Durham University

Durham E-Theses

Diatoms of the River Wear

Anthony John Peabody

How to cite:

Peabody, Anthony John (1969) Diatoms of the River Wear. Masters thesis, Durham University.

Use policy

The full-text may be used and/or reproduced, and given to third parties in any format or medium, without prior permission or charge, for personal research or study, educational, or not-for-profit purposes provided that:

- a full bibliographic reference is made to the original source
- a https://etheses.durham.ac.uk/id/eprint/10425/ is made to the metadata record in Durham E-Theses
- the full-text is not changed in any way

The full-text must not be sold in any format or medium without the formal permission of the copyright holders.

Please consult the full Durham E-Theses policy for further details.

Academic Support Office, The Palatine Centre, Durham University, Stockton Road, Durham, DH1 3LE
e-mail: e-theses.admin@durham.ac.uk Tel: +44 0191 334 6107
https://etheses.durham.ac.uk

DIATOMS OF THE RIVER WEAR

A thesis presented by

ANTHONY JOHN PEABODY

for the degree of Master of Science

of the University of Durham

September 1969.

DURHAM UNIVERSITY
SCIENCE
18 SEP 1969
LIBRARY

ABSTRACT

This work was undertaken to study aspects of the distribution of diatoms in the River Wear, and to equate the changes in the diatom communities with changes in the substrates and in river conditions. This investigation was extended to show the variation in cell motility, shape and volume, from the relatively unpolluted upper reaches to the more polluted lower reaches of the river.

I hereby declare that the work herein, now submitted as a thesis for the degree of Master of Science, is entirely the result of my own investigations, and has at no time been submitted for another degree.

E. J. Leaper ..... Candidate.

I certify that this statement is correct.

R. Whitton ..... Supervisor.

CONTENTS

I wish to thank Professor D.H. Valentine for the use of the facilities of the Department of Botany, in the University of Durham. I am also grateful to the Northumbrian River Authority for their financial support during this work.

I am greatly indebted to Dr. B.A. Whitton for his helpful advice, criticism and encouragement during the course of this work, which he supervised.

Thanks are also due to Mr. J.R. Carter for invaluable help and discussion on points of taxonomy.

1.1 Aims.

Because of the difficulties of describing and comparing diatom communities containing large numbers of species, the development of an objective method of analysis appeared to be a useful contribution to the field of diatom ecology.

By the expansion of the data made available by such a study, the diatom communities could also be studied in relation to their cell biology.

Some degree of comparison with diatoms in the River Tees would be feasible, using the available data.

1.2 The River Wear.

The limits of the River Wear are considered to be Wearhead, and Wearmouth Bridge, Sunderland (Figure 1). It is formed at Wearhead by the confluence of the Killhope Burn, and the Burnhope Burn. The Burnhope Burn flows out of the Burnhope reservoir, whilst the Killhope Burn rises upon the watershed above Wearhead.

The distance along the River from Wearhead to Wearmouth Bridge is 104 kilometres, but 59 kilometres when the distance is measured as a straight line.

Below Wearhead, the River Wear runs through mainly arable farmland, passing through Stanhope, Wolsingham, and Frosterley. Disused lead mines with their spoil heaps are found in this area, and there is evidence of former mining activities in many of the tributary streams, in particular, the Rookhope Burn.

The River Wear meets the more densely populated coastal strip at Bishop Auckland, and flows on through Durham and Chester-le-Street, until it meets the sea at Sunderland. It is in this part of the river, below Bishop Auckland that pollution from industrial and domestic sources is heaviest.

Lamb Bridge, (at the ninety second kilometre from Wearhead,) marks the highest point of tidal influence.

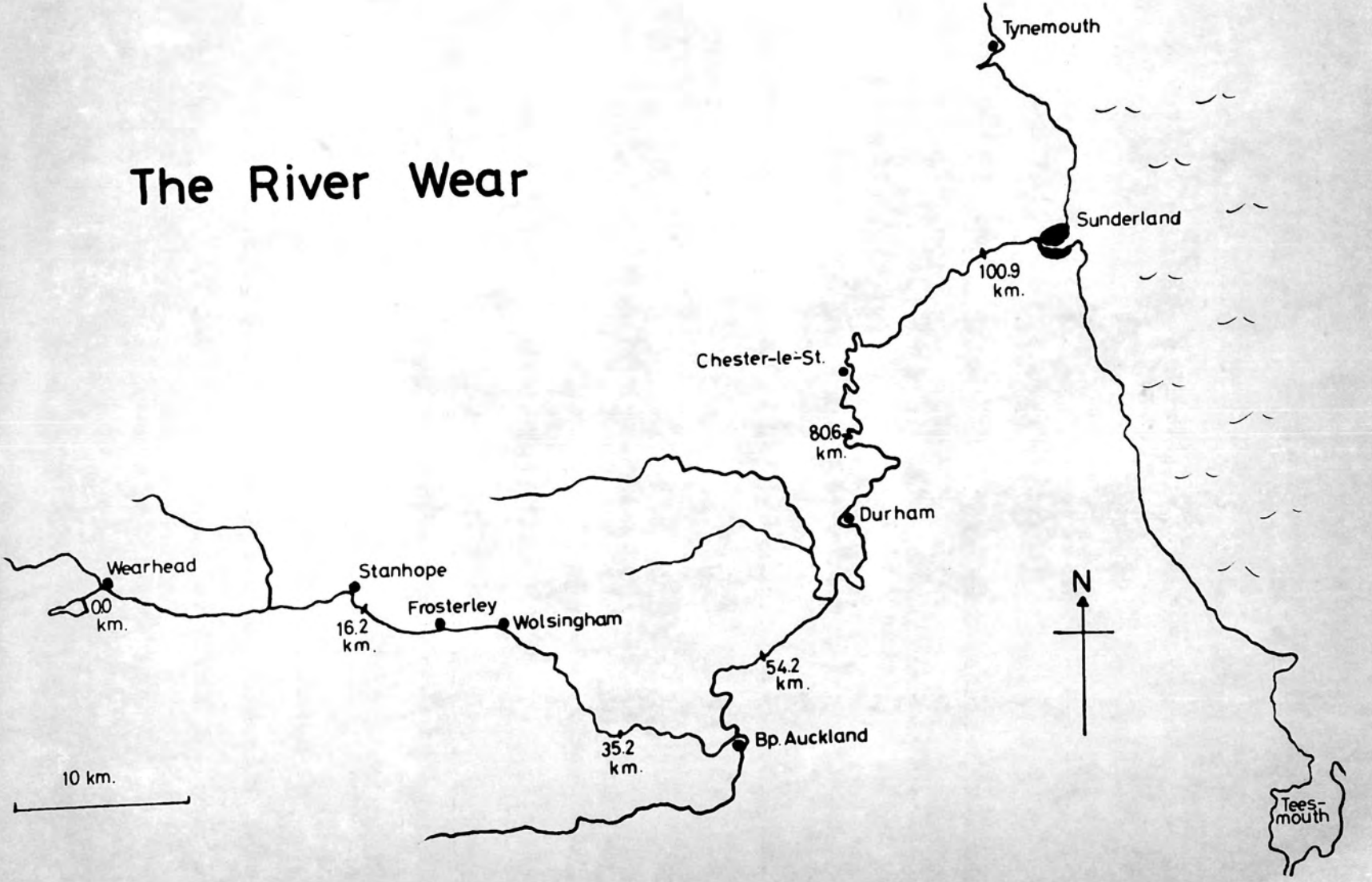

The River Wear
Tynemouth
Sunderland
100.9 km.
Chester-le-St.
80.6 km.
Durham
Wearhead
0.0 km.
Stanhope
16.2 km.
Frosterley
Wolsingham
54.2 km.
Bp. Auckland
35.2 km.
10 km.
N
Tees-mouth

Fig. 1

1.3 Lotic Diatoms.

The physiological requirements of diatoms vary greatly, and thus the group is widely distributed through many different environments. However, diatoms are apparently ubiquitous in lotic environments throughout the world, and are usually an important component of the algal populations associated with such environments.

1.31 Biology of Lotic Diatoms.

Environmental Factors. Lotic diatoms are continually surrounded by flowing water, and their growth and survival is dependant to a great extent on the characteristics of this environment.

McIntire (1966), in experiments using laboratory streams, has demonstrated that a fast current favours diatoms, rather than other algal groups. However, Cholnoky (1960), is of the opinion that algal associations are affected more by the fluctuations in oxygen content than by the mechanical effect of water movement. It is possible nonetheless, that particularly turbulent water flow is disadvantageous to those filamentous diatoms which form long chains, and those growing attached by mucilaginous stalks.

Other factors are also important, e.g. the level of mineral and organic nutrients (Chu, 1942), the nature of

the substrate (Pieczynska and Spodniewska, 1963), and climatic factors. In a lotic ecosystem, the time factor is especially important, since short periods of time may witness great changes in the environment, with concomitant changes in the algal populations (Butcher, Longwell, and Pentelow, 1937).

Biology of Individual Diatoms. An additional factor associated with the diatom community is the volume of the cells comprising the community. It is possible that the greater surface area to volume ratio of the smaller cells allows greater success in competition for nutrients, in nutrient deficient waters. Liebman (1942), (in Fjerdingstad 1950), holds that the smaller the cell, then the more readily the organism reacts to its environment. Johnson (1963), says that the greater sensitivity of small unicellular algae to antimetabolites may be explained by the large surface area to volume ratio. After the reasoning of Johnson, it is possible that larger cells, having a decreased surface area to volume ratio may be at less of a disadvantage in nutrient rich waters, since nutrients may be readily available from the habitat. In a survey of the neighbouring R. Tees, (Butcher, Longwell, and Pentelow, 1937), it was found that the small cells of Achnanthes minutissima were

very common in the relatively "clean" upper reaches of the river, where larger-celled species were most predominant.

Motile cells may also be at an advantage over non-motile cells in waters with a large amount of suspended particles. Non-motile cells will tend to be smothered by the continual deposition of these particles, whereas motile cells are theoretically able to migrate to more favourable positions on top of the deposited silt and detritus. Those cells with a large length to breadth ratio should be more efficient in the performance of this than more rounded, or oval cells.

1.32 Diatoms as Pollution Indicators.

It has often been suggested that diatoms may be used as indicators of pollution. However, Fjerdingstad (1964) discards diatoms as being unreliable indicators of pollution, with the exception of the Meridion circulare community, which he regards as an indicator of clean water conditions. Patrick, (undated), however, suggests that diatoms are a convenient group to use as indicators of pollution, because of the sensitivity of some species, and the abundance of the group in lotic environments.

This view is supported by Zelinka and Marvan (1961), who, in a modified saprobity system, hold that many diatoms reliably indicate levels of pollution, and express this reliability as a "fidelity factor" ranging from one to five.

Although the division of species into these arbitrary categories must be somewhat subjective, it is an indication of the use of diatoms as pollution indicators.

The concept of indicator species, however, may be invalid. A postulated indicator may have wide parameters of tolerance, so that whilst the species may reach a point of maximum development in an optimum environment, its physiological requirements are such that it may also occur in quantity in other, suboptimal environments, e.g. Nitzschia palea. This species, although widely regarded as an indicator of pollution, can often be found in association with Meridion circulare. It is for this reason that Fjerdingstad (1964) and Zelinka and Marvan (1961) doubt the value of indicator species.

The many saprobic systems suggested by many workers, e.g. Kolkwitz and Marsson (1908)(1909), Kolkwitz (1950), Zelinka and Marvan (1961), Fjerdingstad (1964)(1965), reflect the difficulties in the analysis of algal communities. The present knowledge of the methods involved in the use of a system relying on the saprobic valencies of species, and the classification of rivers by their saprobity, is too small and confused to be of wide application. Cholnoky (1960), holds that the saprobic systems are untenable, since the saprobic categories were the result of the nitrogen content of the

water, rather than of the degree of pollution.

1.33 Analysis of Diatom Communities.

It is often difficult to demonstrate the similarities and differences between several communities merely by lists of the component species and their relative abundance. In the past, workers have used this purely descriptive method to compare algal communities from a range of habitats, e.g. Butcher, Longwell, and Pentelow (1937). The results of such methods are often difficult to interpret, and there is also a subjective element inherent in the method.

Purely descriptive methods also have the disadvantage of not being easily presentable for the rapid interpretation of the results. The method proposed by Maucha (1932), uses a simple diagram to express the percentage compositions of natural waters. Such a method can be modified to express the composition of diatom communities, and would provide a means of rapid visual comparison. Unfortunately, the diagram can only accommodate a few species, so that some form of drastic selection would be necessary. If a large number of species were introduced onto the diagram, then the advantage of rapid visual interpretation would be lost.

The statistical approach of Patrick and Strawbridge (1963), whilst eliminating the subjective element, will probably be of but limited use to the majority of limnologists, due to its practical difficulties.

The present author is unhappy with the phytosociological treatment given by Margalef (1949), since it appears to be inapplicable to micro-organisms, and it may also give rise to a misleading nomenclature. For instance, he describes the Melosiretum rivularis association, which is characterised by the presence of Melosira varians. This is a common and widespread community in rivers. However, 10% of the communities described as Melosiretum rivularis by Margalef, lacked Melosira varians. The absence of this species must surely indicate that these communities be placed elsewhere, even though the associated, sub-dominant species were the same as those in true Melosiretum rivularis. In the description of communities, due regard must be paid to the dominant and most characteristic species present, rather than to species which might be expected to be present but which are not. The communities described by Symoens (1950), are too large to show small changes in the algal flora.

Butcher (1932), prefers to designate algal communities according to the dominant constituents, e.g. the Melosira varians-Navicula viridula community. This description is certainly more applicable than the phytosociological term of Melosiretum rivularis used by Margalef.

Ideally, a method is required which combines the minimum of subjectivity with the maximum of ease in interpretation. Of the systems available, a numerical method of comparison,

based on the index of similarity suggested by Czekanowski ((1913)-in Greig Smith (1964)), would appear to approach most closely these requirements.

METHODS

2.1 Collection of Samples.

Between the boundaries of Wearhead and Wearmouth Bridge, nineteen stations were chosen as parts of a sampling programme (Table I). These sampling stations were chosen so as to show to the greatest effect, the influence of progressive eutrophication on diatom communities down the river.

The first sixteen kilometres of the river, from Wearhead to Stanhope, (where enrichment of the relatively obligotrophic waters occurs by field drainage and small sewage outflows), were sampled at approximately two kilometre intervals. Thereafter, the river was sampled at approximately ten kilometre intervals, except where a major pollution source called for closer sampling, as at Bishop Auckland (Table I).

At each sampling station, an attempt was made to sample all the major habitats, and also any other important local habitats. The most commonly occurring habitats, or substrates, were stones, mosses, and filamentous algae. Other substrates of a more local nature include blue-green algal mats, mud, and submerged leaf litter.

No attempt was made to collect quantitative samples, using the methods described by Douglas (1958), since the considerable time required for such an operation, would necessarily have extended the time period over which the sampling procedure operated.

In the case of the communities on filamentous algae and algal mats, sampling was a simple operation of carefully removing a part of the submerged thallus, and placing it in a suitable screwcap container.

Mosses were sampled by squeezing out the water held between the leaves, and repeating the operation until all the material had been expressed. The sample of moss was repeatedly rewetted with river water, and the squeezings caught in a screwcap container. This material forms a flocculent sediment at the bottom of the container.

Epilithic algae were scraped off the stone by means of a blunt pen-knife, and washed into the screwcap container with river water. This method was also used to sample other epiphytic communities on hard substrates, e.g. submerged twigs.

Mud samples were collected by gently scooping the uppermost centimetre into the collecting bottle, with minimal disturbance of the underlying sediments.

Table I SAMPLING STATIONS

No.	Km.	Station
1	0	Wearhead
2	1.0	West Blackdene
3	2.7	Broken Way Ford
4	4.4	Bridge End
5	9.2	Cambo Keels
6	10.5	above Rookhope Burn
7	13.7	Briggen Winch
8	16.2	Shittlehope Burn
9	24.3	Wolsingham Bridge
10	26.3	Scotch Isle
11	35.2	weir above Witton Bridge
12	43.2	Newton Cap Bridge
13	44.2	Jock's Bridge
14	54.2	Page Bank
15	65.6	downstream of Shincliffe Bridge
16	70.6	Kepier
17	80.6	Cocken Bridge
18	92.2	Lamb Bridge
19	100.9	S.Hylton Ferry

The sampling programme was carried out on 3rd September 1966 (3/IX/66), during a period of low river level, when consequently more of the river bed was exposed to sampling.

The mean daily water flow on 3/IX/66 was 199 cusecs at Sunderland Bridge. The mean monthly rates at the same site were 377 cusecs in August 1966, and 266 cusecs in September 1966. Peaks of 2700 cusecs and 2000 cusecs were recorded in March and December respectively.

2.2 Examination and Preparation of Samples.

The collected samples, preserved in potassium iodide solution, were examined microscopically prior to acid treatment, in order to determine the presence of other, non-diatomaceous components of the populations. A portion of the sample was removed for cleaning.

The object of cleaning diatom material, (i.e. the removal of occluding organic and inorganic material), is to prepare the cells for subsequent microscopic examination. The desired end-product is a suspension of diatom frustules in distilled water. This cannot always be achieved easily, especially in samples containing a great amount of organic material, or sand intimately associated with the diatom frustules.

The following procedure was found to give satisfactory

results:

1. Centrifuge the sample, and discard the supernatant liquid. If it was thought that the sample contained calcareous material, a few drops of concentrated hydrochloric acid were added, until effervescence ceased with excess acid present. Centrifuge again.

2. Add up to 1g. solid potassium dichromate to the residue, followed by 5ml. concentrated sulphuric acid, added drop by drop. Allow to cool.

3. Add, with great care, 100 volume hydrogen peroxide, a few drops at a time, until little evolution of gas occurs with further addition of hydrogen peroxide. If the reaction is slow, allow to stand for several hours, or apply gentle heat, taking care to guard against the contents of the tube frothing over the top. Centrifuge, and discard the supernatant.

4. Boil the residue for up to 4 hours at 100°, in a mixture of concentrated nitric and hydrochloric acids, in a ratio of 5:1. Centrifuge and discard the supernatant.

5. Wash thoroughly in distilled water, and mount the frustules by drying off a drop of the cleaned suspension on a clean coverslip. The cleaned suspension can be stored after the addition of a few drops of absolute alcohol.

This procedure, though lengthy, and at times troublesome

due to violent effervescence, gives much more satisfactory results than treatment with concentrated acids alone. Carter (personal communication) reports that if, after boiling, the suspension is still somewhat dark, then addition of sodium hydroxide to an acid free suspension, and almost immediate decanting into an excess of water, will aid in cleaning. Evans (1961), also recommends the use of sodium hydroxide to deflocculate the suspension. However, sodium hydroxide should be avoided if possible, since dissolution of silica occurs, which is particularly detrimental to those forms with thin cell walls.

Mounting Media. When examining diatoms microscopically, it is desirable that a mounting medium with a high refractive index is used. "Hymount" was used in earlier work, but its refractive index of 1.66 was found to be too low for the identification of critical species. "Naphrax" (R.I.=1.75) was found to give superior definition, important where small diagnostic characters were being examined.

2.3 Counting Procedure.

The permanent preparations, mounted in "Naphrax", were examined using a Zeiss Standard GFL microscope, with a 100x oil immersion objective, and 10x eyepieces. An Optovar attachment gave a possible magnification of 2000x. The cells were counted along random traverses across the microscope slide, with the aid of a mechanical stage.

Castenholz (1960), in an investigation into benthic algae in certain N. American lakes, counted 300 cells in any one sample. It is not clear whether this refers to the number of valves counted, (i.e. 150 cells), or to the number of whole cells (i.e. 600 valves). In the present investigation, 600 valves were counted, (the equivalent of 300 complete cells).

After 600 valves had been counted, the slide was searched for any species present in small numbers, and which were missed in the standard counting procedure.

2.4 Cell Volume and Motility.

All those diatom species which possess a raphe structure are theoretically at least, capable of movement. Of the genera found in the River Wear, the following possess a raphe:

Cocconeis
Achnanthes
Rhoicosphenia
Amphipleura
Frustulia
Gyrosigma
Pleurosigma
Caloneis
Neidium
Diploneis
Stauroneis
Anomoeoneis
Navicula
Pinnularia
Amphora
Cymbella
Didymosphenia
Gomphonema
Denticula
Rhopalodia

Hantzschia

Nitzschia

Cymatopleura

Surirella

Movement in those forms with but one raphe, e.g. Cocconeis, and the attached forms, e.g. Didymosphenia, is not a common phenomenon, and is always slower than the rapid movements seen in some of the forms with two raphes, e.g. Navicula, Nitzschia.

The distribution of these various forms between the substrates was examined, together with an analysis of the shape, (i.e. length/breadth ratio) of these forms.

The length/breadth ratio was calculated for each species by examining and measuring at least ten cells. Where this was not feasible, due to the scarcity of the species, cell dimensions quoted by several authors, were used to calculate the length/breadth ratio.

2.41

At least five cells were measured for each species whenever possible, but often, less than five cells were present or available for measurement in the case of the rarer species. Up to twenty individuals were measured in the case of the more common species, e.g. Navicula gregaria.

It was not possible to calculate the cell volumes for all the less common species in the river, since many of

the cells were not amenable to measurement.

Nevertheless, it was possible to calculate the cell volumes of seventy species.

2.42 Calculation of Cell Volume.

The cell volumes were calculated after the method described by Castenholz (1960). The valve faces were drawn to scale by means of a Reichert camera lucida apparatus. The area of this valve face was determined by an "Albrit" planimeter. In girdle view, many diatoms are rectangular, and the cell volumes of these diatoms can be calculated from the product of the girdle width and the area of the valve face. In diatoms where the girdle aspect is cuneate, e.g. Surirella, Gomphonema, or irregular, e.g. Cymatopleura, the mean width of the girdle was found by dividing the area of the girdle face (determined by the camera lucida and planimeter) by the length. The product of this mean width, and the area of the valve face gave, as above, the cell volume. The cell volume is expressed in microns^3.

2.5 Comparison of Communities.

In the present investigation, a numerical method of comparison is used, based on the index of similarity suggested by Czekanovski.

