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ABSTRACT

While the importance of determining the filtration efficiency of plankton nets has been recognized for decades, a survey of recent literature indicates that fresh water zooplankton ecologists rarely employ flow meters in their plankton hauls. As a reminder of the hazards of this omission, we document large inter- and intra-annual variability in plankton net filtration efficiency in a ten year data set from an oligotrophic Canadian Shield Lake. We determine the stall speeds of two plankton net flow meters used by Dorset Research Centre staff, the DRC plankton meter and the Rigosha meter. Finally, we experimentally demonstrate the influence of net design (i.e., the open area ratio), haul speed, and zooplankton community structure on net filtration efficiency.

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b) for a Rigosha & Co Ltd model 5571-A zooplankton flow meter, in Lake of Bays.

INTRODUCTION

Nets are still the most popular gear for collecting zooplankton. They are inexpensive, easy to deploy, and provide depth and/or horizontally integrated samples. If properly designed, metered, maintained and deployed, they can provide samples useful for the quantitative estimation of zooplankton abundance (Tranter and Smith 1968, Langeland and Rognerud 1974, Filion 1991).

Fifty years ago Ricker (1938) noted that the quantification of zooplankton standing stocks could be compromised by the variable filtration efficiency of plankton nets. Yentsch and Duxbury (1956) realized that this problem could be solved by measuring the filtration efficiency of plankton nets directly, using a meter mounted in the mouth of the net. They also cautioned that deployment protocols must consider the stall speed of the meters, if quantitative samples were required. While this advice has been repeated more recently (e.g., Edmondson and Winberg 1971), our recent review of the fresh water literature suggests most users of plankton nets have not heeded it. If meters are used, the necessity of hauling nets at speeds exceeding the meter's stall speed have apparently been almost universally ignored.

It is our intention to remind zooplankton ecologists of the importance of the proper use of meters in their plankton hauls. We have three specific objectives:

1) to determine, by reference to the literature, whether zooplankton ecologists have accepted metered nets as the gear of choice for quantifying zooplankton abundance,

2) to demonstrate the importance of metering plankton hauls, by quantifying the seasonal and annual changes in net filtration efficiency in a single lake over a ten year period using a conventional plankton net, and

3) to demonstrate the influence of open area ratio, meter stall speeds, and attributes of the zooplankton community on estimates of net filtration efficiency.

METHODS

To estimate the proportion of users of plankton nets that calibrate their nets, we reviewed all of the zooplankton papers that were published in each of four journals between 1980 and 1991. The journals were: the Journal of Plankton Research, Limnology and Oceanography, the Canadian Journal of Fisheries and Aquatic Sciences, and Verhandlungen der Internationalen Vereinigung für Theoretische and Angewandte Limnologie. We restricted our search to papers that reported field work from freshwater lakes and quantified the abundances of crustacean zooplankton. A total of 246 studies were included in the analysis.

We documented seasonal and annual changes in the net filtration efficiency in zooplankton collections in Plastic Lake (45°11′ N, 78° 50′ N). The lake is small (A_o = 32 ha, z_{max} = 16 m), and nutrient poor (1980-1988 ice-free season averages of TP of 4.7 to 8.26 μg/L). It has low conductivity (21-24 μS), transparent (Secchi 6.2-7.5 m) waters (P.J. Dillon, Ontario Ministry of the Environment, Dorset, Ontario, unpubl. data), as is typical of Precambrian Shield waters. The lake has an average pH of 5.6 to 5.8, having been influenced by the deposition of strong acid from the atmosphere (Dillon *et al.* 1987). Additional attributes of the water chemistry and zooplankton communities of the lake are described by Dillon *et al.* (1987) and Yan *et al.* (1989), respectively.

We collected zooplankton from the lake twice each month in vertical hauls through 15 m at the deepest location in the lake during the ice-free seasons of 1980 to 1989. The hauls were taken with what we will henceforth call the DRC (Dorset Research Centre) zooplankton net. This was constructed from the 12.2 cm diameter meter impeller of a Clarke-Bumpus sampler (WILDCO Wildlife Supply Co. Catalog No. 39) to which either a 76 μm nitex or 80 μm polyester mesh, 75 cm long conical tow net was attached. The impeller was outfitted with a rotary ratchet drive, flange case, uni-directional counter (model number 746125 001 YP07M, Veeder-Root Co, Digital System Division). This drive permits uni-directional counting, but it has a higher stall speed than the conventional Clarke-Bumpus sampler. The open area ratio of the DRC net (porosity*filtration area/mouth area) was a respectable 4.4. The net was outfitted with a WILDO Wildlife Company Model No. 40B plankton bucket.

