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Zdzisław KAJAK

# ANALYSIS OF QUANTITATIVE BENTHIC METHODS*

The work gives informations how large samples and series and how often shoud be taken in concrete field situations, to obtain maximal credibility (in estimating quantity of organisms and number of species), and maximal effetiveness; besides the work informs when particular care would be preserved in benthic methods.

In many cases, particulary when the abundance of organisms was law and number of samples was small, great mistakes may occur in estimating the number of fauna; even the use of statistical methods (error of arithmetic mean) does not prevent the occurrence of such mistakes.

When there are great abundances of organisms and the numbers of samples are not very small, small surface samplers yield results no worse than those obtained with large surface samplers and save us much time and labour.

## INTRODUCTION

The methods used in ecological field work, which would also include work on benthos, is of prime importance for the reliability of the conclusions in each investigation. Thus far there has been insufficient work done in elaborating problems concerning methods. The procedures most frequently employed have evolved as a result of general custom, intuition, etcetera (amount of time needed for taking samples or working on them), and are not based on any scientifically established method. This applies not only to benthic methods but is typical of ecological research generally (Tarwid 1956). In the overwhelming majority of cases investigators simply do not concern themselves with the question of the reliability of the materials but tacitly assume their great reliability. For example frequently very scanty material taken from one station is considered to be representative of the entire reservoir and then the arithmetic mean is calculated

* From Institue of Ecology Polish Academy of Sciences, Warszawa.

and carried over by several decimal points what creates an impression of great accuracy. This was pointed out by Lenz (1955), who sharply criticised this procedure.

While a great number of papers have treated the devices in new apparatus and their improvement (for review of apparatus and references see Welch 1948, Żadin 1956 and others), there have been practically no papers in the field of benthos research dealing with the reliability of the material, size of the sample and series, and the distribution of samples. The need for such investigation has taken on greater urgency with the coming into general use of small surface dredges such as the 100 cm$^2$ Ekman dredge, or Morduchaj-Boltowski sampler, and various types of tubular samplers ranging from a few to several score square centimetres (Czernowski 1938, Ułomski 1952, Szczepański 1953, Overbeck 1957, Lenz 1955, Sander 1957, Mundie 1957, Kajak 1958 and others).

The great number of materials which are obtained when working with a large sample is frequently the factor which hampers progress in research. This has been pointed out, among others, by Romaniszyn (1954) in a reference to research on littoral. The tendency to reduce the size of the sample is thus a consequence of this and not of any methodical research. Nevertheless the question of the reliability of the material is dealt with in a marginal way by a number of investigators. This fact is undeniable proof that the importance of these questions is felt and understood. Yet their resolution in field work, as noted above, is determined by general custom, time possibilities, and the availability of apparatus.

The number of samples to be taken is generally decided arbitrarily. Samples taken with a 225 to 250 cm$^2$ Ekman dredge usually range from one to ten and most often they are either three or four; those taken with tubular samplers range from several to about fifty.

Żadin (1956) suggests taking four samples with an Ekman dredge at one station. Welch (1948) leaves the decision to the investigator, cautioning however that a single sample has little if any value in arriving at any estimate of the number of organisms.

A survey of the works on the question of the reliability of benthic materials discloses a great variety of opinions, probably arrived at on the basis of the experience of the given worker, his method of gathering materials, etcetera.

Lenz (1951, 1955) approaches the question in a very rigorous fashion, holding that many of the papers on benthos are practically worthless because of the scantiness of the material. On the other hand, Lundbeck (1926) for example, who began by working with a larger series (as many as ten samples) later limited himself to a very few samples per series maintaining that this was quite sufficient. Deevey (1941) defended the reliability of single samples taken with the Ekman dredge when there were sufficiently large quantities of benthos. Berg (1938) in analyzing the problem of the reliability of the material in Lake Esrom and Lake Tjustrup came to a quite clear conclusion that double samples (joined two samples taken with Ekman dredge) provided more satisfactory results than single samples; a similar opinion was advanced by Lang (1931). It appeared however that certain double samples also demonstrated great differences in the quantity of organisms making it therefore advisable to take a series of such samples. One would undoubtedly have to agree with Berg (1938) that double samples have greater validity than single samples because of the greater quantity of material; however the two single samples which are the component of the double sample would give the same mean value thereby permitting an estimate of the dispersion of the organisms.

From the above it is clear that Berg limited the problem of the size of the series of samples to the total quantity of the gathered material. Mundie (1957) and Deevey (1941) took a similar approach in their theoretical considerations of this problem. These authors came to the conclusion that when the space dispersion of the animals agrees with the Poisson distribution the reliability of the quantitative data depends on the number of caught individuals; the smaller apparatus the more samples should be taken in order to obtain this number.

On the other hand, many authors point to the uneven space distribution of benthos (Lundbeck 1926, Rzóska 1935, Lenz 1951, 1955, Tebo 1955) and, in this connection, to the necessity of 1) taking a greater number of samples (not only the total number of materials) and 2) distributing them according to the extent and differentiation of the given zone. In this connection Lenz (1955) points out that in certain situations a greater number of samples taken with a small apparatus can give a better estimate than a few large samples. Small samples save time thereby permitting an estimate of the dispersion of the organisms in the area. All these matters, like the question of the superiority of a greater number of smaller samples over a few large samples in connection with the environmental differentiation was already dealt with by Beklemiszew (1931).

Some authors point out that the quantity of organisms has a bearing on the reliability of the obtained results (Deevey 1951, Lundbeck 1926). Vollenweider (1949) demonstrated the importance of this question in his work on plankton material. Beklemiszew (1931) had also called attention to this question, pointing out that an error in the estimation of quantity can be reduced by increasing the size of the sample (and thereby the quantity of organisms in one sample), or the number of samples.

Ułomski (1952) in comparing the results of 20 to 50 sample series taken with pneumatic tubular sampler devised by himself with the results of one or two samples taken with the Peterson dredge, found that with his sampler it is possible as a rule to obtain a several times greater number of organisms; in that case however the difference was probably due to the different operation of the apparatus (in many environments Peterson's dredge does not work in a strictly quantitative fashion) and not to the differences in the size and number of samples.

Recently Longhurst (1957) demonstrated on marine benthos materials that in the environment which he investigated several large samples (0.1 m² each) provided reliable materials when considered from the point of view of estimating the general abundance of the fauna as well as the abundance of the species numbering many individuals.

In some of the mentioned works, the authors draw conclusions as to the reliability of their materials or as to the necessary number of samples for obtaining the required reliability, on the basis of their statistical estimates (Mundie 1955, Tebo 1955, Vollenweider 1949). Properly evaluating the usefulness of statistical methods, it would be worthwhile to consider whether they are quite sufficient.

Some reservations seem to be occasioned by the following things:

1. Statistical methods require large numbers of samples, which are frequently not possible to obtain during the field investigations. It is therefore essential to test to what extent they are suitable when dealing with a small number of materials.

2. The most frequently used index – standard error of arithmetic mean – is employed, strictly speaking, in the case of normal distribution and this does not by any means always occur in the materials. In field investigations, when we obtain the materials (and even when we work on them, if the material is not numerous) we often do not know the type of distribution we are dealing with.

3. The investigated environment may differ in different places. Therefore it is essential to keep this in mind when estimating the distribution, because it is frequently unknown at the time the sampling is being done. It is of course desirable to take the samples in a uniform environment, but generally this can only be confirmed after the material has been worked on and only in instances where there are a large number of samples and the suitable distribution. Vollenweider (1949) who worked on plankton materials, where one may expect to find a greater uniformity in distribution of organisms than may be found in benthos, showed a great differentiation within the given series; the error in the small series being a part of the large one could be smaller than in the entire large series. Diaczenko (1960) also pointed to the great differentiation among the plankton samples.

Nor can we forget that statistical theories generally deal with numbers of abiotic materials whereas the biologist in his field work generally deals with live material about which the unforeseen eventuality can never be predicted.

4. The decision on the size, number and distribution, of the samples must be made at the latest at the moment of taking the material, that is, at the moment when one still cannot apply statistical criteria, and yet it is really the character of the material which decides to a great degree the possibilities of obtaining good results.

Besides, the real situation must be taken into account: In most of the work on benthos statistical evaluation of the materials is not employed and in this connection it would be useful to indicate criteria which are not based on statistics.

As indicated above, the relatively few works dealing with the question of the reliability of data are based on a small number of materials, which the authors have taken for the basic purposes of their investigations. There appears to be a complete lack of original publications devoted to the question of quantitative benthic methods which are based on a large number of materials. In addition, the majority of comments in the various works on the question of methods deals with conditions which are not precisely formulated, although Lenz (1955) has correctly pointed out that methods should be applied to the specific circumstances; one cannot speak about universal methods.

In this work I have attempted to make an analysis of several problems concerning benthic methods. I shall attempt to demonstrate which methods under which circumstances supply the most objective picture.

The greatest emphasis will be placed on the size of the samples and the series in various situations, that is, with a different abundance of organisms in diverse kinds of environments, and finally, with respect to various taxonomic groups. I shall also call attention to the question of the unevenness of distribution of organisms in the given environment. In each of the above mentioned matters Ishall be dealing with two aspects: estimates of the number of organisms and estimates of the numbers of species. I shall consider these problems on the basis of large materials which are not usually taken, even in works where authors do deal with the question of reliability of materials in some fashion.

In my analysis I shall employ both empirical and statistical methods to find a criterion for choosing the proper methods at the moment of taking the materials and not only after they have been taken and analyzed.

For statistical purposes a large amount of materials are required; I shall attempt to establish empirically whether statistical criteria can be applied to a small number of samples which are most frequently the types of samples taken in field work.

I shall also deal with the question of temporal changes in abundance during one or several years, and in connection with this, the question of the required frequency of sampling to obtain the truest possible picture of benthos in the given environment.

Lastly, I shall devote some space to an analysis of technical questions (mesh gauge and sieving time) connected with the taking of samples and how they effect the estimate of the abundance of organisms.

## I. MATERIAL AND METHODS

For purposes of analysis we used 920 samples taken with the Ekman dredge, 3440 samples taken with the 10 cm$^2$ tubular sampler and 100 samples taken with 5 cm$^2$ tubular sampler – all taken from lakes and ox-bow lakes. This material consists of:

1) Series of samples taken from a relatively uniform, about 2000 m² environment of a section of the ox-bow lake, Konfederatka (Fig. 1) with a muddy bottom and depth of about 1 m. Samples were taken twice (at very high and at quite low abundance of *Tendipedidae*). Each time the series consisted of 30 samples taken with the Ekman dredge of 225 cm² surface, 80 to 90 samples taken with the Łastoczkin-Ułomski tubular sampler of 10 cm² surface, and of 50 samples taken with a tubular sampler of the same type but of 5 cm² surface. The samples were

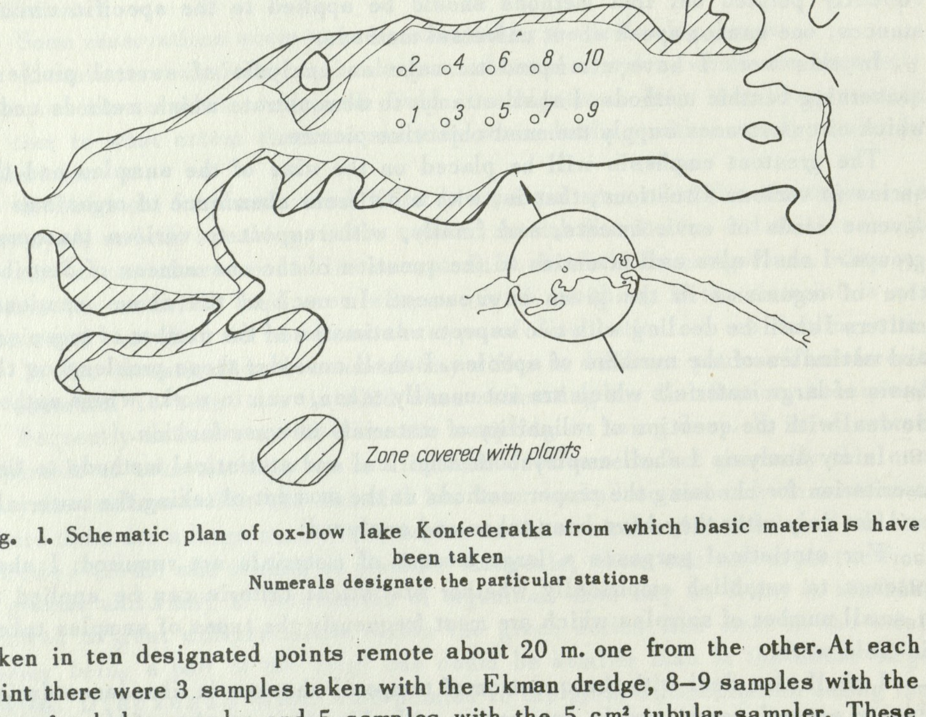


Fig. 1. Schematic plan of ox-bow lake Konfederatka from which basic materials have been taken

Numerals designate the particular stations

taken in ten designated points remote about 20 m. one from the other. At each point there were 3 samples taken with the Ekman dredge, 8–9 samples with the 10 cm² tubular sampler and 5 samples with the 5 cm² tubular sampler. These samples we have considered as our basic materials in this work.

2) Materials from the different reservoirs:

a. Ekman dredge series:

17 series of 8–30 samples taken from the ox-bow lake Konfederatka and from lakes: Śniardwy, Tajty, and Mikołajskie;

122 series of 5 samples taken in the profundal of 35 Mazurian lakes

b. Series with 10 cm² tubular sampler:

11 series of 50 samples from the littoral of Lake Tajty and Lake Grajewko,

11 series of 50 samples from the sublittoral of Lake Tajty and Lake Grajewko,

13 series of 50 samples and 26 series of 40 samples from the profundal of Lake Tajty and Lake Grajewko,

12 series of 16 samples and 12 series of 10 samples from the profundal of Lake Tajty Długie,

10 series of 10 samples from the littoral and 17 series of 10 samples from the sublittoral of Lake Tajty.

The chief purpose of these data was to check whether the results obtained from the basic materials are representative under different conditions.

Apart from this we have based ourselves on certain reference materials.

Our analysis has been concentrated chiefly on basic forms of stagnant water benthos: *Tendipedidae*, *Oligochaeta* and *Chaoborus*. The basic material contained about 7600 *Tendipedidae*, 38.000 *Oligochaeta* and 350 *Heleidae* individuals. All the materials together contained about 13.000 *Tendipedidae*, 44.000 *Oligochaeta*, 8.000 *Chaoborus*, 900 *Mollusca* and 350 *Heleidae* individuals.

The *Tendipedidae* in all the materials were classified according to the species. The decidedly predominant *Tendipedidae* in the basic materials were *Tendipes plumosus* (L.) and *Pelopia kraatzi* Kieff. The list of the remaining species is given in Table IV.

For greater clarity I give a list of symbols and equations used in this work:

$M$ – arithmetic mean

$m$ – mean error of arithmetic mean

$$m = \frac{1}{n(n-1)} \Sigma (x - M)^2 = \frac{1}{n(n-1)} (\Sigma x^2 - nM^2)$$

where: $n$ – number of samples in the series

$x$ – the number of individuals in the particular samples

$cV = m/M\%$ – variation coefficient of arithmetic mean

$M$ max – arithmetic mean having the greatest numerical value among all means for a series of a given size and given apparatus

$M$ min – arithmetic mean having the smallest numerical value among all the means for a series of a given size and given apparatus

$M$ max/$M$ min – index of variation of the arithmetic means for a series of a given size and given apparatus.

## II. SIZE OF SERIES AND RELIABILITY OF ESTIMATES OF ABUNDANCE

### A. Differentiation of means within homogeneous material

We accepted the differentiation of the arithmetic means calculated on the basis of a large number of series within homogeneous material as one of the methods of estimating the reliability of quantitative data. This material has been obtained from two large series, each consisting of 30 samples taken with

Ekman dredge, 80–90 samples with 10 cm$^2$ tubular sampler and 50 samples with 5 cm$^2$ tubular sampler. These series were large enough to provide an adequate picture of the abundance of the analyzed benthos forms in the investigated environments; that this is so is shown by the fact that beginning with a certain number of samples in the series, the further enlargement of the series did not yield any or yielded minimal changes in the arithmetic mean (Fig. 2–4).