2.51 Outline of Original Czekanovski Method.

The index of similarity, in its original form, expresses the number of species common to the two communities (A,B) being compared, as a percentage of the mean number of species in both communities:

$$\frac{2c \times 100}{a + b} = \text{Index of Similarity (Czekanovski)}$$

where:

a = the number of species in community A

b = the number of species in community B

c = the number of species common to both communities.

However, since this system compares communities on the basis of the presence or absence of species, it will not be satisfactory in comparing communities which vary rather in the relative abundance of the constituent species.

2.52 Adaptations of the Czekanovski method.

In the system adopted, Brisch-Vistem 1000 item centre punch cards were used. One punch card was alloted to each community. The punch card is divided into 100 vertical divisions, and each vertical column is divided into ten horizontal divisions or ranks. Each vertical column was

alloted to one species, and the horizontal ranks were used to indicate the level of abundance of the species. In this way, it was possible to compare the communities in respect of 100 of the diatom species in the River Wear, and their relative abundance. It will be noted that this necessarily includes a comparison on the basis of presence or absence of a species.

The abundance of a species was taken to be the number of cells of that species which occurred in the 600 cells counted. It was measured on an arbitrary scale of 'Units of Abundance':

No. of cells/ 600 cell sample.	Units of Abundance.
1- 30	1
31- 60	2
61-120	3
121-180	4
181-240	5
241-300	6
301-360	7
361-420	8
421-480	9
481-550	10

Thus a species accounting for 500 of the 600 cells counted in the sample, would warrant 10 units of abundance

in that community, and thus 10 holes in the vertical column alloted to that species on the punch card.

On any one punch card therefore, the number of punched holes represents the number of 'Units of Abundance' in one community.

In the application of the modified Czekanovski index of similarity, these 'Units of Abundance' take the place of the species in the unmodified form of this method.

Thus:

$$\frac{2c \times 100}{a + b} = \text{Index of Similarity (modified)}$$

where:

a = number of 'Units of Abundance' in community A

b = number of 'Units of Abundance' in community B

c = number of 'Units of Abundance' common to both communities, A and B.

Since one 'Unit of Abundance' is equivalent to one punched hole in the punch card, the comparison of two communities is made by superimposing one card on the other. The number of holes in common is the value "c".

Indices of similarity of communities from different substrates were entered onto a matrix, and ordinated to show areas of greatest similarity, after the method of Sneath and Sokal (1962).

A list of the species incorporated onto the cards is

given below. (Table II) The compilation of such a list from the greater number of species which occur in the River Wear, could not be done by random selection, since common, or important species may have been excluded. Such species, e.g. Cymbella ventricosa, and Navicula gregaria were automatically included on the list, and the remainder of the 100 divisions were filled by random selection from the remaining, less common species.

Thus the 100 species selected for comparison include all the common species, most of those species with a limited distribution, and some of the species which occur in but one community.

Table II

1 Achnanthes conspicua
2 A. flexella
3 A. lanceolata
4 A. minutissima
5 A. pyrenaica
6 Amphora ovalis
7 Amphipleura pellucida
8 A. rutilans
9 Caloneis bacillum
10 C. silicula
11 Ceratoneis arcus
12 Cocconeis pediculus
13 C. placentula
14 Cyclotella meneghiniana
15 Cymbella affinis
16 C. delicatula
17 C. leptoceros
18 C. microcephala
19 C. prostrata
20 C. sinuata
21 C. ventricosa
22 C. helvetica
23 Denticula tenuis
24 Diatoma hiemale

Table II (continued)

25 Diatoma vulgare

26 Diploneis ovalis

27 Eunotia exigua

28 E. lunaris

29 E. tenella

30 E. trinacria

31 Fragilaria intermedia

32 Frustulia vulgaris

33 Gomphonema abbreviatum

34 G. acuminatum

35 G. angustatum

36 G. gracile

37 G. longiceps

38 G. olivaceoides

39 G. olivaceum

40 G. parvulum

41 G. sphaerophorum

42 Melosira varians

43 M. nummuloides

44 Meridion circulare

45 Navicula anglica

46 N. atomus

47 N. avenacea

48 N. certa

Table II (continued)

49	Navicula	cincta
50	N.	contenta
51	N.	gracilis
52	N.	gregaria
53	N.	hungarica
54	N.	lapidosa
55	N.	menisculus
56	N.	minima
57	N.	minuscula
58	N.	muralis
59	N.	mutica
60	N.	pelliculosa
61	N.	pupula
62	N.	schonfeldtii
63	N.	subhamulata
64	N.	cryptocephala
65	N.	vitabunda
66	N.	bryophila
67	Nitzschia	acicularis
68	N.	acuta
69	N.	acuminata
70	N.	amphibia
71	N.	communis
72	N.	dissipata

Table II (continued)

73	Nitzschia	dubia
74	N.	fonticola
75	N.	frustulum
76	N.	hantzschiana
77	N.	ignorata
78	N.	kutzingiana
79	N.	linearis
80	N.	palea
81	N.	sigmoidea
82	N.	stagnorum
83	N.	thermalis
84	N.	tropica
85	N.	apiculata
86	Pinnularia	interrupta
87	P.	microstauron
88	P.	viridis
89	P.	wijkensis
90	Rhoicosphenia	curvata
91	Surirella	angustata
92	S.	biseriata
93	S.	ovata
94	Synedra	acus
95	S.	affinis
96	S.	rumpens

Table II (continued)

97 Synedra ulna

98 S. vaucheriae

99 Tabellaria flocculosa

100 Thallassiosira fluviatilis

RESULTS

3. Motility.

3.1 Introduction.

Diatom motility in those cells with one raphe is certainly possible, in at least some species, but the phenomenon is more usually regarded as a characteristic of the Biraphideae. However, since the Monoraphideae are also theoretically capable of movement, albeit often sluggish and infrequent, the distinction between motile and non-motile species has been made solely on the presence or absence of one or more raphe structures.

3.2 Epilithic and Eurhynchium Substrates.

The effect of these two substrates on the numbers of motile cells in the first 43 Kilometres of the River Wear is shown in Table III. The epilithic substrates support more motile cells than do the Eurhynchium substrates. At Km. 4.4, 99% of the cells present on the epilithic substrate are motile. The highest proportion of motile cells on the Eurhynchium substrate is 92.5% at Km. 9.2.

The mean figures for the first 43 Kilometres show that on the epilithic substrate 89.4% of the cells are motile, whilst on the Eurhynchium substrate, only 78.1 are motile. (Table III).

The fluctuations in the first 15 Kilometres are due to variations in the numbers of Achnanthes minutissima, which is particularly abundant.

Table III

Distribution of Motile Cells on Different Substrates

Km.	Eurhynchium	Epilithic	Unbranched green filamentous algae.
0.0	71.0	77.0	85.0
1.0	61.3	-	72.5
2.7	80.0	94.0	50.5
4.4	74.0	99.0	97.0
9.2	92.5	91.0	-
10.5	79.0	83.0	64.5
13.7	83.5	90.5	-
16.2	88.0	87.0	69.0
24.3	89.0	97.5	-
35.2	88.0	91.0	-
43.2	73.0	84.0	-
mean %	78.1	84.0	73.7

3.3 Unbranched Green Filamentous Algal Substrates.

From the incomplete data available, (Table III), it appears that the unbranched green filamentous algal substrate supports fewer motile cells than either the epilithic or Eurhynchium substrates. From the data, the mean figures for motile cells on this substrate is only 73.9%.

4. Shape.

4.1 Introduction.

By the simple methods described above, the length to breadth ratios of 66 potentially motile species were measured and calculated. Not all of these species were observed to be motile in the samples collected from the river, but each species possesses at least one fully formed raphe structure.

4.2 Comments on Length/Breadth Ratio.

Table IV shows the length to breadth ratios for the species occuring in the communities which were investigated with respect to cell shape. The species with the greatest length to breadth ratio is Nitzschia acuta (31.0), followed by Nitzschia sigmoidea (30.0), N. acicularis, (28.5), and N. linearis (22.7). The lowest ratios were shown by Surirella ovata (1.6), and Cocconeis pediculus (1.4).

Of the species measured, 40 have ratios lower than 4.5. Of the remaining 26 species, with ratios of 4.6 and over, 13 are species of Nitzschia.

Table IV.

Nitschia acuta	31.0
N. sigmoidea	30.0
N. acicularis	28.5
N. linearis	22.7
N. ignorata	15.0
N. filiformis	12.0
N. palea	9.0
Pinnularia wijkensis	7.8
Nitzschia amphibia	7.7
Cymbella cesati	7.0
Nitzschia tropica	6.8
N. communis	6.6
Rhoicosphenia curvata	6.2
Navicula cryptocephala	5.9
Nitzschia frustulum	5.8
N. thermalis	5.8
Gomphonema olivaceoides	5.6
Rhopalodia parallela	5.6
Caloneis silicula	5.5
Navicula gracilis	5.5
Pinnularia viridis	5.5
Gomphonema gracile	5.4
G. abbreviatum	5.2
Amphipleura rutilans	5.0

Table IV. (continued)

Caloneis bacillum	4.6
Gomphonema sphaerophorum	4.5
Navicula certa	4.5
N. contenta	4.5
Nitzschia kutzingiana	4.3
Pinnularia microstauron	4.3
Achnanthes minutissima	4.0
Cymbella leptoceros	4.0
Gomphonema angustatum	4.0
Nitzschia dissipata	4.0
Cymbella parva	3.9
Surirella biseriata	3.9
Gomphonema parvulum	3.8
G. olivaceum	3.7
Navicula avenacea	3.7
N. minima	3.6
Cymbella microcephala	3.5
C. delicatula	3.3
Navicula menisculus	3.2
Surirella angustata	3.2
Navicula lapidosa	3.1
Nitzschia fonticola	3.0
Cymbella prostrata	2.8

Table IV. (continued)

Achnanthes lanceolata	2.8
A. conspicua	2.6
Cymbella sinuata	2.6
Navicula anglica	2.6
N. mutica	2.6
Achnanthes pyrenaica	2.5
Amphora ovalis	2.4
Denticula tenuis	2.4
Navicula minuscula	2.4
N. subhamulata	2.4
N. gregaria	2.3
N. pelliculosa	2.1
N. atomus	2.0
Cocconeis placentula	1.9
Navicula muralis	1.9
N. subatomoides	1.9
Surirella ovata	1.6
Cocconeis pediculis	1.4
Cymbella ventricosa	1.8

4.3 Explanation of Histograms.

The range of length to breadth ratios is divided into 7 ranks (Figure 2):

	No. of species
1.4--1.9	6
2.0--2.4	7
2.5--2.9	7
3.0--3.4	5
3.5--3.9	7
4.0--4.5	9
4.6+	26

The most common diatoms fall into the ranks at the extremes of the range, e.g. Achnanthes minutissima (4.0), and Cymbella ventricosa (1.8), whilst many of the less common species fall into the ranks in the centre of the range. Thus a histogram based upon these ranks tends to be biased towards the extremes of the range. However, no other scheme for the division of the range proved to be superior to the form adopted.

4.4 Effect of Substrate and Position Downstream on the Motile Cell Component of the Community.

Figures 3-7 show the distribution of the potentially motile cells of the various length to breadth ratios on 3 substrates, at five sites from Km. 0.0 to Km. 16.2 Figure 8

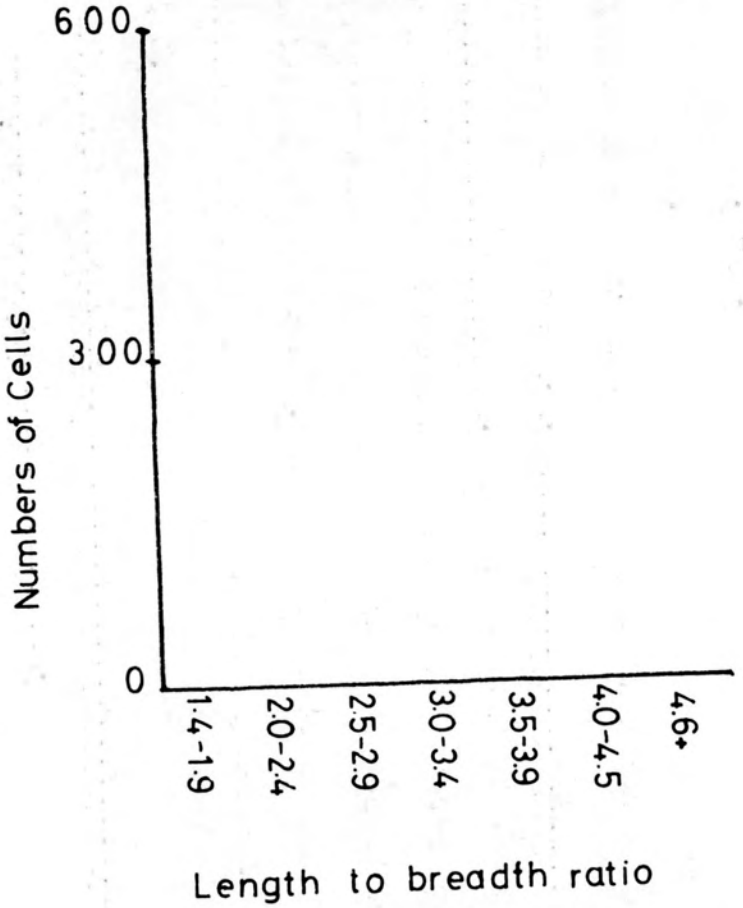
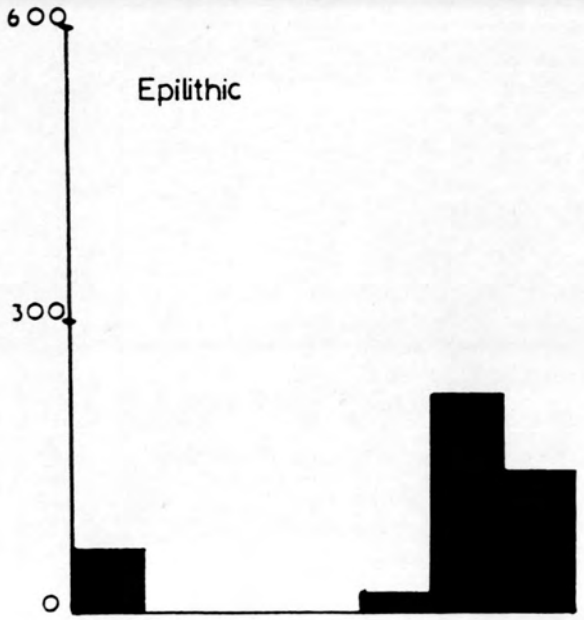
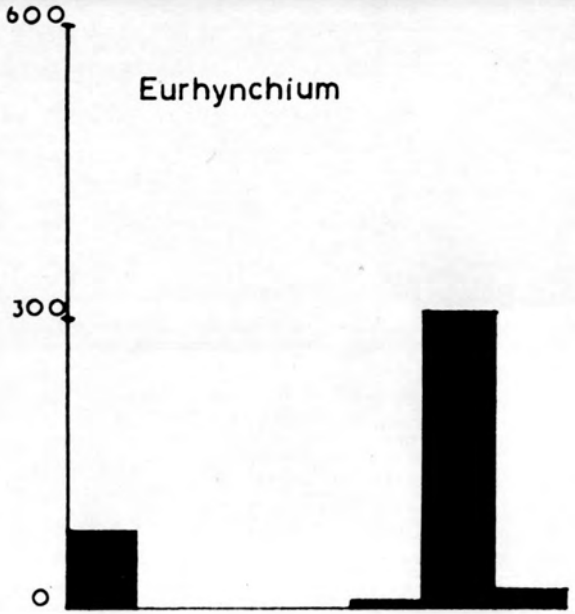
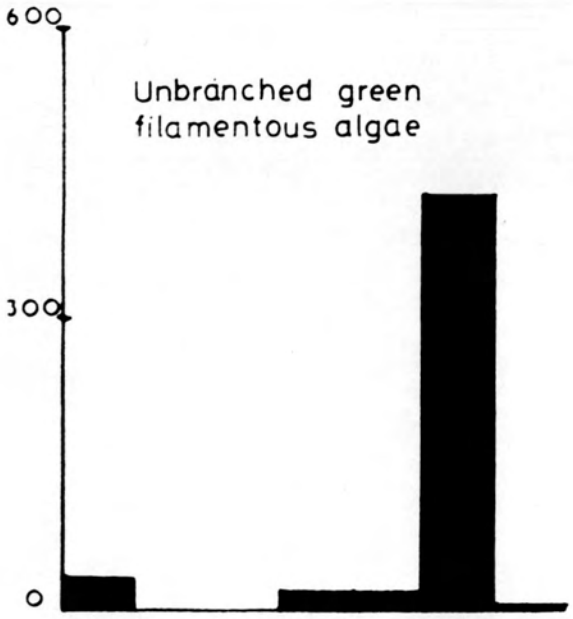


