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A Comparison of Freshwater Zooplankton Sampling Gear: Nets, Traps and Submersible Pump

by

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ABSTRACT

Johannsson, Ora E., Margo A. Shaw, Norman D. Yan, Jean-Marc Filion and Diane F. Malley. 1992. A comparison of freshwater zooplankton sampling gear: nets, traps and submersible pump. Can. Tech. Rep. Fish. Aquat. Sci. 1894. i-vii + 30pp.

Differences in the performance of zooplankton sampling gear may confound comparisons among data sets. We examined the relative efficiencies of six different gear used by government and local institutions in long-term monitoring programs in central Canada (a pump, three nets, and two traps). The study was conducted in a typical Canadian shield lake to establish guidelines for comparing our data. The zooplankton community consisted of rotifers, immature copepods, and cladocerans. The magnitude of the differences in species abundances between the best and worst gear ranged from 1.9 to 30.5: the median was 3.2.

A multivariate analysis of variance followed by six a priori contrasts revealed significant gear effects in 8 of the 12 species. The pump and nets performed equally for 10 of the 12 species: both were more efficient than the traps. Small sample volumes may be partly responsible for the poorer performance of the traps. Size selectivity was evident between traps but not between nets constructed with 53-µ and 76-µ mesh netting. This may also have contributed to the relatively poorer performance of the traps.

The relative efficiency of nets and pumps compared with traps equipped with 53-μ mesh was 1.14 for small species (minimum width <100 μ) and 1.72 for larger species. Similarly, the relative efficiencies of nets and pumps compared with traps equipped with 76-μ mesh were 3.08 for small species and 1.94 for large species.

Key words: zooplankton sampling, nets, traps, pump

RÉSUMÉ

Johannsson, Ora E., Margo A. Shaw, Norman D. Yan, Jean-marc Filion et Diane F. Malley. 1992. A comparison of freshwater zooplankton sampling gear : nets, traps and submersible pump. Can. Tech. Rep. Fish. Aquat. Sci.

Les différences de rendement des divers dispositifs d'échantillonnage du zooplancton peuvent compliquer la comparaison d'ensembles de données. Nous avons étudié l'efficacité relative de 6 échantillonneurs différents utilisés par le gouvernement et des établissements locaux dans le cadre de programmes de surveillance à long terme menés dans le centre du Canada (une pompe, trois types de filets et deux types de trappes à zooplancton). L'étude a été effectuée dans un lac typique du Bouclier canadien et était destinée à établir des lignes directrices à des fins de comparaisons de données. La communauté zooplanctonique se composait de rotifères, de copépodes immatures et de cladocères. L'ampleur des différences d'abondance des espèces observées entre l'échantillonneur le moins efficace et le plus efficace variait de 1,9 à 30,5; la médiane était de 3,2.

Une analyse de variance à plusieurs variables, suivie de six comparaisons a priori, a révélé que les échantillonneurs avaient des effets significatifs sur 8 des 12 espèces. La pompe et les filets ont donné des résultats similaires pour 10 des 12 espèces et ils étaient tous deux plus efficaces que les trappes à zooplancton. Les plus faibles volumes d'échantillonnage expliqueraient en partie le piètre rendement des trappes. On a pu constater une sélectivité en fonction de la grosseur d'une trappe à l'autre, mais non pas entre des filets à mailles de 53 μ et 76 μ. Cette sélectivité pourrait également avoir contribué au rendement relativement moins bon des trappes à zooplancton.

L'efficacité relative des filets et des pompes en comparaison des trappes munies de filets à mailles de 53 μ était de 1,14 dans le cas des petites espèces (largeur minimale inférieure à 100 μ) et de 1,72 dans le cas des espèces plus grosses. De la même façon, l'efficacité relative des filets et des pompes en comparaison des trappes munies de filets à mailles de 76 μ était de 3,08 pour les petites espèces et de 1,94 pour les espèces plus grosses.

INTRODUCTION

Differences in the selectivity and efficiency of plankton, sampling gear may confound comparisons among data sets. Although the physical behaviour, efficiencies and deployment of plankton nets (Heron 1968, Tranter and Smith 1968, Clutter and Anraku 1968, Vannucci 1968) and of traps, tubes and pumping systems (de Bernardi 1984) have been reviewed, we can not determine what portions of the differences among data sets collected with different gear types are artifacts of the sampling methodologies. Consequently, there is disagreement in the literature on the relative performance of different gear. Traps and large bottles have been reported to perform better than nets (Hensen et al. 1962 in Clutter and Anraku 1968, Schindler 1969, Kankaala 1984) or the same as nets (Ohlund 1977 in Kankaala 1984, Lewis 1978). Similarly, disagreement in the relative performance of pumps and nets can be found in the studies of (Patalas 1954, Aron 1958 in Clutter and Anraku 1968, Icanberry and Richardson 1973, Allard 1982 in Farquhar and Geiger 1984, Geiger 1983, Pillar 1984, and Waite and O'Grady 1980).

Zooplankton, long-term monitoring data are collected by several government and local instituations in central Canada, each using a different sampling gear and deployment protocol. The gear include plankton nets, a pump and Schindler-Patalas traps. In order to integrate these data sets, the performance of the gear need to be compared systematically. Comparisons need to be made at the taxa level (DeVries and Stein 1991), and weightings need to be developed for integrating the data sets. In the present study, we compared the performance of 1) nets, 2) traps and 3) a pump, in a typical, oligotrophic, Canadian Shield lake. We provide some guidelines for integrating data sets collected with these diverse gear types.

METHODS

SAMPLING GEAR

We compared the performance of six types of zooplankton sampling gear: three plankton nets, two Schindler-Patalas traps, and a submersible, centrifugal pump (Table 1, Figure 1). All equipment could be handled from a small boat.

Net 1 (N1) had a 30 cm square mouth with a plexiglass collar 10 cm in depth which housed an electronic flow meter (Filion 1991). The flow meter was calibrated in situ. The net, itself, was composed of a 60-cm long, rectangular collar and 80-cm long cone, both of 76-μ mesh (Figure 1). A weight was suspended from the bottom of the net to ensure that it moved vertically through the water column.

