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A STUDY OF POLLUTION IN THE RIVER TEAM, AND AN INVESTIGATION OF THE FEASIBILITY OF USING PLANT MATERIAL TO MONITOR ZINC LEVELS.

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ABSTRACT

Surveys of the water chemistry of the River Team were carried out from April to July 1979 in order to establish the extent of organic and metal pollution in the river. Selected aquatic bryophytes and algae were analysed to determine the possibility of using plant material as a means of monitoring zinc pollution.

The possibility was investigated that different enrichment ratios in populations of Stigeoclonium tenue might be related to differences in tolerance to zinc found in the parellel study by C.S. Craggs.

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1 INTRODUCTION

1.1 ZINC IN WATER

1.11 Sources

Although described by Skinner (1969) as a scarce metal, zinc does occur in concentrated localised sources of zinc ores such as sphalerite (ZnS) and calamine ($ZnCO_3$). It is not, therefore, surprising to find considerable variation in estimates of levels of the metal in natural unpolluted waters. Wedepohl (1972) quotes a figure of 0.01 mg l^{-1} as a mean. Abdullah and Royle (1972) found a mean of 0.011 mg l^{-1} for a number of rivers and lakes in North West Wales. Durum et al. (1971) found 0.02 mg l^{-1} to be the mean for 726 river locations in the U.S.A. However, O'Connor et al. (1964) found much higher levels in rivers in the Chesapeake Bay region, their values ranging from 0.01 to 0.2 mg l^{-1}. It seems from the literature that natural levels of zinc may approach 0.1 mg l^{-1} in heavily mineralized areas, but that levels above this are almost certainly due to human activity.

The principal two sources of zinc pollution in rivers are mining activity and the effluents of certain chemical works. In addition a certain amount of zinc may reach rivers from airborne dust or contaminated rainfall. Mining activity can cause metal pollution in two ways; water pumped or naturally drained from mine workings often carries high levels of zinc due to the large areas of ore exposed to erosive forces; rainwater percolating through spoil heaps, where the fragmented nature of the mine waste results in a large surface area of metal bearing rock being exposed, may also carry high levels of zinc. In addition to the effect of exposing a greater area of rock, where sulphide ores are involved, mining may also create acidic conditions, under which metals are more readily dissolved from rocks.

Many studies of zinc pollution due to mining have been carried out in areas such as the North Penine Orefield (Lloyd 1977, Say 1977, Critchley 1978, Harding 1978) or North Wales (Jones 1940, 1958), where metals, particularly zinc and lead, have been extensively mined. However, a certain amount of zinc pollution is also often associated with coal mining. Wedepohl (1972) states that coal contains about 100 $\mu g\ g^{-1}$ Zn. The biological effects of metal pollution from mining have been shown by Jones (1940, 1958) to be serious and persistent. 35 years after the cessation of mining in the area, the River Ystwyth was found to contain zinc levels up to 0.7 $mg\ l^{-1}$, the flora below mine workings was poor in quantity and variety, and the fauna consisted almost entirely of lithophilous insects.

The industrial activities responsible for zinc pollution include galvanising, electroplating, paper processing, paint manufacturing and various processes associated with the electronics industry. Since these sources are so diverse, few generalisations can be made, and further discussion will therefore be delayed to section 3.12 where the effluents directly relevant to the present study will be described.

2

Since the effects of atmospheric fallout were not considered in this study, no further mention of this source of pollution will be made here.

1.12 Solubility

Once zinc has been leached from mine workings, or released in an industrial effluent, its solubility is dependent on a variety of factors. Ernst et al. (1975) found that zinc solubility decreases as alkalinity increases, and that there is a rapid loss of zinc from solution at all alkalinities when the pH rises above 7.5. Smith (1973) found that in a simple laboratory system, zinc was precipitated as zinc hydroxide as the pH rose. The solubility of zinc has also been found to fall in the presence of high levels of phosphate (Jurniak and Inouye 1962).

The principal factor responsible for the mobilisation of zinc in non-acid natural waters is probably complexing with various organic compounds. Perhac (1974) found that large amounts of metals occur in colloidal form (10-100 nm) associated with organic acids due to plant decay. The importance of this factor is emphasised by Schnitzer (1971), who states that zinc can be mobilized by fulvic acids at pH levels where it would normally be insoluble, and by Stevenson (1976), who states that practically every aspect of the chemistry of heavy metals in soils, sediments and natural waters is related in one way or another to the formation of complexes with humic substances.