Fig. 2

Explanation of Figs. 3~8

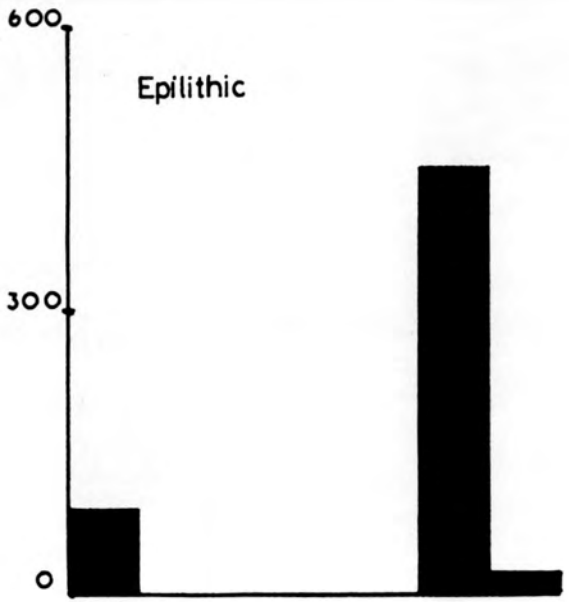


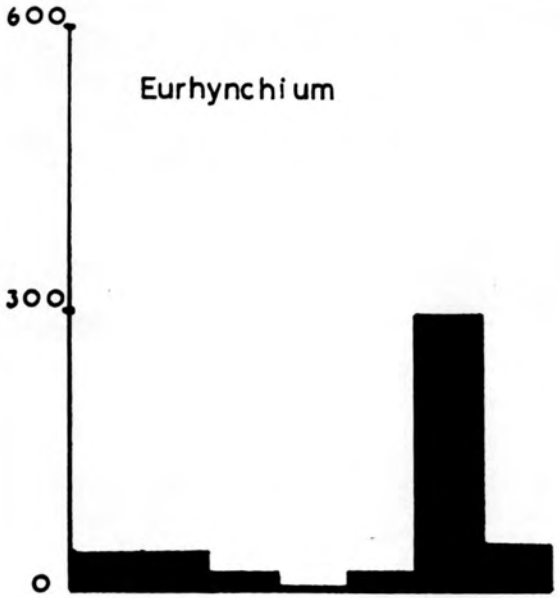


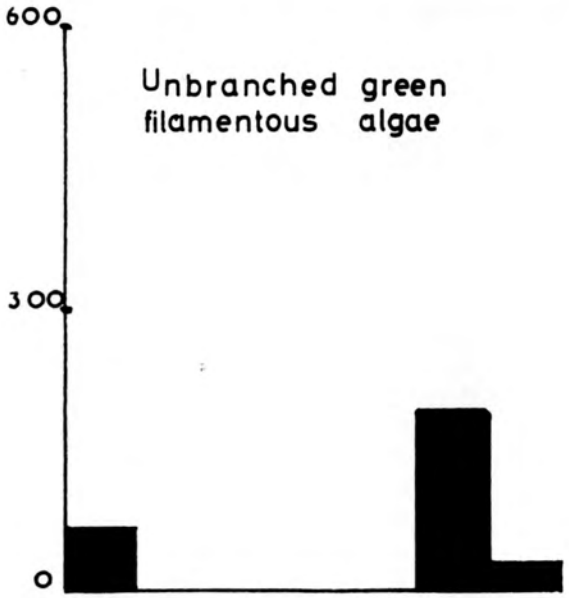


Wearhead Km.0·0

Fig. 3

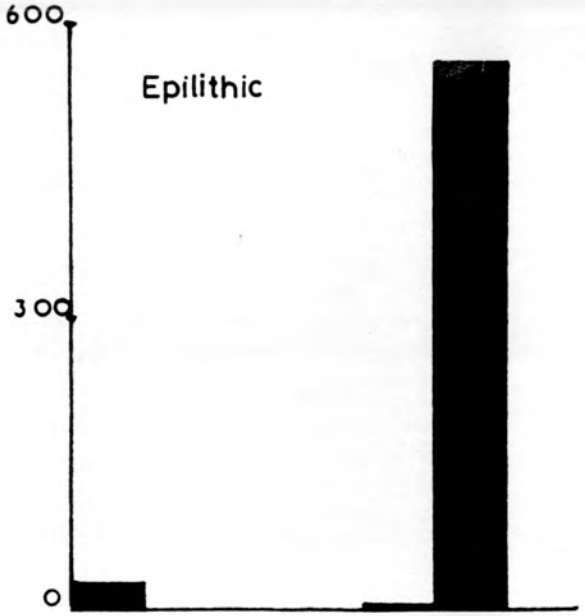


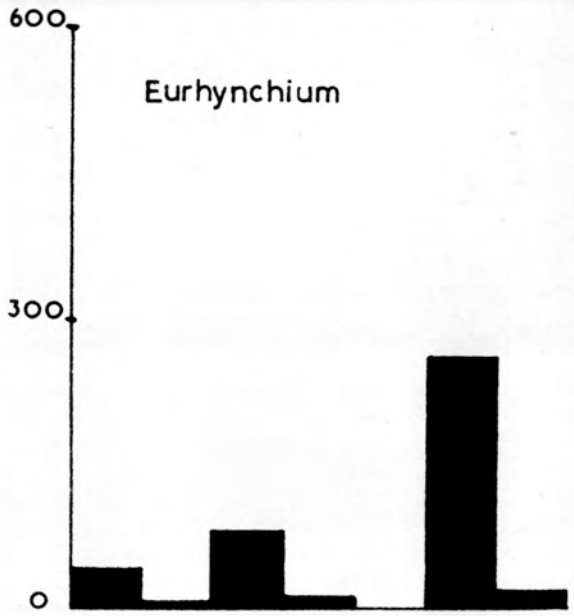


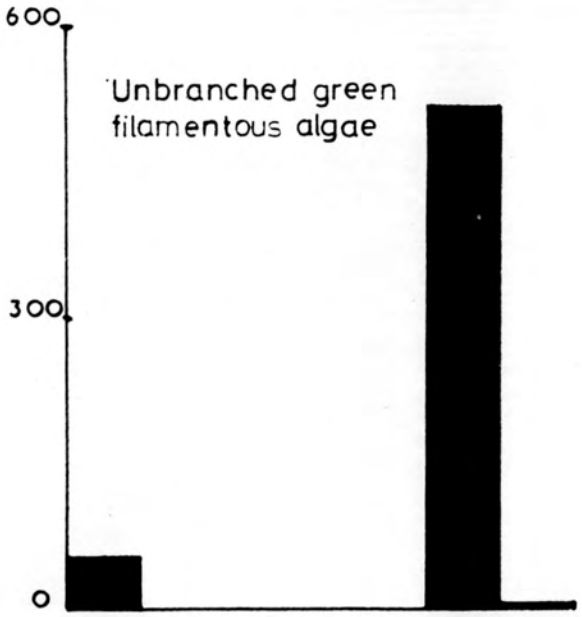


Broken Way Ford
Km. 2·7

Fig. 4

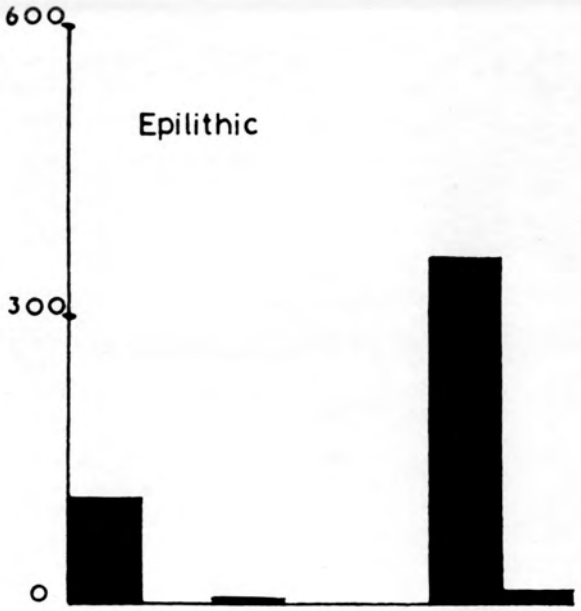


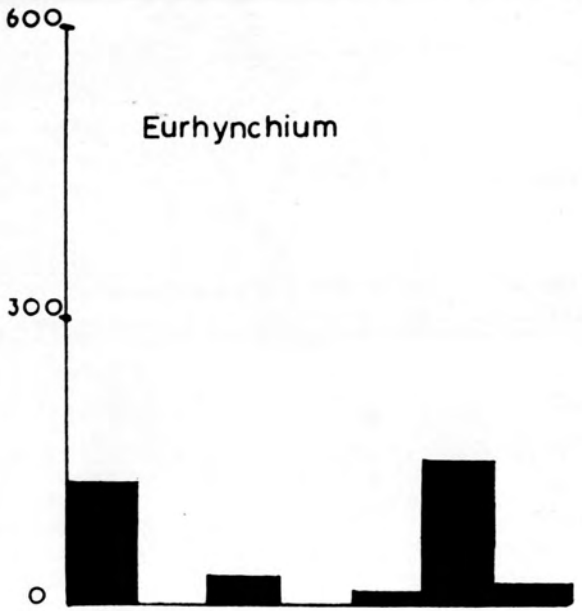


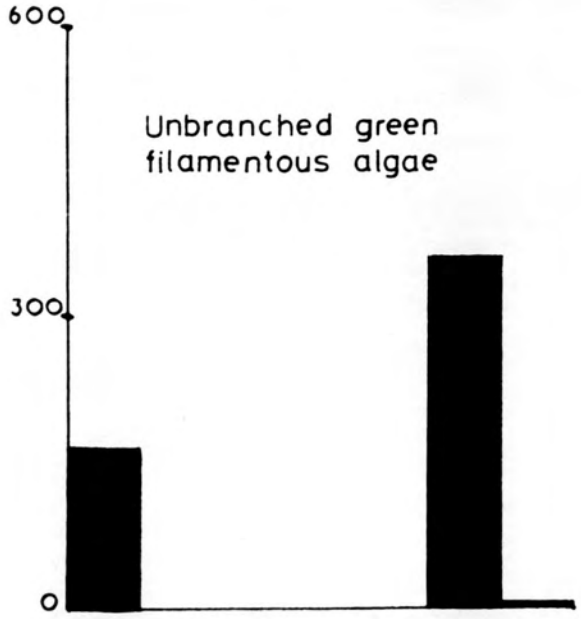


Bridge End Km.4·4

Fig. 5

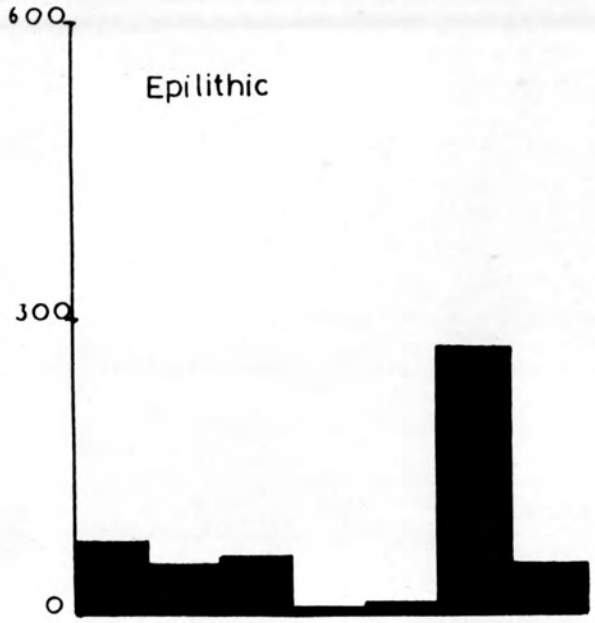


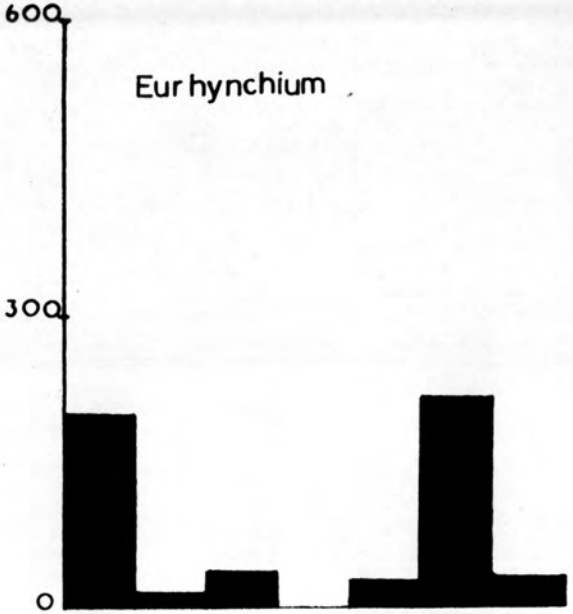


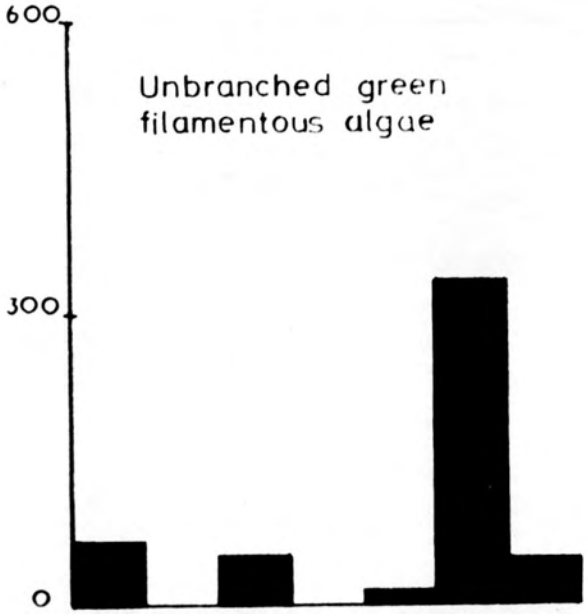


Rookhope Burn Km. 10·5

Fig. 6







Shittlehope Burn
Km. 16·2

Fig. 7

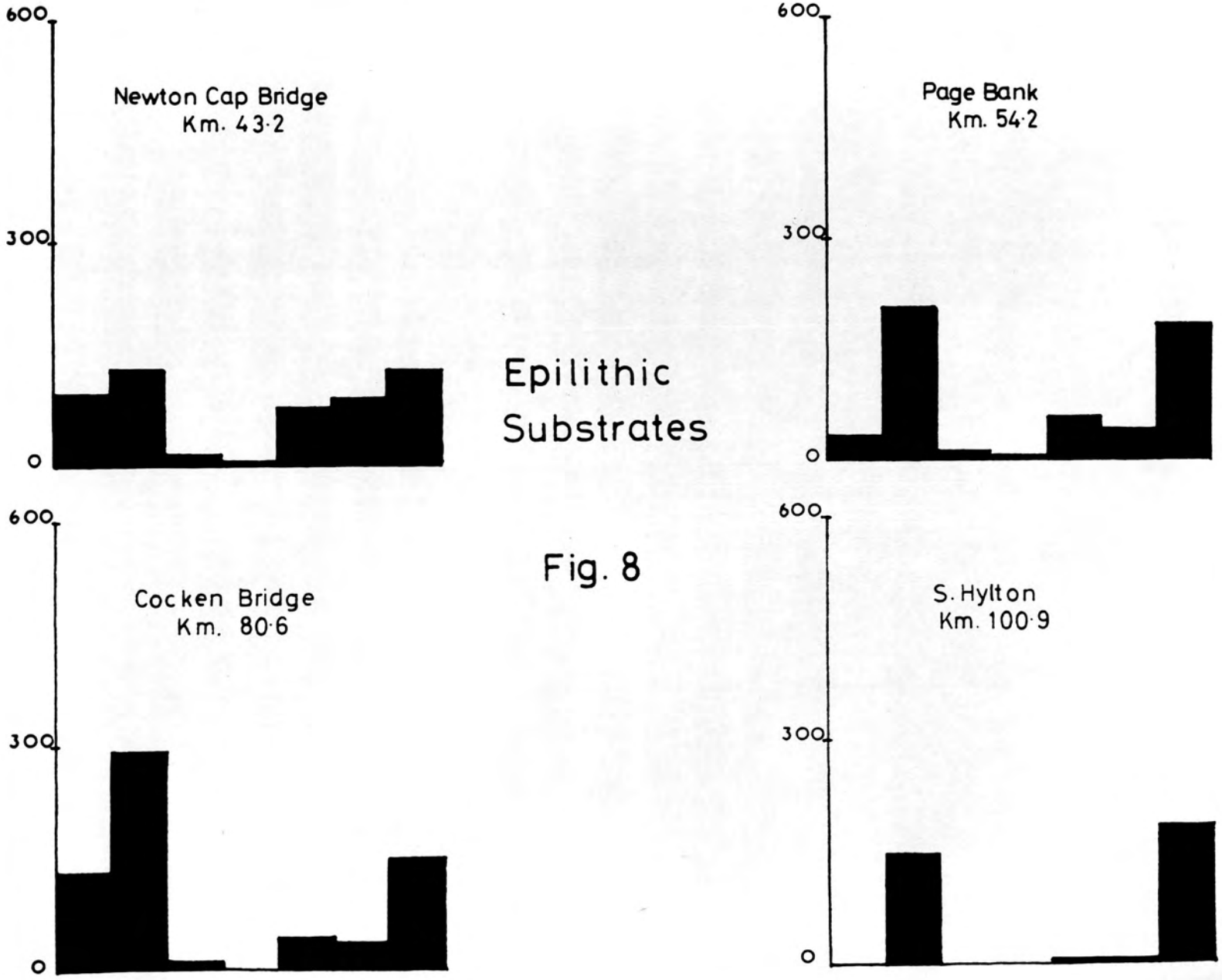

600
300
0
Newton Cap Bridge
Km. 43·2
600
300
0
Page Bank
Km. 54·2
Epilithic
Substrates
600
300
0
Cocken Bridge
Km. 80·6
600
300
0
S. Hylton
Km. 100·9

Fig. 8

shows the situation on four epilithic substrates further downstream than in Figures 3-7.

Some of the more interesting features arising from the data are:

(a). The epilithic substrates support a larger number of cells in the higher ranks, than does the Eurhynchium substrate. It is possible that the more narrow cells, e.g. Nitzschia spp., are more fitted to moving through obstructing debris than are the wider forms. A second contributory factor to the differences between the two substrates are the larger numbers of cells which are often attached, and which have smaller length to breadth ratios.

(b). There is a tendency for the Eurhynchium substrate to support more motile cells in the middle ranks than either the epilithic or the unbranched green filamentous algal substrates.

(c). The unbranched green filamentous algal substrate is somewhat variable in the length to breadth ratios of the diatoms upon it as compared from site to site. This variability may be ascribed to the length of the filament, and to the density of the filaments in the tuft. In any case this substrate resembles the epilithic rather than the Eurhynchium substrate, in tending to support more cells with high length to breadth ratios, rather than those with low

ratios.

(d). Species with a higher length to breadth ratio might have been expected to become more abundant with progression downstream, due to the postulated ease of movement of the former through the debris deposited by the abatement of river current speeds. Figure 8 shows that this is scarcely so, since with the exception of S. Hylton Ferry (100.9 Km.), there are roughly equal numbers on either side of the median line. The situation at 100.9 Km. should be considered atypical in that the bulk of the diatom community at this point is composed of the non-motile Melosira nummuloides.

VOLUME

5.1 Introduction.

By the methods described above, it was possible to calculate the average cell volume for 68 species of diatoms. These values, expressed in μ^3 are shown in Table V.

5.2 Comments on Cell Volume Figures.

Interesting points shown by Table V are:

(a). The species with the greatest cell volumes are:

Nitzschia sigmoidea	(22,000)
Cymatopleura solea	(15,578)
Cymbella prostrata	(10,178)

These three species are potentially motile.

(b). The species with the lowest cell volumes are:

Navicula atomus	(18)
N. pelliculosa	(22)
N. minima	(33)

(c). Between the two extremes, half the species have volumes between $101\mu^3$ and $1000\mu^3$ (Figure 9), and most species (19), fall within the range $251\ \mu^3$-$1000\mu^3$.

(d). *Achnanthes minutissima*, a common diatom, particularly in the upper reaches, has a relatively low cell volume, ($70\mu^3$).

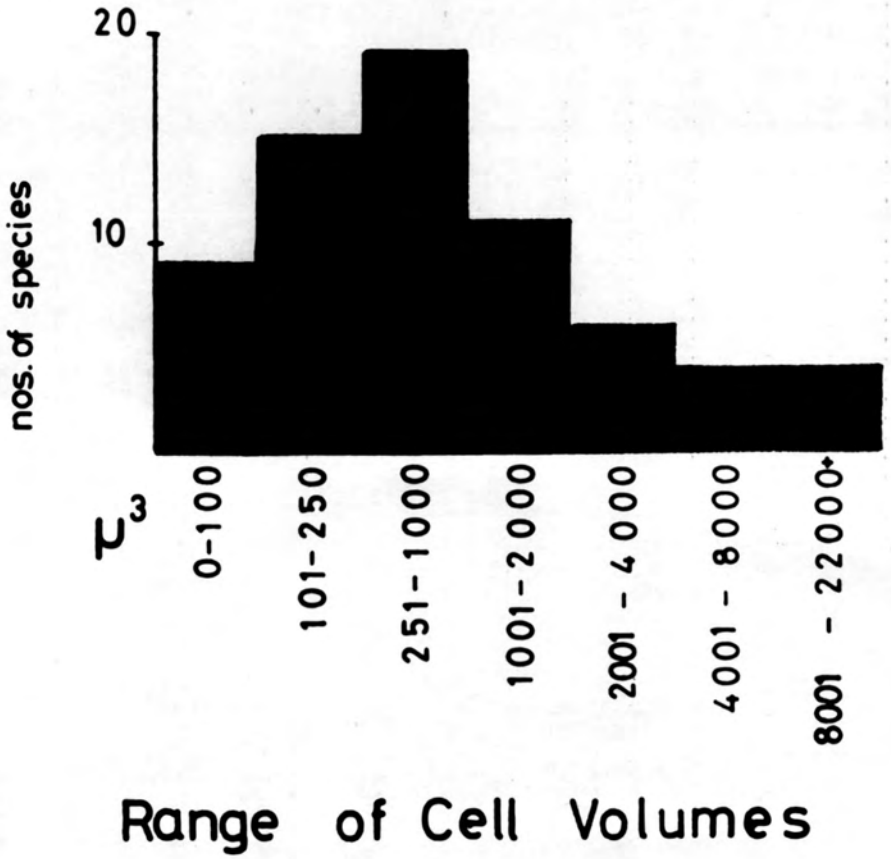

20
10
nos. of species
μ^3
0-100
101-250
251-1000
1001-2000
2001-4000
4001-8000
8001-22000+
Range of Cell Volumes

Fig. 9

(e). It is noteworthy that Navicula gregaria ($144\mu^3$), and N. cryptocephala ($159\mu^3$), which have been shown above to have close length to breadth ratios, are also close together in their cell volumes.

DURHAM UNIVERSITY
SCIENCE
18 SEP 1969
REDPATH
LIBRARY

Table V.

	μ^3
Nitzschia sigmoidea	22000
Cymatopleura solea	15578
Cymbella prostrata	10178
Caloneis amphisbaena	8827
Nitzschia dubia	5051
Surirella biseriata	4256
Pinnularia viridis	4170
Thalassiosira fluviatilis	3528
Cocconeis pediculus	3245
Synedra ulna	3250
Surirella ovata	3124
Nitzschia sigma	2964
Melosira varians	2422
Gomphonema acuminatum	2332
Melosira nummuloides	1997
Surirella angustata	1796
Navicula gracilis	1780
Diatoma vulgaris	1477
Nitzschia hungarica	1409
Navicula avenacea	1407
Rhoicosphenia curvata	1225
Nitzschia acuminata	1166
Synedra affinis	1080
Cyclotella meneghiniana	1035

Table V. (continued)

	μ^3
Nitzschia acuta	1029
Cymbella parva	945
Ceratoneis arcus	835
Tabellaria flocculosa	800
Nitzschia linearis	793
Nitzschia thermalis	790
Gomphonema olivaceoides	676
Nitzschia dissipata	579
Meridion circulare	558
Nitzschia communis	461
Cymbella delicatula	448
Nitzschia fonticola	392
Eunotia lunaris	367
Cocconeis placentula	349
Fragilaria intermedia	320
Gomphonema angustata	307
Cymbella ventricosa	293
Synedra vaucherii	283
Navicula anglica	283
Amphora ovalis	236
Navicula hungarica	230
Navicula subhamulata	211
Denticula tenuis	211
Navicula mutica	207

Table V. (continued)

	μ^3
Cymbella sinuata	198
Navicula menisculus	193
Gomphonema parvulum	192
Navicula cryptocephala	159
Nitzschia palea	150
Navicula gregaria	144
Eunotia exigua	136
Achnanthes lanceolata	129
Navicula lapidosa	109
Navicula minuscula	104
Navicula cincta	90
Cymbella microcephala	79
Achnanthes pyrenaica	75
Achnanthes minutissima	70
Gomphonema olivaceum	69
Synedra rumpens	63
Navicula minima	33
Navicula pelliculosa	22
Navicula atomus	18

5.3 Effect of Position Downstream on Cell Volume.

The average cell volume of all populations at all sites in the river were calculated (Table VI):

Table VI

Km.	Volume μ^3
0.0	260
1.0	385
2.7	331
4.4	143
9.2	220
10.5	338
13.7	353
16.2	332
24.3	249
35.2	316
43.2	707
44.2	697
54.2	404
65.6	737
70.6	835
80.6	911
100.9	1451

Figure 10 shows these results graphically. There is a definate trend towards an increase in cell volume with

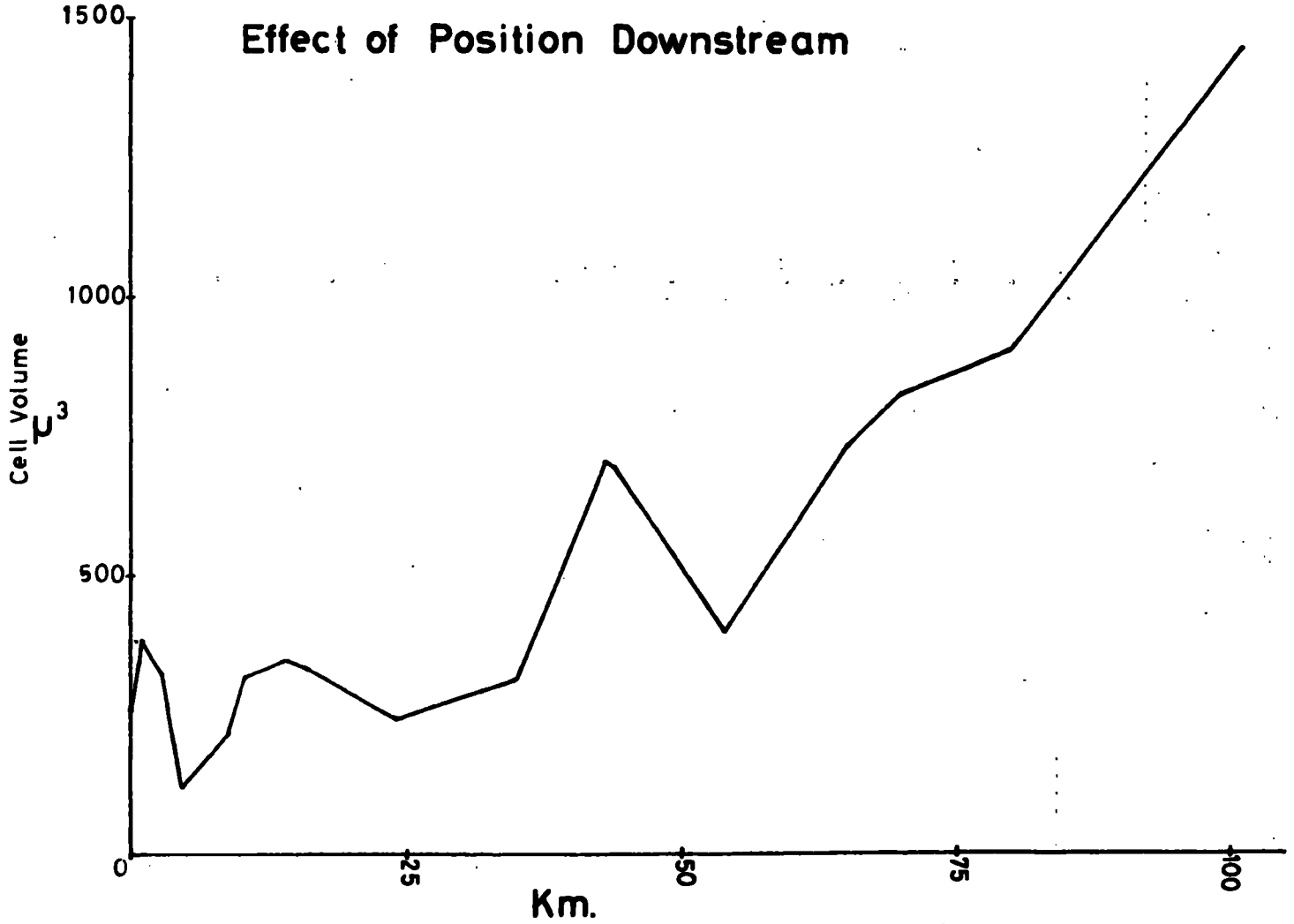

Effect of Position Downstream
1500
1000
500
0
Cell Volume
μ^3
25
50
75
100
Km.

