly smaller than manufacturer's specifications. The #20-mesh net had a lower porosity (0.28) than the #10-mesh net (0.46). Filtration area ratio also was lower for the #20-mesh net (1.86) than the #10-mesh net.

Seasonal abundance patterns (average of 4 stations) of the numerically dominant taxa were similar for the #10- and #20-mesh net collections (Fig. 3). The greatest difference between the two collections was associated with standing stock estimates for nauplii.

Most taxa occurred in significantly ($p < 0.05$) greater abundances in the #20-mesh net collections than in the #10-mesh net collections: exceptions were *Epischura lacustris, Eurytemora affinis,* and *Eubosmina coregoni* (Table 4). Nauplii abundances averaged 12 times greater in the #20-mesh net collections than in the #10-mesh net collections. However, for most of the remaining taxa, these differences approximated 50%, i.e., a density ratio of 1.5. This ratio was consistent although these taxa varied substantially in size, i.e., between imature and adult forms, and small verusus large taxa.

Discussion

The #2-mesh net clearly was unsuitable for providing accurate estimates of the abundances of the common Lake Michigan copepods and cladocerans. However, such a coarse mesh net may be useful for studies of larger zooplankton such as *Limnocalanus macrurus* copepodites. Finer nets such as the #10- or #20-mesh net can provide more representative estimates of zooplankton abundances. However, each of these nets suffers from a different sampling bias.

Filtration efficiency of the #10-mesh net averaged 98.2%, increasing slightly with station depth. Similarly high filtration efficiencies for #10-mesh nets have been observed in the open waters of Lake Michigan by Vandeploeg (Great Lakes Environmental Research Laboratory, Ann Arbor, Michigan, pers. commun.). Conversely, the filtration efficiency of the #20-mesh net averaged 70.3%,

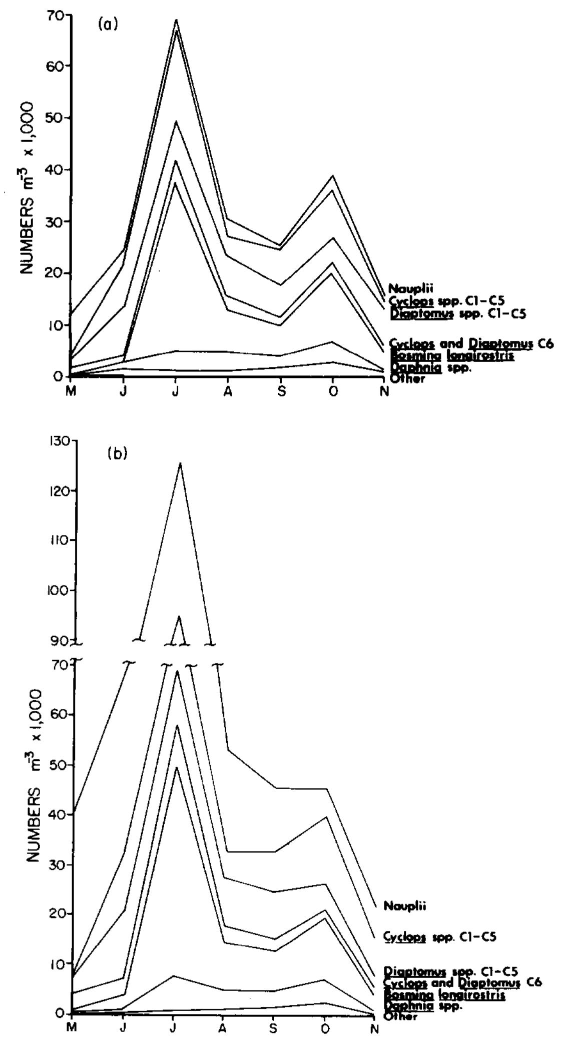

Fig. 3. Average (mean of four stations) abundance of the numerically dominant taxa, May through November 1979, as determined from the (a) #10-mesh and (b) the #20-mesh net collections.

Table 4. Results of rank sum test comparing taxa abundances as determined by #10- and #20-mesh net collections. Zooplankton were collected at 4 stations. May through November 1979, in southeastern Lake Michigan. N = 27.

	Attained significance level	Rank observations		Density ratios
	Rank sum	#20 > #10	#10 > #20	Mean #20 / Mean #10
Nauplii	0.00	27	0	12.0
Cyclops spp. C1–C5	0.00	25	2	1.5
Cyclops spp. C6	0.00	27	0	1.5
Tropocyclops sp. C1–C6	0.01	13	6	1.5
Diaptomus spp. C1–C5	0.00	22	5	1.4
Diaptomus spp. C6	0.00	21	6	1.5
Epischura lacustris C1–C6	0.50	10	12	0.7
Eurytemora affinis C1–C6	0.28	7	14	1.4
Limnocalanus macrurus C1–C6	0.02	9	6	1.7
Bosmina longirostris	0.00	20	6	1.4
Daphnia spp.	0.02	15	10	1.3
Eubosmina coregoni	0.49	9	9	1.7
Total	0.00	27	0	2.0

decreasing from 79.6% in shallow waters to 64.7% in deeper (42 m) waters. If 85% filtration efficiency is assumed to be the point at which significant clogging occurs (Tranter & Smith, 1968), the #20-mesh net which we used was prone to clogging even in the shallowest regions of our study area.