It can be seen from this brief review that the factors affecting the mobilization of zinc in natural waters are extremely complex, and present knowledge does not allow us fully to understand the distribution of metal ions between water and suspended matter (Stumm and Bilinski 1972). A further complication is produced by the binding of zinc in sediments. Jackson and Nichol (1975) identify hydrous iron and manganese oxides as important factors affecting heavy metal distribution in sediments. Once bound to the sediments, the zinc is probably only released when conditions change.

1.2 BIOLOGICAL ASPECTS

1.21 Toxicity

Unlike lead and cadmium, with which it is often associated, zinc is an essential micronutrient both for plants and animals. As levels rise, however, toxic effects are produced. Sellers et al. (1975) describe the acute inflammatory action of zinc poisoning on rainbow trout gills, with subsequent respiratory collapse. De Filippis and Pallaghy (1976) describe the inhibitory effect of zinc on photosynthesis in a strain of *Chlorella*, associated with reductions in pigment content, rates of cell division and metabolic activity. A variety of factors have been found to modify these toxic effects.

Much of the research into factors modifying zinc toxicity has concerned fish. Lloyd (1960) found that the toxicity of zinc to rainbow trout (Salmo gairdneri) is greatly reduced in hard water. Lloyd and Herbert (1962) found metals to be more toxic to fish at low oxygen tensions, probably due to greater accumulation across the gills, associated with increased respiratory rate. Temperature may affect accumulation of metals in animals due to differences in food intake (Davis and Foster 1958).

Hard water has also been found to reduce the toxicity of zinc to algae. Harding and Whitton (1977) report that high PO_4-P, Ca and Mg all reduce the toxicity of zinc to laboratory populations of Stigeoclonium tenue. The same factors were found by Say, Diaz and Whitton (1977) to reduce the toxicity of zinc to Hormidium species, while Pb and Cd were found to increase the toxicity.

1.22 Resistance

Water bearing a high load of heavy metals typically has fewer plant and animal species than unpolluted waters, and may, therefore, be thought of as an extreme environment as defined by Brock (1969). Jones (1940), in his study of the zinc and lead polluted River Ystwyth, found fish to be entirely absent, the fauna being restricted to Insecta, Platyhelmia and Hydracarina. Scapania undulata was the only bryophyte to tolerate the zinc levels in excess of 1 mg l^{-1} which were found below mine adits. The algal flora was greatly restricted and dominated by the red alga Lemanea, which has been reported as resistant to both lead and zinc (Whitton and Say 1975).

Although the number of species is greatly reduced in environments with high levels of heavy metals, plant species which are resistant to the metal or metals in question may be able to achieve a high standing crop, due to reduced competition and grazing pressure. In some cases, resistance may be specific to a particular metal, so that the plant may be used as an indicator. Thus, the "copper moss" (Mielichhoferia mielichhoferi) has been used by prospectors to locate areas rich in copper ores (Hartman 1969).

In other cases resistance may be less specific. Whitton (1972) suggests that the green algae Microspora and Ulothrix may be resistant to high levels of lead, zinc and copper. McLean and Jones (1975) state that the presence of Hormidium rivulare in clear flowing waters indicates probable high levels of heavy metals. Whitton (1970) states that Stigeoclonium tenue found alone in abundant growths in a clear, well illuminated, fast flowing body of water should lead to suspicion of metal contamination. Stigeoclonium is also listed by Weimann (1952) as resistant to metal pollution. McLean (1974), however, found no Stigeoclonium in high heavy metal waters in South Wales, and suggests that metals may not be tolerated by this alga in the absence of organic pollution.

It seems clear that the presence of certain resistant species may provide an indication of metal contamination. One approach to assessing the degree of metal pollution in water is to examine the extent to which such resistant species accumulate the polluting metals.

1.23 Accumulation

Bowen (1966) found that aquatic plants concentrate all of a range of metals studied, except sodium, above the levels in the surrounding water. There have been two main approaches to the study of the phenomenon:

1) experiments using radioactive isotopes such as ^{65}Zn to trace the movements of the element between water and plant;

2) a comparison of metal levels in the plant and in the surrounding water by calculation of an enrichment ratio:

$$ER = \frac{\text{Concentration of metal in plant } (\mu g\ g^{-1} \text{ dry wt})}{\text{Concentration of metal in medium } (mg\ l^{-1})}$$

The first approach has been used mainly to study the mechanisms of metal uptake, while the second has been concerned mainly with assessing the possibility of using plant material to monitor the metal status of the water. Both approaches have also been used to look for connections between degree of accumulation and metal tolerance of the plant.