Fig.10

progress downstream. The peak between Km. 35.2 and Km. 54.2 coincides with the increased pollution from the conurbation of Bishop Auckland and its environs. This peak is followed by a decline, probably due to self-purification of the river. After Page Bank however, (Km. 54.2), the average cell volume increases steadily, until the maximum recorded value ($145\mu^3$), at S. Hylton (100.9 Kilometre).

There is a fivefold in cell volume between Km. 0.0 and Km. 100.9, and a tenfold difference between the lowest value recorded ($143\mu^3$), and the highest ($145\mu^3$), at Km. 4.4 and Km. 100.9 respectively.

5.4 Effect of Substrate on Cell Volume.

Complete data for two substrates only is available, these being the epilithic and the Eurhynchium substrates. The average cell volumes of populations on these substrates appear in Table VII.

Table VII.

Km.	Epilithic	Eurhynchium
0.0	270	274
1.0	-	445
2.7	155	296
4.4	91	230
9.2	205	234
10.5	406	285
13.7	267	441
16.2	259	406
24.3	169	329
35.2	244	388
43.2	556	859

The average value for these two sites are $215\mu^3$ for the epilithic substrate, and $381\mu^3$ for the Eurhynchium substrate. After Km. 43.2, populations on these two substrates do not always occur at the same site, and the value of a comparison between the two substrates after this point is lost. The table is shown graphically in Figure 11.

From Figure 11 it will be seen that at one site only does the population on the epilithic substrate exceed the Eurhynchium substrate in cell volume, at Km. 10.5. At every other station, the Eurhynchium substrate is characterised by a higher cell volume.

The reason for this difference remains obscure, and

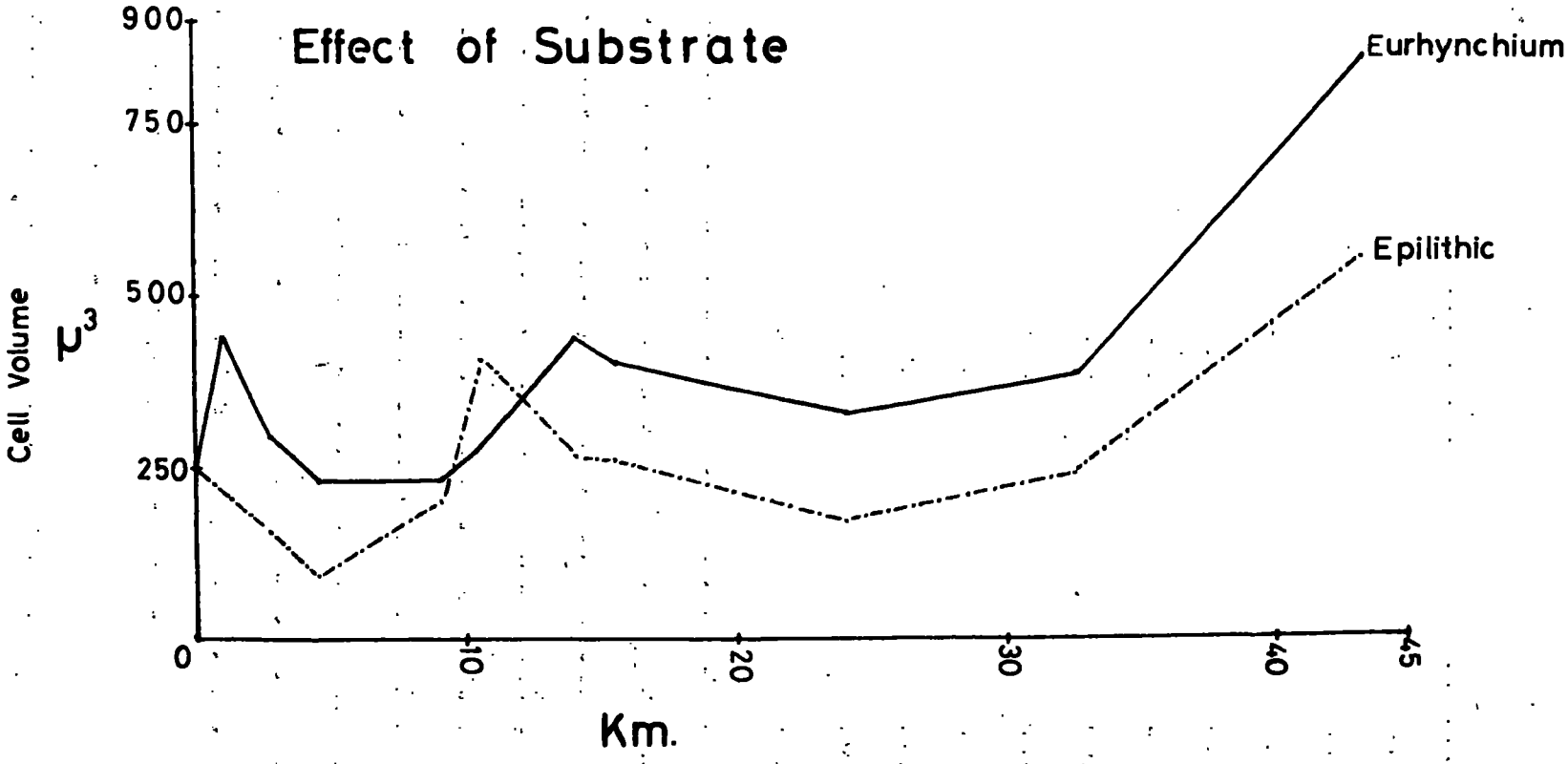

Effect of Substrate
Eurhynchium
Epilithic
900
750
500
250
0
Cell Volume
r^3
10
20
30
40
45
Km.

Fig. 11

further investigation, beyond the scope of this work, is required.

3.9 The Behaviour of Individual Species.

Figures 12-1) show the variations with respect to volume, of several species with progression downstream. The variations are expressed as a percentage of the volume of the population in which that species or genus occurs.

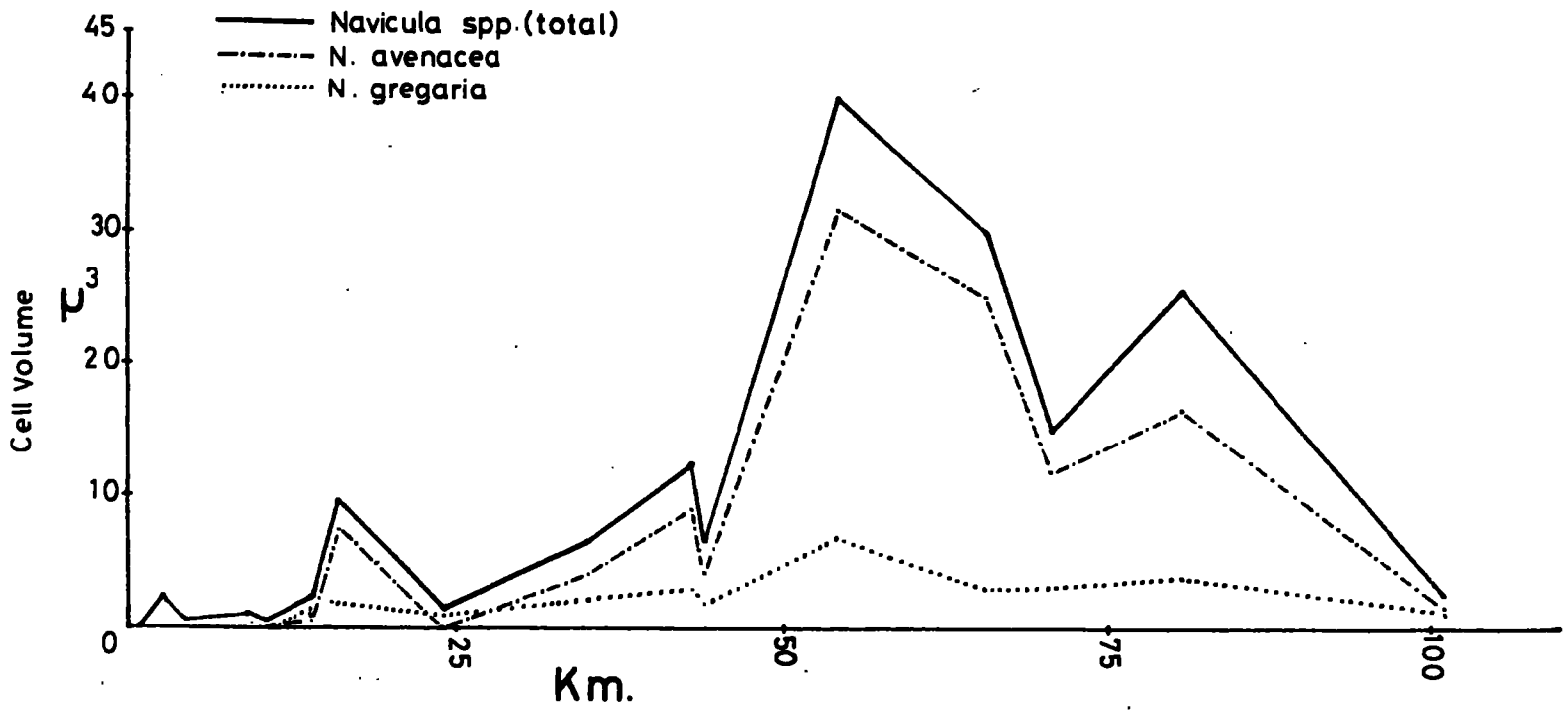
3.91 Daphnia spp.

23 species of Daphnia were recorded in the R. Nene, but only three occur in sufficient numbers to affect appreciably the volume relationships of the populations.

List of species at sites where they reach their highest numbers.

	R.	Maximum % Volume
D. cucullata	54.2	31.6
D. hyalina	24.2	6.71
D. magna	60.6	3.4

In the first 14 kilometres, Daphnia spp. play a minor role in the population from the point of view of volume (Figure 13). The volume of D. cucullata in the populations increases after R. 13.7 to reach the point of maximum development at Sage Bank (R. 24.2). It is significant that the inflow of the R. Harpers and the passage through Stoke Bruerne increase the population of this river between



Navicula

Fig. 12

Km. 44.2 and Km. 54.2. A zone of apparent self-purification from Km. 54.2 is accompanied by a decline in the volume of N. avenacea.

A small increase in the volume of N. avenacea to 25% at Cocken Bridge (Km. 80.6) is probably partly due to the added pollution of the river by the sewage works of Durham city, and its surrounding conurbation. The combined, and increasing effects of salinity and tidal influence with progress downstream cause a decrease in the volume of this freshwater species.

Like N. avenacea, N. gregaria is relatively unimportant in the upper reaches of the river, in terms of cell volume. This species increases gradually in total volume until its maximum at Page Bank (Km. 54.2). Its subsequent behaviour resembles N. avenacea in showing a second peak, smaller than the first, at Cocken Bridge (Km. 80.6), but decreasing as estuarine conditions become more pronounced.

N. gracile, whilst occuring in small numbers throughout the river, remains at a low level of about 2% of the population volume until Cocken Bridge (Km. 80.6), where it reaches its point of maximum development of 5%.

In Figure 12, the total volume of Navicula spp, expressed as a percentage of the population volume, is dominated by N. avenacea, which occurs in relatively large amounts. However

it is possible that both N. avenacea and N. gregaria can be used as indicators of pollution, or at least of increased eutrophy in the R. Wear.

5.52 Nitzschia spp.

This large genus, well represented in the R. Wear, contains seven species important in a study of volume relationships:

List of species at sites where they reach their highest numbers.

	Km.	Maximum % volume
N. dissipata	13.7	19.5
N. linearis	16.2	6.5
N. fonticola	24.3	2.4
N. palea	54.2	10.8
N. dubia	70.6	2.0
N. sigmoidea	80.6	12.3
N. acuminata	100.9	2.5

In the upper part of the river, above Wolsingham Bridge (Km.24), N. dissipata is the most important Nitzschia species in terms of volume (Figure 13). Between Km. 0.0-13.7, where N. dissipata reaches its maximum development of 19.5% of the average population volume, there are sharp fluctuations in the population levels. These may be due to the effects of variable effluent quality and quantity from small sewage works, and irregular drainage from farmland.

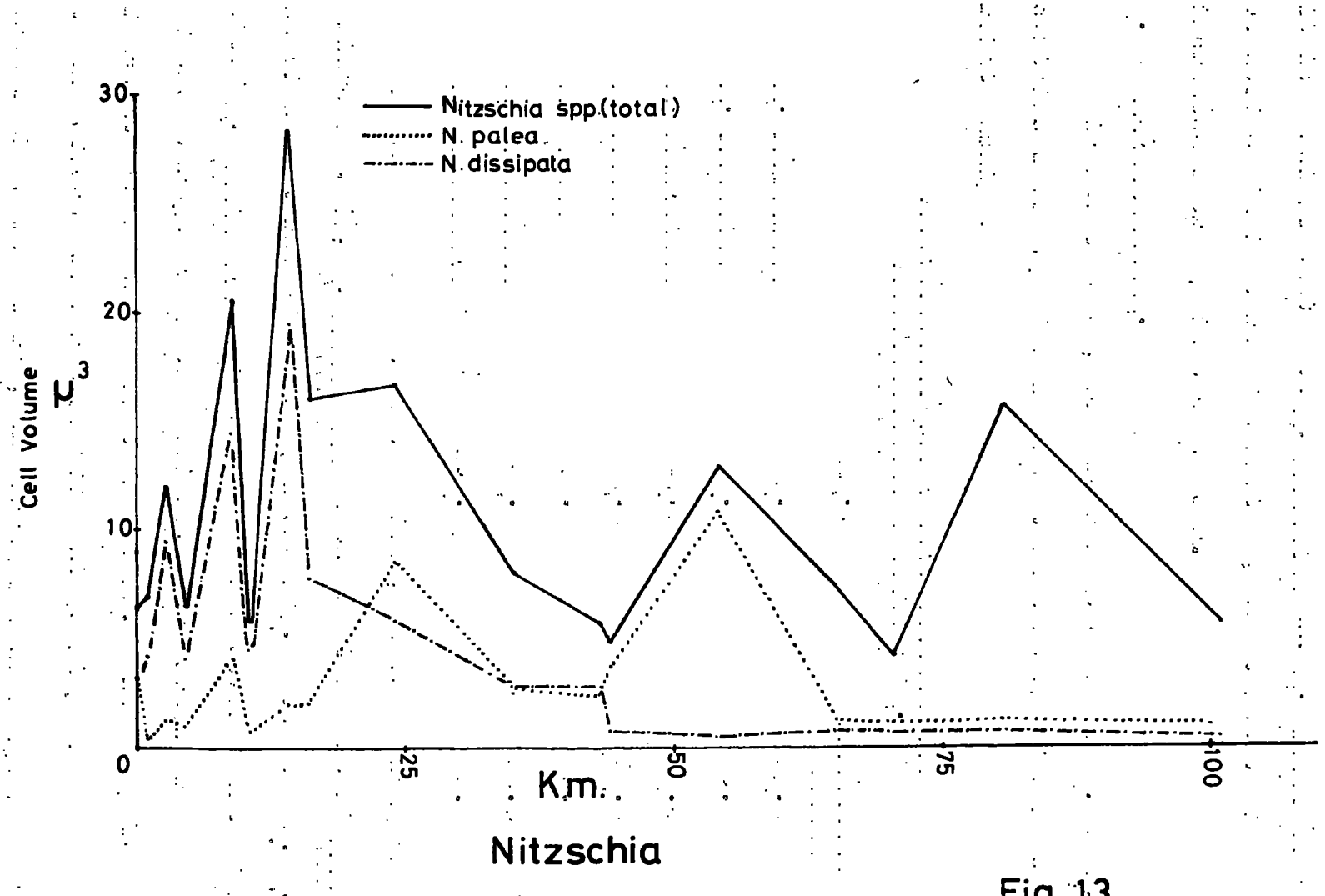

Nitzschia spp.(total)
N. palea
N. dissipata
Cell Volume
μ3
30
20
10
0
25
50
75
100
Km.
Nitzschia

Fig. 13

At Wolsingham Bridge (Km. 24.3), N. fonticola reaches its maximum development of 2.4% of the average population volume. This species is present in small volumes (less than 1% of the average population volume) throughout the river. Also at Wolsingham Bridge, N. palea replaces N. dissipata as the prominent Nitzschia species. Maximum development of N. palea is delayed until Km. 54.2, where it is a little over half that recorded for N. dissipata. This may be caused by the larger number of larger celled species in the population at this point.

N. dubia and N. acuminata are present only in the slower flowing, lower reaches of the river, and are relatively minor constituents of the population.

N. sigmoidea, with its large average cell volume ($22,000\mu^3$) can influence the population volume even though it occurs in small numbers. At its point of maximum development at Km. 80.6 of 12.3% of the average population volume, only three cells were recorded.

5.53 Cymbella spp.

Five species of Cymbella occur in sufficiently large numbers, so as to influence volume relationships:

List of species at sites where they reach their highest numbers

	Km.	%
C. microcephala	0.0	0.3
C. delicatula	1.0	15.4
C. ventricosa	9.2	16.9
C. prostrata	9.2	2.6
C. sinuata	35.2	3.0

C. ventricosa is the most important species in the genus in a consideration of volume relationships (Figure 14). At the species highest point of development, at Km. 9.2, this species constitutes 16.9% of the average population volume. The presence of large numbers of C. ventricosa influences the behaviour of the genus as a whole (Figure 14).

C. sinuata reaches maximum development at Km. 35.2, of 3% of the average population volume, with a second smaller peak of 2.3% at Km. 44.2. In the rest of the river, however, this species doe not rise above 2% of the average population volume.

C. delicatula reaches a peak of 15.4% of the average cell volume at Km. 1.0 where it replaces C. ventricosa as the most important Cymbella species. The species is present

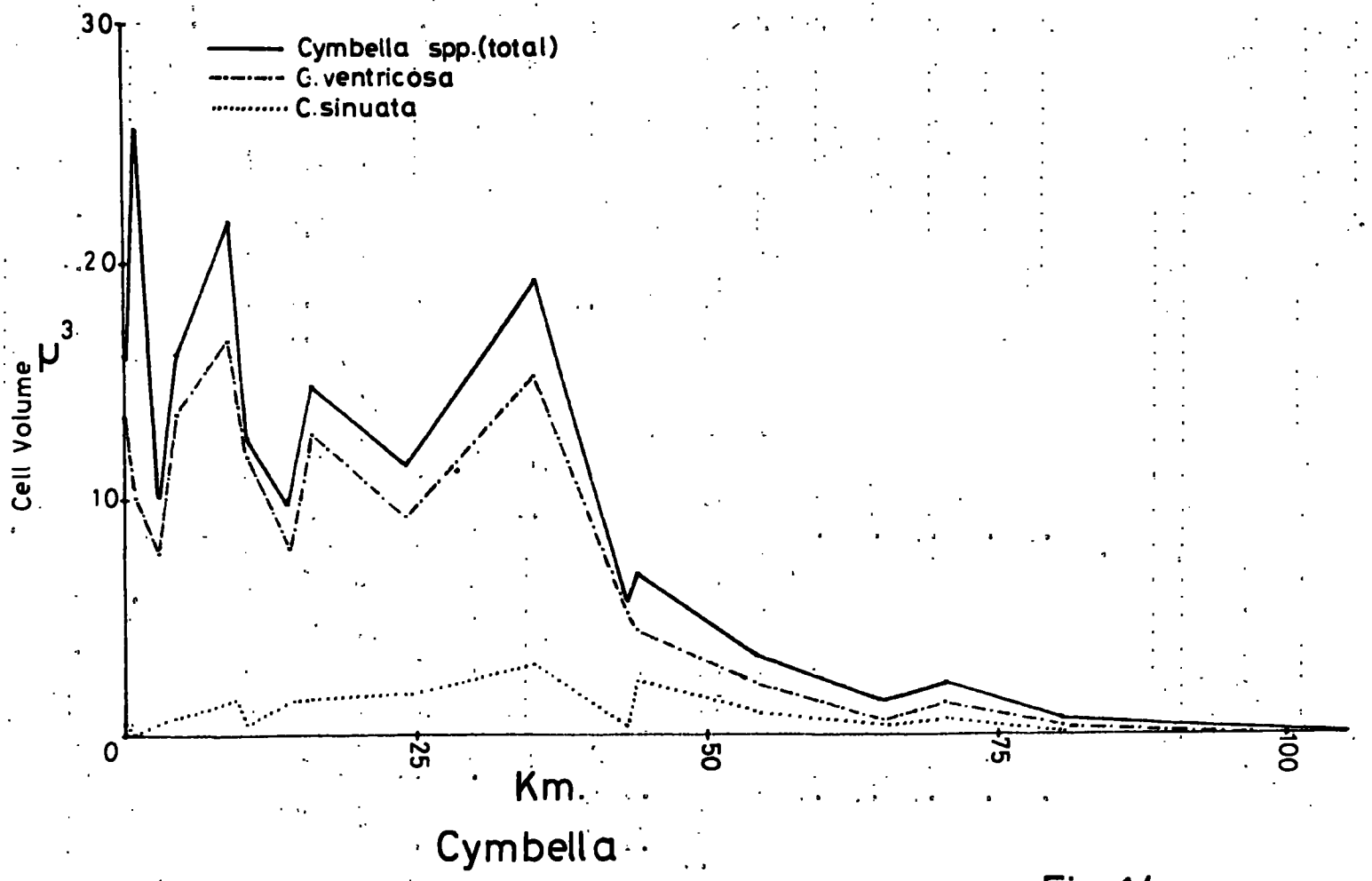

Cymbella spp.(total)
C. ventricosa
C. sinuata
30
20
10
0
Cell Volume μ^3
25
50
75
100
Km.
Cymbella

Fig. 14

at a low level throughout the rest of the river.