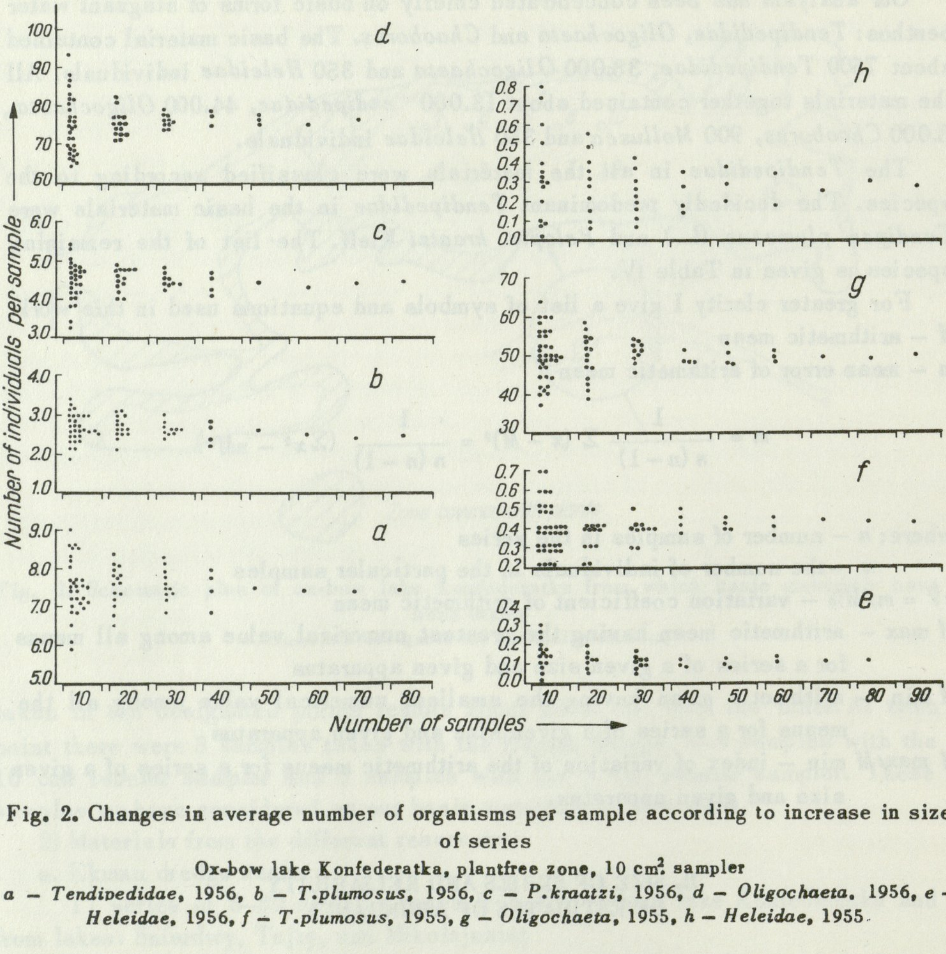


**Fig. 2. Changes in average number of organisms per sample according to increase in size of series**

**Ox-bow lake Konfederatka, plantfree zone, 10 cm$^2$ sampler**

***a – Tendipedidae*, 1956, *b – T.plumosus*, 1956, *c – P.kraatzi*, 1956, *d – Oligochaeta*, 1956, *e – Heleidae*, 1956, *f – T.plumosus*, 1955, *g – Oligochaeta*, 1955, *h – Heleidae*, 1955**

In this connection it may be accepted that any arbitrary choice of samples from this material will yield the same results as those from samples taken directly in the field.

Several variants of the series with different numbers of samples – 3, 5, 8, 10, 20 and 30 – were made up, maintaining an evenness in the special distribution of the samples, that is, the choice was such that within a given series there would be the same number of samples from different places in the invest-

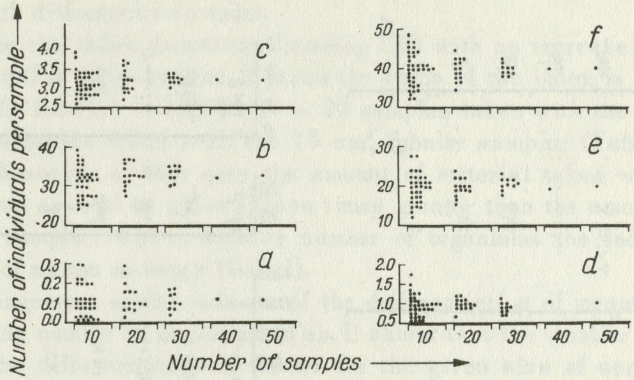


**Fig. 3. Changes in average number of organisms per sample according to increase in size of series**

**Ox-bow lake Konfederatka, plant-free zone, 5 cm² sampler**

**a – *T.plumosus*, 1955, b – *Oligochaeta*, 1955, c – *Tendipedidae*, 1956, d – *T.plumosus*, 1956, e – *P.kraatzi*, 1956, f – *Oligochaeta*, 1956.**

igated environment. In the ten-sample series – for instance – we took one sample from each of the ten places; in the three-sample series we took the first sample from one end, the second sample from the center the third from the other end of the investigated environment.

Each of the variants of a series of a given size obtained in this way could occur provided that only one such series was taken.

First I shall consider the question of the representativeness of the material on the basis of empirical criteria. The empirical indication as to the reliability of the estimate of the abundance of organisms by means of a series of a given number of samples can be the relation between the largest (Mmax) to the smallest (Mmin) arithmetic mean among all the variants of the series of a given size. For example, the material containing 90 samples taken with the 10 cm². tubular sampler were grouped in 30 variants of ten-sample series. The mean was calculated for each variant. Then we found the largest (*M*max) and smallest (*M*min) among all the means and calculated their relation (*M*max) (*M*min) which constitutes the index of differentiation of the means for the series of given size[1].

[1] It was possible to obtain a greater number of variants with the smaller series than with the larger (Tab. 1). Nevertheless, as a rule, the *M*max and *M*min, or the means very close to *M*max and *M*min for the large number of variants (e.g. thirty) were already found within the first ten variants. In this connection the differentiation of the values of the mean for the series of different size is fully comparable despite the not identical number of variants.

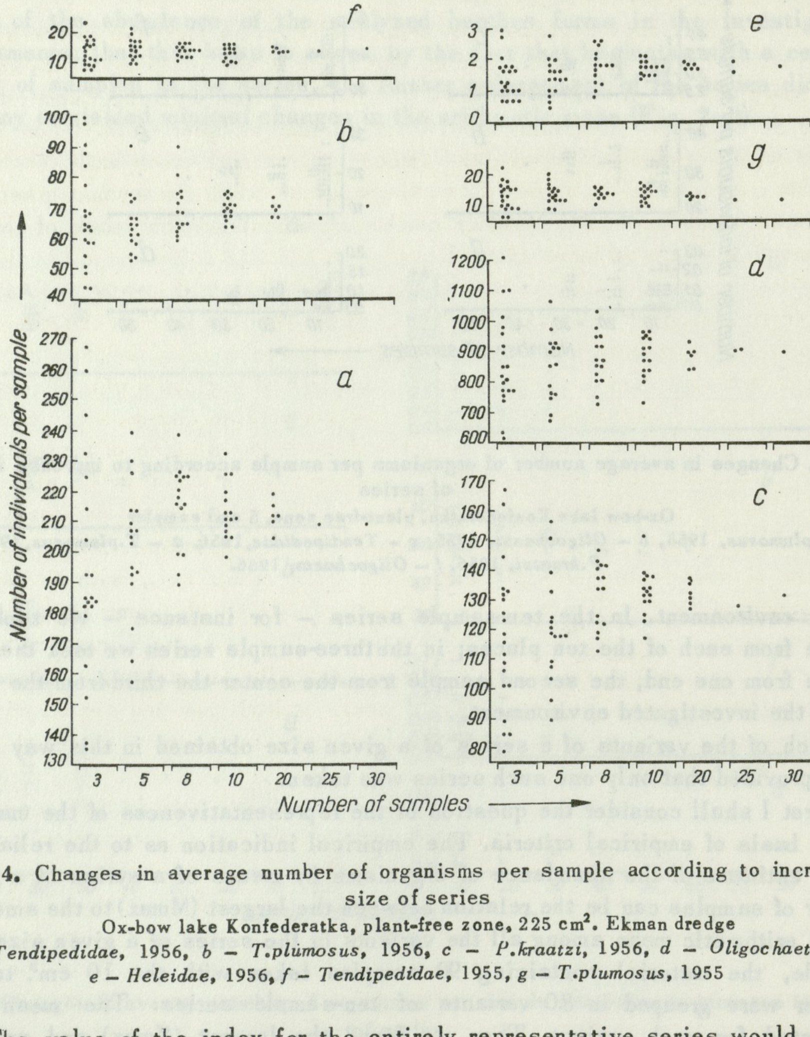


Fig. 4. Changes in average number of organisms per sample according to increase in size of series

Ox-bow lake Konfederatka, plant-free zone, 225 $cm^2$. Ekman dredge

*a* – *Tendipedidae*, 1956, *b* – *T.plumosus*, 1956, *c* – *P.kraatzi*, 1956, *d* – *Oligochaeta*, 1956, *e* – *Heleidae*, 1956, *f* – *Tendipedidae*, 1955, *g* – *T.plumosus*, 1955

The value of the index for the entirely representative series would be 1.0, because the mean for each of them would be identical. The closer the value of the index is to 1.0, the more representative, reliable, is the series of the given number of samples. The index shows the range of the possible miscalculations in estimating the abundance of organisms if one happened to take a series of given size containing the largest number of organisms and then a series containing the smallest possible number of organisms. Such a situation may occur, for example, in the investigation of the quantitative dynamics in time or of the differentiation of distribution in space. If in sampling in two different places or at two different times one accidentally strikes the *M*max and *M*min, one might conclude that there are significant differences in number when in actuality there are none (Tab. I and II), or on the contrary, that there are no differences when in actuality such differences do exist.

As a rule the index decreases (nearing 1.0) with an increase in the size of the series; with a large number of fauna the value of the index is established at approximately 1.0 (1.1 – 1.2) for 10 – 20 samples taken with the Ekman dredge and for 30 samples taken with the 10 $cm^2$ tubular sampler (Tab. I and II). In working with series of this size the amount of material taken with the Ekman dredge is from several to about fifteen times greater than the amount taken with the tubular sampler. With a smaller number of organisms the index of the differentiation of means is larger (Tab. I).

The arrangement of the indexes of the differentiation of means according to the decreasing number of organisms (Tab. I) shows that the smaller the abundance the larger the differentiation of means for the given size of series. It can be seen from a comparison of the indexes of samplers of various surfaces that with the same number of organisms per unit of bottom surface and size of series the differentiation of means increases with the decreasing surface of the apparatus (except in those cases of very great abundance when there is no significant variation in the differentiation of means with the different apparatuses). To a great degree these three factors – abundance of organisms, size of series and size of sample (apparatus) compensate each other, e.g., with a 3-sample series taken with the Ekman dredge the differentiation of means rises sharply when the abundance equals several hundred individuals per square metre; as the series size increases the differences gradually decreases; in 20-sample series the index of the differentiation of means is still low and almost constant when the abundance ranges from several score to several score thousand individuals per square metre.

With a 10 $cm^2$ tubular sampler there is also a sharp jump in the index when the abundance equals several hundred individuals per square metre and the differences also decrease with an increase in the size of the series.

The $M_{max}/M_{min}$ index tells us of the least favourable situations possible in investigating changes of abundance in time or its differentiation in space. The relation of the maximum or minimum mean for the given size of series to the mean calculated on the basis of a large number of samples, that is, the mean of unquestioned reliability, is a good proof of the reliability of the sampled material and the degree to which it represents the actual abundance of organisms in the investigated environment at a given time. This relation was calculated for the maximum mean (Tab. III) on the assumption that for the minimum mean it would be analagous. Just as in Table I, the closer the value of the index to 1.0, the more reliable is the material.

For the range of abundance from several hundred to about eighty thousand individuals per square metre, we obtained values of the index close to 1.0 (1.1 – 1.2) for 8 and more than 8-sample series taken with the Ekman dredge as well as for 20 and more than 20-sample series taken with a 10 $cm^2$ tubular sampler.

Correlation of *M*max/*M*min index with the size of series, number of organisms and size of sample

Tab. I

| Bottom sampler | Number of samples in a series | Number of series | Number of individuals per 1 m² | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 78000 *Oligochaeta* | 60000 *Oligochaeta* | 9500 *Tendipedidae* | 5900 *Pelopia kraatzi* | 3200 *Tendipes plumosus* | 630 *Tendipedidae* | 590 *Tendipes plumosus* | 80 *Heleidae* |
| Ekman 225 cm² | 3 | 20 | $\frac{1209.7}{582.0} = 2.1$ | | $\frac{267.7}{135.0} = 2.0$ | $\frac{168.0}{78.7} = 2.1$ | $\frac{99.7}{44.0} = 2.3$ | $\frac{22.7}{8.3} = 2.7$ | $\frac{22.3}{7.0} = 3.2$ | $\frac{3.0}{0.0}$ |
| | 5 | 15 | $\frac{1066.6}{677.8} = 1.6$ | | $\frac{239.2}{155.8} = 1.5$ | $\frac{157.6}{89.8} = 1.8$ | $\frac{90.6}{53.8} = 1.7$ | $\frac{21.2}{9.8} = 2.2$ | $\frac{19.8}{8.8} = 2.3$ | $\frac{2.8}{0.6} = 4.7$ |
| | 8 | 15 | $\frac{1033.6}{731.9} = 1.4$ | | $\frac{238.8}{189.3} = 1.3$ | $\frac{146.9}{113.6} = 1.3$ | $\frac{90.5}{60.0} = 1.5$ | $\frac{16.3}{11.5} = 1.4$ | $\frac{15.8}{10.6} = 1.5$ | $\frac{2.6}{0.8} = 3.3$ |
| | 10 | 15 | $\frac{970.0}{719.4} = 1.3$ | | $\frac{232.8}{196.1} = 1.2$ | $\frac{151.6}{123.0} = 1.2$ | $\frac{75.8}{64.0} = 1.2$ | $\frac{17.1}{10.7} = 1.6$ | $\frac{15.7}{9.7} = 1.6$ | $\frac{2.1}{1.4} = 1.5$ |
| | 20 | 10 | $\frac{929.4}{804.4} = 1.2$ | | $\frac{219.5}{205.1} = 1.1$ | $\frac{135.5}{128.2} = 1.1$ | $\frac{74.1}{67.5} = 1.1$ | $\frac{14.4}{13.4} = 1.1$ | $\frac{13.6}{12.6} = 1.1$ | $\frac{1.9}{1.7} = 1.1$ |
| | 30 | 1 | 859.4 | | 212.4 | 131.3 | 70.7 | 13.9 | 13.1 | 1.8 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Tubular 10 cm² | 10 | 30 | $\frac{93.1}{63.8} = 1.5$ | $\frac{60.1}{37.9} = 1.6$ | $\frac{9.0}{6.1} = 1.5$ | $\frac{5.4}{3.3} = 1.6$ | $\frac{3.4}{1.9} = 1.8$ | $\frac{0.7}{0.2} = 3.5$ | | $\frac{0.5}{0.0}$ |
| | 20 | 15 | $\frac{83.4}{71.9} = 1.2$ | $\frac{58.3}{41.7} = 1.4$ | $\frac{8.4}{6.5} = 1.3$ | $\frac{4.9}{4.0} = 1.2$ | $\frac{3.1}{2.1} = 1.5$ | $\frac{0.6}{0.2} = 2.5$ | | $\frac{0.35}{0.05} = 7.0$ |
| | 30 | 10 | $\frac{78.2}{73.1} = 1.1$ | $\frac{53.3}{45.4} = 1.2$ | $\frac{7.9}{6.5} = 1.2$ | $\frac{4.7}{3.7} = 1.3$ | $\frac{2.8}{2.2} = 1.3$ | $\frac{0.6}{0.3} = 2.0$ | | $\frac{0.30}{0.07} = 4.3$ |
| | 50 | 1 | 75.0 | 50.6 | 7.5 | 4.4 | 2.6 | 0.4 | | 0.16 |
| Tubular 5 cm² | 10 | 30 | $\frac{48.0}{34.1} = 1.4$ | $\frac{37.6}{25.4} = 1.6$ | $\frac{3.9}{2.7} = 1.4$ | $\frac{2.7}{1.3} = 2.1$ | $\frac{1.7}{0.6} = 2.8$ | $\frac{0.3}{0.0}$ | | $\frac{0.3}{0.0}$ |
| | 20 | 15 | $\frac{44.5}{37.3} = 1.2$ | $\frac{36.6}{28.1} = 1.3$ | $\frac{3.4}{2.8} = 1.2$ | $\frac{2.4}{1.7} = 1.4$ | $\frac{1.2}{0.7} = 1.7$ | $\frac{0.25}{0.0}$ | | $\frac{0.2}{0.05} = 4.0$ |
| | 30 | 10 | $\frac{43.5}{38.4} = 1.1$ | $\frac{34.6}{30.3} = 1.1$ | $\frac{3.3}{3.0} = 1.1$ | $\frac{2.3}{1.8} = 1.3$ | $\frac{1.0}{0.7} = 1.4$ | $\frac{0.17}{0.03} = 5.7$ | | $\frac{0.2}{0.07} = 3.0$ |
| | 50 | 1 | 39.1 | 32.5 | 3.1 | 1.9 | 1.0 | 0.13 | | 0.1 |

Ox-bow lake Konfederatka
Numerator-*M*max.
Denominator-*M*min.
Quotient – *M*max/*M*min – index of differentiation of arithmetic means

Correlation of index of differentiation of arithmetic means with size of series

Tab. II

| No. of samples in series | No. of series | Differentiation of means |
|---|---|---|
| 3 | 20 | $\frac{11.3}{4.3} = 2.6$ |
| 5 | 20 | $\frac{9.0}{5.4} = 1.7$ |
| 10 | 15 | $\frac{8.7}{6.0} = 1.3$ |

Lake Śniardwy, depth of 7 m., *Tendipes plumosus* – 337 ind./1 m², 7·6 ind. per sample, Ekman dredge
*M*max – Numerator
*M*min – Denominator
Quotient – *M*max/*M*min – Index of differentiation of means

Even if the number of organisms was very small – below one hundred individuals per square metre – for all considered sizes of Ekman dredge and for 20 or more tubular samples, the values of the index did not exceed (or exceeded to a minimal degree) 2.0; thus the material while not providing an exact number, indicates the approximate level of abundance.

The series of 50 samples taken with the 10 cm² tubular sampler gives reliable data even if the number of organisms is quite small (several hundred individuals per square metre); there are no essential changes in the values of the mean when the size of the series increases (Fig. 2). The differences of the means between the 50-sample series and the 70- to 90-sample series are not greater than 4%. For the 20- to 30-sample series taken with the Ekman dredge, these differences are of the same level or greater (Tab. I, Fig. 4) – up to 10%.