On each visit to the lake the net was hauled by hand as rapidly and smoothly as possible (>0.75 m/sec) from 15 m to the surface, first with the net attached, and, subsequently, removed. The filtration efficiency was calculated as the ratio of the two total counts. Samples were collected at the same station, using the same protocol under the direction of the same crew chief for the entire decade.

Seasonal and longer term trends in variability in the filtration efficiency data were described using the seasonally detrended, robust locally-weighted regression methodology of Bodo (1989), with a 12 point smooth to detect long term trend.

We examined the influence of net design, haul speed and zooplankton community composition on apparent filtration efficiency in an experiment conducted in Plastic Lake and Harp Lake in 1990. These lakes were chosen because we thought their dominant zooplankton would have differing tendencies to clog nets. The gelatin-sheathed *Holopedium gibberum* dominates the zooplankton of Plastic Lake (Yan *et al.* 1989). Further, filamentous algae are often abundant in the plankton of the lake (Yan *et al.* 1989). In contrast, the zooplankton of Harp Lake is dominated by *Daphnia* and copepods (Hitchin and Yan 1983), which we expected to have less capacity to clog the nets.

Harp Lake is larger than Plastic Lake (A_o = 71 ha, z_{max} = 37 m). Like Plastic Lake, it is nutrient poor (ice-free averages of TP ranging from 6.8 to 8.9 μg/L), and has low conductivity (32.7 to 35.4 μS), transparent (Secchi = 3.5 to 4.5 m) waters (Dillon *et al.* 1991, Dillon *et al.* 1987 and unpublished data).

The haul speeds in the experiment were chosen to represent a range commonly used by other investigators (nominally, 0.33, 0.67 and 1.00 m/sec). The three nets had 12.2 cm diameter mouths and were newly constructed of 80 μm polyester mesh with a porosity of 39%. The nets ranged in length from 75 to 105 to 135 cm. The accompanying open area ratios were 4.4, 6.5 and 8.5, respectively. For each lake, by gear by haul speed combination, quadruplicate fully randomized hauls were taken over 12 m depths in August of 1990. Haul speed was calculated for each timed tow. Apparent filtration efficiency was calculated from the observed DRC net impeller counts recorded with the empty impeller frame and with attached nets. We use the term "apparent" in recognition of the possibility that estimated filtration efficiency may be invalid if haul speeds fall below the stall speed of the meter for the particular net design and clogging attributes of the plankton community are high. The resulting data were analyzed using balanced two and three way ANOVA models.

To characterize the zooplankton community composition in Harp and Plastic Lakes during the experiment, we collected morphometrically-weighted composite samples using a DRC zooplankton net equipped with 80 μm mesh, using the methods of Girard and Reid (1990). Because our primary interest was in a taxonomy that related to the clogging of nets, we identified only 5 taxa in the subsequent enumerations - nauplii, copepodids, *Daphnia* spp., *Holopedium gibberum*, and other Cladocera. Filamentous algae and colonial rotifers were rare in these samples.

We determined the approximate stall speeds of the DRC zooplankton net meter impeller and the Rigosha & Co. model 5771-A flow meter. The DRC impeller testing was performed in Plastic and Harp Lakes and in Lake of Bays, the Rigosha meter testing in Lake of Bays alone. In each case, the meter (without net) was hauled vertically, by hand as smoothly as possible, through either 10 or 12 m, at various timed rates. Total counts were divided by haul lengths, and the resultant standardized counts were plotted against haul speed.

RESULTS AND DISCUSSION

Six major zooplankton sampling gear types were identified in the literature search. By far the most numerous category (53%) was plankton net. The proportion of net users did not change over the 1980 to 1991 data set (Fig. 1A). Only 30 of the 129 studies employing plankton nets reported the use of metering equipment. This proportion (23%) also did not change over time (Fig. 1B). Assuming the journals we searched reflect the behaviour of freshwater zooplankton ecologists in general, we conclude that many zooplankton researchers do not recognize the importance of metering their plankton hauls. As we will show, this is likely to produce significant biases or imprecision in estimates of zooplankton abundance.