Net 2 (N2) was cone-shaped with a mouth diameter of 12.4 cm, a length of 78 cm, and mesh size of 76-μ (Figure 1). Filtration efficiency was determined from a Clark-Bumpus flow-meter impeller, modified with a ratchet-driven, one-way counter made by Veeder Root, situated in the centre of the mouth. The flow-meter was calibrated in situ.

Net 3 (N3) was a bongo-style, closing net designed by Chang et

Table 1. Zooplankton gear specifications. N = nets, S = Schindler-Patalas trap, MS = modified Schindler-Patalas trap, P = pump, h = height, d = diameter.

	Nets						Traps/Pump			All Gear	
Gear Type*	Mouth Diam. (cm)	Mouth Area (cm^2)	Net Length (cm)	FA/MA**	Filtration Efficiency (%)	Tow Speed ($m.s^{-1}$)	Volume (L)	Dimensions (cm)	Velocity ($L.min^{-1}$)	Volume Filtered (L)	Mesh Size (μ)
N1	30.0	900	120	4.6	62.5	0.3	-	-	-	563	76
N2	12.4	121	78	4.4	76.6	1.0	-	-	-	93	76
N3	12.9	130	150	4.8	N/A	0.3	-	-	-	522	53
S	-	-	-	-	-	-	31.3	39.8x28.2x27.9	-	188	53
MS-1 m	-	-	-	-	-	-	12.0	47.0x18.0x18.0	-	120	76
MS-2 m	-	-	-	-	-	-	12.0	47.0x18.0x18.0	-	70	76
P	-	-	-	-	-	-	-	15.0 (d) x 24.0 (h)	54	540	64

*Gear Reference
N1 - J.M. Filion, Ecole Secondaire Algonquin, pers. comm.
N2 - Yan (1986)
N3 - Chang et al. (1980)
S - Schindler (1969)
MS - Redfield (1984)
P - Dorazio

**Filtration Area (porosity x area of net)/Mouth area, where porosity is the open area of the mesh expressed as a %

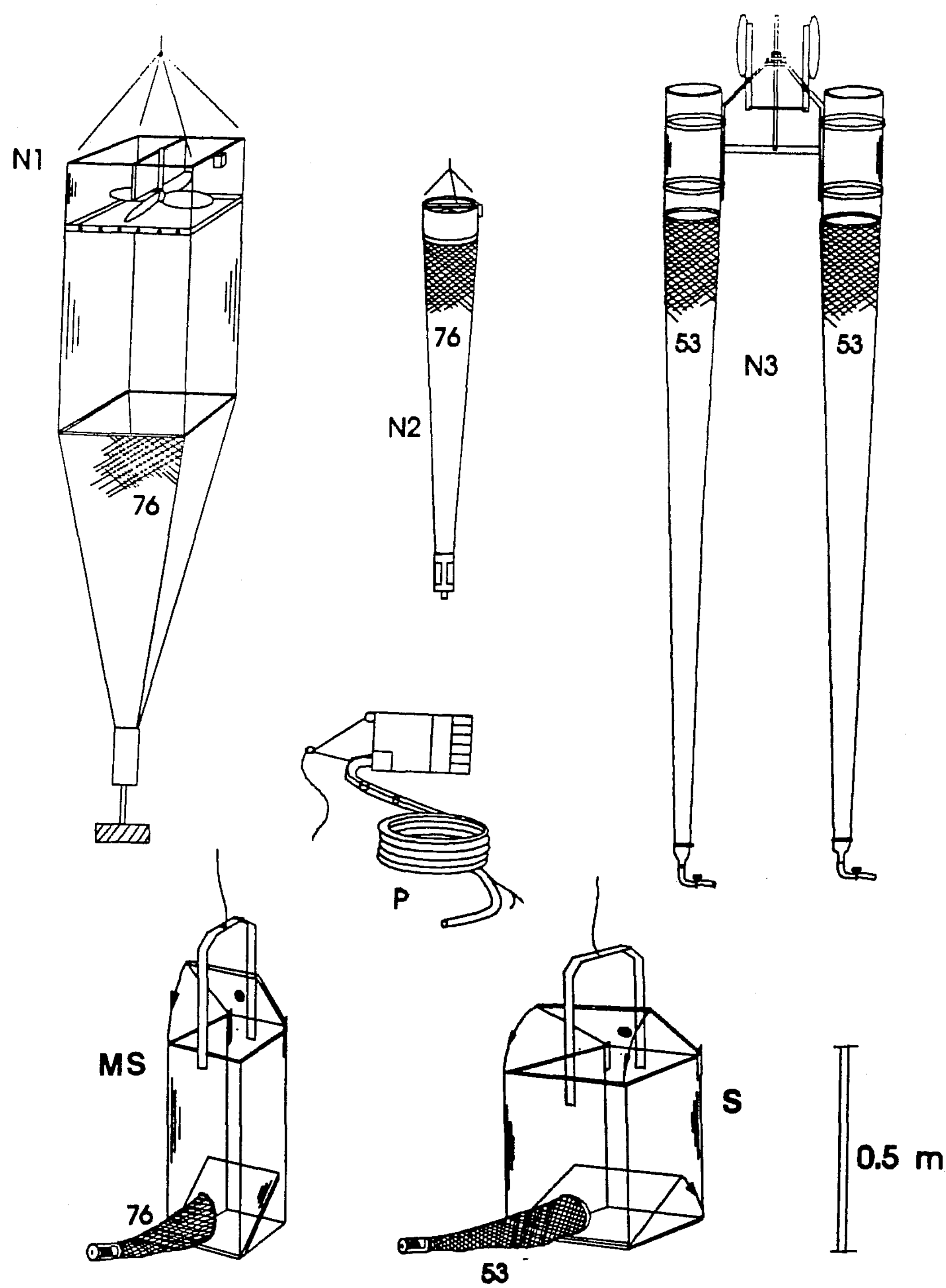

Figure 1. Sampling gear illustrated at the same scale. The number by the netting refers to the mesh size in microns. See Table 1 for dimensions, performance characteristics and references for specific gears.

al. (1980). The bongo-style of net does not have a bridle directly above the net mouth (Figure 1). The two nets were cylindrical-conical in shape with a mouth diameter of 12.9 cm, a cylindrical collar of 25 cm and a total length of 150 cm (Figure 1). Both nets were constructed of 53-μ mesh. Filtering efficiency was assumed to be 100%, no current meters were employed. For each sample with this net, two hauls were made through the water column and the contents of the four buckets pooled.