Even with a very small number of organisms-several dozen per square metre – the 50-sample series taken with a tubular sampler provides a fairly good indication of the abundance of organisms (Tab. IV).

Of course, with tubular samplers of small surface it is not possible to estimate the abundance of very large organisms such as *Unionidae*, because these organisms are generally too large to fit into the apparatus.

Since it sometimes happens that one takes samples singly, particularly with large samplers, we make a comparison of the number of organisms in the richest and in the poorest samples within the relatively large series taken with the Ekman dredge and with the 10 cm² tubular sampler (Tab. V).

In one of these samples the abundance of organisms could be several times and even sometimes more than twenty times greater than the abundance in another sample. A similar range of fluctuation of abundance in the particular samples was also demonstrated by other authors (Berg 1938, Allen 1949).

The relation of the mean with the greatest numerical value (*M*max) in all the variants of the given series size and taxonomic group to the mean calculated of the basis of all the samples taken with the given apparatus, according to the size of the series and size of the sample taken, and to the number of organisms

Tab. III

| Bottom sampler | No. of samples in series | No. of individuals per 1 sq. m. | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 78000 *Oligochaeta* | 60000 *Oligochaeta* | 9500 *Tendipedidae* | 5900 *Pelopia kraatzi* | 3200 *Tendipes plumosus* | 630 *Tendipedidae* | 590 *Tendipes plumosus* | 80 *Hekeidae* |
| Ekman | 3 | 1.41 | | 1.26 | 1.28 | 1.41 | 1.63 | 1.70 | 1.73 |
| | 5 | 1.20 | | 1.13 | 1.20 | 1.28 | 1.53 | 1.51 | 1.56 |
| | 8 | 1.16 | | 1.12 | 1.12 | 1.28 | 1.17 | 1.21 | 1.50 |
| | 10 | 1.13 | | 1.10 | 1.16 | 1.07 | 1.23 | 1.20 | 1.21 |
| | 20 | 1.08 | | 1.03 | 1.03 | 1.05 | 1.04 | 1.04 | 1.10 |
| 10 cm² tubular | 10 | 1.24 | 1.19 | 1.20 | 1.23 | 1.31 | 1.50 | | 3.13 |
| | 20 | 1.11 | 1.15 | 1.12 | 1.11 | 1.19 | 1.25 | | 2.19 |
| | 30 | 1.04 | 1.13 | 1.07 | 1.08 | 1.11 | 1.19 | | 2.15 |
| 5 cm² tubular | 10 | 1.23 | 1.16 | 1.26 | 1.42 | 1.70 | 2.31 | | 3.00 |
| | 20 | 1.14 | 1.13 | 1.10 | 1.26 | 1.20 | 1.92 | | 2.00 |
| | 30 | 1.11 | 1.07 | 1.21 | 1.00 | 1.00 | 1.31 | | 2.00 |

Ox-bow lake Konfederatka 1955–1956

## B. Differentiation of errors of the arithmetic mean

The most common method employed in estimating the reliability of the arithmetic mean is to calculate its error. In order to compare the evaluation of the reliability of the materials through error and through the index of differentiation of means (*M*max/*M*min), the errors of the means for all the materials gathered in Table I were calculated. For purposes of comparison we used the coefficients of variation of means – $Cv\% = m/M\%$ – instead of the absolute values of the errors of the means (Tab. VI). The nature of the changes of the variation coefficients is analogous to the changes of the index of the differentiation of means (*M*max/*M*min); it decreases with the increase in the size of the series and with the growth in the number of organisms. In the latter case the correlation is not however a simple one. Errors are relatively too great for *Oligochaeta* and

Changes in average number of organisms per sample according to series size, when the number of organisms is very small
10 cm² tubular sampler. Ox-bow lake Konfederatka, 1955–1956

Tab. IV

| No. of samples in a series | *Heleidae* | *Tendipes thummi* Kieff. | *Procladius Skuse* | *Polypedilum nubeculosum* (Meig.) | *Cryptochironomus defectus* (Kieff.) | *Cryptochironomus conjugens* (Kieff.) | *Einfeldia carbonaria* (Meig.) | *Cryptochironomus viridulus* (Fabr.) | *Mollusca* |
|---|---|---|---|---|---|---|---|---|---|
| 50 | 0.16 | 0.10 | 0.02 | 0.02 | 0.12 | 0.10 | 0.00 | 0.02 | 0.04 |
| 80 | 0.13 | 0.10 | 0.06 | 0.02 | 0.10 | 0.11 | 0.02 | 0.01 | 0.03 |

Differences in number of organisms between the most and the least abundant samples in the given series

Tab. V

| Bottom sampler | No. of samples in a series | No. of individuals per sample | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Ox-bow lake Konfederatka, plant-free zone | | | | | | | | |
| 225 cm² Ekman dredge | 10 | $\frac{62}{32}$ *T.p.* | $\frac{42}{10}$ *T.p.* | $\frac{35}{5}$ *T.p.* | $\frac{49}{14}$ *V.p.* | $\frac{30}{10}$ *V.p.* | | | | |
| | 14 | $\frac{49}{6}$ *T.p.* | $\frac{32}{10}$ *V.p.* | | | | | | | |
| | 30 | $\frac{1625}{305}$ *Ol.* | $\frac{366}{99}$ *T.* | $\frac{166}{19}$ *T.p.* | $\frac{204}{42}$ *P.k.* | $\frac{7}{0}$ *H.* | | | | |
| | | Lake Tajty – profundal | | | | | | | | |
| | 10 | $\frac{169}{85}$ *Ol.* | $\frac{26}{1}$ *Ol.* | $\frac{10}{0}$ *Ol.* | $\frac{29}{6}$ *Ch.* | $\frac{25}{1}$ *Ch.* | $\frac{21}{2}$ *Ch.* | $\frac{3}{0}$ *T.* | $\frac{6}{0}$ *T.* | $\frac{2}{0}$ *T.* |
| | | Lake Śniardwy – profundal | | | | | | | | |
| | 8 | $\frac{9}{5}$ *T.p.* | | | | | | | | |
| | 16 | $\frac{4}{0}$ *T.p.* | | | | | | | | |
| | 21–28 | $\frac{11}{1}$ *T.p.* | $\frac{5}{0}$ *T.p.* | $\frac{13}{3}$ *T.p.* | | | | | | |
| 10 cm² tubular sampler | | Ox-bow lake Konfederatka, plant-free zone | | | | | | | | |
| | 50 | $\frac{121}{11}$ *Ol.* | $\frac{192}{25}$ *Ol.* | $\frac{2}{0}$ *T.* | $\frac{16}{1}$ *T.* | $\frac{9}{0}$ *T.p.* | $\frac{10}{0}$ *P.k.* | | | |
| | | Lake Tajty | | | | Lake Grajewko | | | | |
| | Profoundal | | Sublittoral | Littoral | | Profundal | | Sublittoral | | |
| | 50 | $\frac{7}{0}$ *Ch.* | $\frac{6}{0}$ *T.* | $\frac{11}{0}$ *T.* | $\frac{6}{0}$ *T.* | $\frac{4}{0}$ *T.* | | $\frac{6}{0}$ *T.* | | |

Numerator – no. of individuals in the most abundant sample
Denominator – no. of individuals in the least abundant sample

*T.p.* – *Tendipes plumosus*
*V.p.* – *Valvata piscinalis*
*Ol.* – *Oligochaeta*
*H.* – *Heleidae*
*Ch.* – *Chaoborus crystallinus*
*T.* – *Tendipedidae*
*P.k.* – *Pelopia kraatzi*

Coefficients of variation of the means(m/M%)according to the size of the series, the size of the sample and the abundance of organisms

Tab. VI

| Bottom sampler | No. of samples in a series | Number of individuals per 1 sq.m. | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 78000 *Oligochaeta* | 60000 *Oligochaeta* | 9500 *Tendipedidae* | 5900 *Pelopia kraatzi* | 3200 *Tendipes plumosus* | 630 *Tendipedidae* | 590 *Tendipes plumosus* | 80 *Heleidae* |
| | | Coefficients of the variation of the means | | | | | | | |
| Ekman, 225 cm² | 3 | $\frac{41.0}{5.3}$ 20.9 | | $\frac{34.0}{7.0}$ 18.5 | $\frac{33.0}{9.0}$ 21.4 | $\frac{47.0}{9.0}$ 28.5 | $\frac{50.0}{16.2}$ 28.8 | $\frac{48.8}{16.8}$ 29.8 | $\frac{100.0}{30.0}$ 79.4 |
| | 5 | $\frac{29.0}{7.0}$ 17.3 | | $\frac{21.9}{6.0}$ 12.4 | $\frac{25.0}{9.0}$ 16.1 | $\frac{33.0}{10.0}$ 20.4 | $\frac{32.0}{15.7}$ 22.0 | $\frac{32.0}{10.3}$ 22.9 | $\frac{71.0}{10.0}$ 41.4 |
| | 8 | $\frac{15.2}{7.2}$ 11.1 | | $\frac{14.7}{5.6}$ 10.4 | $\frac{17.6}{9.0}$ 12.6 | $\frac{26.5}{11.8}$ 18.8 | $\frac{22.0}{13.0}$ 18.2 | $\frac{22.0}{16.0}$ 19.4 | $\frac{47.3}{20.0}$ 34.4 |
| | 10 | $\frac{14.0}{5.1}$ 10.4 | | $\frac{11.6}{7.7}$ 9.8 | $\frac{12.8}{8.8}$ 11.1 | $\frac{19.5}{11.4}$ 16.6 | $\frac{17.8}{14.2}$ 15.9 | $\frac{20.6}{12.1}$ 16.3 | $\frac{44.7}{27.9}$ 33.8 |
| | 20 | $\frac{8.2}{5.4}$ 7.4 | | $\frac{6.9}{6.4}$ 6.7 | $\frac{8.3}{7.0}$ 7.6 | $\frac{11.9}{9.7}$ 10.8 | $\frac{12.5}{10.4}$ 11.6 | $\frac{13.0}{10.9}$ 11.9 | $\frac{26.1}{18.4}$ 23.2 |
| | 30 | 6.3 | | 5.5 | 6.2 | 8.5 | 9.4 | 9.9 | 17.8 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Tubular 10 cm². | 10 | 23.7/9.2 16.4 | 22.0/9.0 15.7 | 20.1/6.3 12.2 | 20.0/11.1 15.1 | 26.4/9.6 19.1 | | 100.0/30.0 50.3 | 100.0/34.0 60.3 |
| | 20 | 14.2/8.8 10.9 | 13.0/8.0 11.1 | 10.3/6.3 8.7 | 13.0/7.2 10.2 | 16.8/9.6 13.6 | | 55.0/22.0 34.0 | 100.0/30.2 51.0 |
| | 30 | 10.4/7.3 9.0 | 11.6/7.4 9.4 | 9.1/5.1 6.8 | 11.0/6.6 9.4 | 14.2/9.0 11.9 | | 40.0/26.0 31.2 | 68.7/28.3 52.9 |
| | 50 | 7.0 | 7.5 | 5.5 | 6.6 | 9.0 | | 17.5 | 32.5 |
| Tubular 5 cm². | 10 | 20.4/7.2 14.3 | 30.8/7.0 16.0 | 28.3/10.9 20.3 | 37.8/15.4 27.4 | 86.7/21.0 32.5 | | 100.0/52.0 87.0 | 100.0/50.0 87.1 |
| | 20 | 12.0/8.0 10.0 | 13.6/8.6 11.5 | 17.8/10.6 14.0 | 23.7/15.5 18.8 | 26.7/17.3 22.2 | | 100.0/39.3 62.8 | 100.0/45.0 68.5 |
| | 30 | 10.0/7.1 8.5 | 9.7/6.0 8.7 | 13.4/9.3 12.4 | 17.8/13.3 15.7 | 20.8/15.7 18.6 | | 100.0/39.3 52.1 | 66.0/35.0 52.5 |
| | 50 | 6.3 | 7.4 | 9.0 | 11.0 | 13.0 | | 34.6 | 40.0 |

Ox-bow lake, Konfederatka, 1955–1956
Numerator – maximum coefficient of variation
Denominator – minimum coefficient of variation
Quotient – average coefficient of variation

} within the 10 to 30 series of the given number of samples relatively too small for *Tendipedidae* and *Tendipes plumosus*. When comparing cases of smaller abundance with cases of larger abundance differences in abundance are great, differences in coefficients of variation are minimal, or in certain cases coefficients of variation are even greater with a greater abundance and smaller with a smaller abundance. The deviation mentioned above does not disqualify however the general tendency towards the decrease in the variation coefficients of the arithmetic means with the increase in the number of organisms (Tab. VI).

Table VI presents data from the ox-bow lake, Konfederatka which however are analogous to the data from other areas (Fig. 5). Thus we may conclude that the former data have a general character.

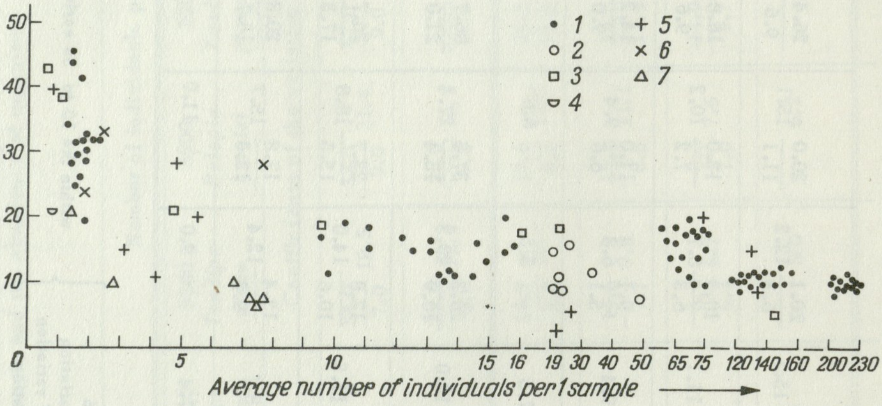


Fig. 5. Coefficient of variation of means $CV\% = m/M\%$ of relatively large series (8–20 samples) taken with Ekman dredge from different environments

*1* – ox-bow lake Konfederatka, basic materials, *2* – ox-bow Konfederatka, other materials, *3* – Lake Tajty, *4* – Lake Mikołajskie, *5* – Lakes Esrom and Tjustrup (acc. Berg 1938), *6* – Lake Wigry (acc. Tarwid 1939), *7* – Lake Śniardwy

*Tendipedidae Oligochaeta Chaoborus*

## C. Reliability of estimating of the arithmetic means through their errors

The error of the arithmetic mean indicates the possible range of its fluctuations. This only applies however to large series of samples numbering at least several dozen.

At most the error of the mean may only be equal to the value of the mean, whereas the value of the maximum mean as shown in Table I may be several times greater than the value of the minimum mean in cases of small series.

Since it is often impossible to take large series in field work the reliability

Average coefficients of variation of means for different taxonomic groups (calculated jointly for profundal, sublittoral and littoral, for the values of the means ⩾0.6 individual per sample in series of 50 samples and ⩾ 1.0 individuals in series of 5, 10 and 16 samples)

Tab. VII

| Taxonomic groups | 225 cm² Ekman dredge | | 10 cm² tubular sampler | | | | | |
|---|---|---|---|---|---|---|---|---|
| | No. of samples in series | | | | | | | |
| | 5 | | 10 | | 16 | | 40 – 50 | |
| | N | *Cv* | N | *Cv* | N | *Cv* | N | *Cv* |
| *Oligochaeta* | 89 | 37.8 | 12 | 33.4 | | | 35 | 23.5 |
| *Tendipedidae* | 74 | 30.2 | 21 | 28.3 | | | 22 | 18.0 |
| *Chaoborus* | 72 | 29.8 | 10 | 31.2 | | | 25 | 16.1 |
| *Tendipedidae* *Chaoborus* | 146 | 30.0 | 31 | 29.3 | 11 | 20.6 | 47 | 17.0 |
| Average for all the taxonomic groups | 235 | 33.0 | 43 | 30.4 | 11 | 20.6 | 82 | 19.8 |

N – No. of series
*Cv* – Average coefficient of variation of means in percent

of which can be estimated with the use of statistical methods, it becomes important to find a means of estimating the reliability of a small amount of sampled material.

For the purpose of analysing this question we used the above mentioned material from many variants of the series of the same size taken from uniform material. Variants with the smallest (*M*min) and the largest (*M*max) arithmetic mean were taken from all the variants of the series of a given size. Then we calculated the values *M*max – *m*, and *M*min + *m*.

A good indicator of the reliability of the estimate of the abundance of organisms by means of *M*± *m* with the help of the series of a given size is the relation *M*max – *m* or *M*min + *m* to the fully representative mean calculated on the basis of a large material (Tab. VIII). The quotient close to one or smaller than one, proves that the estimate of abundance by means of *M*± *m* is fully reliable. In Table VIII the data is given only for *M*max-*m* on the assumption that the results for *M*min + *m* would be analogous.