The filtration efficiency of the 133 zooplankton hauls taken in Plastic Lake ranged from 32-100%, with a grand mean of 76% (Fig. 2a). There were substantial differences among years (Fig. 2b). The robust locally-weighted regression analysis also detected a non-trivial contribution (8% of the total) of seasonality to the total variance in the filtration efficiency data (Fig. 2c), but about half of the variance (52%) could not be attributed to either seasonality or trend in the 12 point smooth. Clearly, calculated sample volumes, and resultant estimates of zooplankton abundance would have been substantially different if filtration efficiency had not been determined for each haul.

It is not our intent to suggest that net filtration efficiency is equally variable in other lakes. However, Plastic Lake is an oligotrophic lake, and we did use a plankton net with a respectable open area ratio of 4.4. We suggest that other investigators consider the design of their nets, particularly the open area ratios, the frequency of net maintenance, the volumes of lake water they filter, and the density and composition of their plankton communities to decide whether variance in filtration efficiency might be a concern. Our review of the literature suggests that such factors are not often considered (Fig. 1).

We investigated the effect of zooplankton community composition, net design and hauling speed on filtration efficiency by experiment in Plastic and Harp Lakes. In both lakes there was a strong, significant effect ($p<0.001$) of haul speed on apparent filtration efficiency (Table 1, Figs. 3 and 4). We attribute this to the propensity of the DRC net to stall at haul speeds less than about 0.75 m/sec (Fig. 5a). There was a significant effect of net length on apparent filtration efficiency in Plastic Lake but not in Harp Lake (Table 1, Figs. 3 and 4). We attribute this to the higher clogging capacity of the net plankton of Plastic Lake on the day of the experiment. *H. gibberum* was 46 times more abundant in Plastic Lake than in Harp Lake during the experiment (Table 2).

The Rigosha meter had a lower stall speed (about 0.5 m/sec, Fig. 5b) than the DRC impeller. In consequence, it can provide accurate estimates of filtration efficiency at somewhat lower haul speeds than can the DRC net.

Virtually all of the conceptual content of this note was first published by Yentsch and Duxbury in 1956. Despite this, it is clear that students of zooplankton ecology rarely meter their plankton hauls or pay much attention to the filtration efficiency of their nets. The great variability in measured filtration efficiency we have documented in Plastic Lake over the decade of the 1980s makes the importance of measuring filtration efficiency obvious. If you wish to quantify zooplankton abundance using net-derived collections, the actual lake water volume sampled must be known precisely. Investigators wishing to meter their plankton hauls must first determine the stall speed of their chosen meters, then confirm adequate meter performance as part of routine QA/QC protocols. In doing so they must recognize that both net design and the abundance and composition of the zooplankton communities of study lakes will influence meter performance, and consequent estimates of filtration efficiency and water volumes sampled.

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Table 1 Probability summary from an ANOVA analysis of the effects on apparent net filtration efficiency of changes in haul speed, net length, and test lake. Significant (alpha = 0.05) results are noted with an asterisk.

Lake	Treatment	Probability
Plastic	Haul speed	0.001*
	Net length	0.043*
	Net x Speed	0.078
Harp	Haul Speed	0.022*
	Net Length	0.671
	Net x Speed	0.524
Both Lakes	Lake	0.689
	Haul speed	<0.001*
	Net Length	0.474
	All interactions	>0.050