Pickering and Puia (1969), on the basis of ^{65}Zn experiments with the moss Fontinalis antipyretica, proposed that zinc is taken up from the water in three distinct stages:

i) rapid absorption and uptake into the free space of the cell membrane;

ii) penetration into the protoplast, the outer layer functioning as a diffusion barrier;

iii) active accumulation into the cell vacuole, dependent on metabolic activity.

The first two phases involve physical processes and last for about 20 min and 90 min respectively, while the third stage involves active biological processes and may last for several days until a saturation value is reached. This three phase model depending on physical and biological processes may explain the divergent opinions of some previous workers in this field. Bachman and Odum (1960) found that ^{65}Zn was taken up by six species of marine benthic algae in light but not in darkness, the rate of uptake being related to the rate of photosynthesis, and the accumulation in the cell being a function of growth or net production. They therefore argue for metabolic involvement. Broda (1965), however, found no supression of ^{65}Zn uptake by Chlorella pyrenoidosa due to uncoupling agents or anaerobis, and therefore emphasized physical processes.

The degree to which different organisms concentrate metals from the environment has been found to vary considerably, and in some cases this may be related to differences in tolerance. McLean and Jones (1975) found that Scapania undulata took up less ^{65}Zn than the less tolerant Fontinalis squamosa, and suggested that tolerance in this case may be due to a bar to metal entry. The same authors also found that Brachythecium rivulare contained similar levels of zinc to *Scapania*, although the former existed at much lower environmental zinc levels. Harvey and Patrick (1967) suggested that among freshwater algae, similarities and differences in the concentration of ^{137}Cs, ^{65}Zn and ^{85}Sr are more closely related to cell morphology, particularly to surface to volume ratios, than to systematic relationships.

1.24 Monitors

Two main advantages have been suggested for using plant material to monitor the metal status of the environment:

1) Heavy metals often occur in concentrations that are too low to be easily measured. By concentrating metals, plants facilitate their detection (Empain 1976).

2) Plant material can provide an integrated figure for metal concentration over a long period of time, smoothing out short term environmental fluctuations (Goldberg 1965).

Research into the possibility of using plants as monitors has often yielded inconclusive results. Although some studies have provided promising results, the number of variables involved means that generalizations are hard to make, and each case should be considered on its own merits. The following examples will illustrate some of the requirements for a good monitor species.

Keeney *et al*. (1976) found that the enrichment ratio of *Cladophora glomerata* in Lake Ontario was stable enough for this alga to act as a monitor of a variety of metals, including zinc. They point out that one advantage of using *Cladophora* is that it is independent of the substratum for its nutrition, so that levels in the plant will reflect only levels in the water.

Lloyd (1977) found widely varying zinc enrichment ratios in the bryophytes *Fontinalis antipyretica*, *Scapania undulata* and *Hygrohypnum ochraceum*, in the River Wear system, but nevertheless concluded that plant material can, in general terms, give a guide to the metal status of the river. The use of algae as monitors in this system was made difficult due to no single macrophytic alga existing throughout the river.

Harding (1978) suggested that *Lemanea fluviatilis* might be a useful monitor of zinc, lead and cadmium levels in the River Derwent catchment. The enrichment ratios were not constant over the range of concentrations found in the water, but linear relationships were apparent between the concentrations of metals in the water and in the algal filaments.

Foster (1976), working with the marine brown algae *Fucus vesiculosus* and *Ascophyllum nodosum* in the Menai Straits, concluded that in highly polluted waters it is unlikely that the heavy metal content of the algae will reflect dissolved concentrations of those heavy metals which constitute only a small proportion of the dissolved load. There may be a finite number of non specific binding sites, and the presence of more than one metal competing for these sites seems likely to cause considerable complications in interpreting enrichment ratios.

The possibility that there are a finite number of binding sites leads Critchley (1978) to express doubt about the use of plants as monitors at very high zinc levels. Once these sites are saturated, a rise in environmental levels will not be reflected by a similar rise in the metal content of the plant.

The implications of these studies will be discussed in more detail in 6.4.

1.3 AIMS

The present study was undertaken with four aims:

1) to carry out surveys of the water chemistry of the River Team from source to mouth;

2) to investigate the effects of zinc from mining and industrial sources on the chemistry and biology of the river;

3) to assess the possibility and usefulness of using plant material to monitor zinc concentrations in the river;

4) to investigate any possible relationship between zinc accumulation and tolerance in the alga Stigeoclonium tenue. Toxicity studies on this alga were carried out in a parallel MSc project by C.S. Craggs.