This quotient had the highest and therefore the least favourable value a) for small 3- and 5-sample series taken with the Ekman dredge when the abundance of organisms was several hundred individuals per square metre and less, b) for series of different sizes taken with the 10 cm² tubular sampler when the

**The relation of the means with the greater numerical values minus the values of their errors ($M$max $-$ $m$) to the mean calculated on the basis of all samples taken with the given apparatus, according to the size of the series and samples and with the number of organisms**

Tab. VIII

| Bottom sampler | No. of samples in a series | No. of individuals per 1 sq.m. | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 78000 *Oligochaeta* | | 60000 *Oligochaeta* | | 9500 *Tendipedidae* | | 5900 *Pelopia kraatzi* | | 3200 *Tendipes plumosus* | | 630 *Tendipedidae* | | 590 *Tendipes plumosus* | | 80 *Heleidae* | |
| | | a | b | a | b | a | b | a | b | a | b | a | b | a | b | a | b |
| 225 cm² Ekman dredge | 3 | 1.13 | 889.0 | | | 1.02 | 212.4 | 1.10 | 131.3 | 1.0 | 70.7 | 1.29 | 13.7 | 1.33 | 13.1 | 1.0 | 1.8 |
| | 5 | 1.12 | | | | 1.0 | | 1.09 | | 1.0 | | 1.29 | | 1.27 | | 1.08 | |
| | 8 | 1.04 | | | | 1.01 | | 1.02 | | 1.08 | | 1.0 | | 1.01 | | 1.04 | |
| | 10 | 1.08 | | | | 1.0 | | 1.05 | | 1.0 | | 1.0 | | 1.0 | | 1.0 | |
| | 20 | 1.0 | | | | 1.0 | | 1.0 | | 1.0 | | 1.0 | | 1.0 | | 1.0 | |
| 10 cm² tubular sampler | 10 | 1.0 | 75.4 | 1.01 | 50.6 | 1.08 | 7.5 | 1.05 | 4.4 | 1.04 | 2.6 | 1.0 | 0.4 | 1.0 | 0.4 | 2.06 | 0.16 |
| | 20 | 1.0 | | 1.01 | | 1.04 | | 1.0 | | 1.04 | | 1.0 | | 1.0 | | 1.53 | |
| | 30 | 1.0 | | 1.02 | | 1.0 | | 1.0 | | 1.0 | | 1.05 | | 1.05 | | 1.50 | |
| 5 cm² tubular sampler | 10 | 1.02 | 39.9 | 1.0 | 29.9 | 1.0 | 3.1 | 1.05 | 2.0 | 1.0 | 1.0 | 1.0 | 0.13 | 1.0 | 0.13 | 1.50 | 0.10 |
| | 20 | 1.03 | | 1.0 | | 1.0 | | 1.05 | | 1.0 | | 1.54 | | 1.54 | | 1.10 | |
| | 30 | 1.02 | | 1.0 | | 1.0 | | 1.0 | | 1.0 | | 1.00 | | 1.00 | | 1.30 | |

Ox-bow Konfederatka, 1955–1956

a – relation of $M$max – $m$ to mean calculated on the basis of all samples

b – average abundance per sample calculated on the basis of all samples taken vith given type of sampler abundance of organisms was several dozen individuals per square metre, and c) for series of different sizes taken with the 5 cm$^2$ tubular sampler when the abundance of organisms was several hundred individuals and less.

Analyzing the value of the quotient in relation to the abundance of individuals per sample instead of per square metre, it should be stated that with series of ten or more samples, values greater than 1.0 ( > 1.1) occurred when the number of individuals was smaller than 1 ind./sample, and with smaller series of 3 to 5 samples such values greater than 1.0 ( > 1.1) already occurred when the number of organisms was 10 to 20 individuals per single sample (Tab. VIII).

It should be rememberad that the calculated quotients present the worst of ten or even several dozen situations[2]. Thus in majority of cases we are dealing with a more favourable situation. Therefore we may assume that the abundance calculated with $M \pm m$ on the basis of series of different size – 3 or more samples taken with the Ekman dredge and 10 or more samples taken with the tubular sampler – is close to the real abundance when the number of organisms is sufficiently large. Slightly greater deviations are possible in those cases when the number of organisms ranges from several to about 20 individuals per sample for small 3- to 5-sample series as well as in cases, when the number is smaller than 1 individual per sample for the 10-sample series and sometimes even for larger series (Tab. VIII).

On the diagrams (Figs. 6–9) the changes in the variation coefficients of the arithmetic means are shown in relation to the changes in abundance of organisms from materials sampled in different environments of 40 lakes. As a rule, as the mean increases, the values of the coefficient decrease (very sharply at the begining, moderately after a certain point). The coefficient has the highest values (100%) when only one sample among all the obtained material is full (then the error equals the arithmetic mean). There is a sharp decrease in the coefficient up to the point where the value of abundance is so high as to insure that each sample or most of them are full ones. With the further increase in the abundance there is an increasingly lower reduction in the value of the coefficient. The moment of transition from a rapid to a slow rate of decrease of the coefficient occurs when the value of the arithmetic mean for a series of about fifty samples equals 0.5 – 0.6 individual per sample and when the value of the arithmetic mean for a smaller series – several to about fifteen samples – equals approximately 1.0 individual per sample.

The further insignificant decrease in the coefficient with the growth in the abundance of organisms is not the result of the greater percentage of chances of full samples but of the more even distribution of the organisms which occurs when their abundance is greater.

---

[2] The values of $M - m_{min}$, that is, of the mean of the smallest variation coefficient minus its error were as a rule smaller than the values of $M_{max} - m$, and therefore the relatiom $M - m_{min}$ to the mean calculated on the basis of the large material was smaller than the analogous relation for $M_{max} - m$. This confirms the statement mentioned above that the values given in Tab. IX present the least favourable situations.

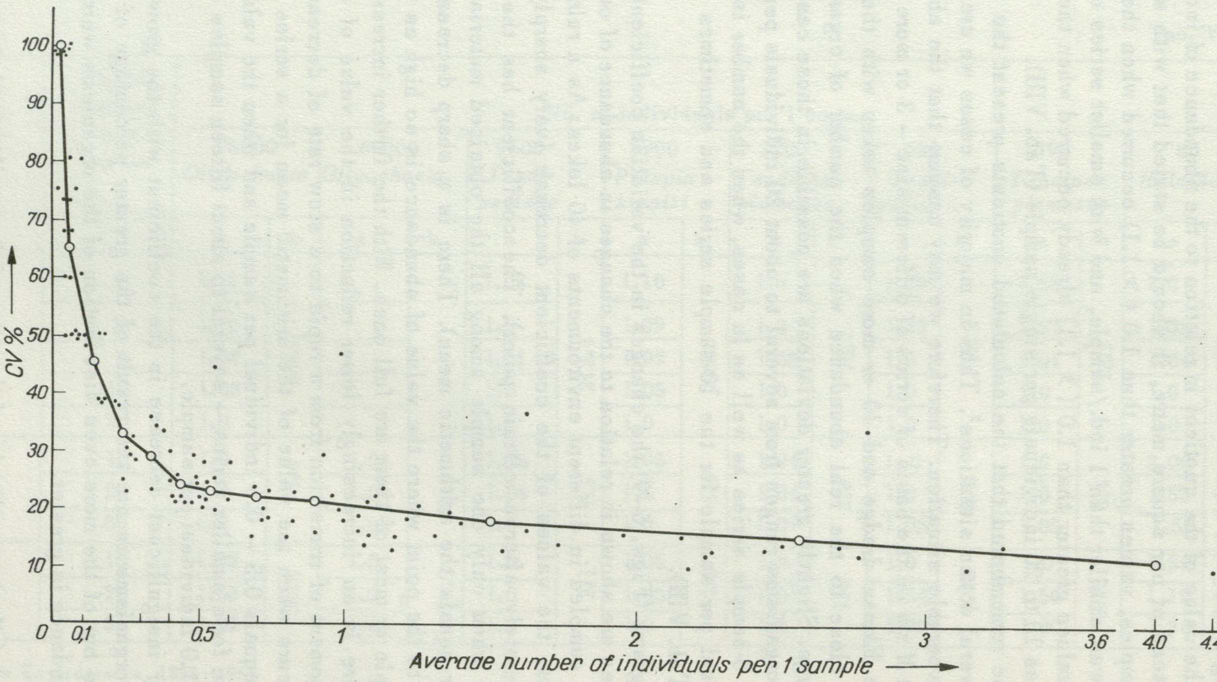


**Fig. 6. Corelation of coefficient of variation of means with number of organisms**

Series of 40—50 samples taken with 10 cm$^2$ tubular sampler. Profundal of Lakes Tajty Wrońskie, and Grajewko *CV%* — coefficient of variation of means in percentages

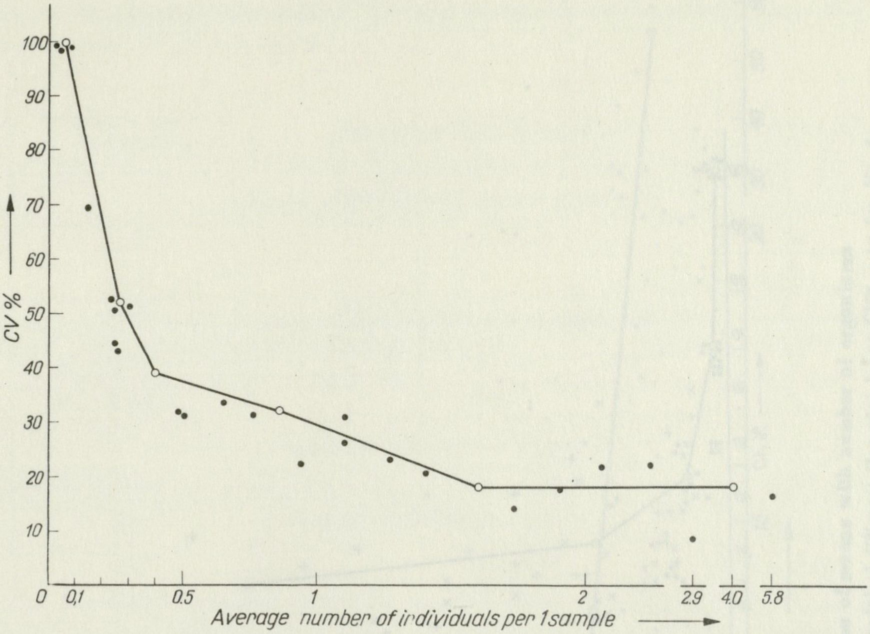


**Fig. 7. Correlation of coefficient of variation of means with number of organisms**
**Series of 16 samples taken with 10 cm² tubular sampler. Profundal of Lake Tajty Długie**
**Profundal of Lake Tajty Długie *CV%* – as for Fig. 6**
***Oligochaeta Tendipedidae Chaoborus***

The variation coefficient of the arithmetic mean may be considered as a gauge of the evenness of distribution of organisms – it becomes smaller as the distribution becomes more even (when there is an identical number of organisms in each sample the variation coefficient equals 0.0; when all the organisms are concentrated in one sample and the rest of the samples are empty and thus the aggregation is at the maximum, the coefficient equals 100%). Taking this into consideration we may state on the basis of a comparison of the data (Tab. IX) of the above mentioned diagrams (Fig. 6–9) that when there is an increase in abundance there is generally a more even and less aggregated distribution of organisms.

The average value of the variation coefficient is of course smaller the larger the series of samples (with the same abundance of organisms) taken with a given type of sampler (Tab. VI and VII).

### III. NUMBER OF SPECIES IN MATERIALS ACCORDING TO NUMBER OF SAMPLES AND TOTAL SIZE OF EXPLOITED AREA

We often use as a guage of the reliability of the material the relation of the number of species found in the sampled material to the total number of species occurring in the investigated environment (Jones 1957, Tarwid 1956).

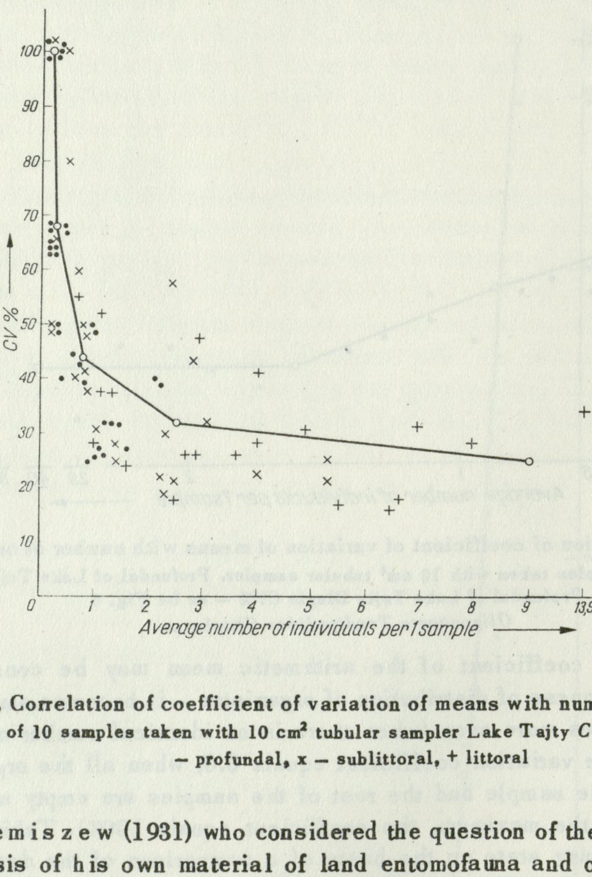


**Fig. 8.** Correlation of coefficient of variation of means with number of organisms
Series of 10 samples taken with 10 cm² tubular sampler Lake Tajty *CV%* – as for fig. 6
– profundal, x – sublittoral, + littoral

B e k l e m i s z e w (1931) who considered the question of the number of species on the basis of his own material of land entomofauna and on the basis of the results of Arrhenius work on botanical material, stated that the number of species found depends on the size of the investigated area.

Of course, the amount of material containing a full or almost full number of species depends on their density and distribution. A proportionately greater number of samples is needed in order to catch a species which occurs very rarely or is very unevenly distributed.

Long before all the species are caught it is possible to make a sufficiently precise estimate of the abundance of the dominant species. However the reliability of the estimate of the abundance of species occurring very rarely may not be sufficiently precise even after the full number of species in the investigated environment has been found (L o n g h u r s t 1959, T a r w i d 1956).

A comparison of the materials taken with apparatuses of various sizes (the same bottom area with each apparatus) (Fig. 10) shows that the more samples taken

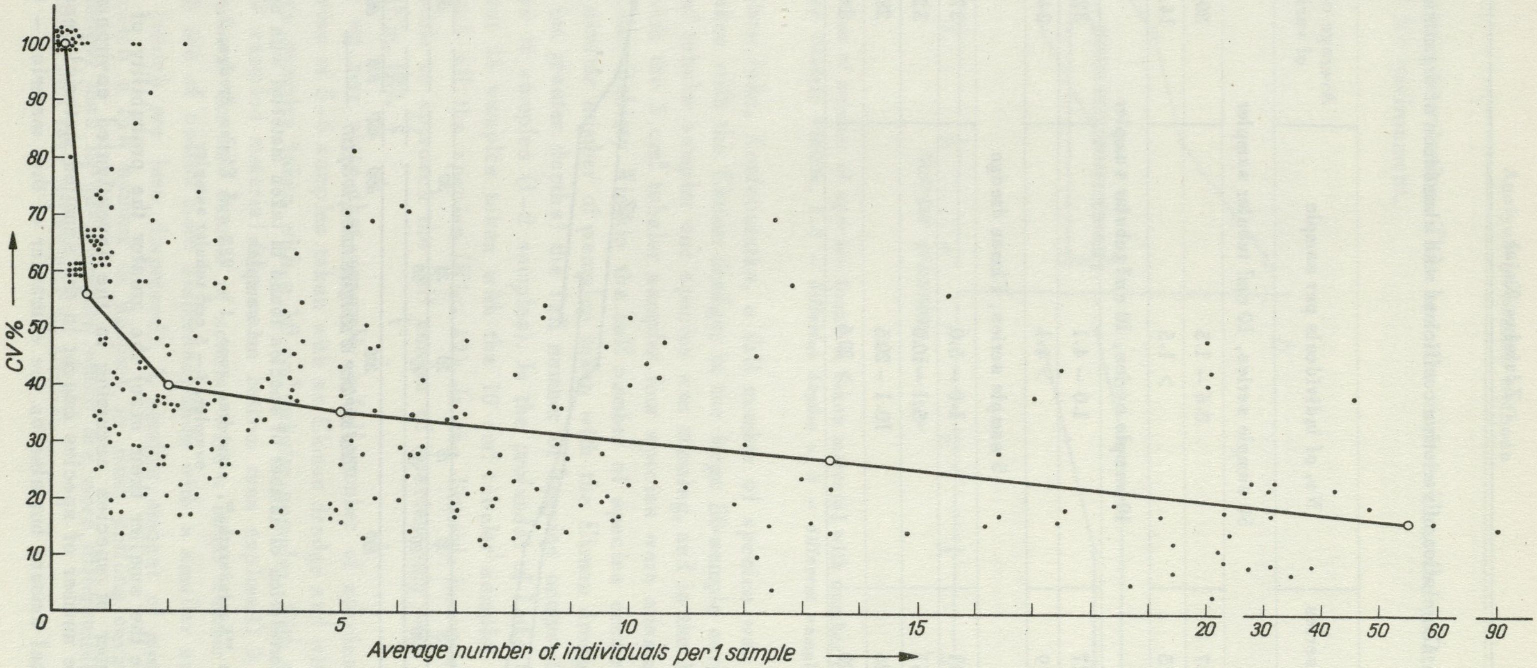


**Fig. 9. Correlation of coefficient of variation of means with number of organisms**
**Series of 5 samples taken with 225 cm² Ekman dredge. Profundal of different Mazurian lakes. *CV%* – as for fig. 6**
***Oligochaeta Tendipedidae Chaoborus***

Correlation of variation coefficient with abundance of organisms

Tab. IX

| No. of series | No. of individuals per sample | Average coefficient of variation |
|---|---|---|
| 50 sample series, 10 cm$^2$ tubular sampler | | |
| 37 | 0.6 – 1.5 | 20.4 |
| 25 | > 1.5 | 14.0 |
| 10 sample series, 10 cm$^2$ tubular sampler | | |
| 27 | 1.0 – 4.1 | 32.5 |
| 9 | > 4.1 | 24.8 |
| 5 sample series, Ekman dredge | | |
| 121 | 1.0 – 5.0 | 37.6 |
| 61 | 5.1 – 10.0 | 32.0 |
| 26 | 10.1 – 20.5 | 28.2 |
| 20 | > 20.6 | 16.8 |

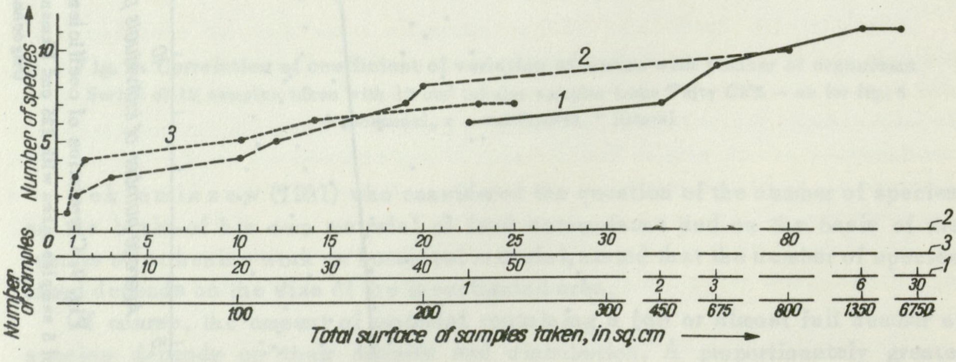


Fig. 10. Correlation of number of species found in taken material with number and size of samples

Ox-bow lake "Konfederatka", plant-free zone, *1* – 225 cm$^2$ Ekman dredge, *2* – 10 cm$^2$ tubular sampler, *3* – 5 cm$^2$ tubular sampler

(and hence the smaller their size) the greater the probability of obtaining the total number of species occurring in the investigated environment. In other words, the number of species caught in the sampled material depends not only on the total amount but also on the character of this material – the number of samples and their distribution. This becomes more evident the greater the differentiation of the environment.