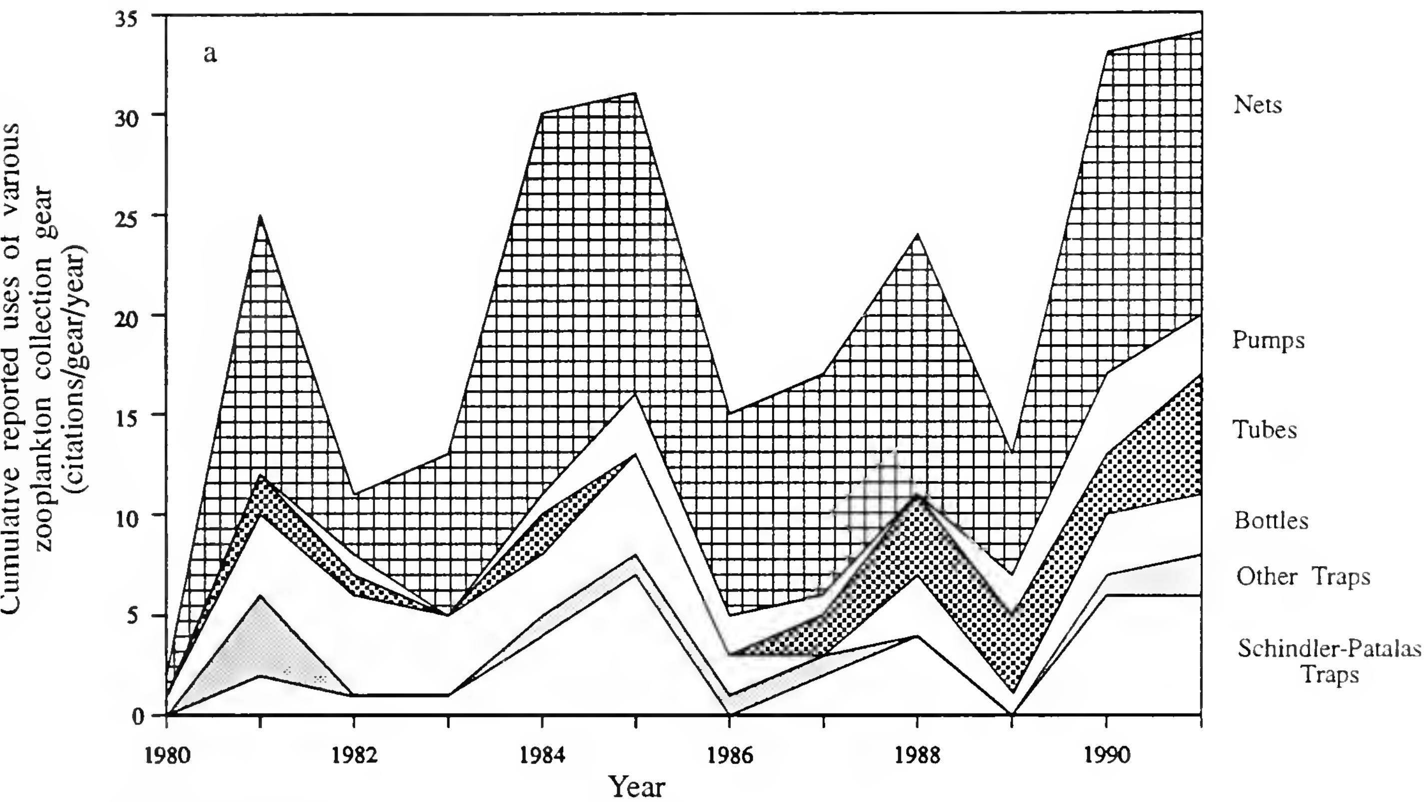
Table 2 Abundance (#/L) of selected zooplankton taxa in Harp and Plastic Lakes on the day of the net filtration experiment.

Taxon	Plastic	Harp
nauplii	31.75	28.04
copepodids	32.88	45.18
Daphnia spp.	0.47	0.19
Holopedium gibberum	2.26	0.05
bosminids and *Diaphanosoma*	3.1	19.5

Fig. 1 Summary of the literature search of fresh water zooplankton collection methodology

a) cumulative reported uses of each of six gear types.

b) the proportion of studies using nets that reported using meters in the nets.