2 MATERIALS AND METHODS

2.1 WATER CHEMISTRY

2.11 Collection of samples

Samples were collected from the end of April to the end of July 1979. All water samples were collected from just below the surface in mid-stream. All glass and plastic vessels used had previously been acid washed by soaking for at least one hour in 10% HCl, and rinsing six times with distilled water.

2.12 Metals

Water for metal analysis was collected in a 2000 ml polythene beaker and allowed to stand for 5 minutes to achieve a standard suspension. One sample of this was then transferred directly to a 30 ml snap top vial, while a second sample was filtered through a 0.2 µm polycarbonate Nuclepore filter into a similar vial. Both samples were then acidified with one drop of atomic absorption grade nitric acid, in order to keep the metals in solution, and stored at $4^{\circ}C$ until analysis. Samples were analysed for zinc, calcium, magnesium, iron and manganese using a Perkin Elmer 403 atomic absorption spectrophotometer. Analysis for calcium and magnesium involved the addition of six drops of lanthium chloride to 4 ml of sample to reduce interference effects. Blanks, prepared by adding a drop of nitric acid to distilled water were similarly analysed.

2.13 Anions

Samples for chloride and phosphate analysis were filtered in the field through sintered glass funnels (Sinta No. 2) into 300 ml polythene bottles. These were stored at 4°C until returned to the laboratory, where they were deep frozen until analysis.

Chloride levels were estimated by titration of 10 ml of sample with 0.0141 N silver nitrate, using a potassium chromate indicator (A.P.H.A. 1971). Each figure presented is the mean of three replicates.

Analysis for soluble reactive phosphorus was carried out by addition to the sample of an acid molybdate-antimony reagent, with ascorbic acid providing reducing conditions. The absorbance of the resulting blue colour was measured at 885 nm using a 4 cm cell in a Uvispek photoelectric spectrophotometer Mk 9 (A.P.H.A. 1971).

2.14 Field tests

Measurements of dissolved oxygen, temperature, pH and total alkalinity were taken in the field. Dissolved oxygen was measured using a Lake Instruments Ltd. oxygen meter. Temperature was measured with a thermometer and a thermister in the oxygen probe. pH was determined using a Pye model 293 pH meter. Total alkalinity was determined by titration of 100 ml of sample with 0.02 N sulphuric acid to an end point of pH 4.2. Total alkalinity, expressed as mg l^{-1} $CaCO_3$ was calculated as follows:

Total Alkalinity =

$$\frac{\text{ml } H_2SO_4 \text{ to end point x normality of acid x 50,000}}{\text{ml of sample used.}}$$

2.15 Laboratory tests

Measurements of pH, conductivity and optical density were carried out in the laboratory on the same day as the samples were collected. Water samples for these measurements were collected in 300 ml polythene bottles, sealed under water to exclude air.

pH was measured with an Electronic Instruments pH meter 7020, in order to check the value obtained in the field. Conductivity was measured using a Kent Electronic Instruments electrolytic conductivity measuring set with a K = 1.0 cell. Optical density was measured at 240 nm and 254 nm using a Uvispek photoelectric spectrophotometer Mk 9.

2.2 PLANT DIGESTS

2.21 Collection and cleaning of material

Plant material was collected, except where stated, from near the middle of the river, and from continuously submerged substrates. As much silt and other contaminating material as possible was removed in the field by vigorous shaking in the river water. The samples were then placed in polythene bags, and as much water as possible was drained off to reduce the possibility of leaching of metals.

As soon as possible after returning to the laboratory, the plants were washed in distilled water. The enormous variation in the degree of contamination of samples produced problems in developing a standardized washing technique. All samples were washed in five dishes of distilled water. They were then removed to a sixth dish and inspected. Any moss leaves or algal filaments bearing debris which could not easily be removed were then discarded. This procedure was adequate for the majority of samples, but some of the algae from the most polluted sites required further washes, and in some cases it was still not possible to be certain that all contamination had been removed. This problem is discussed in 6.4.