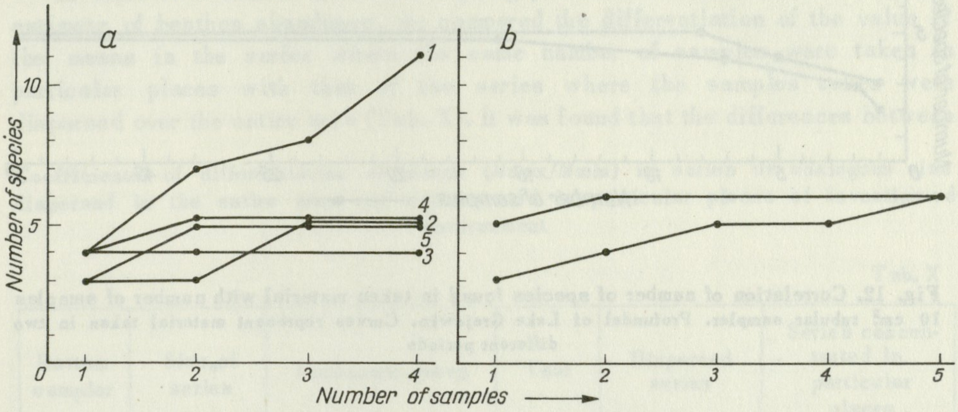


Fig. 11. Correlation of number of species found in taken material with number of samples Profundal of Lake Babięty Wielkie, *1–5* – different depths *a*, *b* – different sampling periods

In the ox-bow lake, Konfederatka, a full number of species was found in six samples taken with the Ekman dredge; in the large 80-sample series taken with the 10 cm² tubular sampler one species was missing, and in the 50-sample series taken with the 5 cm² tubular sampler four species were missing. In the profundal of Lake Babięty Wielkie the full number of species occurred in an approximately similar number of samples taken with the Ekman dredge and in certain cases (at greater depths) the full number of species occurred even in smaller numbers of samples (1–2 samples). In the profundal of Lake Grajewko several to about 15 samples taken with the 10 cm² tubular sampler were necessary to catch all the species (Fig. 12). In the littoral, however, it was generally possible to approach the full number of species only with a 30–50 sample series (Fig. 13).

To sum up we may state that generally a full number of species can be caught with series of 5–6 samples taken with an Ekman dredge and with series of several score samples taken with a 10 cm² tubular sampler. With the same total amount of sampled material (the same bottom area explored) it is more possible to approach the full number of species with a larger number of small samples (which are of course more dispersed) than with a smaller number of large samples (which are less dispersed). A smaller amount of material is necessary to catch a full number of species in more uniform environments (deeper lake zones) than in environments which are more differentiated such as the ox-bow lakes and lake littorals (Fig. 10–13).

samples and their distribution. This becomes more evident the greater the differentiation of the environment.

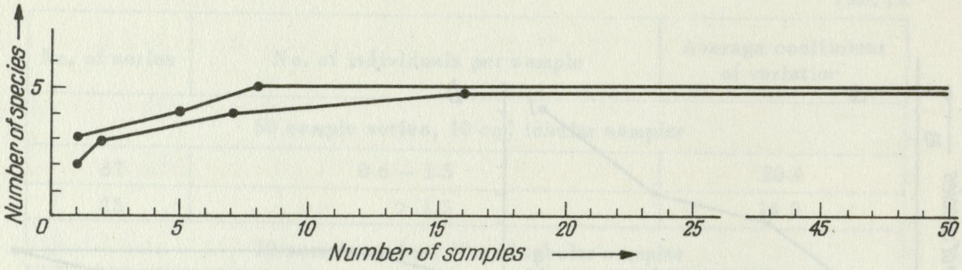


**Fig. 12. Correlation of number of species found in taken material with number of samples 10 cm². tubular sampler. Profundal of Lake Grajewko. Curves represent material taken in two different periods**

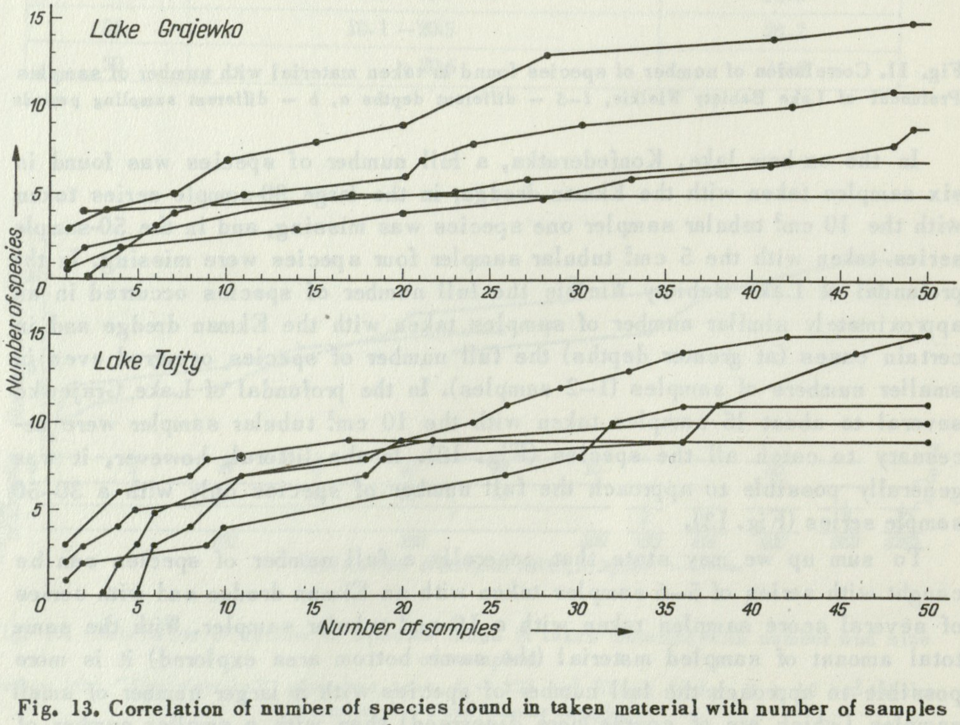


**Fig. 13. Correlation of number of species found in taken material with number of samples 10 cm². tubular sampler. Littoral**

The fact that we can catch the full number of species in several sample series taken with an Ekman dredge is proof of the great regularity of occurrence of benthos and also of species of small abundance.

## IV. MANNER OF DISTRIBUTION OF SAMPLES AND RELIABILITY OF THE ESTIMATE OF BENTHOS ABUNDANCE

In order to determine how the sampling pattern affects the reliability of the estimate of benthos abundance, we compared the differentiation of the value of the means in the series where the same number of samples were taken in particular places with that of the series where the samples taken were dispersed over the entire area (Tab. X). It was found that the differences between

Coefficients of differentiation of means (*M*max/*M*min) in series of analogous size dispersed in the entire area and concentrated in particular places of investigated environment

Tab. X

| Bottom sampler | Size of series | Taxonomic group | Year | Dispersed series | Series concentrated in particular places |
|---|---|---|---|---|---|
| 10 cm² tubular sampler | 8–10 samples | *Tendipedidae* | 1956 | 1.5 | 2.4 |
| | | *Tendipes plumosus* | " | 1.8 | 3.8 |
| | | *Pelopia kraatzi* | " | 1.6 | 2.8 |
| | | *Tendipes plumosus* | 1955 | 3.5 | 11.0 |
| Ekman dredge | 3 samples | *Tendipedidae* | 1956 | 2.0 | 2.3 |
| | | *Tendipes plumosus* | " | 2.3 | 6.2 |
| | | *Pelopia kraatzi* | " | 2.1 | 3.2 |
| | | *Tendipes plumosus* | 1955 | 2.7 | 2.3 |

Ox-bow lake, Konfederatka, 1955–1956

the series taken in particular places (concentrated sampling) are as a rule greater (with the one exception of *Tendipes plumosus* caught in 1955 in the series taken with the Ekman dredge) than the differences between the series of the samples dispersed in different points of the investigated area. This is the reason that differences between particular samples which are close to one another are smaller than differences between samples more distant from one another. Thus, for example, the average differentiation of abundance (from ten series) between single samples within a ten-sample series (relation of abundance in richest samples to abundance in poorest samples in one series) was as follows: (data taken from ox-bow lake, Konfederatka):

| | dispersed series | concentrated series |
|---|---|---|
| *Tendipedidae* | 3.84 | 2.67 |
| *T.plumosus* | 7.38 | 4.27 |
| *P.kraatzi* | 8.56 | 5.36 |

**Differences in abundance of benthos organisms in successive 10-sample series in profundal of Lake Tajty and Lake Grajewko (10 cm² tubular sampler)**

Tab. XI

| Lake | Depth in m. | Taxonomic group | Date | Arithmetic means in successive 10-sample series: 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|---|
| Tajty | 32 m. | *Chaoborus* | 4.12.49 | 2.7 | 0.8 | | | |
| | | | 16.12.50 | 1.9 | 0.6 | 0.9 | 2.1 | 1.5 |
| | | | 3.3.51 | 3.0 | 3.5 | 1.9 | 1.6 | 0.9 |
| | | | 21.4.51 | 1.2 | 1.2 | 4.3 | 4.5 | |
| | | | 10.11.51 | 1.5 | 2.6 | | | |
| | | | 10.2.53 | 0.4 | 1.4 | 1.3 | 1.1 | |
| | | | 23.4.54 | 3.5 | 2.6 | 3.0 | 1.8 | |
| | | *Oligochaeta* | 7.7.53 | 0.4 | 1.1 | 0.4 | 0.2 | |
| | 25 m. | *Chaoborus* | 29.11.52 | 2.0 | 2.2 | 2.6 | 3.7 | |
| | | | 26.3.54 | 3.1 | 3.2 | 5.0 | 3.0 | |
| | | | 23.4.54 | 5.3 | 5.8 | 3.5 | 3.1 | |
| | | *Oligochaeta* | 29.11.52 | 0.5 | 1.9 | 1.7 | 0.5 | |
| | | | 18.9.53 | 2.4 | 1.5 | 0.8 | 1.9 | |
| Grajewko | 16 m. | *Chaoborus* | 10.7.52 | 2.5 | 1.0 | 1.9 | 2.0 | |
| | | | 7.7.53 | 0.7 | 0.4 | 0.3 | 0.1 | |
| | | *Oligochaeta* | 7.7.53 | 1.6 | 1.8 | 0.4 | 0.6 | |
| | | | 1.6.54 | 0.6 | 1.0 | 1.7 | 0.8 | |
| | | *Tendipedidae* | 7.7.53 | 0.4 | 0.0 | 0.1 | 0.4 | |
| | | | 26.3.54 | 1.3 | 1.4 | 2.3 | 1.1 | |
| | | | 1.6.54 | 0.6 | 1.0 | 1.7 | 0.8 | |
| | 9 m. | *Tendipedidae* | 5.12.49 | 1.7 | 0.7 | 0.7 | 1.2 | 0.9 |
| | | | 23.4.50 | 1.4 | 0.9 | 0.6 | 0.8 | 0.7 |
| | | | 9.8.50 | 0.2 | 0.4 | 0.2 | 0.3 | 0.8 |

We also found a great unevenness in benthos distribution in the lake profundal, that is, in an environment exceedingly little differentiated. In Lake Tajty and Lake Grajewko the abundance in the successive series of samples (each ten to twenty metres distant from the other) can be several times greater or smaller (Tab. XI). A similar differentiation was found in the series taken simultaneously with the Ekman dredge in the lake profundal at points about 20 metres distant from each other (Tab. XII). Of course such a great differentiation is not the rule; there is often very little differentiation in profundal material. In Tables XI and XII cases of maximum differentiation are given. Such cases, however, are not very rare; they occur in 40 to 50 percent of materials obtained from the lake profundal.

Differences in abundance of benthic organisms in series taken with Ekman dredge simultaneously over a distance of ten to twenty metres

Tab. XII

| Lake | Depth | No. of samples in series | Taxonomic group | Arithmetic means in the series: | |
|---|---|---|---|---|---|
| Tajty | 32 m. | 5 | *Chaoborus* | 6.0 | 13.4 |
| | | 5 | *Oligochaeta* | 4.3 | 13.3 |
| | 25 m. | 5 | *Tendipes sp.* | 1.6 | 0.4 |
| Śniardwy | 7 m. | 15–20 | *Tendipes plumosus* | 1.4 | 2.8 |

Since the abundance in particular places, including those located close to each other in an apparently uniform environment may differ considerably (as also indicated by Morduchaj-Bałtowskoj and Poddubnaja, 1958), the samples must be dispersed over the entire area if we want to characterize the average abundance in the environment. In the more greatly differentiated environments it is of course more important than in the less differentiated environments. Naturally a great dispersion of series is possible only with a large number of samples which can be obtained without any increase in the amount of material by decreasing the size of the sample.

## V. CORRELATION OF RELIABILITY OF ESTIMATE OF ABUNDANCE WITH THE TYPE OF ENVIRONMENT

In connection with the far greater unevenness of the littoral and sublittoral environments in comparison to the profundal environment one would expect quantitative data from the littoral and sublitoral to be less reliable than that from the profundal. However, the analysis of the quantitative data obtained in several cases (Tab. XIII) which was carried out in the same way as that of materials from the ox-bow lake, Konfederatka (Tab. I) did not support this assumption. The quotients of the maximum to the minimum means are similar in all three types of environments and for the series of different sizes. Some differences appeared only in analysing the larger material with the aid of the variation coefficients of the arithmetic means (Tab. XIV); in the case of *Oligochaeta* they are a little greater; they are not however very great. In certain cases

Correlation of differentiation of means (*M*max/*M*min) with type of environment and size of series. 10 cm² tubular sampler

Tab. XIII

| No. of samples in a series | No. of series | Profundal: Grajewko 9 m. *Tendipedidae* 1160 | Profundal: Tajty 32 m. *Chaoborus* 1400 | Sublittoral: Tajty 4 m. *Tendipedidae* 1900 | Sublittoral: Grajewko 4 m. *Tendipedidae* 1200 | Littoral: Tajty 1.0 – 1.5 m. *Tendipedidae* 3900 | Littoral: Tajty 1.0 – 1.5 m. *Tendipedidae* 1000 |
|---|---|---|---|---|---|---|---|
| 5 | 20 | $\frac{2.0}{0.4} = 5.0$ | $\frac{2.8}{0.2} = 14.0$ | $\frac{4.2}{0.8} = 5.3$ | $\frac{2.6}{0.2} = 13.0$ | $\frac{6.8}{1.8} = 3.8$ | $\frac{2.2}{0.2} = 11.0$ |
| 10 | 15 | $\frac{1.8}{0.7} = 2.6$ | $\frac{2.1}{0.6} = 3.5$ | $\frac{3.2}{1.4} = 2.3$ | $\frac{2.3}{0.4} = 5.8$ | $\frac{5.2}{1.9} = 2.7$ | $\frac{2.1}{0.3} = 7.0$ |
| 20 | 10 | $\frac{1.5}{0.85} = 1.8$ | $\frac{1.65}{0.95} = 1.7$ | $\frac{2.3}{1.65} = 1.4$ | $\frac{1.95}{0.7} = 2.8$ | $\frac{4.8}{2.7} = 1.8$ | $\frac{1.5}{0.4} = 3.8$ |
| | | Average number per sample and error | | | | | |
| 50 | | 1.16 ± 0.17 | 1.4 ± 0.25 | 1.9 ± 0.23 | 1.2 ± 0.18 | 3.9 ± 0.48 | 1.0 ± 0.23 |
| | | Coefficient of variation of arithmetic mean | | | | | |
| | | 14.7 | 17.9 | 12.1 | 15.0 | 12.3 | 23.0 |

Numerator – *M*max
Denominator – *M*min
Quotient – *M*max/*M*min index of differentiation of mean

indicated above the differentiation of spacial distribution of benthos in the littoral or sublittoral need not be greater than in the profundal (nor need the reliability of the quantitative data be less).