The Schindler-Patalas trap (S), designed by Schindler (1969), sampled 31.3 L of water. The sample was filtered through a 53-μ mesh sleeve attached to one wall of the trap (Figure 1). The modified Schindler-Patalas trap (MS) (Redfield 1984), collected 12.0 L of water which were filtered through a 76-μ sleeve. Two series of samples, one with the Schindler-Patalas trap and the other with the modified Schindler-Patalas trap, were collected at two meter intervals starting just under the water's surface. An additional series of samples was taken at one meter intervals with the modified Schindler-Patalas trap. All samples from a series were combined to produce a single integrated sample.

The submersible, Robusta 201W, centrifugal pump (P) was calibrated in situ and moved 54 L of water.min^{-1}. Water entered through a grated region around the circumference of the pump at the bottom edge (Figure 1). The dimensions of the individual open areas were 4 mm x 25 mm: the total open area was 60 sq.cm. At the surface, the water emptied into a 64-μ mesh net suspended in the lake on the other side of the boat. When taking an integrated sample, the pump was lowered to the bottom of the sampling depth and 54 L of water were collected from each one meter depth interval to the surface.

SAMPLING PROTOCOL

We compared the performance of the six gears in a small Precambrian Shield lake. Plastic Lake covers 32 ha, has a mean and maximum depth of 7.9 m and 16.3 m respectively, and is relatively clear (colour = 22 hazen units) and oligotrophic (chlorophyll a concentration = 1.6 $ug.L^{-1)}$ (Table 2). The gear comparison was conducted in August when zooplankton species diversity was expected to be greatest.

The epilimnion extended from the surface to 7.5 m and the metalimnion from 7.5 m to 10.5 m at the time of the study. All samples were collected from the bottom of the metalimnion to the surface. This depth was chosen to include species which form metalimnetic population peaks, such as, Holopedium gibberum (Plastic Lake, Yan and Larson 1988). The depth was also shallow enough not to restrict sampling to the deepest region of the lake. Five off-shore sites were chosen where water depth was greater than 10 m. One integrated sample of the water column was collected by each gear at each site. At each site, the order in which the gear were deployed was determined by a random number generator in a pocket calculator. The volume of water filtered per sample ranged from 72 to 563 L (Table 1).

Table 2. Selected water chemistry and morphometric characteristics of Plastic Lake (P.J. Dillon, unpub. data). Chemistry data are given as ice-free season averages for 1988.

Parameter	Value
TIA Alkalinity (mg.L Ca CO)	0.41
pH	5.82
True Colour (hazen units)	22.00
Conductivity (µS.cm)	22.10
Chlorophyll a (µg.L)	1.62
Secchi Depth (m)	6.10
Dissolved Organic Carbon (mg.L)	1.98
Ammonia, NH (µg. L)	24.80
Nitrate, NO (µg. L)	24.30
Total Kjeldahl Nitrogen (µg.L)	187.00
Total Phosphorus (µg.L)	5.00
Lake Area (ha)	32.10
Mean Depth (m)	7.90
Maximum Depth (m)	16.30

SAMPLE PROCESSING

All samples were fixed immediately in 4% sugar-buffered formalin. The twelve most abundant species were selected for counting. The number of subsamples examined depended on species density. Table 3 summarizes the medians and ranges of individuals counted per sample. Sample volume was adjusted in a graduated cylinder. Subsamples of 1 ml were extracted with a pipette from the well-mixed sample and enumerated for rotifers in a Sedgewick Rafter cell at 100X magnification (Pennak 1953). Subsamples of 10 ml were dispensed directly from the well mixed sample into 10 ml rectangular counting cells where the crustaceans were identified and counted at 25X magnification.

Table 3. Median and range of number of specimens counted per sample. Thirty five samples were enumerated, 5 for each of 7 gear types. Species are ranked by their mean abundance.

	No. counted per sample	
Species	Median	Range
Eubosmina tubicen	13	2-33
Calanoid nauplii	13	0-41
Polyarthra vulgaris	2	0-28
Kellicottia longispina	6	2-17
Cyclopoid copepodids	33	4-46
Holopedium gibberum	31	4-45
Diaphanosoma birgei	33	7-66
Keratella crassa	10	3-35
Keratella taurocephala	16	2-48
Asplanchna priodonta	42	12-76
Gastropus stylifer	44	15-73
Calanoid copepodids	77	29-151

Edmondson (1959) was the basic taxonomic reference employed for Crustacea. Other monographs employed included Brooks (1959) as modified by Dodson (1981) for Daphnia, Korineck (1981) for Diaphanosoma, and Deevey and Deevey (1971) for Eubosmina. Rotifer taxonomy followed Stemberger (1979) and Ahlstrom (1943). Rotifers, Cladocera, and C6 copepodids were identified to the species levels, immature copepods to suborder. The lengths and maximum widths, including terminal and lateral projections, were measured on 25 individuals of each species. *Holopedium gibberum* did not retain its shape well in fixed samples. Postabdominal length was measured and converted to body length by using a regression relationship developed on freshly fixed animals.