C. microcephala, a small celled species ($79\mu^3$) is present in volumes representing less than 1% of the average population volume.

C. prostrata with its relatively large cell volume ($10178\mu^3$) need occur in only small numbers to constitute a significant fraction of the average population volume. The species occurs at two stations in the 600 cell samples, at Km. 9.2, where it constitutes 2.6% of the volume, and 1.2% at Km. 43.2.

The overall picture is dominated by the presence of C. ventricosa, but it is apparent that Cymbella species in general are more important in less heavily polluted waters, and that they are sensitive to salinity.

5.54 Melosira varians.

This species has been regarded as a reliable indicator of B-mesosaprobic conditions (Kolkwitz and Marsson, 1908). In the R. Wear, M. varians does not appear in the samples before Stanhope (Km. 13.7), (Figure 15), and not in significant volumes before Km. 35.2. After this point in the river, the volume of this species continues to rise, irregularly, until Km. 80.6, when the volume decreases sharply with the increase in salinity. M. varians is replaced in the estuarine conditions around Km. 101 by M. nummuloides, a brackish water species.

Rhoicosphenia curvata.

This species is probably an indicator of B-mesosaprobic conditions, but this factor is confused by the substrate requirements. R. curvata is an attached diatom, a mucilaginous tube or pad being the form of attachment. Fast river flow, as at Page Bank (Km. 54.2), may inhibit the colonisation of an otherwise suitable habitat. R. curvata behaves similarly to M. varians (Figure 15), but reaches its point of maximum development at Shincliffe Bridge (Km. 65.6).

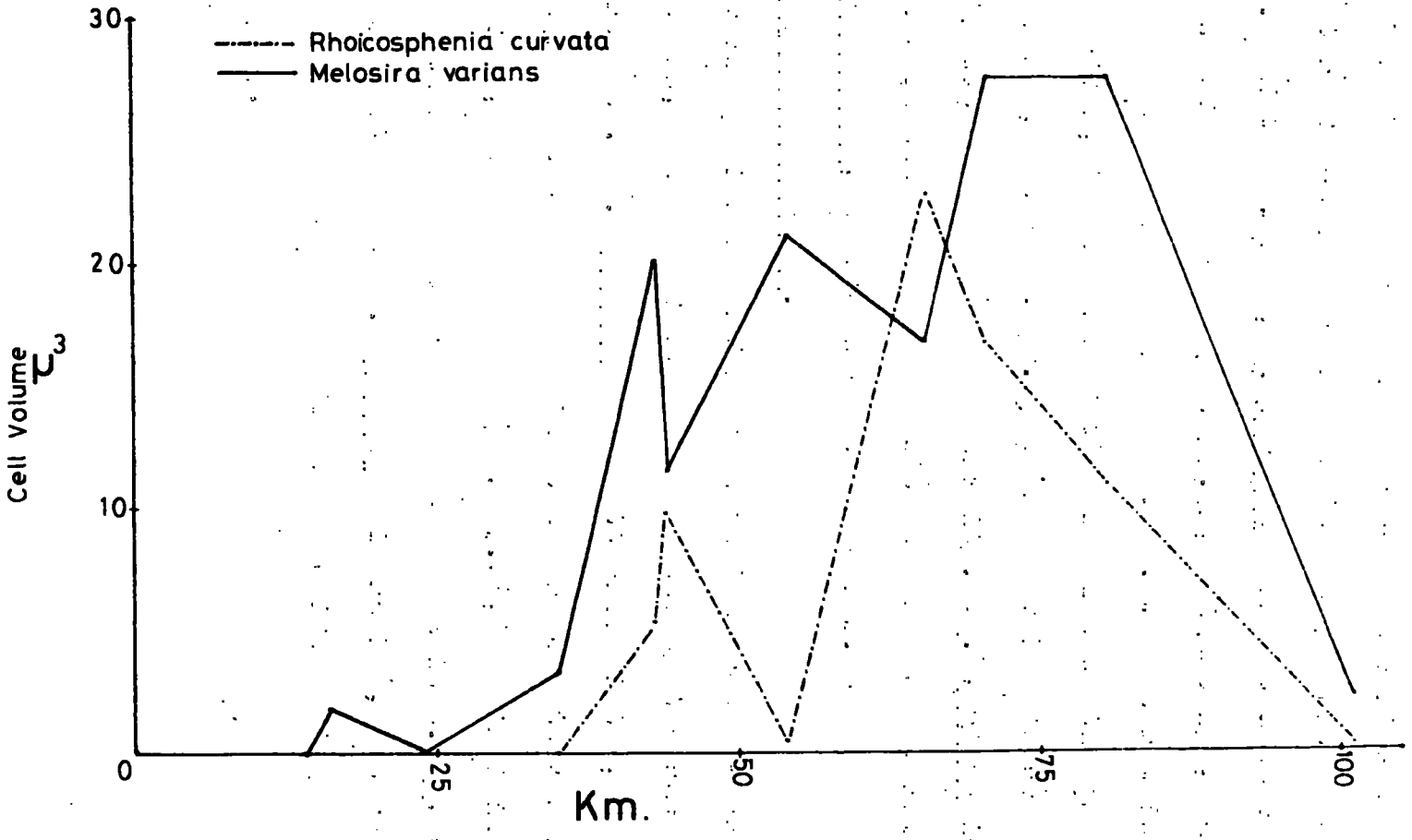

Rhoicosphenia curvata
Melosira varians
Cell Volume
μ^3
30
20
10
0
25
50
75
100
Km.

Fig. 15

COMMUNITY STRUCTURE

6.1 Introduction.

Sessile diatoms occur on a variety of different substrates, but some of these substrates bear typically small populations, e.g. sand, gravel, and submerged leaf litter. The four substrates investigated here, namely mosses, stones, unbranched green filamentous algae, and Cladophora, are those which usually support a large and healthy diatom population, and which are usually represented at the majority of sampling stations.

6.2 Variation with Geographical Location.

In comparing the communities on differing substrates in the river, attention must be paid to the mutual geographical ranges of the substrates under consideration.

The presence or absence of the epilithic substrate is primarily dependant upon geomorphological factors, whereas living substrates depend on a combination of geomorphological and other factors, (e.g. nutrients, light, temperature, etc.) The epilithic substrate is present at most of the sites sampled, but in varying degrees of importance.

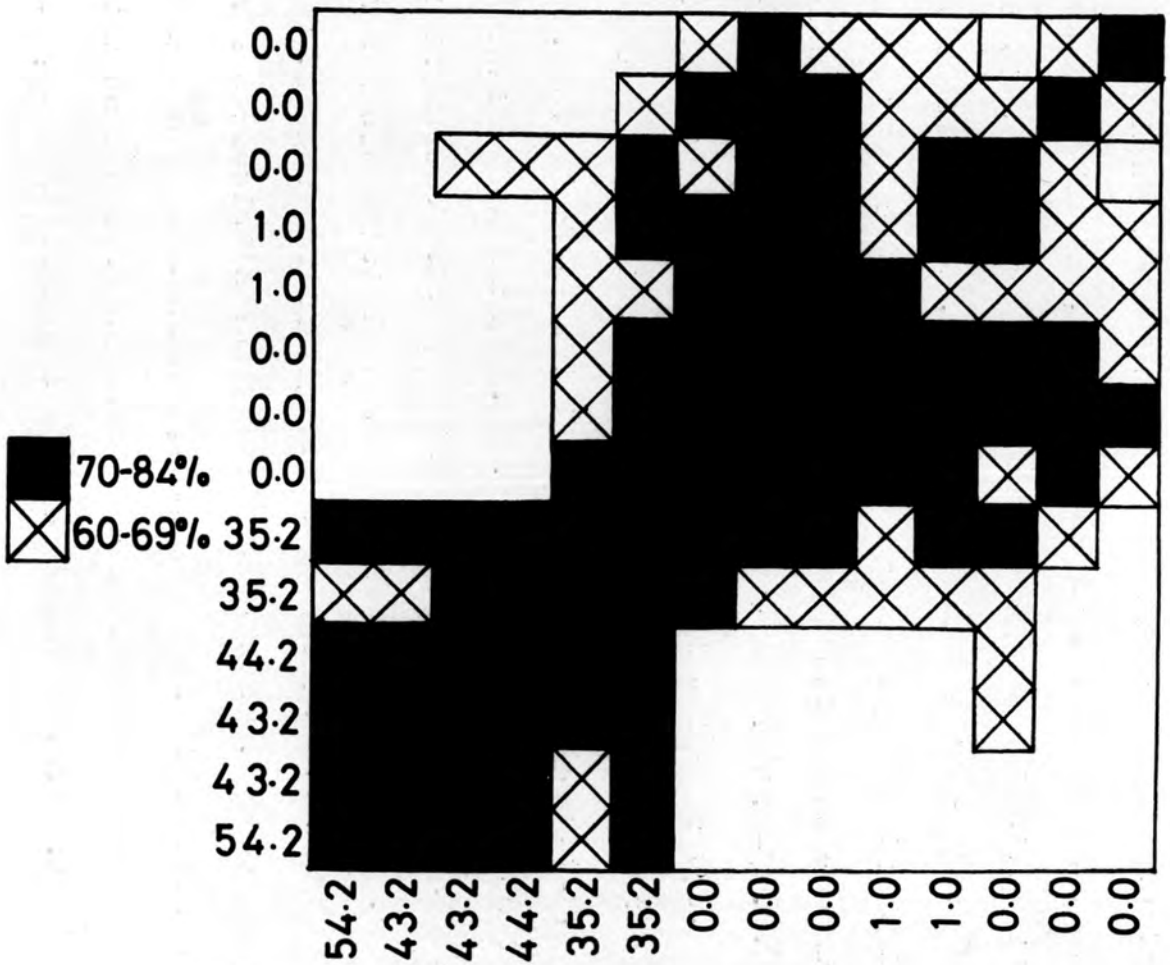
It may be pointed out that the absence of a particular substrate from any sampling station does not necessarily indicate its absence from areas adjacent to, but outside

the area searched. For instance, the absence of Eurhynchium from sampling sites below Km. 43.2 is not an indication of the limits of this substrate in the river. Cladophora, however, is uncommon in the river above the site where it is first sampled, at Km. 16.2.

The changes in community as one proceeds downstream are usually gradual, and thus changes taking place over a small distance may be overlooked. The cumulative effect of these small changes, however, may be considerable. The effect of geographic location may be seen in Figure 16, where communities from the first kilometre are compared on the same matrix with communities from Km. 35.2-44.2. A distance of 34 Kilometres separates the two groups.

From the ordination it is apparent that the two groups do not have marked affinities. Only one community, a Eurhynchium community at Km. 35.2 shows significant affinities with the opposite group. It is also apparent that the communities in the 19 kilometres from Km. 35.2 to Km. 54.2 show a slightly greater affinity to each other than do the communities in the first kilometre. Thus in the comparison of communities, it is important to distinguish differences due to substrate or to some other ecological factor, and those due to geographical location.

In this present work, those communities sampled on an epilithic substrate share approximately the same



Variation with Geographical Location

Fig.16

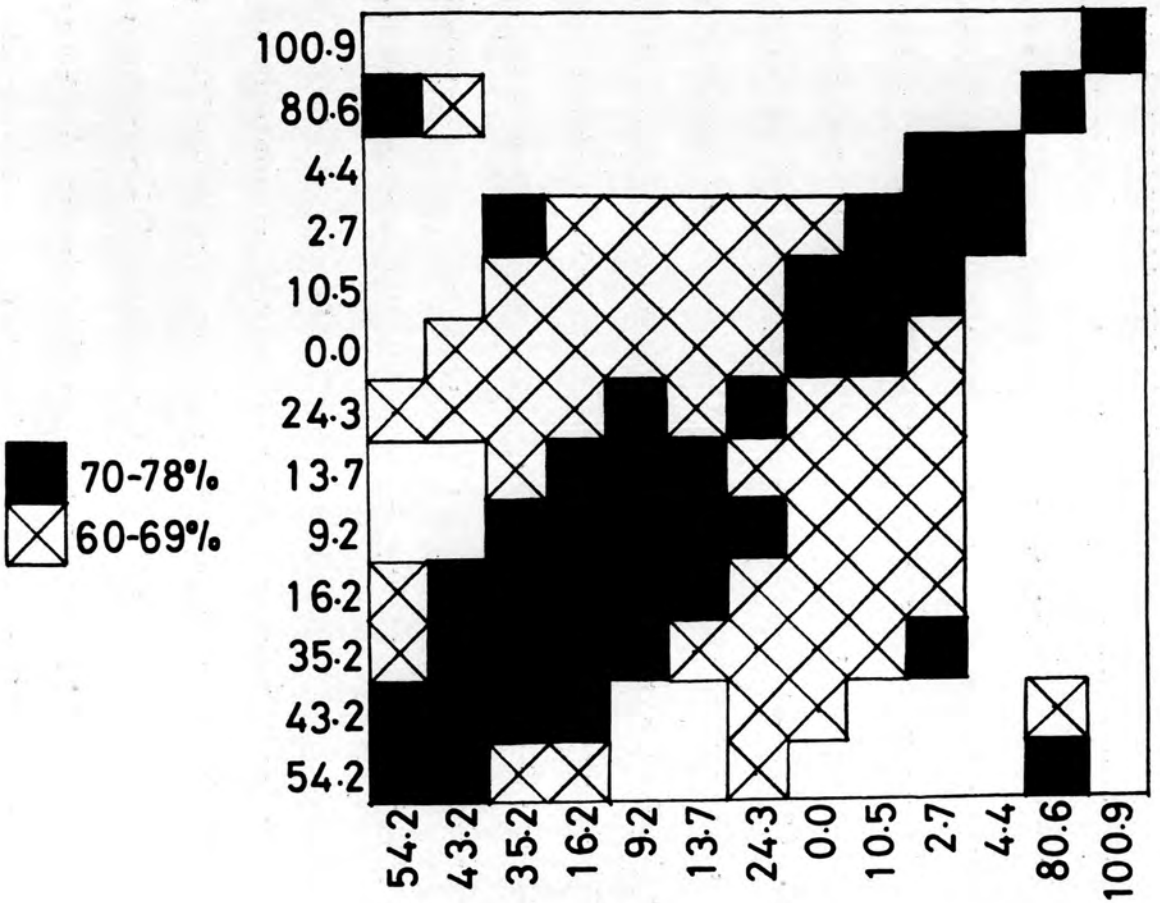
geographical area as those sampled on the Eurhynchium substrate. Those communities sampled on Cladophora and unbranched filamentous algae share a mutual range, but parts of their ranges are outside this common area.

6.3 The Epilithic Substrate.

The communities to be found on this substrate form a relatively heterogeneous group, i.e. any community may show only limited similarities to another community on the same substrate. The epilithic substrate is liable to changes due to the rate of stream flow, which is a prime factor in the rate of settlement of organic particles borne along the river. In quiet stretches of the river, these particles will tend to settle out onto the substrate, whereas in rapid stream flow, these particles are swept along, and are not deposited. Thus the microtopography of the substrate may change, partly as a result of the current speed, and partly due to the growth of microscopic lengths of filamentous algae.

As a result, the epilithic substrate may support a thin, surface layer of diatoms enclosed in a mucilaginous sheet, or a thick blanket of detritus in which diatoms and other algae are freely intermingled.

The complex nature of the epilithic substrate is reflected in the ordination Figure 17.



The Epilithic Substrate

Fig. 17

Those communities sampled fall into two major groups, one satellite community, and one solitary community.

The two major groups (i.e. those communities sampled at Km. 0.0; 2.7; 4.4; 10.5 and 9.2; 13.7; 16.2; 24.3; 35.2; 43.2; 54.2) overlap, and have some similarity with each other.

The satellite community at Km. 80.6 shows affinities with the community at Km. 54.2, but has little in common with the communities at the other stations.

The solitary community at Km. 100.9 is a brackish water community, with consequently many estuarine and marine forms among its constituents.

It is apparent that some factor is operating at or about Km. 9.2-10.5, which affects the epilithic communites. In this region, at approximately Km. 10, is the newly constructed cement works, the operation of which results in periodical increases in the amounts of particulate material in the river. It is possible that there may be some correlation between the siting of the cement works, and the observed change in the epilithic diatom flora.

6.4 Eurhynchium Substrates.

Eurhynchium riparioides was chosen as a substrate because it is the most common moss in the R. Wear. It is

found in almost all parts of the river, but did not occur at some of the sites sampled.

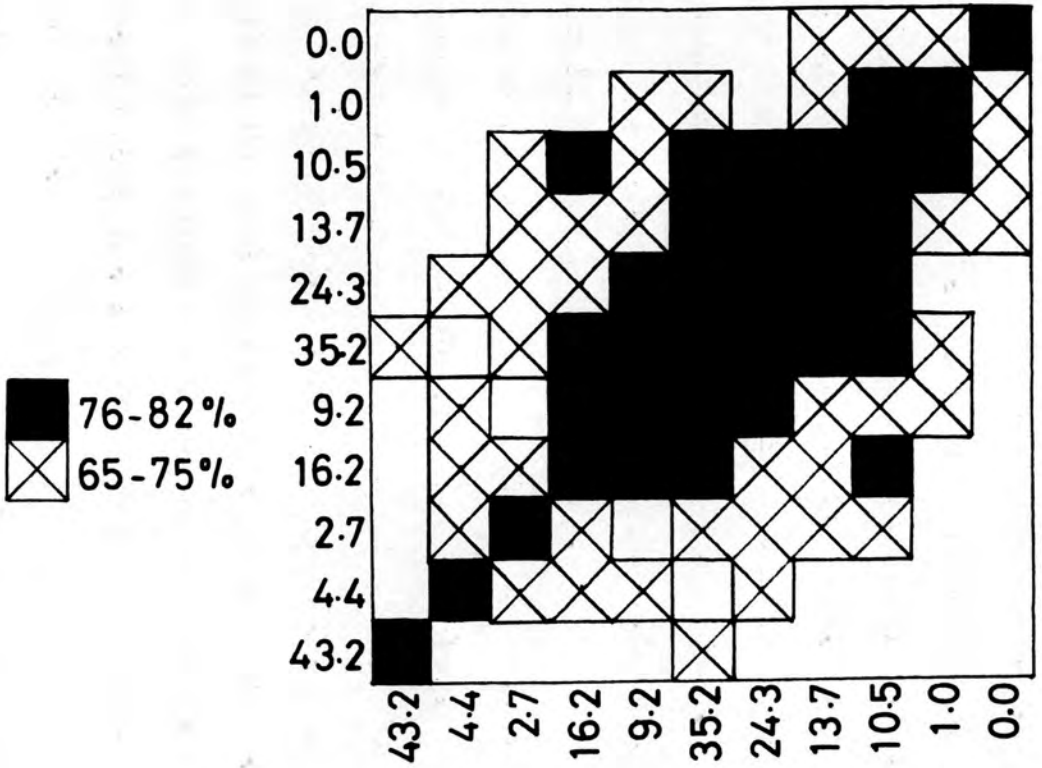
This group of communities is relatively homogeneous, i.e. each community shows some affinity to most of the other communites.

The substrate is not so deeply affected by the presence of increased organic particles in the water, as the epilithic communities. Some organic material is always present in the interstices of the plant, and the quantity does not appear to change significantly. Any tendency to a greater deposition of organic material is counteracted by the mechanical effect of the stream flow. This situation results in a substrate which remains essentially the same whereever it is found in the river.

This constancy in the physical aspects of the substrate is reflected in the ordination (Figure 18), on which is recorded relatively high indices of similarity throughout.

Whilst recognizing this homogeneity, certain affiliations may yet be seen within the group. There is one main group, those communities sampled at Km. 9.2; 10.5; 13.7; 16.2; 24.3; 35.2, which have very strong affinities with each other.

Besides the main group, there are two satellite groups, at Km. 0.0-1.0, and 2.7-4.4. Both these groups have affinities with the main group, but not to each other.



The Eurhynchium Substrate

Fig. 18

The relationships of the solitary community at Km. 43.2 remain problematical, but it does have high indices of similarity with other communities on this substrate, and should not therefore, be termed "atypical".