2.22 Digestion

2 cm tips were removed from the cleaned moss samples for digestion. The whole plant was used in the case of the algae. These samples were then placed in acid washed glass tubes, dried in an oven at 105°C for 48 h and allowed to cool in a desicator. In order to confirm the necessity of using 2 cm tips of the mosses, plants from which the tips had been removed were also digested in a few cases (Table 12). When cool, 25 mg of each sample was digested by boiling for 30 min in 4 ml atomic absorption grade nitric acid in Kjeldahl flasks. After cooling the digested samples were diluted to 25 ml with distilled water and stored at 4°C until analysis. The purity

of the acid was tested each time digestion was carried out, by analysing blanks, prepared by boiling 4 ml of acid without any plant material, and diluting as before. Analysis for zinc only was carried out using a Perkin Elmer 403 atomic absorption spectrophotometer.

2.3 SEDIMENT DIGESTS

Four samples of sediments from each site were dug from the river bed with a trowel, and stored in polythene bags. The sediments were then dried in an oven at 105°C for 48 h , sieved through a 210 µm mesh, replaced in an oven for 12 h and placed in a desicator to cool. 50 ml of each sample were then digested by boiling for 30 min in 5 ml Analar nitric acid in a Kjeldahl flask. After cooling the samples were diluted to 25 ml with distilled water and stored and analysed in the same way as the plant digests (2.22). The sediment digests were also analysed for iron content.

2.4 INVERTEBRATE SURVEY

Limited time prevented any attempt to conduct a quantitative survey of invertebrates. The results in table are based on two sources:

1) any invertebrates encountered during collection of plant and water samples were recorded;

2) on 11.V1.79 a survey of all the sites was carried out, involving a 30 min search for invertebrates by turning over rocks and by netting disturbed sediments.

3 STUDY AREA

3.1 THE RIVER

3.11 General

The river Team is a tributary of the river Tyne. It rises North of Annfield Plain, Co. Durham (165 528) and enters the Tyne about 19 km from its mouth in an industrial area of Gateshead (233 626). The total length of the river is 25.5 km. The geological substratum consists of coal measures for the entire length of the river, with limestone outcrops to the south and east. Most of the catchment has been extensively mined, but only one colliery affecting the river is still operational.

3.12 Sources of pollution

The sources of pollution affecting the river can be divided into three main types:

1) organic pollution from sewage discharges;
2) metal pollution due to mining activity;
3) a variety of forms of chemical pollution from industrial sources.

There are three major concentrations of pollution sources. The first begins 5 km from the source, where drainage water from tips associated with the Ever-Ready factory on Tanfield Lea Industrial Estate enters the river.

Figure 1.

Map showing location of sampling sites on the River Team.