Clogging may create sampling artifacts even when flowmeters are used. As a net clogs, flow velocities are reduced and flow patterns altered. Tranter & Smith (1968) recommend that the flowmeter be mounted one-quarter along the diameter to provide the best estimate of mean water flow through a net. A flowmeter located in the center of a net, as ours was, may underestimate flow through the meshes. Two consequences of underestimating the volume of water filtered are that filtration efficiency is understimated and zooplankton abundances are overestimated. This apparently occurred in our study.

Nauplii clearly were severely undersampled by the #10-mesh net: abundance estimates averaged 12 times greater for the #20-mesh net collections than for the #10-mesh net collections. However, abundance estimates for larger zooplankton were similar, differing only by a factor of 1.5. The similarity in abundance ratios despite significant variations in taxa size (e.g. from immature to adult copepodites within a given genus, and from small (*Tropocyclops*) to large (*Limnocalanus*) genera) suggests that some bias occurred other than the loss of these zooplankton through the meshes of the #10 net. Furthermore, the meshes of the #10-net clearly were sufficiently small (Table 3) to prevent the loss of relatively large animals such as *Cyclops bicuspidatus thomasi* (average length 0.9 to 1.17 mm, Edmondson 1959) and *Limnocalanus marurus* adults (average length 2.2 to 3.2 mm, Edmondson 1959). Therefore, we hypothesize that the sampling bias was associated with the #20-mesh net rather than the #10-mesh net. Specifically, we hypothesize that, as the #20-mesh net clogged, the centrally-mounted flowmeter underestimated the volume of water filtered resulting in an overestimate of taxa abundances.

Our study suggests that two potentially different sampling artifacts can arise through the use of a #20-mesh net. When estimates of the volume of water filtered are based on the distance of the plankton tow and where significant clogging occurs, taxa abundances will be underestimated: this occurs because the volume of water filtered is overestimated. Reported filtration efficiencies for #20-mesh nets range from 40% to 60% (Gannon 1972) suggesting that, when flowmeters are not used, taxa abundances may be underestimated by similar amounts. Conversely, when a flowmeter is used but incorrectly placed in the mouth of the net (as in our study), the opposite error occurs.

In our study, we apparently overestimated the abundances of the larger zooplankton taxa in the

#20-mesh net collections by a factor of 50%. If we assume that such an error arose through an incorrect flowmeter location, the filtration efficiency of the #20-mesh net may have been up to 33% ((150–100)/150) greater than our previous estimate. Thus, for station DC-6 where clogging was severe, the actual filtration efficiency may have been closer to 86.1% than to 64.7%. Furthermore, nauplii may have been underestimated by the #10-mesh net a factor closer to 8 than to 12.

One method for improving the filtration efficiency of a plankton net of a given diameter and mesh construction is to increase the filtration area ratio. According to Tranter & Smith (1968), a filtration efficiency of 85% should be achieved when nets have a ratio of about 3 while the filtration efficiency should exceed 95% for nets with a filtration area ratio of 5. However, the operational filtration efficiency of a net will depend on the distance of the tow and seston concentrations (Smith *et al.*, 1968). Filtration area ratios can be improved by increasing the filtration area of the net (see Equations 2 and 3) through the construction a net with a longer cone or the addition of a cylinder to the front of the net.

Using Equations 2 and 3, we calculated the necessary dimensions to achieve a filtration area ratio of 3 and 5 respectively. To achieve a filtration area ratio of 3 for the #20-mesh net, the net length (excluding bridles, codend, weight) must be lengthened from 1.6 m to 2.0 m for a cylinder-cone design or to 2.7 m for a simple cone design. To achieve a filtration area ratio of 5, the required length is 2.8 m (cylinder-cone) to 4.2 m (cone), excluding bridles, codend, and weights. The #10-mesh net in our study had a filtration area ratio of 3: to achieve a filtration area ratio of 5, the length must be increased from 1.6 m to 2.1 m (cylinder-cone) or to 2.7 m (cone).

Relatively long nets pose other sampling problems. In shallow waters (<10 m), use of long nets presents difficulties in obtaining an integrated water column sample of zooplankton standing stocks; long nets cannot be lowered sufficiently deep in the water column to effectively sample the sediment-water interface. In areas where net clogging is not severe and where depths are shallow, the use shorter nets with the consequent reduction in filtration efficiency may be a preferred option. Alternately, a smaller volume of water could be sampled with plankton traps such as described in Schindler (1969).

In summary, a #10-mesh net provides representative estimates of microcrustacean zooplankton abundances with the exception of small taxa such as nauplii. Such a net operates at a relatively high filtration efficiency. Small zooplankton are more effectively sampled by a #20-mesh net. However, because such nets clog relatively easily, a flowmeter must be used to accurately measure the volume of water filtered. As a net clogs, a centrally-mounted flowmeter underestimates the total volume of water filtered: this bias may be reduced by locating the flowmeter one-quarter along the mouth diameter. Where seston concentrations are high, nets may require redesign or alternate collection gear must be employed.

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