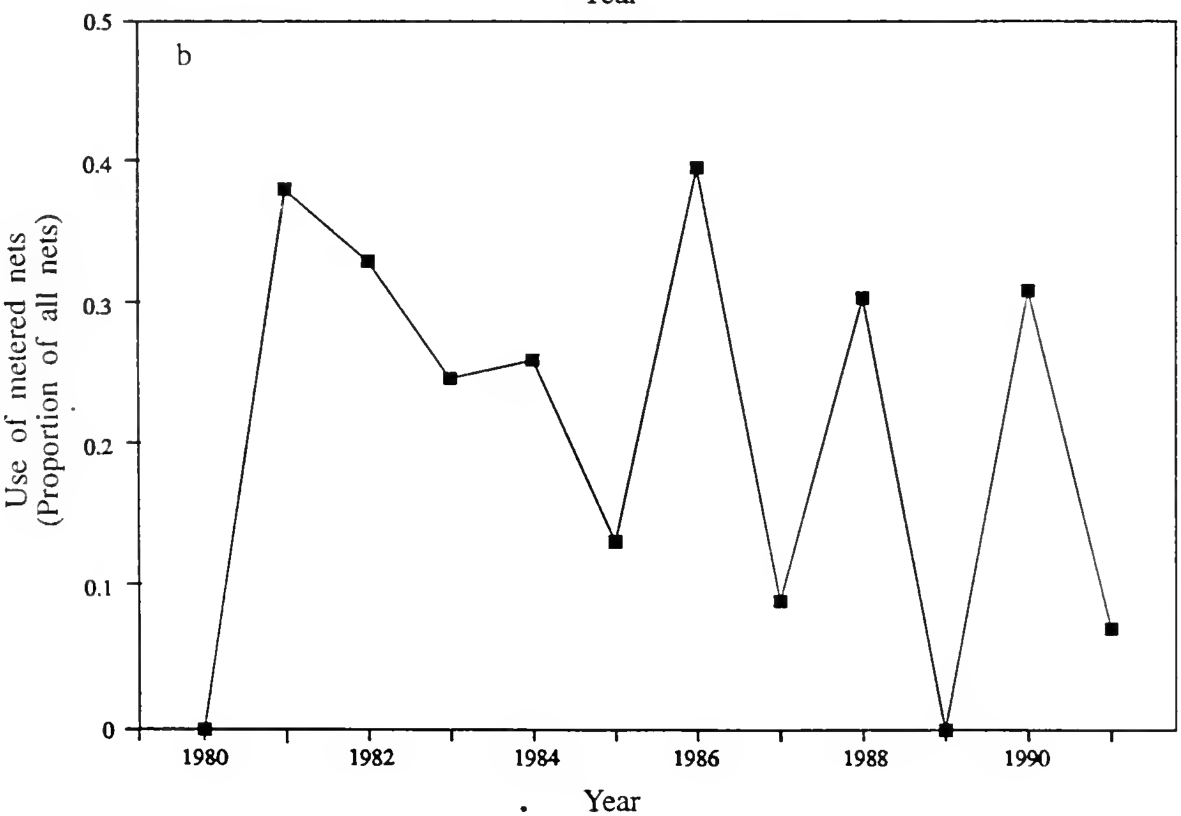


Fig. 2 a) Changes in zooplankton net filtration efficiency in Plastic Lake, 1980-1989.

b) Box plots (median, quartiles and range) of distribution of filtration efficiency within each year in Plastic Lake.

c) Modelled seasonal trend in median (with quartiles) filtration efficiency of plankton hauls in Plastic Lake calculated by robust locally-weighted regression analysis with a 12 point smooth.