STATISTICAL DESIGN

This study was designed to test the null hypothesis that estimates of species abundance were not affected by the type of sampling gear employed. All species abundances were ln(x+1) transformed which successfully normalized the data and reduced heteroscedasticity. Statistics were performed using SYSTAT 4.0 (Wilkinson 1988). We analyzed the data using a multivariate analysis of variance (MANOVA) model (Wilkinson 1988). The data conformed to a 'mixed-effects' model: site was considered a random effect, gear type a fixed effect, and species abundances were the dependent variables. First we analyzed the full model for all species:

Species Abundance ln(x+1) Sp1-Sp12 = constant + site + gear

Based on these results, we ran the reduced model:

Species Abundance ln(x+1) Sp1-Sp12 = constant + gear

We examined the univariate F values for each species because the multivariate test statistic (Wilk's Lambda) of the reduced model was significant. For those species with significant F values, we conducted six preplanned contrasts chosen to test for differences of interest between sampling gears. This approach, (as opposed to making all possible pair-wise comparisons) was chosen to protect against Type I errors. The preplanned contrasts were performed in the following order:

1) modified Schindler-Patalas-1m vs modified Schindler-Patalas-2m
2) Schindler-Patalas vs. modified Schindler-Patalas (both)
3) Net 3 vs. Net 2
4) All nets vs. Pump
5) Pump vs. all traps
6) All nets vs. all traps

Contrast 1 compared the effects of sampling depth interval. Contrast 2 examined the effect of mesh size and volume: the Schindler-Patalas trap had both a smaller sampling mesh and larger sample volume than the modified Schindler-Patalas trap. Contrast 3 was of interest because the Canadian Department of Fisheries and Oceans and the Ontario Ministry of the Environment have long-term zooplankton data sets collected with these nets (Net 3, Net 2) to assess the impact of acid rain. Contrasts 4 to 6 compared the relative performance of different gear types.

RESULTS

The mean abundance and coefficient of variation (CV = 100% * standard deviation/mean) are presented by gear type for each species in Table 4. Species were ranked according to their average abundance for all gear types. Replicate variability was similar amongst the different sampling gear. The average of the CVs associated with each sampling gear ranged from 37% to 56%: modified Schindler-Patalas-1m and modified Schindler-Patalas-2m had the highest CVs. As expected, CVs of the individual species decreased with increases in species abundance. The average CV for the least abundant organism (Eubosmina tubicen, 0.28 - $0.53.L^{-1}$) was 73.3%, while the average CV for the most abundant zooplanktor (calanoid copepodids, 12.5 - $25.6.L^{-1}$) was 28.5% (Table 4).

The magnitude of the difference in species abundance between the best and worst gear ranged from a factor of 1.9 to 30.4 (Table 4). The distribution of these ratios was highly skewed and all but one ratio was below five: the median was 3.2.

There was no evidence that the majority of species (10/12) were patchily distributed: only the abundance of Holopedium gibberum differed greatly amongst sites (Table 5). Consequently we dropped site effects from the statistical model.

Table 4. Average abundance (no.L^{-1}) and coefficient of variation (CV) in brackets, for each species collected by each gear. N1, N2, and N3 are nets, P is a pump and S, MS-2m, and MS-1m are Schindler-Patalas traps taken at 2, 2 and 1m depth intervals respectively. Species are ranked by their abundance. Max/Min = maximum/minimum abundance within a species.

	Gear								
Species	N1	N2	N3	P	S	MS-2m	MS-1m	Mean CV	Max/Min
Eubosmina tubicen	0.53 (53.0)	0.45 (68.1)	0.51 (81.1)	0.37 (98.6)	0.28 (81.5)	0.48 (60.9)	0.38 (60.9)	73.3	1.9
Calanoid nauplii	0.43 (51.3)	0.56 (34.8)	0.26 (6.4)	0.74 (118.2)	0.66 (41.2)	0.36 (99.7)	0.22 (99.7)	58.2	3.4
Polyarthra vulgaris	0.99 (82.4)	0.54 (95.0)	0.67 (54.5)	3.04 (50.0)	1.54 (37.4)	0.39 (45.6)	0.10 (45.6)	73.3	30.4
Kellicottia longispina	2.76 (35.1)	1.11 (57.3)	1.44 (25.5)	2.22 (37.4)	2.08 (44.7)	1.14 (51.7)	0.94 (51.7)	43.8	2.9
Cyclopoid copepodids	2.06 (40.4)	2.28 (11.6)	1.46 (39.5)	2.04 (37.6)	1.17 (37.7)	1.74 (63.3)	1.50 (63.3)	40.3	1.9
Holopedium gibberum	3.22 (53.9)	1.37 (58.7)	1.66 (44.3)	2.99 (38.2)	1.12 (63.8)	1.48 (34.4)	1.11 (34.4)	51.2	2.9
Diaphanosoma birgei	3.60 (49.6)	3.54 (49.4)	3.26 (26.1)	3.08 (59.1)	2.13 (70.6)	0.82 (56.9)	1.52 (56.9)	49.6	4.4
Keratella crassa	4.65 (25.2)	3.55 (45.0)	2.11 (60.3)	5.72 (21.0)	2.98 (34.8)	1.70 (36.9)	1.72 (36.9)	34.1	3.4
Keratella taurocephala	6.28 (28.1)	5.53 (24.7)	5.89 (29.2)	7.43 (18.7)	5.94 (37.6)	2.14 (61.3)	1.54 (61.3)	36.7	4.8
Asplanchna priodonta	15.47 (12.7)	8.79 (46.5)	13.89 (36.3)	17.25 (18.2)	9.13 (54.0)	15.17 (40.2)	8.84 (40.2)	32.9	2.0
Gastropus stylifer	18.28 (18.8)	12.89 (26.9)	19.83 (35.8)	19.13 (17.0)	14.91 (19.6)	7.14 (46.4)	4.55 (43.4)	30.3	4.4
Calanoid copepodids	25.60 (17.5)	18.64 (18.6)	22.18 (13.5)	15.18 (11.8)	12.50 (38.0)	16.11 (52.0)	13.05 (52.0)	28.5	2.1
Mean Abundance	6.99	4.94	6.10	6.60	4.54	4.06	2.96		5.4
Mean CV	39.0	44.7	37.7	43.8	46.7	53.8	56.4	46.0	

Table 5. Univariate F statistics and p values for full model (site effects) and reduced model (gear effects) by species.