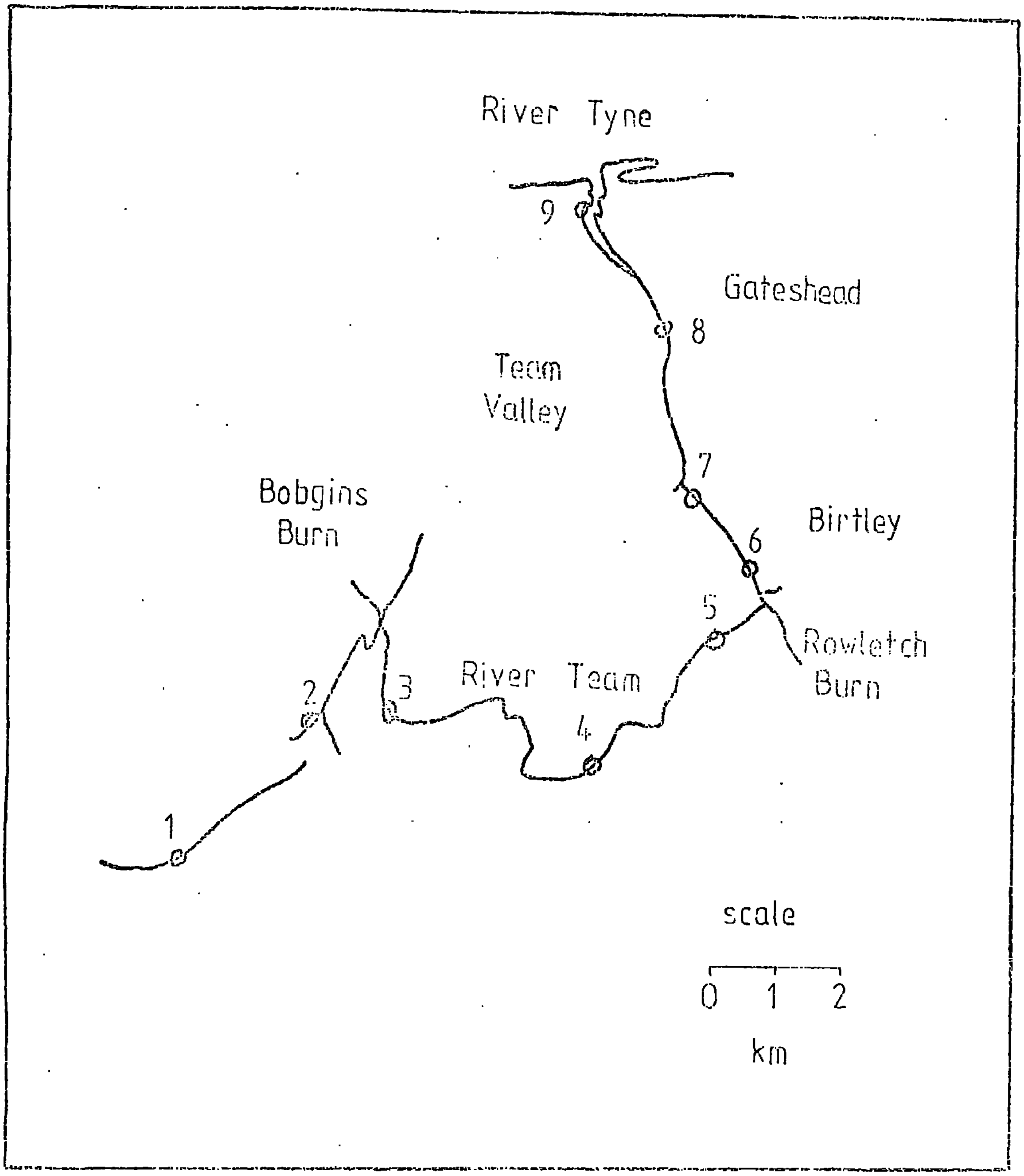
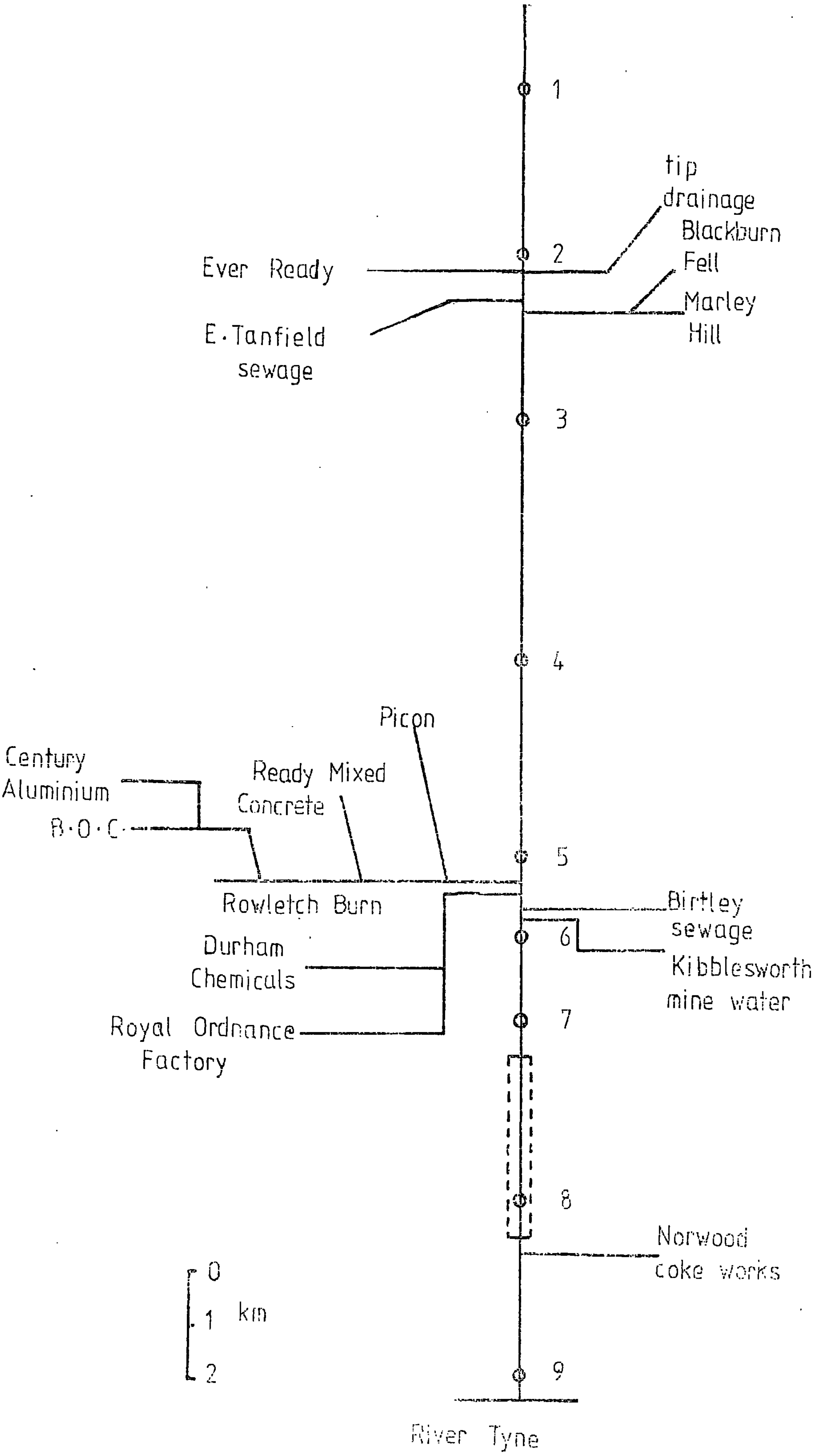