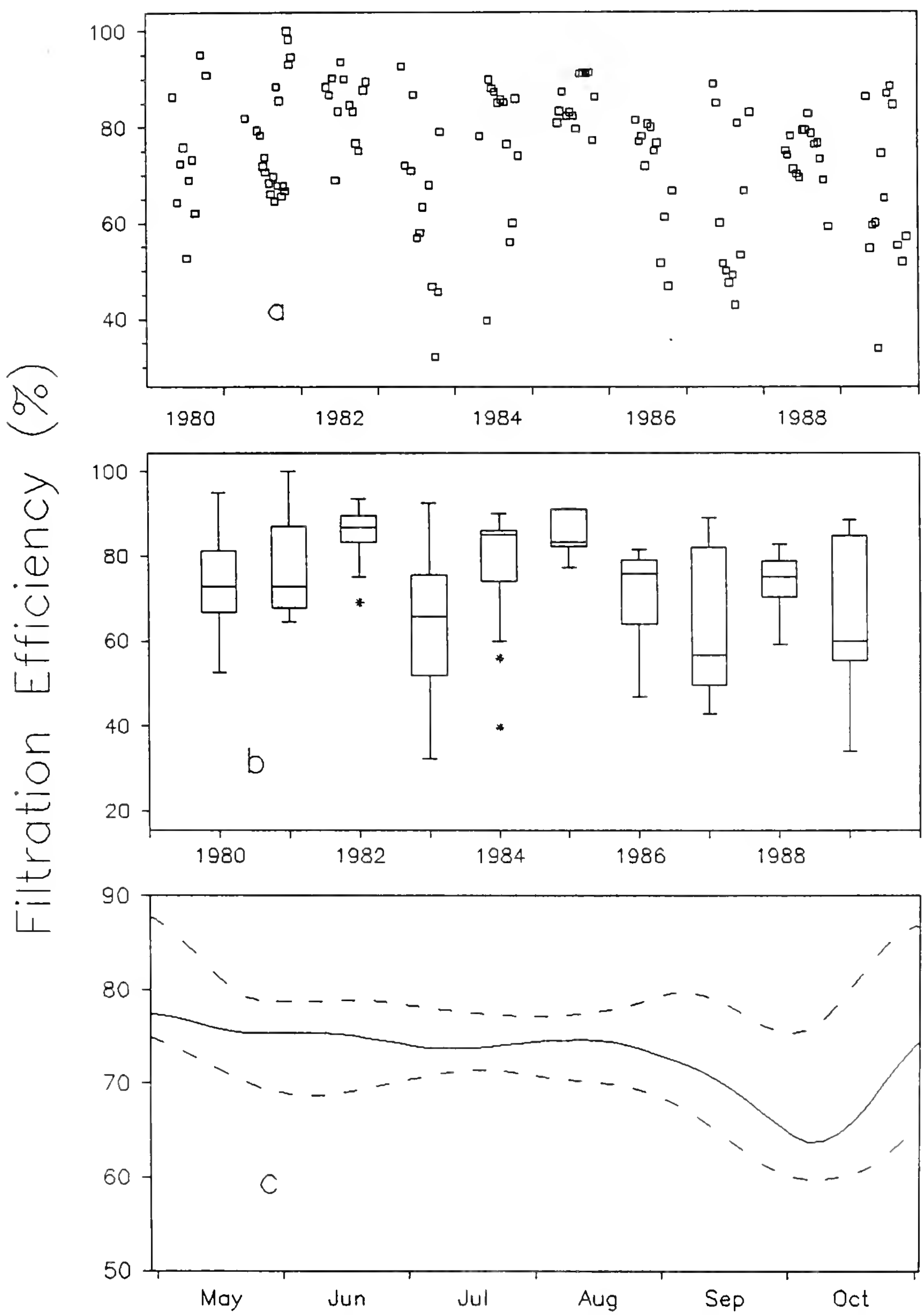
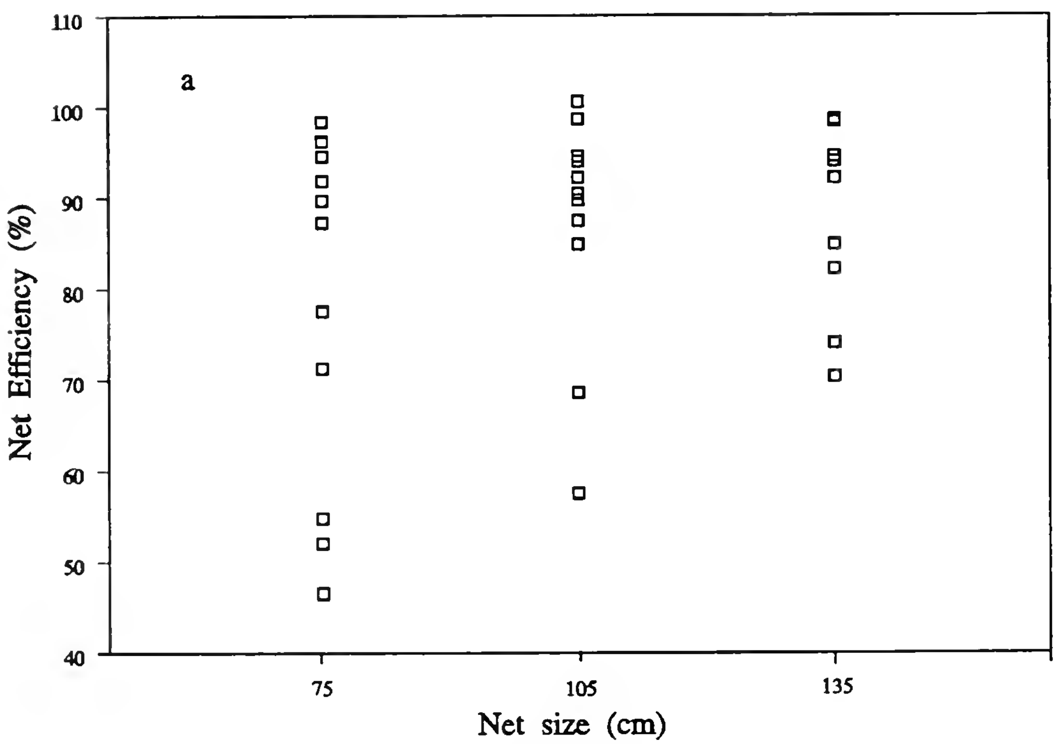