From the ordination, it would appear that conditions in the river from Km. 9.2 to Km. 35.2 remain fairly constant as far as the communities on Eurhynchium are concerned. Communities outside this range appear to be slightly more variable, but are, even so, close to the main group.

6.5 Unbranched Green Filamentous Algal Substrate.

The main constituents of this substrate are filamentous Chlorophyta. The dominant genus encountered was Ulothrix, the species of which were identified as U. zonata, U. aequalis, U. tenuissima, and U. subtilis. Other filamentous algae associated with the Ulothrix spp were Oedogonium sp., Stigeoclonium sp., Oscillatoria sp., Lyngbya sp., and occasionally Cladophora sp.

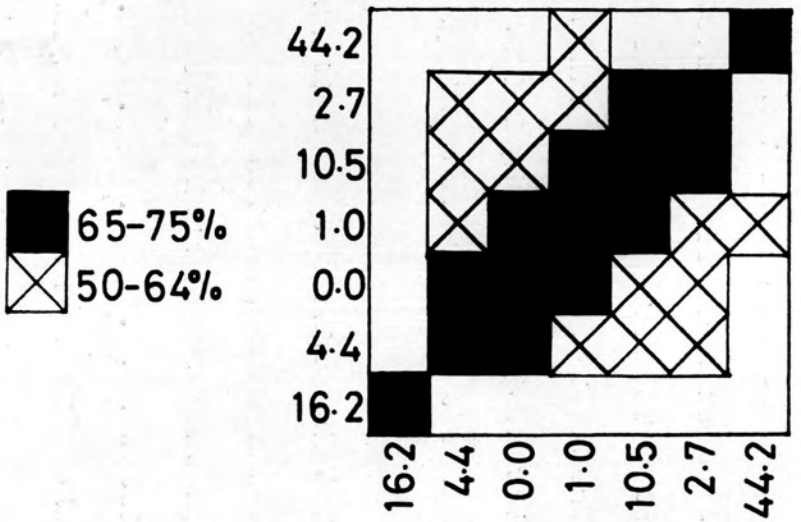
The unbranched green filamentous algae substrate is set aside from the Cladophora substrate, since whilst the thalli of the latter are hard and rigid, the thalli of Ulothrix and its associated filaments are both soft and flexible, more mucilaginous, and generally of a smaller diameter. There is an exception, in that Oedogonium resembles the Cladophora thallus in certain characteristics.

Epiphytes were not usually found on Oscillatoria and Lyngbya.

The distinction between the unbranched green filamentous algal substrate and the epilithic substrate is often blurred, since short filaments of algae, in particular Ulothrix spp., may become established on stones and rocks. Every attempt has been made to sample only those communities which can be said to be definately on of these two substrates.

The unbranched filamentous algal substrate appears to act as a sieve for small organic particles suspended in the river, and these form a film of potentially nutritive material around and between the filaments. The flexible nature of the thalli enables the community present upon them to be aerated by the movement of the thalli with the water movement.

The communities on the unbranched filamentous algal substrate are a well defined, homogeneous group, (Figure 19). The communities sampled fall into one major group, those at Km. 0.0; 1.0; 2.7; 4.4; 10.5, a satellite community at Km. 44.2, which shows a limited affinity with the main group, and a solitary community at Km. 16.2. This solitary community was sampled on a filamentous substrate which contained Oedogonium as the dominant form. The morphological similarity of the Oedogonium thallus to that of Cladophora



The Unbranched Green Filamentous Algal Substrate

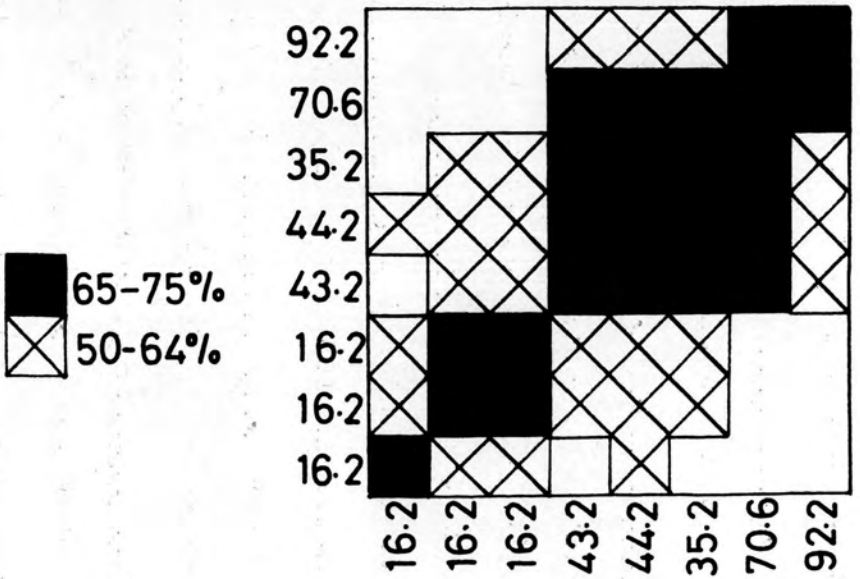
Fig. 19

has resulted in an epiphytic community which has few affinities with the other communities on the unbranched filamentous algal substrate. It is possible that those communities on Oedogonium should be referred to Cladophora.

6.6 The Cladophora Substrate.

From the data it is evident that the diatom communities associated with Cladophora form a distinct group with its own characteristics. In the R. Wear, these communities are characterised by having a high proportion of Cocconeis pediculus, and C. placentula. In many cases, the Cladophora thalli are almost completely encrusted with the cells of these two species. C. pediculus is the more numerous of the two species, and it may be significant that the markedly arched frustule is better able to accommodate itself to the wide Cladophora thallus than is the more flat frustule of C. placentula, which is thus at a theoretical ecological disadvantage in the colonization of this substrate.

The dominance of Cocconeis spp. does diminish however, in those Cladophora communities in relatively slow flowing waters. Here, the encrusting Cocconeis spp. are ousted by other, none encrusting species. Less turbulent conditions in these waters appear to be more favourable to attached species, e.g. Melosira varians, and Rhoicosphenia curvata. Free living forms are also better represented in these less



The Cladophora Substrate

Fig. 20

turbulent conditions.

The diatom communities on Cladophora are, therefore capable of a wide variation, although these same communities are different in many ways to communities on other substrates. This variation is shown in the ordination (Figure 20), where half of the comparisons made fall below the level of 50% similarity. There are two major groups:-

(i) Those communities sampled at Km. 16.2.

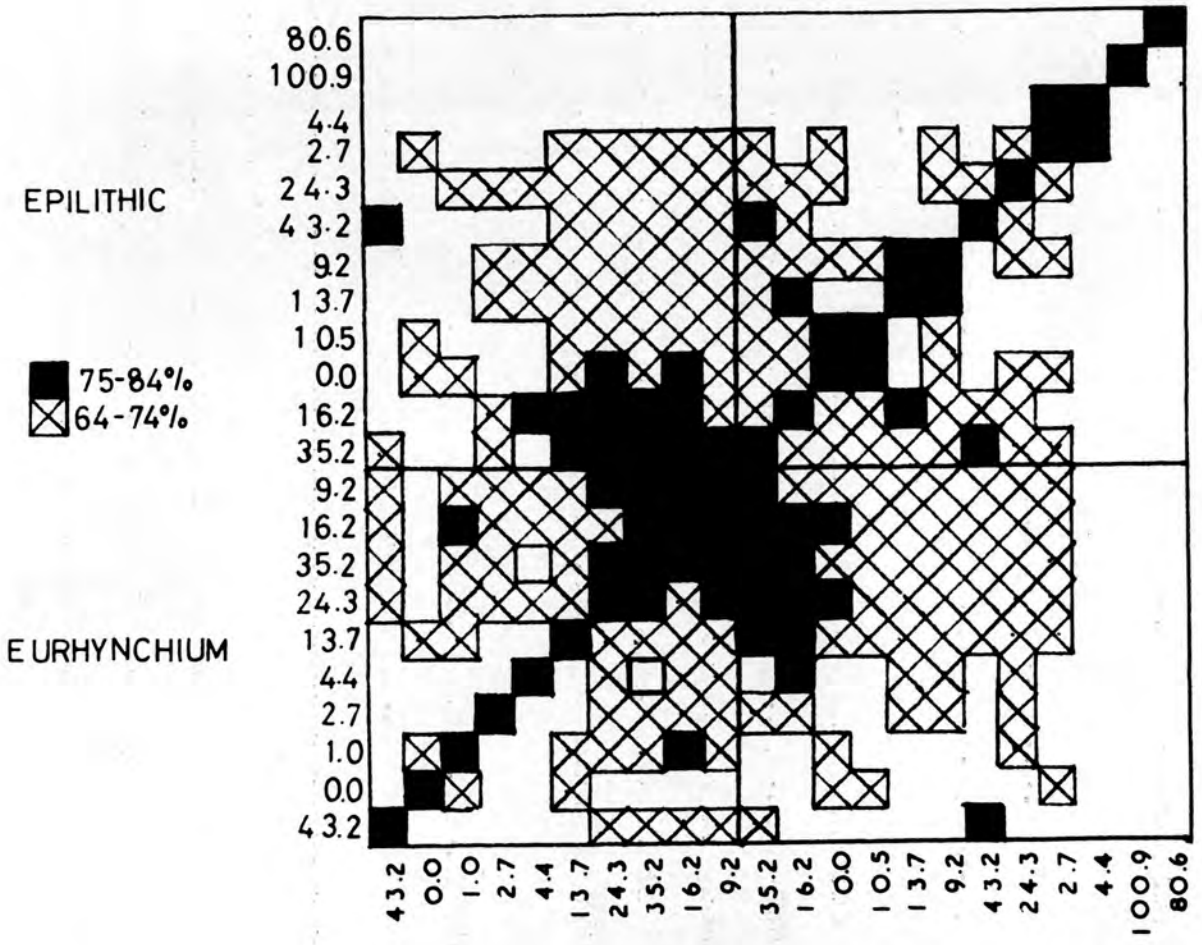
(ii) Those communities sampled at Km. 35.2; 43.2; 44.2; 70.6.

There are limited relationships between these two groups, but those communities sampled at Km. 16.2 appear to be significantly dissimilar to the second major group. No satisfactory explanation can be offered, but it is possible that the inflow of the Shittlehope Burn at this point may be of significance.

There is also a satellite community at Km. 92.2 with affinities with the second major group (ii).

6.7 Relationships between the Epilithic and the Eurhynchium Substrates.

A comparison of these two groups of communities, shows the strong affinities between them (Figure 21). The communities in either group show as much relation to the



Comparison of Epilithic & Eurhynchium Substrates

Fig. 21

communities in the other group as they do to the communities within its own group. On this analysis therefore, it is not possible to distinguish the two. In these two groups, the effect of the substrate appears to be either negligable, or similar to both.

The differences between the two groups of populations become progressively diminished with passage downstream. If the indices of similarity are computed and ordinated as in (Figure 22), it is apparent that there is a trend to a higher average value in the lower left hand corner (representing the stations sampled in the lower parts of the river.) Likewise, there is an opposite trend to lower average value in the upper right hand corner, (which represents those stations sampled in the upper parts of the river.) This phenomenon may be due to the more uniform ecological conditions which are encountered in slower moving waters. The logical progression of this theory, a situation where all possible substrates are occupied by the same community may never be reached in the R. Wear, due to the effect of far-reaching changes brought about by the progression into brackish, estuarine waters.

6.8 Relationships between the Unbranched Green Filamentous Algal and the Cladophora Substrates.

A comparison of these two groups, (Figure 23) shows them to be quite distinct from each other. There is little

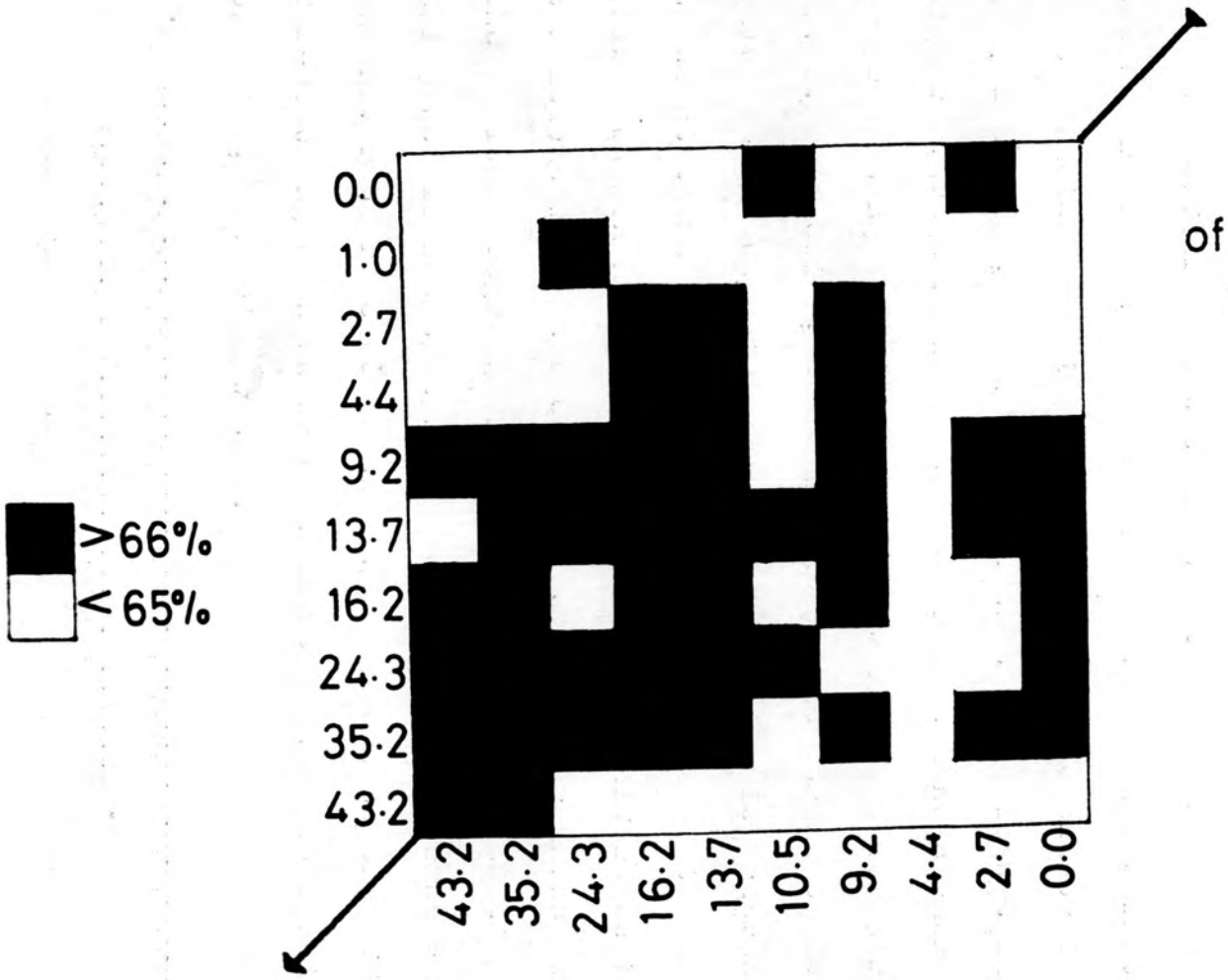
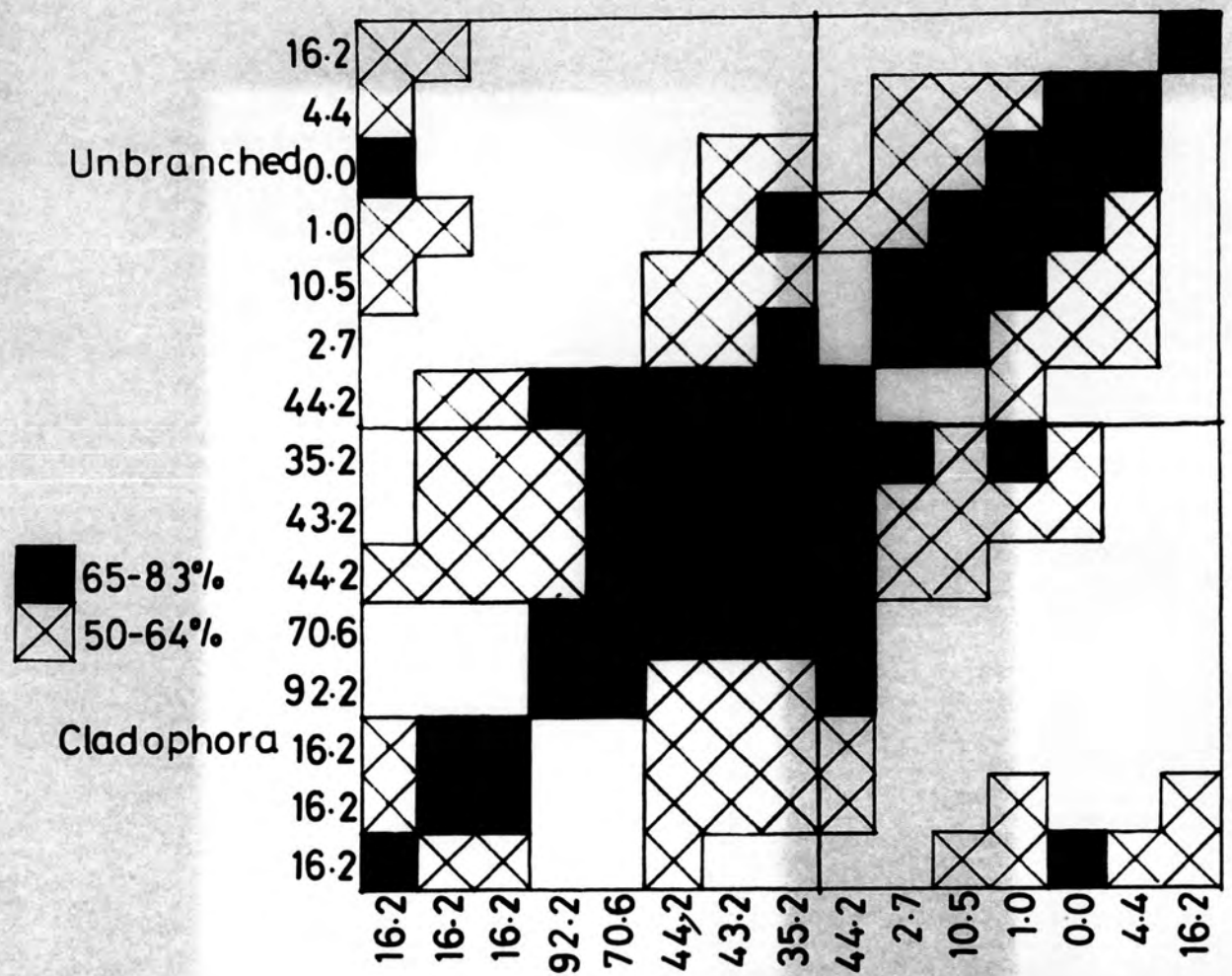

>66%
<65%
0·0
1·0
2·7
4·4
9·2
13·7
16·2
24·3
35·2
43·2
43·2
35·2
24·3
16·2
13·7
10·5
9·2
4·4
2·7
0·0
Effect
of progression
Downstream

Fig. 22



Comparison of the two filamentous algal substrates

Fig. 23

similarity with each other, with the exception of one community. The excepted community, sampled on Oedogonium at Km. 44.2, resembles those communities on Cladophora more closely than those on the unbranched substrate.

However, a community on Oedogonium at Km. 16.2 appears to be quite dissimilar to all other communities except those Cladophora communities also occurring at Km. 16.2. This group of communities at Km. 16.2 appear to comprise a separate entity, and yet show a 70% similarity with a community on Ulothrix tenuissima at Km. 0.0.

TAXONOMY

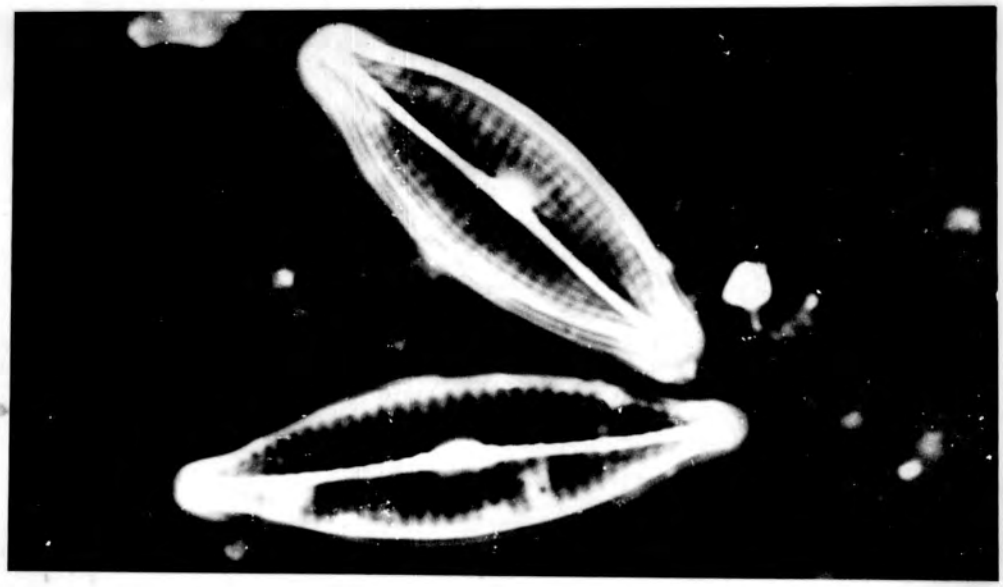
7.1

As a result of the investigation, 168 diatom species were identified in the River Wear. An account of these diatoms and their distribution in the River Wear is set out in Peabody and Whitton (1968).

An interesting point arising from this account is the possibility of confusion between N. gregaria and N. cryptocephala in investigations on other river systems.

Figure 24 shows the characteristic appearance of N. gregaria in the R. Wear, in particular the assymetrical central area and the longitudinal striations, which serve to separate these two species.

10μ



Navicula gregaria.

Figure 24.

DISCUSSION.