	Site Effects		Gear Effects	
Species	F	p	F	p
Rotifera				
Keratella taurocephala	0.520	0.722	11.009	<0.0001
Keratella crassa	0.660	0.626	9.077	<0.0001
Kellicottia longispina	0.395	0.810	4.024	0.006
Gastropus stylifer	1.417	0.261	16.513	<0.0001
Asplanchna priodonta	1.532	0.228	3.451	0.012
Polyarthra vulgaris	0.630	0.646	9.689	<0.0001
Calanoida				
Calanoid copepodids	5.625	0.062	2.011	0.100
Calanoid nauplii	1.321	0.293	1.368	0.264
Cyclopoida				
Cyclopoid copepodids	0.613	0.657	1.218	0.329
Cladocera				
Diaphanosoma birgei	2.279	0.093	3.904	0.007
Holopedium gibberum	7.743	<0.0001	3.306	0.015
Eubosmina tubicen	3.004	0.040	1.128	0.329
Multivariate statistics	2.013	0.010	2.495	<0.0001

Table 6. Rank performance across gear types for zooplankton species. In the column 'Gear Rank' => indicates the Pump performed better than the traps, but the nets did not.

Species	Sig. Contrasts*	Gear Rank
Rotifera		
Keratella crassa	1,2,3	Pump>Nets>Traps
Gastropus stylifer	2,3	Pump=Nets>Traps
Keratella taurocephala	2,3	Pump=Nets>Traps
Polyarthra vulgaris	1,2	Pump>Nets=>Traps
Asplanchna priodonta	2	Pump=Nets=>Traps
Kellicottia longispina	2	Pump=Nets=>Traps
Calanoida		
Calanoid copepodids	-	Pump=Nets=Traps
Calanoid nauplii	-	Pump=Nets=Traps
Cyclopoida		
Cyclopoid copepodids	-	Pump=Nets=Traps
Cladocera		
Holopedium gibberum	2,3	Pump=Nets>Traps
Diaphanosoma birgei	2,3	Pump=Nets>Traps
Eubosmina tubicen	-	Pump=Nets=Traps

*Contrasts:
1. Pump vs. 3 nets (P vs. N1, N2, N3)
2. Pump vs. Schindler-Patalas traps (P vs. S, MS-1m, MS-2m)
3. Nets vs. Schindler-Patalas traps (N1, N2, N3 vs. S, MS-1m, MS-2m)

Table 7. Comparison of the importance of sample volume and mesh size* on the relative performance of the nets N2 and N3, and the traps S, MS-1m and MS-2m. Species are ordered by body width.

	Body Width (µ)		Significant Contrasts		
Species	minimum	median	N2 vs. N3	S vs. MS	MS 1m vs. 2m
Kellicottia longispina	42	49	N2=N3	S>MS	MS2=MS1
Polyarthra vulgaris	56	63	N2=N3	S>MS	MS2=MS1
Gastropus stylifer	56	77	N2=N3	S>MS	MS2>MS1
Keratella crassa	70	84	N2>N3	S>MS	MS2=MS1
Keratella taurocephala	70	98	N2=N3	S>MS	MS2=MS1
Calanoid nauplii	80	137	N2=N3	S=MS	MS2=MS1
Cyclopoid copepodids	132	186	N2=N3	S=MS	MS2=MS1
Calanoid copepodids	142	214	N2=N3	S=MS	MS2=MS1
Asplanchna priodonta	231	294	N2=N3	S=MS	MS2>MS1
Eubosmina tubicen	284	391	N2=N3	S=MS	MS2=MS1
Diaphanosoma birgei	409	669	N2=N3	S=MS	MS2=MS1
Holopedium gibberum	517	1076	N2=N3	S=MS	MS2=MS1

*Mesh Size: N2=76µ, N3=53µ, S=53µ, MS=76µ

In the reduced model, the multivariate test statistic (Wilk's Lambda) for gear effects was highly significant ($p < 0.0001$). The univariate F statistics indicated that gear effects were significant for 8 of 12 species (Table 5). No differences in the abundances of Eubosmina tubicen, cyclopoid copepodids and calanoid nauplii and copepodids were attributable to gear effects. Three of these species (calanoid nauplii, cyclopoid copepodids and Eubosmina tubicen) were amongst the least abundant species in the lake with average CVs ranging from 40% to 73%. The probability of detecting a significant difference for these species would be low. Thus abundance estimates for the majority of zooplankton species were affected by sampling gear.

We assumed that higher abundance indicated a higher gear efficiency. The nets (Net 1, Net 2, Net 3) and pump performed equally for 10 of the 12 species (contrast 4) (Table 6), but the pump sampled Polyarthra vulgaris and Keratella crassa more efficiently than the nets. The pump also performed better than the traps for 8 of the 12 species, while the nets performed better for 7 of 12 species (contrasts 5, 6) (Table 6). In no instance did the traps perform better than the nets or pump.

Within the gear types, modified Schindler-Patalas-1m sampling was compared with modified Schindler-Patalas-2m sampling (contrast 1), Schindler-Patalas with modified Schindler-Patalas (contrast 2), and Net 2 with Net 3 (contrast 3). For the majority of species, sampling at 1-meter or 2-meter intervals with the modified Schindler-Patalas traps made no difference to abundance estimates

(Table 7). Therefore the data were combined for subsequent contrasts. The two traps, Schindler-Patalas and modified Schindler-Patalas, performed equally well for 7 of the 12 species (Table 7). Differences occurred in the five smallest species (Table 7). Net 3 and Net 2 performed equally well for 11 of 12 species. Only Keratella crassa was significantly more abundant in Net 2 (Table 7).

DISCUSSION

In the following paragraphs we shall consider first the importance of differences in mesh size on these comparisons, and second, the remaining differences in sampling efficiency which are related to gear type and deployment.