Considering the nature of the benthos distribution and the reliability of the sampled materials in the various environments, it must be kept in mind that there are far more environments in the littoral than in the profundal and therefore a single series taken in the profundal is to a great degree representative of the entire environment, whereas a single series taken in the littoral is only representative of a certain limited sector.

## VI. NATURE OF THE DISTRIBUTION OF THE DIFFERENT ORGANISMS

The analysis of the distribution of particular taxonomic groups disclosed that only in the case of *Oligochaeta* were there greater differences in relation to other groups. It was already shown by the variation coefficients of the arithmetic means (Tab. VI), where the values for *Oligochaeta* were relatively greater than could have been expected on the basis of their abundance. This is confirmed by the data taken from the lake areas (Tab. VII and XIV). The values

Average coefficient of variation of means in different lake zones (for values of mean greater or equal to 0.6 individuale per sample). Series of 40–50 samples taken with 10 $cm^2$ tubular sampler

Tab. XIV

| | Littoral | | Sublittoral | | Profundal | |
|---|---|---|---|---|---|---|
| | N | *Cv%* | N | *Cv%* | N | *Cv%* |
| *Oligochaeta* | 9 | 27.6 | 4 | 26.1 | 22 | 21.4 |
| *Tendipedidae* | 9 | 18.5 | 8 | 18.7 | 5 | 16.2 |
| *Chaoborus* | | | | | 25 | 16.1 |

N — no. of series

*Cv* — average coefficient of variation of mean

of the variation coefficients of the arithmetic means in the case of *Tendipedidae* and *Chaoborus* are generally similar; they are higher in the case of *Oligochaeta*. This proves that the spatial distribution of *Oligochaeta* is more uneven than that of *Tendipedidae* and *Chaoborus*.

## VII. DIFFERENCES IN ABUNDANCE EVALUATION BY SAMPLERS WITH DIFFERENT SURFACES

It is worth noting that the smaller the surface of the sampler, the smaller the number of organisms, calculated per unit of surface. The average abundance of organisms per 10 $cm^2$ in the investigated environment of the ox-bow lake, Konfederatka, calculated on the basis of the entire material taken with the particular samplers is as follows:

| | Ekman dredge | 10 cm² tub.sampl. | 5 cm² tub.sampl. |
|---|---|---|---|
| *Tendipes plumosus* 1955 | 0.6 | 0.4 | 0.3 |
| *Tendipedidae*, 1956 | 9.4 | 7.5 | 6.2 |
| *Tendipes plumosus*, 1956 | 3.1 | 2.6 | 1.9 |
| *Pelopia kraatzi*. 1956 | 5.8 | 4.4 | 3.9 |
| *Oligochaeta*, 1956 | – | 76.6 | 78.2 |

The differences in the abundance of organisms obtained by the particular samplers ranged from several to twenty percent for each group. Presumably these differences are due to the fact that the smaller the apparatus the greater the ratio of its perimeter to the surface. For the Ekman dredge the ratio is 0.27, for the 10 cm² tubular sampler it is 1.1, for the 5 cm² tubular sampler – 1.6. Some of the organisms on the perimeter of the sampler presumably escape at the moment of sampling. This interpretation is supported by the fact that the mentioned differences in abundance applies to *Tendipedidae* whereas the abundance of *Oligochaeta* is practically the same in the cases of both tubular samplers. As is known, *Oligochaeta* are more stationary than *Tendipedidae*; when disturbed they do not escape aside but hide in their vertical tubes.

A comparison of the abundance of *Tendipes plumosus* in samples taken with the Ekman dredge with those taken with the tubular sampler from another sector of the ox-bow lake, Konfederatka, showed a conformity between the data from the two apparatuses. The abundance per 10 cm² calculated on the basis of data obtained with the first apparatus was 1.1; with the second – 1.3 (the difference is within the limit of error). It is possible that the circumstances affect the reaction of the *Tendipedidae* to the sampling apparatus; presumably this is related to the state of the environment or of the biocenosis. But this is another problem which we can only mention here.

## VIII. RELATION OF ABUNDANCE OF ORGANISMS TO FINENESS OF SIEVE AND SIEVING TIME

To determine the effect of the mesh size and of the sieving time on the number of organisms sampled, we compared the abundance of fauna in the series of samples (taken with the 10 cm² sampler) some of which were sieved with a 0.4 × 0.4 mm. sieve, others with a 0.25 × 0.25 mm. sieve. In the series which were put through a finer sieve, we sifted ten to twenty entire samples – each sifting lasting about two minutes – and we sifted ten samples which were divided into two layers: one pelogen layer of 3–4 cm. thickness and the other, a 12–20 cm, thick layer of heavy mud-like core. Each layer was sieved separately, the combined results of which are given in Table XV. Sieving time

Correlation of number of benthos with mesh gauge and sieving time (no. of individuals per 10 $cm^2$; samples taken with 10 $cm^2$ tubular sampler) Ox-bow lake, Konfederatka

Tab. XV

| Year | Taxonomic groups | Mesh gauge 0.4 × 0.4 mm. | | | | | | | Mesh gauge 0.25 × 0.25 mm. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Series of samples sieved in 1.5 min. | | | | | | Series (10 samples) sieved in 4 min. | Series of 10 undivided samples (2 min.) | | Series of samples 10 divided into layers (45 sec.) |
| | | of 10 samples | | | | | of 50 samples | | | | |
| | | 1 | 2 | 3 | 4 | 5 | | | 1 | 2 | |
| 1956 | *Tendipes plumosus* | 3.2 | 2.9 | 2.2 | 2.9 | 2.0 | 2.6 | 2.2 | 2.1 | | 2.5 |
| | *Pelopia kraatzi* | 4.5 | 4.6 | 4.9 | 4.8 | 3.4 | 4.4 | 4.7 | 3.8 | | 5.2 |
| | *Oligochaeta* | 71.0 | 75.5 | 75.0 | 74.8 | 78.7 | 75.0 | 84.1 | 77.4 | | 110.0 |
| 1955 | *Tendipes plumosus* | 0.5 | 0.3 | 0.3 | 0.4 | 0.5 | 0.4 | 0.3 | 0.8 | 0.3 | 0.4 |
| | *Oligochaeta* | 56.3 | 52.6 | 42.1 | 41.4 | 60.4 | 50.6 | 46.0 | 50.5 | 41.6 | 67.3 |

of the surface layer which contained the majority of the fauna lasted about 45 sec. (K a j a k 1958).

One of the 10-sample series put through a coarser sieve were deliberately kept in the sieve for a longer time (about 4 minutes).

Compared with all the others, the greater differences in the abundance of organisms occurred only in the case of *Oligochaeta* and *Pelopia kraatzi* in the samples divided into layers and put through a finer sieve (Tab. XV). Both in *Oligochaeta* and in *Pelopia kraatzi* a certain amount of individuals were small enough to escape through the meshes. This fact proves that in every series with the exception of that divided into layers and put through a finer sieve, sieving time was sufficiently long to allow the small organisms to escape. In the case of *Pelopia kraatzi* these were probably larvae of a length $\leqslant$ 3 mm., because after the latter's removal the abundance of *Pelopia kraatzi* in the series of samples divided into layers and put through a finer sieve was equal to the abundance of the other series of samples.

It appears, from the materials discussed above that in the process of sieving the principal factor affecting the abundance of organisms is the sieve mesh size. Sieving time may be of importance only in extreme cases – when it is of very short duration or when it is of very long duration and some of the organisms (e.g. *Oligochaeta*) capable of contracting their bodies have time enough to squeeze through the meshes.

After sieving we obtained fully representative quantitative results only for those organisms whose size prevented them from filtering through the meshes. In the case of the smaller organisms the results cannot be considered as being truly quantitative.

## IX. CHANGES IN BENTHOS ABUNDANCE AND THE REPRESENTATIVENESS OF THE MATERIALS

### A. Changes in benthos abundance in the course of a year

Since it often happens that we are not able to investigate a reservoir over a long period of time, our analysis is based on a single or at most several samplings. Under these circumstances it is essential to know what is the value of the sampled materials for estimating the benthos abundance in the reservoir. Among others, S e g e r s t r a l e (1960) has pointed out the importance of this question. I shall attempt from this point of view to analyse the data selected from my own materials and from literature. I have of course chosen those examples from the literature on the subject where the material had been sampled many times during a year in one environment.

Table XVI gives the ratio of the maximum to the minimum abundance in these materials (minimum abundance is represented by the lowest value above zero since in those cases where the data is equal to zero it is not possible to calculate the quotient).

It appears that the range of fluctuation of abundance of fauna is related to the variability of environmental conditions. Relatively small fluctuations in abundance occur in environments of limited variability: those which are favourable for fauna throughout the year (or where the unfavourable period is so short that the benthos is able to survive), and those in which conditions are generally unfavourable throughout the year. The greatest changes in abundance of fauna occur in environments where conditions for its development are periodically good and periodically very bad.

Environments where conditions vary little and are always favourable for benthos include the majority of the shallow reservoirs (ox-bow lakes, Lake Grajewko, Lake Skadarsko – Tab. XVI), the profundal of eutrophic lakes above the zone of rather great oxygen deficiency (Lake Esrom – 12–15 m., Lake Charzykowo – 7.5–19.0 m.), and oligotrophic lakes (Innaren, Skärshultsjön, Sträken); this is confirmed by data from other oligotrophic or mezotrophic lakes (Corbella 1959; Oliver 1960). Sometimes smaller fluctuations in abundance occur at greater rather than at smaller depths (e.g. in the Uczinski storage reservoir – Sokolowa 1959); the conditions there are probably worse but less variable. Environments where conditions are not very favourable for benthos include the profundal of several eutrophic lakes (Tajty – 24–32 m., Douglas – 21–22 and 21–24 m., the lowest part of the profundal of Lake Charzykowo – see Tab. XVI). In the profundal of many eutrophic lakes conditions are periodically very bad or good. Oxygen is plentiful during the circulation period, it completely disappears during the stagnation period (Lake Third Sister – 18 m., Lake Douglas – 21–25 and 21–28 m., Lake Tajty – 15–26 m., Lake Charzykowo – 20–22.5 m., Lake Eskrom – 10–20 m. – Tab. XVI). This was also confirmed by later data of Jonasson from Lake Esrom (1961).

Many works are concerned not only with the average abundance but also with the detailed changes in abundance. Thus the question arises of the required frequency of benthos sampling for this purpose.

The analysis of the dynamics of abundance of *Tendipedidae* (in the environment from which the basic materials for this work were taken) showed that in comparison with the series taken every ten days, the series taken monthly grossly distorted the picture of the dynamics in the period of the appearance of young generations of *Tendipedidae* (June – July); (since the changes in this period are greatest and most violent) (Fig. 14 and 15). In periods when the changes were smaller and especially when the abundance was low, monthly sampling did not essentially distort the picture of the dynamics. The taking of samples once every quarter might have caused such errors – as shown on Figurs 14 and 15 – so as to indicate an abundance two to ten times greater or smaller than the real abundance.

### B. Differences in benthos abundance in particular years

While sampling materials in a given environment in the course of an entire year, we do not know whether the year is an average year, whether it is an

Relation of maximum to minimum abundance during one or several years calculated on basis of reference data

Tab. XVI

| Taxonomic group | Lake Esrom (Berg, 1938) (during one year) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 12 m. | 15 m. | 18 m. | 20 m. | | | | | | |
| *Tendipedidae* | 23.7 | 26.9 | 58.7 | 36.3 | | | | | | |
| *Oligochaeta* | 4.3 | 5.0 | 14.7 | 39.0 | | | | | | |
| | Lake Charzykowo (Romaniszyn 1950) (during one year) | | | | | | | | | |
| | 7.5–10.0 m. | 12.0–14.0 m. | 16.0–19.0 m. | 20.0–22.5 m. | 23.0–25.0 m. | 26.0–27.0 m. | | | | |
| *Tendipedidae* | 6.0 | 3.9 | 9.9 | 116.2 | 15.6 | 19.5 | | | | |
| | Lake Douglas (Eggleton 1931) (One year cycle on the basis of data compiled over several years) | | | | | Lake Third Sister | | | | |
| | 17–19 m. | 21–22 m. | 21–24 m. | 21–25 m. | 21–28 m. | 7–8 m. | 11.5–13.0m. | 14–15 m. | 16–17 m. | 18 m. |
| *Tendipedidae* | 30.0 | 28.2 | 38.7 | 49.3 | 25.3 | 20.9 | 91.2 | 11.9 | 45.7 | 205.8 |
| | Lake Tajty (Author's material) | | | | | | | | | |
| | During one year 30–32 m. | | For the entire research period – 1950–54 30–32 m. | 24–26 m. | 15–17 m. | | | | | |
| | 1950 | 1953 | 1950–54 | 1952–1954 | | | | | | |
| *Tendipedidae* | 6.5 | 3.0 | 8.7 | 13.3 | 51.0 | | | | | |
| *Oligochaeta* | 9.0 | 4.5 | 24.2 | 55.0 | 53.3 | | | | | |
| | Lake Grajewko Depth 9 m. (Author's material) (During one year) | | | | | | | | | |
| *Tendipedidae* | 2.4 | | | | | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Lake Skadarsko Depth 6 m. | | | | | (Nedeljkovic, 1959) | | | |
| | Profile I | | | | Profile II | | | |
| | During one year | | | For the entire research period | During one year | | | For the entire research period |
| | 1952 | 1953 | 1954 | 1952–54 | 1952 | 1953 | 1954 | 1952–54 |
| *Tendipedidae* | 2.6 | 8.7 | 13.2 | 13.2 | 2.0 | 3.5 | 24.0 | 24.0 |
| *Oligochaeta* | 18.7 | 6.7 | 7.3 | 44.0 | 3.0 | 2.4 | 8.8 | 8.8 |
| Lake Innaren (Brundin, 1949) | | | | | Lake Skärshultsjön (During one year) | | Lake Sträken | |
| | 4–6 m. | | 7–19 m. | | | | | |
| *Tendipedidae* | 4.0 | | 1.5 | | 3.0 | | 3.0 | |
| *Oligochaeta* | 3.0 | | 5.0 | | | | | |
| Ox-bow lake Živaca (Jankovič, 1958) (During one year) | | | | | | | | |
| Benthic macrofauna Total | 9.0 | | | | | | | |
| Ox-bow lakes (Lellak 1953) (During one year) | | | | | | | | |
| | Labicko | | Kozi Chlup | | Poltruba | | | |
| | Station A–1.0 m. | Station B–2.0 m. | Station A–1.0 m. | Station D–2.0 m. | Station A–3.0 m. | Station B–3.0 m. | | |
| Benthic macrofauna (Total) | 2.5 | 5.5 | 2.6 | 3.3 | 11.0 | 10.0 | | |
| Ox-bow lake Konfederatka – 1.0 m. (Kajak 1958) (During one year) | | | | | | | | |
| | 1954 | | | | 1955 | | | |
| *Tendipedidae* | 9.0 | | | | 20.0 | | | |
| *Oligochaeta* | 18.0 | | | | 6.3 | | | |

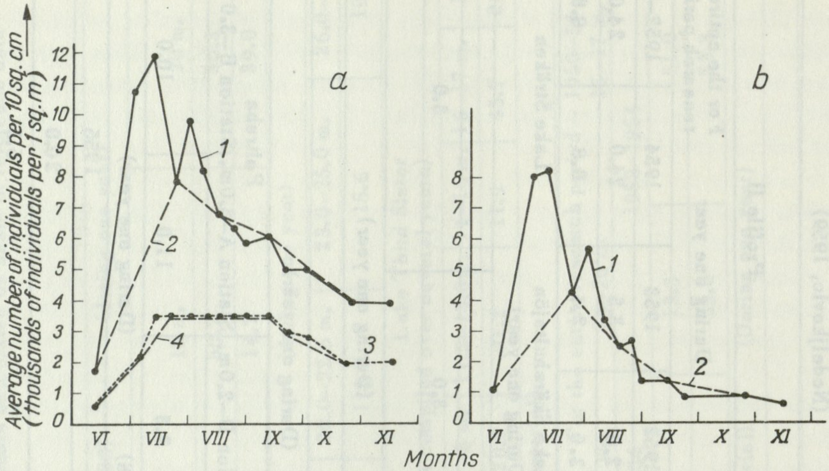


**Fig. 14. Correlation of shape of curve showing quantitative dynamics with sampling frequency**

Ox-bowlake Konfederatka, 1954 *a–1*, *a–3* and *b–1* – sampling done on the average once in 10 days; *a–2*, *a–4* and *b–2* – sampling done on the average once a month

*a–1, 2 Tendipedidae, a–3, 4 – T. plumosus, b– Pelopia kraatzi*

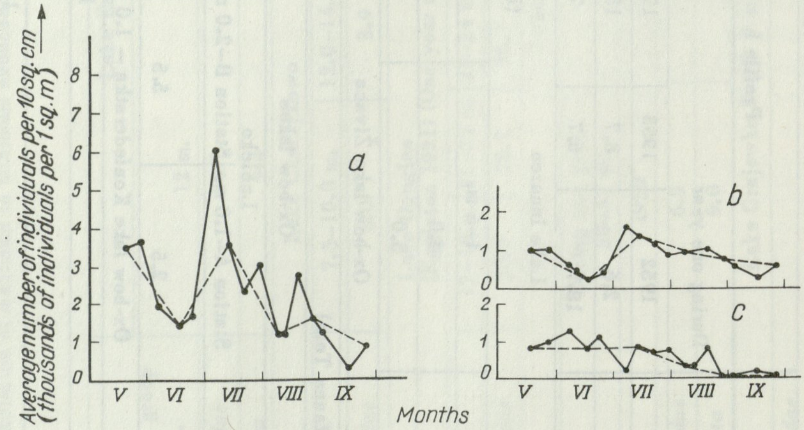


**Fig. 15. Correlation of shape of curve showing quantitative dynamics with sampling frequency**

Ox-bow lake Konfederatka, 1955 *1* – sampling done on the average once in 10 days, *2* – sampling done on the average once a month

*a – Tendipedidae, b – T.plumosus, c – Pelopia kraatzi*

Average no. of individuals in different seasons Lake Tajty

Tab. XVII

| Depth | Season | Year | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1949/50 | | | 1951 | | | 1952 | | | 1953 | | | 1954 | | |
| | | *T.* | *Ch.* | *Ol.* | *T.* | *Ch.* | *Ol.* | *T.* | *Ch.* | *Ol.* | *T.* | *Ch.* | *Ol.* | *T.* | *Ch.* | *Ol.* |
| 30–32 m. | VII–IX | 190 | 360 | 660 | | | | 40 | 190 | 630 | 40 | 690 | 530 | | | |
| | IV–VI; X–XI | 250 | | | 40 | 2430 | 1020 | | | | 30 | 870 | 460 | 50 | 2750 | 290 |
| | | 110 | 500 | 710 | | | | | | | | | | | | |
| 24–26 m. | VII–IX | | | | | | | 80 | 640 | 640 | 40 | 1000 | 1000 | | | |
| | IV–VI; X – XI | | | | | | | | | | 50 | 4420 | 820 | 220 | 2990 | 470 |
| | VII–IX | | | | | | | 370 | 1430 | 650 | 20 | 630 | 1010 | | | |
| | IV–VI; X–XI | | | | | | | | | | 140 | 770 | 540 | 580 | 540 | 1250 |

*T. – Tendipedidae; Ch. – Chaoborus crystallinus; Ol. – Oligochaeta* exceptionally poor or exceptionally rich year. In this connection it is worth determinating to what extent such exceptional years differ from average years and how often they occur.