8.1

The difficulties involved in the analysis of diatom communities, and the need for a more suitable method of comparison have been outlined above. The present author believes that the adaptation of the method suggested by Czekanowski ((1913)- in Greig-Smith (1964)), satisfies this need. Advantages of this method are that it provides an objective approach, with an immediate visual assessment of the results. It also appears to be suitable for use with communities of micro-organisms. A disadvantage is, that to be totally objective, all the species occurring in the two environments or communities should be taken into consideration. However, when a large number of species is involved, the use of a punch card system becomes unwieldy, and the data would probably require analysis by computer.

The results have shown that the communities on the epilithic and Eurhynchium substrates have much in common with each other, despite certain differences in the nature of the substrates (Figure 21). Any explanation of these phenomena must largely be a matter of some conjecture, since detailed studies of environmental factors were not carried

out.

However, since "gross" ecological factors (e.g. light, temperature, nutrients, etc.,) are operating on all the substrates equally at the same site, then one must conclude that some factor or factors are operating in the micro-environment immediately surrounding the community.

Some factors which may operate on the micro-environment and which may affect the community through the substrate are:

(a) Microtopography.

(b) Rate of water flow within the system.

(c) O_2/CO_2 balance within the system.

(d) Rate of nutrient removal by a living substrate.

The effects of these factors on the community are difficult to demonstrate. However, it has been shown above, (Figure 23), that the major difference between the communities on Cladophora and those on unbranched green filamentous algae is the greater amount of Cocconeis pediculus on Cladophora. This species, with its large, arched valves, appears to be better adapted to the broad and relatively rigid Cladophora thalli, than to the smaller and more flexible Ulothrix thalli.

The rate of water flow within the system affects all substrates, in particular those living substrates which are

continually removing nutrients etc., from the micro-environment. Any effect due to this factor should be most apparent in a comparison between the communities on the epilithic and on the Eurhynchium communities. It is indeed probable that this is a contributory factor to the difference between these two communities, but its effects would appear to be slight.

Such differences as there are between these two communities are probably better explained in terms of the mechanical action of the water flow on the substrates. The epilithic substrate supports a larger number of motile cells than does the Eurhynchium substrate, especially the more narrow species (Figure 3-7). The settling of particles onto the epilithic substrate may encourage the greater numbers of motile cells, whereas the Eurhynchium fronds, which are continually agitated by water flow preventing excessive silting, is able to support higher numbers of non-motile cells.

The Eurhynchium also supports more cells with a higher cell volume than does the epilithic substrate (Figure 11). The reason for this remains obscure, and further studies outside the scope of this present work would need to be undertaken.

It is evident that geographical location must be taken

into consideration. Although differences between the substrates are small over short distances, over larger distances, the communities show marked changes (Figure 16). An interesting point arising from the comparison of the Eurhynchium and epilithic substrates is, that the communities on these substrates tend towards similarity with progression downstream (Figure 22). It is tentatively suggested that this is at least partly due to more uniform environmental conditions.

The increase in the numbers of larger celled species with progression downstream (Figure 10), supports the view of Liebman ((1942) - in Fjerdingstad (1950)), and Johnson (1963)., Munk and Riley ((1952) - in Hutchinson (1967)) also hold that small size is metabolically advantageous. The results of their work indicate that spherical and flat discoidal forms are at a considerable advantage over cylindrical forms, when uptake by an organism in turbulent water is considered. Conversely, cells with large volumes are at less of a disadvantage in a nutrient rich environment.

The individual diatom species which are the most important with regards to volume are:

	Km.
Cymbella delicatula	1.0
C. ventricosa	2.7-35.2
Nitzschia dissipata	2.7-13.7
Melosira varians	44.2-80.6
Nitzschia palea	54.2
Navicula avenacea	54.2-80.6
Rhoicosphenia curvata	65.6

Peabody and Whitton (1968), compare the diatoms of the R. Wear with those of the R. Tees.

BIBLIOGRAPHY.

Butcher, R.W. (1932). Studies on the ecology of rivers. II. The microflora of rivers with special reference to the algae on the river bed. Ann. Bot. 46: 813-861.

_____., Longwell, J. and Pentelow, F.T.K., (1937) Survey of the River Tees. III. The non-tidal reaches - chemical and biological. London, H.M.S.O.

Castenholz, R.W. (1960). Seasonal changes in the attached algae of freshwater and saline lakes in the Lower Grand Coulee, Washington. Limnol. Oceanogr. 5 (1): 1-28.

Cholnoky, B.J. (1960). The relationship between algae and the chemistry of natural waters. Pretoria, Commission for Technical Co-operation in Africa South of the Sahara.

Chu, S.P. (1942). The influence of the mineral composition of the medium on the growth of planktonic algae I. J. Ecol. 30 (2): 284-325.

Douglas, B. (1958). The ecology of the attached diatoms and other algae in a small stony stream. J. Ecol. 46: 295-322.

Evans, G.H. (1961). A study of the diatoms in a core from the sediments of Devoke Water. M.Sc. thesis. (Aberystwyth).

Fjerdingstad, E. (1950). The microflora of the River Mølle a Folia limnol. scand. 5: 1-123.

_____. (1964). Pollution of streams estimated by benthal micro-organisms. I.A. saprobic system based on communities of organisms and ecological factors. Int. Revue ges. Hydrobiol. 49(1): 63-141.

_____. (1965). Taxonomy and saprobic valency of benthic micro-organisms. Int. Revue gas. Hydrobiol. 50(4): 475-604.

Grieg-Smith, P. (1964). Quantitative plant ecology, London, Butterworths.

Hutchinson, G.E. (1967). A treatise on limnology. Vol.II. New York, Wiley.

Johnson, R. (1963). Antimetabolites as an aid to the study of phytoplankton. J. mar. biol. Ass. U.K. 43: 409-425.

Kolkwitz, R. (1950). Ökologie der Saprobien. Schriftenreihe d. Vereins f. Wasser-, Boden-, und Lufthygiene. 4.

Kolkwitz, R. and Marsson, M. (1908). Ökologie der pflanzlichen Saprobien. Ber. dt. bot. Ges. 26a: 118.

_____. and _____. (1909). Ökologie der tierischen Saprobien. Int. Revue ges. Hydrobiol. Hydrogr. 2: 302.

Margalef, R. (1949). Las asociaciones de algae en las aguas dulces de pequeño volumen des Noreste España. Vegetatio 1: 258-284.

Maucha, R. (1932). Hydrochemische Methoden in der Limnologie. Die Binnengewässer. Stuttgart, Schweizerbartsche Verlagsbuchhandlung.

McIntire, C.D. (1966). Some effects of current velocity in laboratory streams. Hydrobiologia 27 (3-4): 559-570.

Patrick, R. (undated). Diatoms as an indication of river change. No source given.

_____. and Strawbridge, D. (1963). Variation in the structure of natural diatom communities. Am. Nat. 97 (892): 51-57.

Peabody, A.J. and Whitton, B.A. (1968). Algae of the River Wear. I. Diatoms. Naturalist 906: 89-96.

Pieczynska, E. and Spodniewska, J. (1963). Occurrence and colonization of periphyton organisms in accordance with the type of substrate. Ecol. Pol. (Seria A) 11 (22).

Sneath, P.H.A. and Sokal, R.R. (1962). Numerical Taxonomy. Nature, Lond. 193: 855-860.

Symoens, J.J. (1951). Esquisse d'un systeme des associations algales d'eau douce. Verh. Int. Ver. Limnol. 9: 395-408.

Zelinka, M. and Marvan, P. (1961). Zur Präzisierung der Biologischen Klassifikation der Reinheit fliessender Gewässer. Arch. Hydrobiol. 57 (3): 389-407.

UNIVERSITY OF ALBERTA SCIENCE 18 SEP 1969 SECTION LIBRARY

18 SEP 1969
SECTION
LIBRARY

ALGAE OF THE RIVER WEAR 1. DIATOMS

A. J. PEABODY* AND B. A. WHITTON

(Department of Botany, University of Durham)

The algal flora of British rivers has seldom been studied intensively, and the only fast flowing one for which there is a comprehensive account is the R. Tees. Butcher, in Butcher, Longwell and Pentelow (1937), concluded that diatoms accounted for 70% of the total micro-organisms in the R. Tees, and he dealt with this phylum in some detail. Recently the diatoms of the R. Tees have been surveyed again by Whitton and Dalpra (in press). They concluded that of 148 diatoms listed, there were only five detectable changes in abundance between the two surveys, none of them involving dominant species. As the floristic composition of the R. Tees appears to have changed little in over 30 years, it was therefore decided to see how great is the difference between this river and the river immediately to its north, the R. Wear. Since Butcher's survey a considerable literature has been published on diatoms from rivers in other parts of Europe and North America, but little on attached diatoms of British rivers. The following introductory account of the epilithic and epiphytic diatoms of the R. Wear is presented for comparison with the previous literature, and as part of a general survey of this river.

The data for each species is given under the following headings:

(i) Morphological and taxonomic comments.

(ii) Records made as part of an intensive survey carried out on 3rd September, 1966 (3.IX.66). Diatom samples were taken from each of 19 sites. At each site material was collected from a range of habitats chosen subjectively to give a representative picture of the epitlithic and epiphytic diatoms present. The 19 sites are referred to in the text simply by their distance from the start of the river, and are as follows:

km 0.0	Wearhead	km 35.2	weir above Witton Bridge
km 1.0	West Blackdene	km 43.2	Newton Cap Bridge
km 2.7	Broken Way Ford	km 44.2	Jock's Bridge
km 4.4	Bridge End	km 54.2	Page Bank
km 9.2	Cambo Keels	km 65.6	downstream of Shincliffe Bridge
km 10.5	above Rookhope Burn	km 70.6	Kepier
km 13.7	Briggen Winch	km 80.6	Cocken Bridge
km 16.2	Shittlehope Burn	km 92.2	Lamb Bridge
km 24.3	Wolsingham Bridge	km 100.9	S. Hylton Ferry
km 26.3	Scotch Isle		

600 cells were counted for each site and these are referred to as the 'total diatom population' for that site. Diatoms not recorded under this heading were not found on this date.

(iii) Specific records for other dates (included only if of particular interest).

(iv) Tentative generalizations, where possible.

(v) Interesting comparisons with the literature or other comments.

CENTRALES

Melosira nummuloides (Dillw.) Ag. (i) Chains of cells 12–20 μ diameter (ii) Furthest upstream record at km 80.6; formed the majority of cells at km 100.9 (FIG. 1) (iii) Abundant on 26.VI.66 at Glasshouse Hill (km 104.2). Not recorded from R. Tees, although Butcher's lowest station was in the tidal reach.

M. varians Ag. (i) 8–20 μ diameter (ii) Furthest upstream record at km 16.2, in very low numbers; gradually increased in relative abundance to maximum at km 70.6 (iv) *M. varians* appears largely to be replaced by *M. nummuloides* in the estuarine region.

Sceletonema costatum (Grev.) Cleve (iii) A few cells on 27.VI.66 at Glasshouse Hill (km 104.2).

Thalassiosira fluviatilis Hust. (i) 18–20 μ diameter (ii) A few cells seen at km 65.6, km 70.6, km 80.6.

Cyclotella meneghiniana Kütz. (i) 9–18 μ diameter; the smallest cells found are smaller than the lower limit of 10 μ given by Hustedt (1930b). *C. kützingiana* Thwaites was not recorded from R. Wear (ii) Found in the lower part of the river, at and below km 65.6, forming 2–4% of the population.

Actinoptychus splendens (Shadb.) Ralfs (iii) On 27.VI.66 at Glasshouse Hill (km 104.2) on *Pilayella*.

* Present address: Forensic Science Laboratory, Preston, Lancashire.

PENNALES

Tabellaria fenestrata (Lyng.) Kütz. (i) 30–140 μ × 3–9 μ (ii) five cells seen in samples from km 0.0.

T. flocculosa (Roth) Kütz. (i) 16–25 μ long; 6–10 μ wide in the centre and 3.5–4.0 μ at the poles (iv) Present throughout almost all the river, occurring as single cells, or in small numbers.

Grammatophora serpentina (Ralfs) Ehr. (i) 25–180 μ × 12–18 μ (ii) one cell noted at km 80.6 (iii) Common at Glasshouse Hill (km 104.2) on *Pilayella* on 27.VI.66.

Licmophora ehrenbergii (Kütz.) Grun. (iii) At Glasshouse Hill (km 104.2) on *Pilayella* on 27.VI.66.

Meridion circulare (Grev.) Ag. (i) 16–39 μ × 3–6 μ; somewhat narrower than the width range (4–8 μ) given by Hustedt (1930b). The var. *constricta* (Ralfs) v. Heurck also present (ii) Formed 5% diatom population at km 0.0, decreased in relative abundance on passing downstream; solitary cells only found in the tidal reaches (iv) Possibly relatively more abundant in early spring, at least in the more polluted waters (v) Described by van der Werff (1957) as an 'oligohalobe' and rheophilous. Fjerdingstad (1964, 1965) places this species in his class of saproxenous organisms, i.e. those generally occurring in biotopes other than polluted ones, but which may also be found in the presence of moderate pollution.

Diatoma vulgare Bory (i) 20–50 μ × 6–12 μ; ribs 7–8/10 μ. No attempt made to separate this variable species into its named varieties; at one extreme the forms approach *D. elongatum* (Lyng.) Ag. (ii) Throughout the river, but most abundant at km 1.0, where formed 6% diatom population (iii) A frequent organism throughout the river at all times of year (v) Fjerdingstad (1964, 1965) classed this species as saprophilous, but it does not show any such tendency in either the R. Wear or R. Tees. It is frequent in some unpolluted tributaries of R. Wear, e.g. Burnhope Burn.

D. elongatum (Lyng.) Ag. (ii) Two cells seen at km 43.2 and km 92.2.

D. hiemale (Lyng.) Heiberg (i) As var. *mesodon* (Ehr.) Grun.: 12–20 μ long and 6–12 μ wide (ii) Occurred sporadically, more common above km 35.2.

Opephora martyi Heribaud (i) If the heteropolarity is not well pronounced some confusion may arise between this species and *Fragilaria* spp. (iii) At Glasshouse Hill on *Pilayella* (km 104.2) on 27.VI.66.

Ceratoneis arcus Kütz. (i) shape very variable; includes var. *amphioxys* (Rabh.) Brun. 2.5% of the diatom population at km 1.0 (iv) Frequent throughout the year though always more abundant in the upper reaches.

Fragilaria intermedia Grun. (i) 24–34 μ × 2.5–5.0 μ; striae 11–12/10 μ. This species is not readily determined from the girdle aspect, a problem with many *Fragilaria* spp. Petersen (1938) in fact considered that *F. intermedia* is identical with *Synedra vaucheriae*, and united the two under *F. vaucheriae* (Kütz.) Petersen (iv) One of the more important diatoms of the river, though more abundant in the upper reaches.

F. construens (Ehr.) Grun. (i) As fo. *binodis* (Ehr.) Grun. (ii) A few cells seen at km 70.6 and km 80.6.

F. pinnata Ehr. (i) As var. *lancettula* (Schumann) Hust. (ii) A few cells seen at km 70.6, km 80.6 and km 100.9.

F. brevistriata Grun. (iii) Seen only once at Lumley Bridge (km 88.1) in September 1965.

Asterionella formosa Hass. (ii) One cell seen at km 0.0 (which is however below Burnhope Reservoir).

Synedra ulna (Nitzsch) Ehr. (i) A range of forms occur; perhaps the most clearly delimited is var. *oxyrhynchus* (Kütz.) v. Heurck (ii) Present at almost all stations, though more common in the upstream ones; 2% diatom population at km 0.0 and km 2.7.

S. acus Kütz. (ii) Single cells seen at km 1.0 and km 4.4.

S. rumpens Kütz. (*sensu lato*) (i) This taxon is used here as a receptacle for the smaller *Synedra* species, where the shapes of the frustule and of the central area are both variable. Cells approaching typical *S. minuscula* Grun. and *S. amphicephala* Kütz. were met. An objective separation into the various species could probably be obtained only by numerical methods (ii) Occurred throughout the river, but more abundant in the uppermost three kilometres (iv) The previous statement is probably applicable throughout the year.

S. affinis Kütz. (ii) Occurred at various sites in very low numbers; more common below km 43.2.

S. pulchella Kütz. (i) Both type and var. *lanceolata* O'Meara present.

S. vaucheriae Kütz. See *F. intermedia* above.

Eunotia bigibba Kütz. (i) As var. *pumila* Grun. (iii) Noted once, at Durham (km 67.6) on 11.X.65.

E. exigua (Bréb.) Rabh. (ii) At various sites, but most frequent from km 9.2 to km 24.3.

E. lunaris (Ehr.) Grun. (i) As var. *subarcuata* (Näg.) Grun. Typical cell: 32 μ × 4 μ; striae 16/10 μ. (ii) A few cells noted from widely separated sites.

E. pectinalis (Kütz.) Rabh. (i) Only cell: var. *minor* (Kütz.) Rabh. fo. *impressa* (Ehr.) Hust.: 52 × 5 μ, striae 15/10 μ (ii) km 16.2.

E. polydentula Brun. (i) As var. *perpusilla* Grun. (iii) A few cells seen at Lamb Bridge (km 92.2) on 23.III.66.

E. tenella (Grun.) Hust. (ii) Single cells seen at km 2.7 and at km 10.5 (above the entry of Rookhope Burn).

E. trinacria Krasske (ii) One cell at km 43.2.

Cocconeis pediculus Ehr. (i) 19–31 μ long, 10–23 μ wide (iv) An abundant epiphyte in the warmer months, in particular often smothering *Cladophora glomerata* (v) Due to the rapidity with which this organism can grow and the density of the covering it can form on *Cladophora* it seems likely that this species will prove one of the most ecologically important in the river. Although occasional cells of *Cocconeis pediculus* are found in other habitats, this is more restricted to the epiphytic habitat than any other species.

C. placentula Ehr. (i) 16–22 (−35) μ long, 8–11 (−20) μ wide (iv) Usually associated with filamentous algae other than *Cladophora*.

C. diminuta Pantocsek (i) The one valve noted was 12 × 8 μ and had striae 10/10 μ on the rapeless valve (iii) Valve found at Durham (km 67.6) on 17.IX.65.

Achnanthes minutissima Kütz. (i) 8–20 μ × 4–6 μ; some forms approach var. *cryptocephala* Grun. (ii) Throughout the river, and an important constituent of the diatom population from km 0.0 to km 35.2, reaching 73% diatom population at km 4.4.

A. affinis Grun. (ii) One cell at km 0.0.

A. lanceolata Bréb. (i) 8–20 μ × 4–6 μ. The fo. *ventricosa* Hust. also occurs, a typical cell being 35 × 12 μ, striae 13/10 μ (iv) The type occurs in small amounts throughout almost all the river; the fo. *ventricosa* is less common than the type.

A. pyrenaica Hust. (i) 11–12 μ × 4–5 μ; striae 23–26/10 μ. The alga agrees with the description by Hustedt (1939), except he recorded the striae as 21–25/10 μ (ii) Fairly common between km 4.4 and km 16.2; less common than elsewhere (v) This is apparently the first published record of this organism in the British Isles. Judging by recent European literature this may be a relatively common species which is usually included elsewhere.

A. brevipes Ag. (i) var. *intermedia* (Kütz.) Cleve. Typical cell from km 100.9: 32 × 13 μ; striae 10/10 μ. (ii) One cell at km 80.6, but quite common at km 100.9.

Rhoicosphenia curvata (Kütz.) Grun. (ii) A single cell at km 0.0, but otherwise not noted above km 43.2; most abundant at km 65.6 (iv) A frequent epiphyte, especially in the middle reaches of the river and on *Cladophora*. It is perhaps especially abundant in spring before dense populations of *Cocconeis pediculus* have developed.

Amphipleura pellucida Kütz. (ii) One cell noted at each of km 4.4, km 13.7, km 70.6.

A. rutilans (Trentepohl) Cleve (ii) Present at km 80.6 and km 100.9.

Frustulia vulgaris Thwaites (i) Typical cell: 47–55 μ × 9–10 μ. Cells from R. Wear are generally smaller than described by Hustedt (1930a; 1930b) (ii) At various stations from km 0.0 to km 100.9.

Gyrosigma acuminatum (Kütz.) Rabh. (i) 150–175 μ × 22 μ (ii) A few cells noted from km 80.6 and km 100.9.

Pleurosigma angulatum (Quekett) W. Sm. (iii) A few cells noted on *Pilayella* at Glasshouse Hill (km 104.2) on 27.VI.66.

Caloneis alpestris (Grun.) Cleve (ii) Seen only at km 0.0.

C. amphisbaena (Bory) Cleve (ii) A few cells noted at km 70.6 and km 92.2.

C. bacillum (Grun.) Mereschkowsky (i) This species is easily confused with *C. silicula* var. *truncatula*, which is equally common, and possibly also with certain *Naricula* spp. if the parallel longitudinal striae are not seen clearly (iv) Widespread, but always present in only low numbers.

C. silicula (Ehr.) Cleve (i) As var. *truncatula* Grun. The striae are faint and at least 20/10 μ (ii) At sites above and including km 26.3.

Neidium iridis (Ehr.) Cleve (ii) One cell at km 70.6.

N. dubium (Ehr.) Cleve (ii) One cell at km 70.6.

Diploneis didyma (Ehr.) Cleve (i) Typical cell: 67.5 × 22.5 μ, ribs 10/10 μ (iii) On *Pilayella*, Glasshouse Hill (km 104.2) on 27.VI.66.

D. ovalis (Hilse) Cleve (i) 25–35 μ × 12–14 μ (ii) In small amounts at four widely spaced stations.

Stauroneis smithii Grun. (ii) One cell at km 2.7.