River Tyne
9
Gateshead
8
Team
Valley
7
Bobgins
Burn
Birtley
6
5
Rowletch
Burn
2
3
River Team
4
1
scale
0
1
2
km

Figure 2.

Sources of pollution in the River Team.

Numbers show position of sampling sites.


1
tip drainage Blackburn Fell
Ever Ready
2
Marley Hill
E.Tanfield sewage
3
4
Picon
Century Aluminium
Ready Mixed Concrete
B.O.C.
5
Rowletch Burn
Birtley sewage
6
Kibblesworth mine water
Durham Chemicals
7
Royal Ordnance Factory
8
Norwood coke works
0
1
2
km
9
River Tyne

0.5 km further downstream, the East Tanfield sewage treatment works discharges into the river. Pumped mine water from East Tanfield also joins the river at this point. At 6.5 km the river is joined by Bobgin's Burn, a tributary bearing drainage water from Blackburn Fell and Marley Hill collieries. No water has been pumped from Blackburn Fell since it closed in March 1979. Marley Hill is still operational, but most of the present workings are to the north, so that water is now pumped towards the River Derwent (Carslake pers. comm.). Only a small amount of naturally draining water from these mine workings still finds its way into the Team.

The second major concentration of pollution sources occurs in a 300 m stretch, 16.5 km from the source. Here a small tributary called Rowletch Burn joins the Team, bearing effluents from the following Birtley industrial works: Century Aluminium; British Oxygen Company; Ready Mixed Concrete; Picon. About 100 m downstream, the effluents of Durham Chemicals and the Royal Ordnance factory enter the river. The Durham Chemicals works produces a large variety of organic and inorganic compounds, chiefly zinc compounds, which are used as raw materials by the paint, rubber and plastics industries. It is therefore a very important factor in the present study. In the next 200 m stretch the river receives the effluent of Birtley sewage works, and mine water pumped from the Kibblesworth colliery. Although this is usually pumped only at night, after heavy rainfall, pumping may also occur during the day.

The river then has only 2 km to recover before entering the Team Valley Trading Estate, where it receives the effluents of a variety of factories. During periods of heavy rainfall, storm sewage overflow also adds to the burden. By the time the tidal stretch is reached (km 24) raw sewage is a constant feature of the river, together with large amounts of oil from various sources.

In addition to these three concentrations of pollutants, there are a large number of small drainage streams from disused mine workings, particularly between sites 3 and 4.

3.13 Grading the river

In the Northumbrian Water Authority report on water quality in July 1977, approximately 4 km of the river were classed as grade 2A, 17 km. as grade 3 and 3 km as grade 4, the remainder being tidal and therefore unclassified. So severe is the pollution below the Durham Chemicals effluent, that the 7 km stretch of the Team from there to the beginning of the tidal stretch is the only reach in the Northumbrian Water Authority area destined to remain as bad as grade 3. The criteria for these gradings are shown in Table 1.

Table 1.

Water quality criteria used by the
Northumbrian Water Authority.