In Lake Tajty, 1950 was an exceptionally rich year with respect to the number of *Tendipedidae* which was sampled there at a depth of 30–32 m – their abundance was 5–7 times greater in the period from April to November than it was in the corresponding periods in the year 1951–54 (Tab. XVII). In the month of July – the time of maximum abundance of *Tendipedidae* in the ox-bow lake, Konfederatka, – the following abundance was found (per square metre):

1953 – 4500
1954 – 12000
1955 – 6000

Thus there were two and three-fold differences in abundance between the particular years. Similar differences in abundance (also on the basis of maximum *Tendipedidae* abundance) are also shown in the materials of Nedeljkovic (1959), Jonasson (1961), Oliver (1960), Kajak (1961), Borucki (1946) and Lundbeck (1926) when working with large materials have also found differences of the same order (up to eight-fold).

As was shown above, differences in abundance even within one year can be higher than 100-fold. Of course, among occasionally sampled materials in the different years, the differences can also be of this order or greater. Not basing himself on materials but on theoretical assumptions, Borucki (1946) expressed an opinion that spring biomass is the most representative in reservoirs. This does not appear to be correct; in spring there can also be great fluctuations in abundance without having any relation, as this author would imply, with the dynamics of abundance in the subsequent seasons.

It appears that the estimate of benthos abundance on the basis of several samplings in a given season is more representative for the reservoir. From this point of view the abundance of the given taxonomic group in Lake Tajty in the different seasons of one year[3] as well as in the same seasons of different years were generally not more than several times greater or several times smaller (Tab. XVII); the differences were greater in winter.

Järnefelt (1955), who considered this question, recommends at least four samplings a year – once during spring circulation, twice during summer stagnation, once during autumn circulation; it is also advisable to sample material in winter.

When only one sampling is possible, it would be best to use the method employed in this work for a comparison of abundance in the different years: sampling on the basis of knowledge of the dynamics of abundance in the given reservoir, e.g., at the moment of maximum abundance or of minimum abundance, etc. There is a similarity in the character of the dynamics of abundance in

[3] The periods of spring and autumn circulation are joined because of the similarity of abundance in the two periods.

different years and it is specific for the given environment (Kajak 1958, Nedeljkovic 1959, Eggleton 1931, Szilowa, 1960, Jonasson 1961 and others). Of course the situation is rarely so favourable that the dynamics of benthos abundance in the investigated environment is known beforehand. In cases of environments as yet not investigated, where the exact nature of the dynamics of abundance is not known, the only approach to take is to base oneself on the generally known characteristics of benthos in the given type of environment, e.g. in eutrophic lakes in which there are periods of marked oxygen deficiency, benthos abundance in these periods being smaller and, in periods of curculation, greater, etc.

## X. CONCLUSION

The abundance of benthic organisms in the particular samples taken simultaneously in the same station may be as much as twenty and more than twenty times greater or smaller. (Tab. V). Thus it is evident that series of samples should be taken in order to estimate the abundance in the given environment. The question of the required size of the series, as well as the size of the particular samples and their distribution has not been sufficiently elaborated till now although it has been touched upon in certain works (reference is made to these works in the introduction). Lenz, (1951), in discussing certain problems of quantitative benthic methods in his article, correctly stated that one must suit the methods to the circumstances rather than employ one method in all situations.

From the analysis of the materials dealt with in this work, we conclude that the size and number of samples should depend on the abundance of organisms, on the spatial differentiation and the amount of time available. Since the dispersion of organisms has been found to be non-uniform even in an apparently uniform environment (Tab. X, XI, XII) it is desirable to take a large number of samples dispersed over the entire investigated, relatively uniform, area. And consequently it is better to use small surface samplers by means of which one may take a large number of samples and prevent errors resulting from the environmental differentiation while not burdening oneself with too large an amount of materials.

Good results were obtained from my use, in another work (Kajak 1958), of a dispersed 10-sample series. The dispersion of samples over the entire relatively uniform investigated area is also recommended by other authors (Lenz 1951, Tebo 1955).

Where there is a relatively large abundance of organisms – several hundred or more individuals per square metre, the reliability of the series of a given number of samples taken with an Ekman dredge is as great as that of the series of the same number taken with a 10 $cm^2$ tubular sampler, e.g., 10-sample series or 20-sample series (Tab. III, VIII). Using a 10 $cm^2$ tubular sampler, the amount of material is of course more than twenty times smaller.

On the other hand, when more than several samples cannot be taken because of limited time, a large apparatus should be used; the several sample series taken with a small surface sampler may give a completely false picture of the order of abundance (Tab. XIII – 3-sample series). There are, however, situations where even several sample series taken with a small apparatus provide a fairly good estimate of abundance (Kajak 1958), yet there is never any absolute certainty that one is dealing with such a favourable situation.

Where there is a small abundance of organisms – several score individuals per square metre – better results can be obtained with an Ekman dredge – even in a very small, 3-sample series – than can be obtained in a 20–30 sample series taken with a tubular sampler (Tab. VIII). However, large 50-sample series taken with a tubular sampler provide a fairly good estimate of the order of abundance even when the abundance of organisms is very small; with the further increase in the number of samples per series there is no significant change in the average abundance of organisms (Tab. IV).

A comparison of the estimate of abundance by means of $M \pm m$ with the abundance calculated on the basis of a large number of samples, which may be considered as the real abundance, shows that the error of the arithmetic mean is generally very helpful in estimating abundance of organisms. Even with very small series – 3 to 5 samples taken with the Ekman dredge, the estimate of abundance by means of $M \pm m$ is relatively close to the real abundance. When there is large abundance and an accompanying large series the results obtained with a 10 $cm^2$ tubular sampler are even better, but when the abundance is small – several score individuals per square metre, i.e., about 0.1 ind. per sample, the estimate of abundance by means of $M \pm m$ may, in the 10-sample series, be about 2 times greater or smaller, and in the 20- to 30-sample series, about 1.5 times greater or smaller than real abundance. Undoubtedly, a smaller series taken with a tubular sampler would provide a significantly greater deviation. Thus there are cases when an estimate of abundance by means of $M \pm m$ does not coincide with the real abundance – and sometimes differs to a great degree. These situations will be discussed in greater detail later on.

No conclusions may be drawn only from the value of the error of the arithmetic mean (or from the index of its variation) about the reliability of the estimate of abundance by means of $M \pm m$ and on the basis of sampled materials. It is true that the average variation coefficients decrease when the abundance of organisms increases as well as when the size of the series increases, however, when the average coefficient for the given material is high it may happen that some coefficients are very low and others very high (Tab. VI). Thus we cannot know from the sampling of one series whether the variation coefficient of its arithmetic mean should be ascribed to the highest or the lowest average coefficient. In other words: the low value of the variation coefficient of the arithmetic mean does not prove that in this case the estimate of abundance by means of $M \pm m$ is reliable, nor does the high value give proof of its unreliability.

Since we cannot draw any conclusions from the variation coefficient of the arithmetic mean as to whether the estimate of abundance by means of $M \pm m$ is reliable in the analysed case, there remains only the criterion of the abundance of organisms per one sample and the criterion of the size of the series on the basis of a comparison of $M \pm m$ (for different sample sizes and series as well as for different abundances of organisms) with the "real abundance". The estimate of abundance for the materials analysed here by means of $M \pm m$ (Tab. VIII) was as follows:

1. When the abundance was several score or more individuals per sample[4], the estimate was satisfactory[5] even on the basis of a 3- to 5-sample series;

2. When the abundance ranged from about 0.5 to several score individuals per sample, the estimate was satisfactory on the basis of an 8- to 10-sample series;

3. When the abundance was very small – about 0.1 to 0.2 individual per sample, the "real abundance" could have been two times greater or smaller than the abundance estimated by means of $M \pm m$. Moreover, when the abundances were so small, while taking a 10- or even a 20-sample series, it often happened that the whole series did not yield even one individual – the value of the mean equalled zero;

4. In the case of smaller, 3- to 5-sample series, it was found that the abundance estimated by means of $M \pm m$ could be 1.3 times greater or smaller than the "real abundance" even when the abundance of organisms was relatively large – about 15 individuals per sample (Tab. VIII); and when the abundances were smaller these differences could undoubtedly have been correspondingly greater.

It must, moreover, be kept in mind that as the values of the mean per sample decrease their errors increase proportionately (Fig. 6–9) and thus the estimate of abundance becomes less precise.

The above remarks concerning the reliability of the estimate of abundance by means of $M \pm m$ refer to the least favourable of several dozen situations. In many instances, therefore, these criteria may be too severe, but the possibility of the occurrence of such an unfavourable situation must never be excluded.

If we accept as reliable the value of the mean itself ($M$) irrespective of its error, the estimated abundance may be as much as 2 times greater or smaller than the real abundance – when the average abundance is > 1 ind./sample – and it may be as much as 3 times greater or smaller – when the average abundance is under 1 ind./sample with 10-sample series (Tab. III). With a smaller number of samples the mistakes may undoubtedly be more serious.

The mistakes may be considerably more serious when the error of the arithmetic mean is not taken into account in investigating the changes in

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[4] When we speak of abundance per sample and not per unit of space, the conclusions are valid for all apparatuses, irrespective of their size.

[5] The relation $M \pm m$ to "real abundance" differs from unity by several percents.

abundance in time or in space. With the same abundance, the arithmetic means differ so much that in series consisting of ten or more samples one mean might have been as much as three times greater than another; in 5-sample series one mean might have been as much as five times greater than another and in 3-sample series it might undoubtedly have been more than five times greater. With an abundance smaller than 1 individual per sample, the differences between the means were still greater (in 20-sample series one mean might have been as much as seven times greater than the other; in 10-sample series it was not possible to calculate their differences because the value of $M$min equalled zero – Tab. I).

Of course, all conclusions on the representativeness of sampled material apply to the type of distribution characteristic for the materials analysed in this work, e.g., they will not be valid in cases of extremely concentrated distribution. However the analysis of the dispersion of organisms carried out on very large materials from very different environments showed rather small differentiation of dispersion and thus our conclusions may be extended to cover the great majority of situations.

It must of course be stressed that all conclusions reached in this work apply to uniform environments, for example, to a profundal section with a defined character of bottom and of a given depth, or to a littoral section with a defined character and defined density of vegetation and of the same depth, substratum, etc. They cannot be applied, for example, to an environment of the same depth, but not uniformly overgrown, or covered with patches of vegetation, etc. Of course, when we speak of the uniformity of an environment we mean such a degree of uniformity which can be evaluated by an investigator because, as was shown in Chapter III, that which an investigator may regard as a uniform environment may not be uniform for the organisms living in it (Tab. X – XII). Nevertheless this type of non-uniformity was taken into consideration in this work.

An analysis of the average variation coefficients of arithmetic means which may be treated as indexes of the evenness of the distribution of organisms shows that with the growth in abundance the dispersion of organisms is more even, less concentrated (Tab. IX).

In the environment of the ox-bow lake, Konfederatka, discussed earlier, the abundance per unit of bottom surface evaluated on the basis of samples taken with small surface samplers was somewhat smaller than real abundance in the case of *Tendipedidae*, whereas it did not differ in the case of *Oligochaeta*. This was probably due to the escape of the *Oligochaeta* into the deep layers of ooze at the moment of sampling (their escape however does not prevent them from being taken up into the apparatus which penetrates sufficiently into the deep layers of the ooze) whereas the *Tendipedidae* generally escape horizontally, part of them getting beyond the range of the apparatus. The smaller is the surface of the apparatus, the relatively greater is the number of *Tendipedidae* which escape successfully. These facts may raise some doubts regarding small surface samplers. However, differences in abundance here are not so large as to cause any essential distortion of the results. Besides, judging from the difference in abundance calculated on the basis of 5 and 10 $cm^2$ samplers, these differences rapidly diminish by increasing the sampling surface of the apparatus, and in the case of 20–30 $cm^2$ surface they are probably insignificant. It is difficult to say how often it happens that abundances per unit of area evaluated by means of small samplers are smaller than those evaluated by means of large ones. The analyses carried out show that such situations are not the rule.

The analysis of the importance of the sieve mesh size to the number of organisms obtained confirmed results arrived at previously (Jonasson 1955, 1958, Sander 1957, Kajak 1958). After examining materials put through a sieve of a given size, we can ascertain with certainty only the number of organisms whose escape through the sieve is prevented by their size. That the escape of the smaller organisms is generally very rapid is shown by the fact that they only occur in greater numbers in samples sifted for a very short time – 45 sec. (Tab. XV). Some date however show that the rate of escape varies in different seasons (Kajak 1958).

Some differences can be observed in evenness of distribution between the littoral and sublittoral on one hand and the profundal on the other; the evenness is greater in the profundal than in the littoral and sublittoral (Tab. XIV). The differences however are smaller than one would expect on the basis of the differentiation of the environment (very large in the littoral, smaller in the sublittoral and almost non-existent in the profundal). In addition, these differences are apparent only in the course of comparing the larger materials; this does not signify by any means that differences in particular cases must always be smaller in the profundal than in the littoral (Tab. XIII). Since particular environments do not differ to any great degree, the conclusions as to the size of the sample and of the series, which are discussed on the basis of materials from a plant-free environment similar to the profundal (from the point of view of the environmental differentiation), also refer to the littoral and sublittoral. It should however be kept in mind that the littoral contains considerably more diverse environments than the profundal and that series of samples from the littoral, even fully representative ones, are typical of but a small sector of the profundal. On the other hand, a series of samples from the profundal is to a great extent representative of a large area of this environment.

The distribution of *Oligochaeta* is less even than that of *Tendipedidae* and *Chaoborus*; this regularity is as true for the various lake environments (Tab. XIV) as for the plant-free zone of the ox-bow lake (Tab. VI).

In the investigation of a rather small bottom area, a larger percentage of species are obtained in series taken with a small sampler than in 2–3 samples taken with a large sampler. A full number of species is generally obtained with 5–6 sample series taken with an Ekman dredge or with a series of about 15 to 50 samples taken with a tubular sampler (Fig. 10–13).

The discussion on reliability of the material and on series and sample size has enabled us to come to rather optimistic conclusions. It is possible to make a sufficiently accurate estimate of the abundance of organisms at a given moment on the basis of a rather small amount of material, taking into consideration the error of the arithmetic mean and the danger of great mistakes occurring when there are very small numbers of individuals per sample. The question arises however: what is the relation of the abundance estimated in this way to changes in the number of organisms occurring in the course of a year and from year to year. These changes in abundance can be very great (abundance may be from several to several hundred times greater or smaller); on the average the changes are smaller in less variable environments and greater in more variable environments.

The best way to resolve this question is to apply our knowledge of the dynamics of abundance, which, as many works demonstrate, does not change very much (Eggleton 1931, Kajak 1958, Nedeljkovic 1959, Szilowa 1960, Jonasson 1961). This of course pertains only to the reservoirs investigated during the entire year. In other instances it is useful to conduct several samplings in one season. The average abundance calculated on the basis of these materials may generally be up to several times greater or smaller than the average abundance in other seasons. Likewise it may be up to several time greater or smaller than average abundance in the same seasons of different years (Tab. XVII). When this is also impossible we can only apply our knowledge of the general regularity of the dynamics of abundance in the given type of reservoir.