Anomoeoneis exilis (Kütz.) Cleve (i) 20–21 μ × 5 μ (ii) As with: (iv) Occurs sporadically,

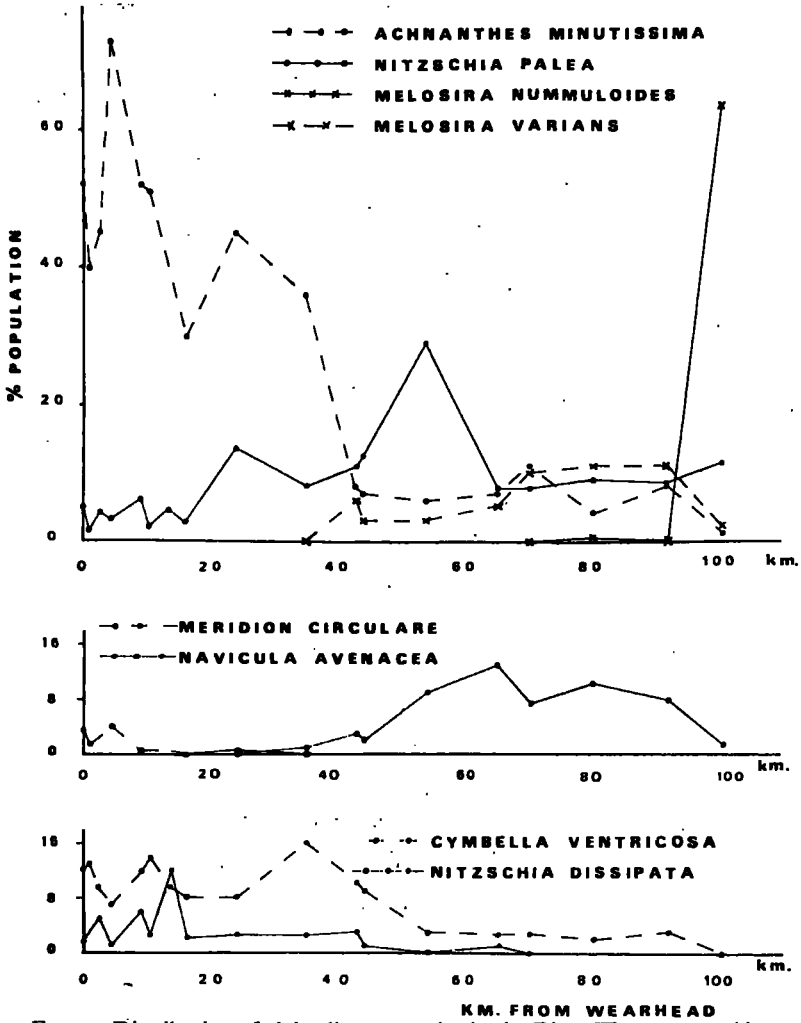


FIG. 1. Distribution of eight diatom species in the River Wear on 3.IX.66.

either singly or in small amounts.

A. zellensis (Grun.) Cleve (i) Occurs as fo. *difficilis* (Grun.) Hust.; 24 × 4 μ, striae indistinct (ii) Single cells seen at km 4.5 and km 9.2

Navicula accomoda Hust. (ii) One cell at km 24.3.

N. anglica Ralfs (i) 26 × 10 μ, striae 11/10 μ (ii) Single cells at km 2.7 and 70.6.

N. atomus (Näg.) Grun. (ii) As with: (iv) Frequent occurrence, though only in small amounts.

N. avenacea Bréb. (i) Hustedt (1930a) included this as a variety of *N. viridula* Kütz. and many subsequent authors have followed him. However by the criteria widely used for the separation of species within *Navicula* there seems no justification for doing this (ii) See FIG. 1 (iv) Generally abundant, but less common in the upper reaches and also decreasing with increasing salinity.

N. bryophila Petersen (ii) A few cells seen at km 0.0.

N. certa Hust. (i) Single cell: 23 × 5 μ, striae 12/10 μ; rather smaller than the form described by Foged (1964) (ii) One cell seen at km 0.0.

N. cincta (Ehr.) Kütz. (i) As var. *heufleuri* Grun. 18 × 4 μ, striae 16/10 μ. Smaller than those forms described by Hustedt (1930a), and Van der Werff & Huls (1955), and with closer striation than the 10/10 μ limit of Hustedt (1930a) (ii) A few cells seen at km 0.0, km 24.3 and km 70.6.

N. contenta Grun. (ii) A few cells seen at km 16.2 and km 44.2 (v) A very small cell, which in many surveys is probably overlooked or confused with certain forms of *Achnanthes minutissima*.

N. cryptocephala Kütz. (i) As var. *intermedia* Grun.: Typical cell: 35 × 6 μ, striae 16/10 μ (ii) In low numbers at km 2.7, 13.7, 16.2, 43.2 (v) See *N. gregaria* below.

N. cuspidata Kütz. (iii) Seen once at Durham (km 67.6) on 11.X.65.

N. gracilis Ehr. (i) 38–50 μ × 7–9 μ; striae 11–12/10 μ (ii) Present at and below km 13.7 but more common below km 43.2, most abundant at km 80.6 and absent at km 100.9.

N. graciloides A. Mayer (ii) A few cells seen at km 0.0.

N. gregaria Donkin (i) 15–27 μ × 6–7 μ (ii) Throughout the river, but infrequent in the upper reaches; most abundant at km 80.6 (v) It is easy to confuse this species with *N. cryptocephala* unless a mountant of high refractive index is used. A useful diagnostic feature is the distinct asymmetry of the central area in *N. gregaria*. Hustedt (1957) states that *N. gregaria* is the most common diatom species in the R. Weser, seldom missing in a single sample, and occurring in large numbers in many samples. This species has probably been included in *N. cryptocephala* in many previous surveys of river diatoms. It has been found in large amounts in many other samples, including several from the R. Tees and several Lancashire rivers.

N. hungarica Grun. (i) Occurs as var. *capitata* (Ehr.) Cleve (ii) A few cells seen between km 70.6 and km 100.9.

N. integra (W. Sm.) Ralfs (i) Typical cell: 38 × 11 μ, striae 17–19 μ. Dimensions are rather larger than the forms described by Hustedt (1930a) (ii) A few cells seen at and between km 70.6 and km 100.9.

N. lapidosa Krasske (i) Typical cell: 17 × 5.5 μ, striae at 22–24/10 μ as compared with 26/10 μ in Hustedt (1930a).

N. menisculus Schumann (i) 25–33 μ × 8.5–10 μ striae 10–11 μ (ii) Occasional throughout the river, always in small amounts.

N. minima Grun. (i) As var. *atomoides* (Grun.) Cleve (ii) As with: (iv) Frequently recorded, but always in small numbers.

N. minuscula Grun. (ii) Single cells at km 2.7, km 26.3, km 43.2, km 80.6.

N. muralis Grun. (ii) Single cells at km 4.4 and km 65.6.

N. mutica Kütz. (i) As var. *cohnii* (Hilse) Grun. (ii) Single cells seen at km 80.6, km 92.2, km 100.9.

N. pelliculosa (Bréb.) Hilse (i) 8–10 μ × 4–5.5 μ (ii) Throughout almost all the river, but most abundant at km 54.2, reaching 10% population.

N. pupula Kütz. (ii) One cell seen at km 24.3.

N. pygmaea Kütz. (ii) Occurred only at km 80.6 and below.

N. schonfeldtii Hust. (ii) A few cells seen at km 2.7 and km 16.2.

N. subatomoides Hust. (ii) A few cells seen at six of the stations between km 4.4 and km 100.9.

N. subhamulata Grun. (i) 15–19 μ × 6.5–7 μ; the striae always indistinct (ii) Seen only at and below km 26.3, most frequent at km 100.9.

N. subocculta Hust. (i) One cell only: 16 × 6 μ, striae 16/10 μ (iii) One cell seen at 1.IV.66 at Jack's Bridge (km 44.2).
N. vitabunda Hust. (ii) One cell seen at km 0.0 and a few at km 70.6.
Pinnularia braunii (Grun.) Cleve (i) Only cell: var. *amphicephala* (A. Mayer) Hust. 65 × 9 μ striae 11/10 μ (iii) In August 1966 at the Rookhope Burn inflow (km 10.5).
P. divergentissima (Grun.) Cleve (ii) One cell seen at km 0.0.
P. intermedia Lagerstedt (i) 16 × 5 μ; striae 10/10 μ (ii) One cell seen at each of km 9.2 and km 13.7.
P. interrupta W. Sm. (i) One cell: 36 × 8 μ, striae 13/10 μ (ii) One cell seen at km 0.0.
P. mesolepta (Ehr.) W. Sm. (i) 45 × 8 μ, striae 13/10 μ (iii) Seen only in August 1966 at the Rookhope Burn inflow (km 10.5).
P. microstauron (Ehr.) Cleve (i) Only cell: 48 × 11 μ, striae 11/10 μ (ii) One cell seen at km 16.2.
P. viridis (Nitzsch) Ehr. (ii) Although only a few cells at km 2.7, km 4.4 and km 35.2, nevertheless the most frequent *Pinnularia*.
P. wijkensis Foged 1964 (i) One cell: 47 × 6 μ, striae 12/10 μ (ii) One cell seen at km 2.7 (iv) Probably the first British record. Before Foged's paper, such cells were possibly referred to *P. gibba* Ehr.
Amphiprora paludosa W. Sm. (i) 24 × 10 μ, striae indistinct. Hustedt's (1930a) limits are 40–130 μ × 25–30 μ (ii) At km 100.9.
Amphora ovalis Kütz. (i) 12 × 6 μ; the small variety *pediculus* Kütz. also present (iv) Frequently present, though usually in low numbers; the var. *pediculus* may occur together with the type.
A. veneta Kütz. (iii) On 27.VI.66 at Glasshouse Hill (km 104.2) on *Pilayella*.
A. lineolatae Ehr. (iii) On 27.VI.66 at Glasshouse Hill (km 104.2) on *Pilayella*.
Cymbella affinis Kütz. (ii) One cell seen at km 0.0.
C. aspera (Ehr). Cleve (i) Typical cell: 58 × 17 μ, striae 8/10 μ, punctae 13/10 μ. The R. Wear form is smaller than the forms described by Hustedt (1930a).
C. angustata (W. Sm.) Cleve (iii) One cell seen in September 1965 at Lumley Bridge (km 87.8).
C. cesati (Rabh.) Grun. (i) 35–48 μ × 5–7 μ, striae 18–20/10 μ (ii) A few cells seen at km 2.7, km 16.2 and km 24.3.
C. cymbiformis (Ag.) v. Heurck (i) 30–33 μ × 8–10 μ, striae 8–10/10 μ (ii) A few cells seen at km 24.3 and km 43.2.
C. delicatula Kütz. (i) 22–32 × 6–7 μ, striae 17–19/10 μ. The R. Wear cells are generally larger than the limits given by Hustedt (1930a) (ii) Occurs throughout almost all the river, but most common in the uppermost stations.
C. helvetica Kütz. (i) Typical cell: 48 × 11 μ; striae 15/10 μ at the ends, 12/10 μ on the ventral side.
C. leptoceros (Ehr.) Grun. (i) 36–55 × 8.5–14 μ, striae 9/10 μ on the dorsal side, 10/10 μ on the ventral side. Cells relatively broader than those described by Hustedt (1930a) (ii) At km 1.0 and km 2.7.
C. microcephala Grun. (i) 13–15 × 3.5–4.5 μ (iv) Frequently present in small numbers.
C. naviculiformis Auerswald (iii) One cell seen on 19.VIII.65 at Wearhead (km 0.0).
C. parva (W. Sm.) Cleve (i) Typical cell: 55 × 14 μ; striae 9/10 μ on the dorsal side, 10/10 μ on the ventral side (ii) A few cells seen at each of km 1.0, km 13.7 and km 16.2.
C. prostrata (Berkeley) Cleve (i) 40–50 μ × 15–17 μ; striae 9–10/10 μ (ii) One cell seen at each of six different stations at and below km 9.2.
C. sinuata Greg. (i) 9–17 μ × 4–6 μ; smaller than the forms described by Hustedt (1930a) (ii) Occurred at almost all stations, but most abundant at km 44.2.
C. tumida (Bréb.) v. Heurck (i) 50 × 15 μ; striae 10/10 μ, punctae 16/10 μ (ii) One cell seen at km 43.2.
C. ventricosa Kütz. (i) 16–28 μ × 5–18 μ; striae 12/10 μ (ii) Throughout the river, but most common at km 35.2.
Didymosphenia geminata (Lyng.) M. Schmidt (i) 100/130 μ × 20–28 μ (ii) A few cells seen at km 0.0 and km 1.0.
Gomphonema abbreviatum (Ag.) Kütz. (ii) At most stations, but more common in the uppermost ones.
G. acuminatum Ehr. (ii) One cell seen at km 2.7.

G. angustatum (Kütz.) Rabh. (i) As var. *producta* Grun. (ii) Throughout the river, but most common from km 43.2 to km 54.2.
G. gracile Ehr. (i) 30–40 μ × 5–8 μ; striae 11–14/10 μ (ii) A few cells seen at km 16.2, km 24.3 and km 44.2.
G. longiceps Ehr. (i) As var. *subclavata* Grun. Only cell noted: 30 × 5 μ; striae 12/10 μ. (ii) At km 9.2.
G. olivaceoides Hust. (ii) A few cells seen at km 4.4, km 16.2 and km 26.3.
G. olivaceum (Lyng.) Kütz. (ii) Throughout the river, but more common below km 16.2.
G. parvulum Kütz. (ii) A few cells seen at five sties from km 0.0 to km 65.6.
G. sphaerophorum Ehr. (ii) One cell seen at km 0.0.
G. tergestinum (Grun.) Fricke (ii) One cell seen at km 26.3.
Denticula tenuis Kütz. (i) 10–16 μ × 5–6 μ (iv) Frequently present in samples, but usually in low numbers.
Rhopalodia parallela (Grun.) O. Müll. (ii) One cell seen at km 4.4.
Hantzschia amphioxys (Ehr.) Grun. (i) Only cell noted: 30 × 5 μ; striae 19/10 μ, carinal punctae 8/10 μ (ii) At km 35.2.
Nitzschia acicularis (ii) As with: (iv) At all times of year and throughout the river, though much more common in the lower reaches.
N. acuta Hantzsch (ii) A few cells seen at km 16.2, km 80.6 and km 92.2.
N. acuminata (W. Sm.) Grun. (ii) From km 80.6 to km 100.9.
N. amphibia Grun. (ii) One cell seen at km 0.0.
N. apiculata (Greg.) Grun. (ii) Three cells seen at km 80.6 (v) This species is usually found in estuarine or saltwater habitats.
N. communis Rabh. (ii) Common at km 80.6 and km 92.2, where it formed over 1% population.
N. dissipata (Kütz.) Grun. (i) 27–37 μ × 6–10 μ; carinal punctae 8–9/10 μ (ii) At almost all stations, but most common from km 2.7 to km 14.2.
N. dubia W. Sm. (ii) A few cells at sites from km 70.6 to km 100.9.
N. filiformis (W. Sm.) Hust. (i) Typical cell: 53 × 6 μ; striae 35/10 μ, carinal punctae 8/10 μ (ii) A few cells seen at km 80.6 and km 100.9 (iii) At km 67.5 on 10.IX.65.
N. frustulum Grun. (i) 23–24 μ × 3.5–4 μ; striae 22/10 μ, carinal punctae 10/10 μ. Var. *perpusilla* (Rabh.) Grun. also present: 9–10 μ × 3–3.5 μ; striae 21–22/10 μ, varinal punctae 10–12/10 μ (ii) A few cells seen at eight stations at and below km 9.2; var. *perpusilla* relatively more frequent in the lower reaches.
N. fonticola Grun. (i) 11–13 μ × 3.5–4 μ; striae indistinct, carinal punctae 14/10 μ (ii) Occasional, more common in the middle reaches, decreasing in the tidal reaches.
N. hantzschiana Rabh. (i) One cell noted: 23 × 3 μ; striae 26/10 μ, carinal punctae 7–10/10 μ (ii) At km 1.0.
N. hungarica Grun. (ii) One cell seen at km 92.2 (iii) At km 67.5 on 11.X.65.
N. ignorata Krasske (ii) At km 0.0, km 10.5 and km 92.2.
N. kützingiana Hilse (ii) At km 0.0 and km 10.5.
N. levidensis (W. Sm.) Grun. = *N. tryblionella* Hantzsch var. *levidensis* (W. Sm.) Grun. (ii) At km 100.9.
N. linearis W. Sm. (ii) Throughout almost all the river, but less frequent in the tidal reaches.
N. palea (Kütz.) W. Sm. (i) 18–35 μ × 2.5–4 μ; carinal punctae 13–14/10 μ (ii) As with: (iv) Throughout the river and usually frequent.
N. romana Grun. (ii) Two cells seen at km 54.2.
N. sigma (Kütz.) W. Sm. (ii) One cell seen at each of km 80.6 and km 100.9.
N. sigmoidea (Ehr.) W. Sm. (ii) Occasional, more common from km 80.6 to km 100.9.
N. stagnorum Rabh. (i) Only cell: 28 × 10 μ; striae 22/10 μ, carinal punctae 8/10 μ.
N. subtilis Kütz. (iii) At km 68.4 on 10.IX.65.
N. thermalis Kütz. (i) As var. *minor* Hilse: 47 × 8 μ; striae 43/10 μ, carinal punctae 11/10 μ (ii) At km 80.6 and km 100.9.
N. tropica Hust. (i) Typical cell: 17 × 2.5 μ; striae 24/10 μ, carinal punctae 10–11/10 μ (ii) at km 9.2 and km 16.2.
N. tryblionella Hantzsch (i) As var. *debilis* (Arnott) A. Mayer: 24–25 μ × 8 μ; striae 12–14/10 μ, carinal punctae 7–9/10 μ (ii) At km 80.6 and km 100.9.
N. vermicularis (Kütz.) Grun. (iii) One cell seen at Lamb Bridge (km 92.2) on 23.III.66.

Cymatopleura elliptica (Bréb.) W. Sm. (ii) At km 80.6 and km 100.9.
C. solea (Bréb.) W. Sm. (ii) at km 70.6 and km 100.9.
Surirella angustata Kütz. (i) 20–35 μ × 7–10 μ; valvar canals 8/10 μ (ii) Occasional, throughout the river.
S. biseriata Bréb. (i) As var. *bifrons* (Ehr.) Hust. *punctata* Meister (ii) Two cells seen at km 2.7.
S. linearis W. Sm. (i) As var. *helvetica* (Brun.) Meister (iii) At inflow of Rookhope Burn (km 10.5) in August 1966.
S. ovata Kütz. (i) 12–54 μ × 10–30 μ (ii) Throughout the river and often frequent.

Discussion

Comparison of diatom floras from different rivers is made difficult by taxonomic problems, and by the fact that many species occur in very small proportions and thus the total list is much influenced by the total number of cells counted. However, it does seem worth making some comparisons. 168 species have now been recorded from R. Wear, 148 for R. Tees and 402 for the whole of the R. Danube (Szemes, 1967).

78 species have been recorded from R. Wear but not R. Tees. At least 54 are probably not due to any taxonomic difficulty. None of these species are so frequent in R. Wear that a real difference in relative abundance would seem to be almost a certainty, but the following are the most likely candidates: *Anomoeoneis exilis, Navicula atomus, N. integra, N. menisculus, N. subatomoides, Gomphonema abbreviatum, Denticula tenuis* (especially), *Nitzschia frustulum.*

58 species have been recorded from R. Tees but not R. Wear. At least 51 are probably not due to any taxonomic difficulty. Of these the following are the species which seem the most likely to show a real difference between the two rivers: *Eunotia arcus, Cymbella cistula, C. lanceolata, C. pusilla, Gomphonema lanceolatum, Nitzschia sublinearis. Cymbella pusilla* was recorded as common by Butcher, and was found again by Whitton and Dalpra, so this seems almost certain to differ in abundance in the two rivers.

In conclusion it may be stated that the diatom floras of the two rivers are rather similar. However, greater differences have been found between R. Wear and R. Tees than between R. Tees sampled at two time intervals separated by over thirty years. *Denticula tenuis* especially appears to be characteristic of R. Wear and *Cymbella pusilla* of R. Tees.

Acknowledgements

The authors are very grateful to Mr. J. R. Carter for advice with taxonomic problems. The work forms part of a survey of the River Wear carried out with financial help from the Northumbrian River Authority and the Natural Environment Research Council.

References

Butcher, R. W., Longwell, J., and Pentelow, F. T. K. (1937): Survey of the River Tees. Part III. The Non-Tidal Reaches — Chemical and Biological. London H.M.S.O.
Fjerdingstad, E. (1964): Pollution of streams estimated by benthal phytomicro-organisms. I. A system based on communities of organisms and ecological factors. *Int. Revue ges. Hydrobiol.* **49** (i): 63–131.
Fjerdingstad, E. (1965): Taxonomy and saprobic valency of benthic phytomicro-organisms. *Int. Revue ges. Hydrobiol.* **50** (4): 475–604.
Foged, N. (1964): Freshwater diatoms from Spitzbergen. Tromsö Museums Skrifter **11**. Tromsö/Oslo.
Hustedt, F. (1930a): Bacillariophyta In: Pascher, A. (Ed.) Die Süsswasser Flora Mitteleutopas **10**. Jena, Gustav Fischer.
Hustedt, F. (1930b). Die Kieselalgen I. In: Rabenhorst's Kryptogamen — Flora.
Hustedt, F. (1939): Diatomeen aus den Pyrenaen. *Ber. deutsch. Bot. Ges.* **56**: 543–572.
Hustedt, F. (1957): Die Diatomeen Flora des Flusssystems der Weser im Gebiet der Hansestadt Bremen. *Abt. naturw. ver. Bremen* **34**(3): 181–440.
Petersen, B. J. (1938): *Fragilaria intermedia — Synedra vaucheriae. Bot. Not.* 164–170.
Szemes, G. (1967): Systematisches Verzeichnis der Pflanzenwelt der Donau mit einer zusammerfassenden Erläuterung. der Donau **3**: 70–131. Stuttgart, E. Schweizerbart'sche Verlagsbuchhandlung. In: (R. Liepolt, Ed.) Limnologie der Donau.
Van der Werrff, A., and Huls, H. (1957): Diatomeeën Flora van Nederland, Abcouda.
Whitton, B. A., and Dalpra, M. (in press). *Hydrobiologia.*

Reprinted from the July–September 1968 issue of *The Naturalist* (No. 906)