MESH SIZE EFFECTS

Within gear types, the greatest differences in sampling efficiency occurred between the Schindler-Patalas and modified Schindler-Patalas traps. Rotifers with mean body widths less than 100 μ were caught less than 50% as effectively by the modified Schindler-Patalas trap which was fitted with 76-μ mesh, as by the Schindler-Patalas trap which was fitted with 53-μ mesh (Table 8). These observations agree with those of Bernhard et al. (1973, in Pillar 1984) and Nichols and Thompson (1991) who determined that soft bodied organisms can squeeze through meshes 25% smaller than their body width. Accordingly, rotifers with a body width <100 μ could be forced through a 76-μ mesh if they encountered it head-on. In this study, that included all rotifers except Asplanchna priodonta and a small proportion of the calanoid nauplii. Rotifers with a body width <72 μ might pass through a 53-μ mesh. Consequently, the abundances of Kellicottia longispina and Polyarthra vulgaris, with minimum and median body widths <72 μ (Table 7), would also be underestimated with a 53-μ mesh. Gastropus stylifer would be well sampled in spite of a minimum observed wiDth of 56 μ because only 4% of the population was narrower than 70 μ.

Although minor differences in mesh size were important in the traps, this did not appear to be the case for the nets. One would expect to find differences between Net 2 and Net 3 similar to those between the two traps above, because the nets were also fitted with 76-μ and 53-μ mesh respectively. Differences did not occur. The filtering efficiency of Net 3 is not normally measured when this net is deployed, and therefore, was not measured during this study. As a result, Net 3 may have underestimated species abundances masking any effect of mesh size.

GEAR COMPARISONS

Overall, the pump sampled more efficiently than the nets and both the pump and nets outperformed the trap samplers.

The differences between pump and net samples were small. Ten of the 12 species were sampled equally well by both gear types. These included four species of rotifers, three cladocerans and three groups of immature copepodids. The average maximum body width of these 10 species ranged from 50 μ for Kellicottia longispina to 1064 μ for Holopedium gibberum (Table 7). Only two rotifers were caught more efficiently by the pump than by the nets: Keratella crassa was 1.7-fold more abundant in the pump than net samples and Polyarthra vulgaris was 4-fold more abundant. The relative abundances of these species in the different samples bore no relationship to either the mesh sizes of the samplers or the volumes sampled. The reason(s) for the increased efficiency is not obvious.

Unfortunately, the more mobile zooplankton, such as the larger Daphnia and mature calanoids did not occur in Plastic Lake. These groups of freshwater zooplankton are the most difficult to sample (Patalas 1954, Clutter and Anraku 1968, Waite and O'Grady 1980, de Bernardi 1984); and consequently, we can not infer that these species would also be sampled equally well by our nets and pump.

Both the pump and nets sampled much more efficiently than the traps for the majority of species. This included not only the rotifers which were affected by the size of the sampling mesh in the traps but not in the nets, but also Asplanchna priodonta, Holopedium gibberum and Diaphanosoma birgei. Only the estimates of copepod abundances were equivalent. This contrasts with literature findings: rarely do traps perform less effectively than nets or pumps (Hensen et al. 1962 in Clutter and Anraku 1968, Schindler 1969, Ohlund 1977 in Kankaala 1984, Lewis 1978, Kankaala 1984).

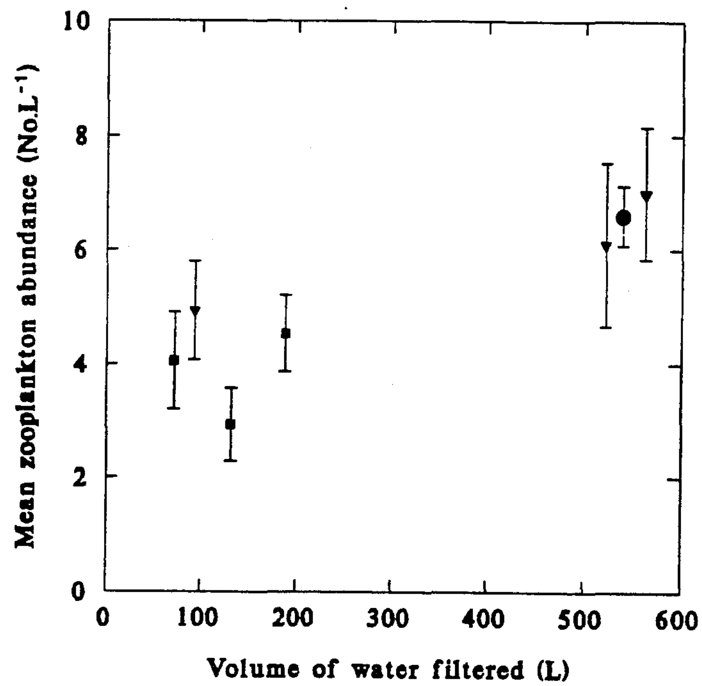

Figure 2. Average total species abundance (n=5 sites) versus volume of water sampled by each gear type. (■) Traps, (●) Pump, (▼) Nets. Bars represent 2 standard errors.

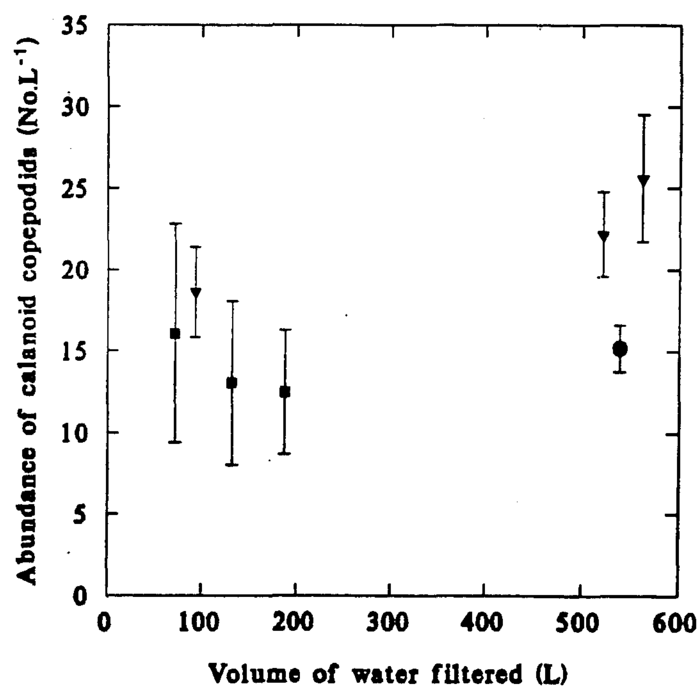

Figure 3. Average abundance of calanoid copepodids (n=5 sites) versus volume of water sampled by each gear type. (■) Traps, (●) Pump, (▼) Nets. Bars represent 2 standard errors.