Fig. 3 Experimental results for Plastic Lake

a) Apparent filtration efficiency of metered plankton nets with respect to net length.

b) Apparent filtration efficiency of metered plankton nets with respect to haul speed.



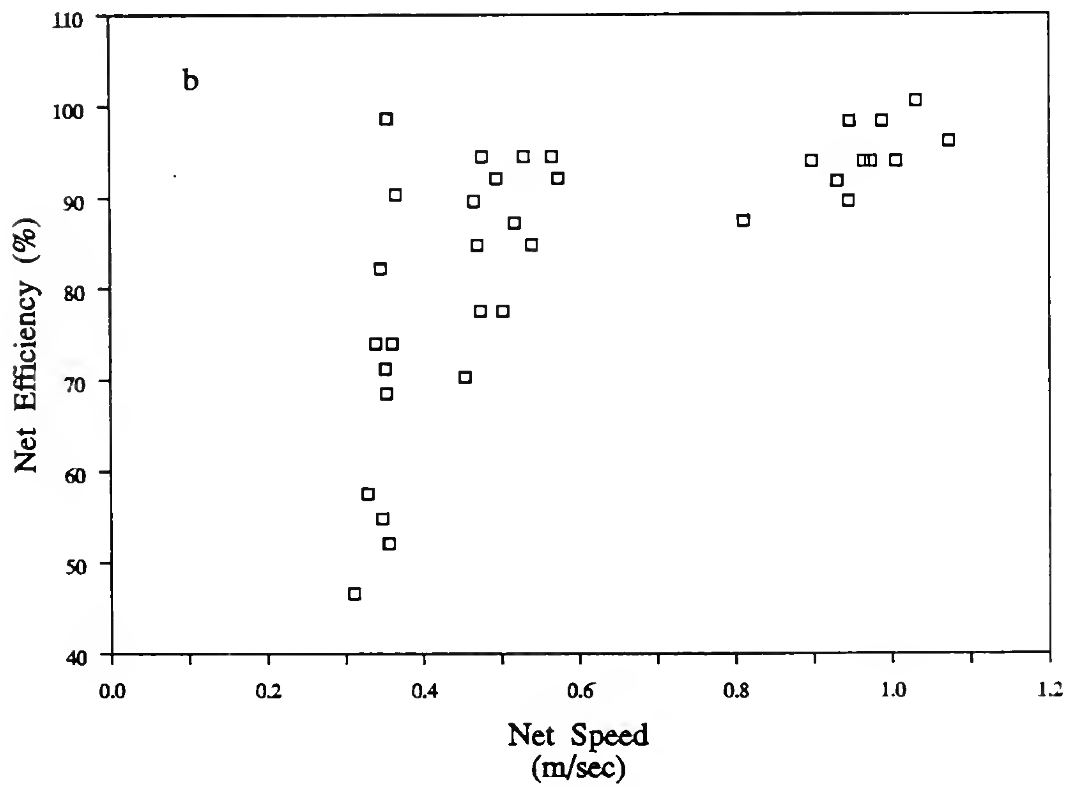


Fig. 4 Experimental results for Harp Lake

a) Apparent filtration efficiency of metered plankton nets with respect to net length.

b) Apparent filtration efficiency of metered plankton nets with respect to haul speed.