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## ANALIZA METOD ILOŚCIOWYCH BADAŃ BENTOSU

### Streszczenie

Celem mojej pracy była analiza na dużym materiale kwestii, jaką metodą należy się posługiwać w określonych okolicznościach, aby uzyskać najbardziej wiarygodne wyniki. Przy analizowaniu tej sprawy zwrócono główną uwagę na wielkość próby, ilość prób i ich rozmieszczenie przy określonej liczebności organizmów, typie środowiska i właściwościach biologicznych różnych grup systematycznych.

Nieco miejsca poświęcono sprawie zmian liczebności w czasie – w obrębie roku i w poszczególnych latach – i koniecznej w związku z tym częstości pobierania materiałów. Wreszcie ostatnia sprawą analizowana były kwestie techniczne – wpływ wielkości oczek sita i czasu płukania na ocenę liczebności organizmów.

Materiał, na którym oparto analizę składał się z 920 prób chwytacza Ekmana, 3440 prób chwytacza rurowego o powierzchni 10 cm² i 100 prób chwytacza rurowego o powierzchni 5 cm². Na materiał ten złożyły się:

1. Serie prób z wybranego, względnie jednolitego środowiskowo wycinka starorzecza Konfederatka (fig. 1) powierzchni około 2000 m², o dnie mulistym i głębokości około 1 m. Pobrano tu dwukrotnie (raz przy bardzo wysokiej, drugi raz przy dość niskiej liczebności *Tendipedidae*) serie po 30 prób chwytacza Ekmana o powierzchni 225 cm². po 80–90 prób chwytacza rurowego typu Łastoczkina-Ułomskiego o powierzchni 10 cm² i po 50 prób chwytacza rurowego tego samego typu o powierzchni 5 cm². Próby pobierano w 10 ściśle oznaczonych punktach, w każdym punkcie po 3 próby chwytacza Ekmana, po 8–9 prób chwytacza rurowego o powierzchni 10 cm² i po 5 prób chwytacza rurowego o powierzchni 5 cm². Materiały te potraktowano w pracy jako pierwszoplanowe.

2. Materiały z różnych zbiorników:

a. serie chwytacza Ekmana po 8–30 prób, głównie z terenu jezior Mazurskich, oraz zbiorników przyrzecznych

b. serie chwytacza rurowego o powierzchni 10 cm², po 10, 40 i 50 prób z litoralu, sublitoralu i profundalu jezior.

Dane te potraktowano głównie jako sprawdzian miarodajności wyników uzyskanych z materiałów pierwszoplanowych, w różnych warunkach.

Poza tym oparłem się o pewne materiały z piśmiennictwa.

Analizę skoncentrowano głównie na podstawowych formach bentosu wód stojących: *Tendipedidae*, *Oligochaeta* i *Chaoborus*. Materiał podstawowy zawierał około 7600 osobników *Tendipedidae*, 38000 *Oligochaeta*, 350 *Heleidae*. Wszystkie materiały łącznie zawierały około 13000 osobników *Tendipedidae*, 44000 *Oligochaeta*, 8000 *Chaoborus*, 900 *Mollusca* i 350 *Heleidae*.

Tendipedidae oznaczano we wszystkich materiałach do gatunku. W materiałach podstawowych z *Tendipedidae* dominowały zdecydowanie *Tendipes plumosus* (L.) i *Pelopia kraatzi* Kieff. Wykaz pozostałych gatunków zawiera tabela IV.

Przy analizie reprezentatywności materiału posłużono się między innymi następującą metodą; z dużego materiału (pkt 1) ułożono, korzystając z tablic liczb losowych i dbając o równomierność rozmieszczenia przestrzennego prób, szereg wariantów serii różnej wielkości po 3 do 30 prób. Każdy z tak uzyskanych wariantów serii mógł się zdarzyć, gdyby pobrano tylko jedną taką serię. Dla każdej z tak uzyskanych serii obliczono średnią arytmetyczną (*M*) i jej błąd (*m*). Przez *M*max określono największą, zaś przez *M*min najmniejszą spośród wszystkich wariantów średnich arytmetycznych dla danej wielkości serii. Wskaźnik *M*max/*M*min mówi, ilokrotnie można by się omylić w ocenie liczebności organizmow biorąc serie danej wielkości, która by zawierała maksymalną ilość organizmów, a następnie biorąc serię, która by przypadkowo zawierała minimalną możliwą ilość organizmów. Wypadek taki może się zdarzyć np. przy badaniu dynamiki liczebności w czasie, bądź zróżnicowania rozmieszczenia w przestrzeni. Przy tej samej liczebności rzeczywistej w 2 momentach czasowych, lub 2 różnych miejscach natrafiając przypadkowo na *M*max i *M*min można by dojść do wniosku o znacznych różnicach liczebności (tab. I i II).

Miernikiem miarodajności oceny liczebności w danym momencie przez pobrany materiał jest stosunek *M*max do przeciętnej liczebności obliczonej na podstawie dużego materiału (tab. III).

Stosunek *M*max – *m* do przeciętnej liczebności obliczonej na podstawie dużego materiału (tab. VIII) informuje o miarodajności oceny liczebności przez *M* – *m*.

Ilości organizmów w poszczególnych próbach pobranych jednocześnie z tego samego stanowiska mogą się różnić do dwudziestu kilku razy (tab. V). Stwierdzono także duże zróżnicowanie rozmieszczenia przestrzennego bentosu, – w miejscach odległych od siebie kilka do kilkunastu metrów liczebność może się różnić kilkakrotnie (tab. X – XII).

Kwestię wielkości i ilości prób należy dostosować do liczebności organizmów, zróżnicowania terenowego i możliwości czasowych. Ze względu na stwierdzoną niejednolitość występowania organizmów nawet w jednolitym środowisku, korzystne jest pobieranie możliwie dużych ilości prób rozproszonych po całym badanym, względnie jednolitym terenie.

Przy względnie dużych liczebnościach organizmów – kilkuset lub więcej osobników na 1 m², zbliżoną wiarygodność dają te same ilości prób chwytacza Ekmana lub chwytacza rurowego o powierzchni 10 cm² – np. po 10 lub po 20 prób (tab. III, VIII). Oczywiście ilośc materiału przy użyciu chwytacza o powierzchni 10 cm² jest dwudziestokilkakrotnie mniejsza.

Gdy na skutek ograniczonego czasu nie można pobrać wiecej niż kilku prób, należy je pobrać dużym aparatem; kilkupróbowe serie chwytacza o małej powierzchni mogą doprowadzić do zupełnie fałszywych wyobrażeń nawet o rzędzie liczebności (tab. XII – serie 5-próbowe).

Przy małych liczebnościach organizmów rzędu kilkudziesięciu osobników na 1 m² lepsze wyniki daje chwytacz Ekmana, nawet przy bardzo małej, 3-próbowej serii, niż serie chwytacza rurowego (tab. III). Jednakże duże, 50-próbowe serie chwytacza rurowego dają niezłą ocenę rzędu liczebności nawet przy bardzo małych liczebnościach organizmów; przy dalszym zwiększeniu ilości prób średnia liczebność organizmów nie ulega już poważniejszym zmianom (tab. IV).

Błąd średniej arytmetycznej jest dobrą pomocą w ocenie liczebności organizmów; nawet przy bardzo małych seriach – 3–5 prób chwytacza Ekmana ocena liczebności przez $M \pm m$ jest bliska liczebności rzeczywistej. Dla chwytacza rurowego o powierzchni 10 $cm^2$ wyniki są jeszcze lepsze z wyjątkiem przypadków bardzo małej liczebności – rzędu kilkudziesięciu osobników na 1 $m^2$, co stanowi 0,1 osobnika na 1 próbę; ocena liczebności przez $M \pm m$ może się wtedy różnić od liczebności rzeczywistej do 2 razy (tab. VIII).

Zasługuje na uwagę, że ocena liczebności przez $M \pm m$ daje dobre wyniki nawet przy liczebnościach poniżej 1 osobnika na próbę mimo, że sądząc po wartościach współczynników zmienności średnich arytmetycznych (fig. 6–9) można by się spodziewać, że średnia = 1 osobnik na próbę będzie granicą wiarygodności materiału (przy niezbyt dużych ilościach prób).

Oczywiście należy się liczyć z tym, że im niższe wartości średnich na próbę, tym stosunkowo większe ich błędy (fig. 6–9) i wobec tego tym mniej precyzyjna ocena liczebności.

Wartość błędu średniej arytmetycznej, czy też współczynnik jej zmienności nic nie mówi na temat miarodajności oceny liczebności przez $M \pm$ na podstawie pobranego materiału. Wprawdzie przeciętne współczynniki zmienności maleją ze wzrostem liczebności organizmów, jak również ze wzrostem wielkości serii, jednakże przy wysokim przeciętnym współczynniku dla danego materiału mogą się trafiać współczynniki bardzo niskie i bardzo wysokie (tab. VI), a mając pobraną 1 serię nie możemy wiedzieć, czy współczynnik zmienności jej średniej należy do najwyższych, przeciętnych, czy najniższych.

Skoro nie można na podstawie współczynnika zmienności średniej arytmetycznej wywnioskować, czy ocena liczebności przez $M \pm m$ jest miarodajna, pozostaje kryterium liczebności organizmów na 1 próbę i kryterium wielkości serii. W analizowanym tu materiale zadowalającą ocenę liczebności przez $M \pm m$ dawały serie od 8–10 prób wzwyż przy liczebności 0,5 osobnika na 1 próbę lub większej (tab. VIII) (przy tym gdy mówimy o liczebności na 1 próbę, a nie na jednostkę powierzchni, wnioski odnoszą się oczywiście do wszystkich aparatów, niezależnie od ich wielkości). Przy mniejszych ilościach przeciętnych – około 0,1 – 0,2 osobnika na 1 próbę, liczebności rzeczywiste mogą się różnić od oszacowanych przez $M \pm m$ dwukrotnie; poza tym przy tak małych liczebnościach, przy serii 10, a nawet 20-próbowej często do prób nie trafia ani jeden osobnik, średnia przybiera wartość zerową.

Powyższe uwagi w sprawie miarodajności oceny liczebności przez $M \pm m$ dotyczą sytuacji najmniej korzystnych spośród co najmniej kilkunastu; w odniesieniu do wielu przypadków kryteria te mogą więc być zbyt surowe, niemniej nigdy nie można wykluczyć możliwości, że zdarzyła się właśnie taka niekorzystna sytuacja.

Jeśli przyjmuje się jako miarodajną samą wartość średniej – $M$, bez uwzględnienia jej błędu, omyłki w ocenie liczebności organizmów mogą być większe; przy średnich liczebnościach > 1 os./1 próbę – do 2 razy, zaś poniżej 1 os./1 próbę – około 3 razy (przy seriach 10-próbowych – tab. III).

Znacznie większe omyłki można popełnić nie uwzględniając błędów średnich arytmetycznych przy badaniu zmian liczebności w czasie lub przestrzeni; przy tej samej liczebności organizmów różnice w średnich dla liczebności > 1 os. 1 próbę dochodziły do 3 razy (przy seriach $\geqslant$ 10 próbom), zaś dla liczebności < 1 os./próbę były jeszcze znacznie większe (przy seriach 20-próbowych do 7 razy; przy 10-próbowych nie można było ich obliczyć ze względu na zerowe wartości $M$min – tab. I).

Oczywiście wszystkie wnioski w sprawie reprezentatywności pobranego materiału odnoszą się do takiego typu rozmieszczenia, jakie wykazywał analizowany tu materiał, a nie będą obowiązywały np. dla przypadków rozmieszczenia wybitnie skupiskowego lub bardzo równomiernego. Jednakże analiza rozproszenia organizmów na bardzo dużym materiale i dla bardzo różnych środowisk (fig. 5–9) wykazała dość małe zróżnicowanie rozproszenia, co uprawnia do rozciągnięcia tych wniosków co najmniej na ogromną większość sytuacji.

Jak wynika z przeciętnych współczynników zmienności średnich arytmetycznych, które można potraktować jako wskaźniki równomierności rozmieszczenia organizmów, ze wzrostem liczebności rozmieszczają się one bardziej równomiernie, mniej skupiskowo (tab. IX).

Liczebność na jednostkę powierzchni dna szacowana na podstawie chwytaczy o małej powierzchni była w omawianym środowisku starorzecza Konfederatka nieco umniejszona w stosunku do rzeczywistej dla *Tendipedidae*, natomiast niezmieniona dla *Oligochaeta*. Wynika to prawdopodobnie stąd, że *Tendipedidae* uciekają na boki, podczas gdy *Oligochaeta* w głąb w momencie pobierania próby. Im mniejsza powierzchnia aparatu, tym większej stosunkowo ilości *Tendipedidae* udaje się umknąć. Fakty te mogą wzbudzić pewien sceptycyzm w stosunku do chwytaczy o małej powierzchni. Różnice liczebności nie są tu jednak zbyt duże, nie wypaczają wyników w sposób zasadniczy. Poza tym, sądząc z różnicy liczebności wyliczonej na podstawie chwytacza o powierzchni 10 $cm^2$ i 5 $cm^2$, przy powiększaniu powierzchni chwytnej aparatu różnice te szybko maleją i prawdopodobnie dla aparatow o powierzchni 20–30 $cm^2$ byłyby już nieznaczne. Trudno też powiedzieć, jak często zdarza się taka sytuacja, że liczebność na jednostkę powierzchni, szacowana przy pomocy małych chwytaczy jest mniejsza, niż szacowana przy pomocy dużych.

Analiza znaczenia gęstości sita dla ilości uzyskiwanych organizmów potwierdziła dotychczasowe wyniki (Jonasson 1955, 1958, Sander 1957, Kajak 1958); na podstawie materiału płukanego przez sito o określonej gęstości można z całą pewnością mówić jedynie o ilości organizmów których wielkość uniemożliwia im ucieczkę przez sito. Organizmy mniejsze na ogół uciekają przez sito bardzo szybko, o czym świadczy fakt wystąpienia większych ich ilości jedynie w próbach płukanych bardzo krótko – 45 sek., (tab. XV). Są jednak dane, że tempo ucieczki jest niejednakowe w różnych okresach (Kajak 1958).

Między litoralem i sublitoralem z jednej strony, a profundalem z drugiej zaznaczają się pewne różnice w równomierności rozmieszczenia organizmów; w profundalu jest ono bardziej równomierne, a mniej w litoralu i sublitoralu (tab. XIV). Różnice te są jednak mniejsze, niżby się można spodziewać na podstawie zróżnicowania środowiska – bardzo dużego w litoralu, mniejszego w sublitoralu i zupełnie znikomego w profundalu; poza tym różnice te uzewnętrzniają się dopiero przy porównaniu większego materiału; w poszczególnych wypadkach bynajmniej nie muszą być mniejsze w profundalu niż w litoralu (tab. XIII). Wobec stosunkowo niewielkich różnic w poszczególnych środowiskach, wnioski w sprawie wielkości próby i serii omówione na podstawie materiałów ze środowiska pozbawionego roślinności, zbliżonego do profundalu (pod względem zróżnicowania środowiskowego) odnoszą się również do litoralu i sublitoralu. Należy natomiast pamiętać o tym, że w litoralu jest znacznie więcej różnych środowisk niż w profundalu i że seria prób litoralnych, nawet w pełni reprezentatywna, charakteryzuje tylko pewien mały jego wycinek, natomiast seria prób profundalnych w znacznym stopniu jest reprezentatywna dla dużego obszaru tego środowiska.

Pełną ilość gatunków uchwytuje na ogół seria 5–6 prób chwytacza Ekmana i kilkunastu do kilkudziesięciu prób chwytacza rurowego o powierzchni 10 $cm^2$ (fig. 10–13). Przy tej samej, niewielkiej powierzchni dna wyeksploatowanej różnymi aparatami ilość gatunków bliższą rzeczywistości dają chwytacze o małej niż o dużej powierzchni.

*Oligochaeta* są rozmieszczone w przestrzeni bardziej nierównomiernie niż *Tendipedidae* i *Chaoborus*; prawidłowość tę stwierdzono zarówno dla różnych środowisk jeziornych (tab. VII i XIV) jak również dla niezarośniętej strefy starorzecza (tab. VI).

Dyskusja na temat wiarygodności materiału, wielkości serii i próby doprowadziła do wniosków dość optymistycznych; na podstawie stosunkowo niewielkiej ilości materiału, uwzględniając błąd średniej arytmetycznej i pamiętając o niebezpieczeństwach poważnych omyłek przy bardzo małych ilościach osobników na próbę, można zupełnie poprawnie oszacować liczebność organizmów w danym momencie. Powstaje natomiast kwestia, w jakim stosunku pozostaje tak oszacowana liczebność do zmian ilości organizmów w ciągu roku i z roku na rok. Zmiany te mogą być bardzo duże – od kilku do kilkuset razy (przeciętnie mniejsze w środowiskach mniej zmiennych, większe w środowiskach bardziej zmiennych)(tab. XVI).

Najlepszym wyjściem z tej sytuacji jest oparcie się o znajomość dynamiki liczebności, która jest dość mało zmienna (Eggleton 1931, Kajak 1958, Nedeljkovic 1959, Szilowa 1960). Oczywiście ma to zastosowanie tylko do zbiorników już przebadanych w cyklu rocznym. W innych wypadkach korzystne jest przynajmniej kilkakrotne pobranie prób w ciągu sezonu; przeciętna liczebność obliczona na podstawie takich materiałów różni się na ogół nie więcej niż kilka razy od przeciętnej liczebności w innych okresach, jak również od przeciętnej liczebności w tym samym okresie w innych latach (tab. XVII); gdy i to jest niemożliwe, pozostaje oparcie się o znajomość ogólnych prawidłowości dynamiki liczebności w danym typie zbiornika.

ADDRESS OF THE AUTHOR:
Dr. Zdzisław Kajak
Institute of Ecology
Warszawa, ul. Nowy Świat 72