Perhaps this is because they are not subjected to the same problems of clogging or disturbance of the water column. Our contrasts grouped the nets (Net 1, Net 2, Net 3) and the traps (Schindler-Patalas, modified Schindler-Patalas-1m, and modified Schindler-Patalas-2m); however, the density of total zooplankton estimated by each gear, irrespective of gear type, appears to be related to the volume of water sampled by that gear (Figure 2).

We would expect a relationship between estimated density and sample volume to occur if the plankton were patchily distributed in the water column. The more patchy, highly skewed, a species distribution in the water column, the larger the volume of water which would need to be sampled in order to accurately estimate the species abundance. Sampling from highly skewed distributions will initially emphasis the values in the tail of the distribution and therefore underestimate abundance. For the traps and pump, which take discrete samples down through the water column, this is true in both the horizontal and vertical planes. For integrated samplers, such as the nets, this is only true in the horizontal plane. The poor performance of traps in this study, compared with that of the nets and pump, may result partially from the much smaller volume of water sampled by the traps than by the nets (on average) or pump. It should be noted that the traps and Net 2 sampled similar volumes of water and produced similar estimates of total zooplankton density.

Calanoid copepodids were an exception because they were sampled equally by all gear types. Most studies report equal or higher sampling efficiencies with traps than with pumps or nets, particularly nets constructed of finer meshes, for highly mobile organisms, such as calanoids (Patalas 1954, Schindler 1969, Kankaala 1984, DeVries and Stein 1991). Plotting calanoid copepodid abundance against sample volume revealed that abundance estimates from the traps were highly variable (Figure 3). Nets and traps of similar volume sampled equally well but the net data had a smaller CV: 18.6% as compared with 38%-52%. The pump was approximately 20% less efficient than nets of a corresponding sample volume. Others have noted that pumps are not as effective as nets at capturing calanoids: calanoids detect the current field around pumps and attempt to escape. (eg. Langford 1953 in de Bernardi 1984, Waite and O'Grady 1980, Boltovskoy and Mazzoni 1988). These data suggest different relationships between sample volume and gear type may exist, at least in some lakes, and that replicate varibility may be affected by gear type as well as volume (cf. Downing et al. 1987).

CONCLUSIONS

Many factors influence sampling efficiency including the design of the equipment, its deployment, mesh size, sample volume, disturbance of the water column, and time of day. We have compared well-designed gear, standardizing the site, mesh size (within 25 μ), time of day and disturbance of the water column (sampling gear deployed randomly), but allowing sample volume and details of deployment to vary according to the normal use of the gear. For the plankton of Plastic lake which is dominated by smaller and/or slower organisms, we found a great similarity in the efficiency of the pump and net samplers. Only calanoid copepodids were caught less effectively by the pump. The poorer performance of the traps may be due to their smaller sample volumes as well as their size-selectivity.

Table 8. Relative performance of the nets (N) and pump (P) vs. the Schindler (S) and modified Schindler-Patals (MS) traps, for species affected by mesh size and those that are not.

Comparison	Species Affected by mesh size*	Species not Affected by mesh size**
N,P/S (53μ)	1.14	1.72
N,P/MS (76μ)	3.06	1.94

* Includes rotifers with median body width <100μ, see Table VII

** Includes crustaceans, and Asplanchna priodonta

From this study we would be confident in directly comparing the abundances of small and/or slow species sampled with well-designed nets and pumps. However, correction factors needed to be calculated in order to compare net and pump data with trap data (Table 8). We combined all species which were sampled size-selectively (median body width < 100 μ) and estimated the relative efficiency of the nets and pump to the small- and large-meshed traps. The small-mesh trap provided abundance estimates similar to those of the nets and pump (ratio = 1.14), however, the large-mesh trap greatly underestimated these species (ratio = 3.08). This ratio will vary with the relative densities of the different-sized 'small species', and therefore, should not be applied indiscriminantly. Correction factors for the larger zooplankton were 1.72 and 1.94 for small- and large-mesh traps respectively.

Within system types, e.g. systems dominated by small-bodied zooplankton or systems dominated by large Daphnia etc., we may be able to generate a series of curves relating relative performance of gear types to sample volume, mesh size and species. These curves would provide quantitative relationships for comparing data from different locations sampled with different gear.

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REFERENCES

AHLSTROM, E.H. 1943. A revision of the rotatorian genus Keratella with descriptions of three new species and five new varieties. Bull. Am. Mus. Nat. Hist. 80:411-457.

ALLARD, D. 1982. Littoral microcrustacean population dynamics in Post Oak Lake, Brazos County, Texas. Ph.D. Thesis. Texas A&M University, College Station, TX.

ARON, W. 1958. The use of a large capacity portable pump for plankton sampling, with notes on plankton patchiness. J. Mar. Res. 16:158-173.

DE BERNARDI, R. 1984. Methods for the estimation of zooplankton abundance. In Downing,J.A. and Rigler,F.H. eds.. A Manual on Methods for the Assessment of Secondary Productivity in Freshwaters. Blackwell Scientific Publications, Oxford, pp. 59-85.

BERNHARD, M., F. MOLLER, A. NASSOGNE, and A. ZATTERA. 1973. Influence of pore size of plankton nets and towing speed on the sampling performance of two high speed samplers Defino I and II. and its consequence for the assessment of plankton populations. Mar. Biol. 20:109-136.

BOLTOVSKOY, D., and H.E. MAZZONI. 1988. The effects of sampling gear and environmental conditions on the abundance estimates of freshwater zooplankton. Rev. Hydrobiol. Trop. 21:21-34.