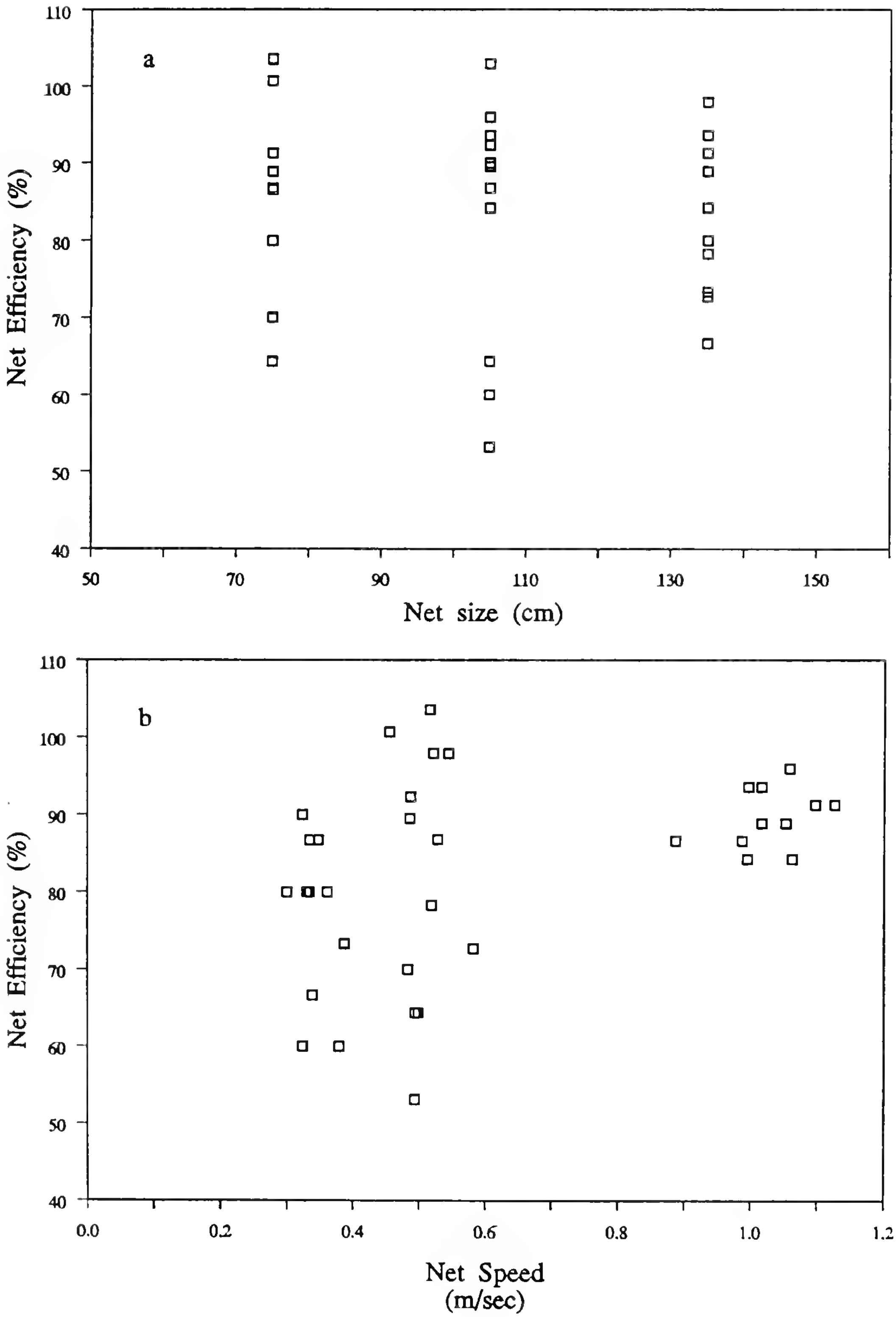


Fig. 5 Relationship between recorded standardized counts (revolutions/m) of plankton meters in hand-pulled, timed vertical hauls and haul speed

a) for a DRC plankton net impeller in 12 m vertical hauls in Plastic and Harp Lakes, and in Lake of Bays, another oligotrophic lake in the region.

b) for a Rigosha & Co. Ltd. model 5571-A zooplankton flow meter, in Lake of Bays.