BROOKS, J.L. 1959. The systematics of North American Daphnia. Mem. Conn. Acad. Arts Sci. 13:1-180.

CHANG, P.S.S., D.F. MALLEY, W.J. FINDLAY, J. MULLER, and R.T. BARNES. 1980. Species composition and seasonal abundance of zooplankton in lake 227, Experimental Lakes Area, NW Ontario: 1969-1978. Can. Data Rep. Fish. Aquat. Sci. No. 182, i-iv, 1-101 pp.

CLUTTER, R.I., AND M. ANRAKU. 1968. Avoidance of samplers. In Tranter, D.J. [ed] Zooplankton Sampling. Monographs on Oceanographic Methodology. UNESCO, Paris, pp. 57-76.

DEEVEY JR., E.S., AND G.B. DEEVEY. 1971. The American species of Eubosmina Seligo Crustacean, Cladocera.. Limnol. Oceanogr. 16:201-218.

DEVRIES, D.R., and R.A. STEIN. 1991. Comparison of three zooplankton samplers: a taxon-specific assessment. J. Plank. Res. 13:53-59.

DODSON, S.I. 1981. Morphological variation of Daphnia pulex Leydig Crustacean, Cladocera. and related species from North America. Hydrobiol. 83:101-114.

DORAZIO, R.M., J.A. BOWERS, and J.T. LEHMAN. 1987. Food-web manipulations influence grazer control of phytoplankton growth rates in Lake Michigan. J. Plank. Res. 9:891-899.

DOWNING, J.A., M. PERUSSE, and Y. FRENETTE. 1987. Effect of interreplicate variance on zooplankton sampling design and data analysis. Limnol. Oceanogr. 32:673-680.

EDMONDSON, W.T. ED. 1959. Freshwater Biology. 2nd edition. John Wiley and Sons, Inc., New York. 1248 pp.

FILION, J.M. 1991. Improving zooplankton samplers with simple electronics. Limnol. Oceanogr. 36:204-210.

FARQUHAR, B.W., and J.G. GEIGER. 1984. Portable zooplankton sampling apparatus for hatchery ponds. Prog. Fish. Culturist 46:209-211.

GEIGER, J.G. 1983. Zooplankton production and manipulation in striped bass rearing ponds. Aquaculture 35:331-351.

HENSEN, V.K., and K.P. ANDERSEN. 1962. Sampling the smaller zooplankton. Rapp. P.-v. Reun. Cons. perm. int. Explor. Mer. 95:35-47.

HERON, A.C. 1968. Plankton gauze. In Tranter, D.J. [ed] Zooplankton Sampling. Monographs on Oceanographic Methodology. UNESCO, Paris, pp. 19-26.

ICANBERRY, J.W., and R.W. RICHARDSON. 1973. Quantitative sampling of live zooplankton with a filter-pump system. Limnol. Oceanogr. 18:333-335.

KANKAALA, P. 1984. A quantitative comparison of two zooplankton sampling methods, a plankton trap and a towed net, in the Baltic. Int. Rev. Gesamten Hydrobiol. 69:277-287.

KORINECK, V. 1981. *Diaphanosoma birgei* n.sp. Crustacean, Cladocera.. A new species from America and its widely distributed subspecies *Diaphanosoma birgei* spp. *lacustris* n. sp. Can J. Zool. 59:1115-1121.

LANGFORD, R.R. 1953. Methods of plankton collection and a description of a new sampler. J. Fish. Res. Board Can. 10:238-252.

LEWIS JR., W.M. 1978. Comparison of temporal and spatial variation in the zooplankton of the lake by means of variance components. Ecol. 59:666-671.

NICHOLS, J.H., and A.B. TOWNSEND. 1991. Mesh selection of copepodite and nauplius stages of four calanoid copepod species. J. Plank. Res. 13:661-671.

OHLUND, E. 1977. A comparative study of three zooplankton communities on the Swedish west coast with respect to composition, dynamics and function. Dissertation, Department of Zoology, University of Gothenburg, Sweden.

PATALAS, K. 1954. Comparative studies on a new type of self acting water sampler. Ekol. Polska 2:231-242.

PENNAK, R.W. 1953. Freshwater Invertebrates of the United States. Ronalds Press Co., N.Y., 769 pp.

PILLAR, S.C. 1984. A comparison of the performance of four zooplankton samplers. S. Afr. J. Mar. Sci. 2:1-18.

REDFIELD, G.W. 1984. Modifications to the Schindler-Patalas zooplankton trap. Verh. Internat. Verein. Limnol. 22:1417-1424.

SCHINDLER, D.W. 1969. Two useful devices for vertical plankton and water sampling. J. Fish. Res. Board Can. 26:1948-1955.

STEMBERGER, R.S. 1979. A guide to the rotifers of the Laurentian Great Lakes. EPA 600/4-79-021. U.S.A. EPA, Cincinnati, Ohio, 45268.

TRANTER, D.J., and P.E. SMITH. 1968. Reviews on zooplankton sampling methods - Filtration performance. In Tranter, D.J. [ed] Zooplankton Sampling. Monographs on Oceanographic Methodology. UNESCO, Paris, p. 27-56.

VANNUCCI, M. 1968. Loss of organisms through the meshes. In Tranter, D.J. [ed] Zooplankton Sampling. Monographs on Oceanographic Methodology. UNESCO, Paris, p.77-86.

WAITE, S.W., and S.M. O'GRADY. 1980. Description of a new submersible filter-pump apparatus for sampling plankton. Hydrobiol. 74:187-191.

WILKINSON, L. 1988. SYSTAT: The System for Statistics. SYSTAT, Inc., Evanston, IL pp 821.

YAN, N.D. 1986. Empirical predictions of crustacean zooplankton biomass in nutrient poor Canadian Shield lakes. Can. J. Fish. Aquat. Sci. 43:788-796.

YAN, N.D., and J.I.R. LARSON. 1988. Prevalence and inferred effects of microsporidia of Holopedium gibberum (Crustacea: Cladocera) in a Canadian shield lake. J. Plank. Res. 10:875-886.