GRADE	QUALITY CRITERIA	REMARKS	CURRENT POTENTIAL USES
2 A	i) D.O. greater than 60% saturation. ii) B.O.D. not greater than 7 mg l^{-1}. iii) Non-toxic to fish in E.I.F.A.C. terms.	Water not showing physical signs of pollution.	i) Waters suitable for potable supply after advanced treatment. ii) Supporting game and good coarse fisheries. iii) Substantial amenity value.
2 B	i) D.O. greater than 40% saturation. ii) B.O.D. not greater than 9 mg l^{-1}. iii) Non-toxic to fish in E.I.F.A.C. terms.	Water not showing physical signs of pollution other than humic colouration and a little foaming below weirs.	i) Waters suitable for potable supply after advanced treatment. ii) Supporting reasonably good coarse fisheries. iii) Moderate amenity value.
3	i) D.O. greater than 10% saturation. ii) Not likely to be anaerobic. iii) B.O.D. not greater than 17 mg l^{-1}.		May be used for low grade industrial abstraction purposes. Considerable potential for further use if cleaned up.
4	Waters inferior to class 3 in terms of D.O. and likely to be anaerobic at times.		Waters which are grossly polluted and likely to cause a nuisance.

3.2 SITES

Nine sites were chosen for a survey of water chemistry, ranging from just over 1 km from the source to about 0.2 km from the mouth. A 10 m stretch at each site was used for the taking of water samples. Plant material was collected from the same 10 m stretch, and, where necessary, from a further 100 m downstream of the water sampling point.

3.21 Site 1 Kyo Burn

Map ref: 174 528.

Distance from source: 1.1 km

Water sample site: immediately upstream of road bridge.

Site description: The river at this point varies from 0.5 - 1 m in width, and from 10 - 50 cm in depth. The bed is rocky, providing a good substrate for algal growth. A species of Ulothrix was seen to achieve almost complete cover at times. The water is clear, except after heavy rainfall. This site was chosen as the nearest easily accessible point to the source of the river.

3.22 Site 2 Houghwell Burn at Tantobie Road Bridge.

Map ref: 194 547

Distance from source: 4.8 km

Water sample site: 20 m upstream of Tantobie
Road Bridge.

Site description: The river at this point is 1.5 - 2.5 m wide and 20 - 70 cm deep. The bed is composed of fine silt, so that algae and some groups of invertebrates depend on rubbish that has been thrown into the river to provide a firm substrate. The water is usually clear, but was observed on one occasion to be extremely turbid. The site was chosen to represent the water quality immediately before the first major concentration of pollutants. This site is also sampled regularly by the Northumbrian Water Authority.

3.23 Site 3 Beamish Burn

Map ref: 205 547

Distance from source: 7.8 km

Water sample site: 50 m downstream of bridge.

Site description: The river here is 4 - 5 m wide and 10 - 70 cm deep. The bed is rocky, providing a good substrate for algae. Cladophora glomerata is the dominant alga at this site. Although the water has been observed to be clear on a few occasions, it is more typically murky due to suspended solids from East Tanfield sewage works. This site was chosen to investigate changes in water chemistry caused by the first concentration of pollutants. It is also a regular sampling point of the Northumbrian Water Authority.

3.24 Site 4 High Urpeth

Map ref: 235 542

Distance from source: 12.4 km

Water sample site: 10 m upstream of High Urpeth road bridge.

Site description: The river here varies between 1.5 and 4 m in width and is from 10 - 80 cm deep. The bed is largely rocky with some areas of fine silt and coarser sand. The water is usually clear, except after heavy rain. Cladophora glomerata was the dominant alga during the survey, with considerable growths of Stigeoclonium tenue. The site was chosen to monitor the recovery of the river from the first group of pollutants.

3.25 Site 5 Above Birtley Sewage.

Map ref: 255 561

Distance from source: 15.9 km

Water sample site: 30 m upstream of road bridge.

Site description: The river at this point is 3 - 4 m wide and 20 - 60 cm deep. The bed is rocky with a considerable amount of rubble. The water is usually clear, except after heavy rain. Cladophora glomerata and Stigeoclonium tenue were both abundant during most of the survey. This site was chosen to show the full extent of recovery from the first group of pollutants.

3.26 Site 6 Below Birtley Sewage

Map ref: 258 570

Distance from source: 17.4 km

Water sample site: immediately upstream of road bridge.

Site description: The river here is 5 - 6 m wide and 20 - 60 cm deep. The bed is rocky, but there are no bryophytes or filamentous algae. Bryophytes on the bank close to the water exist only as protonemata. Small amounts of Stigeoclonium tenue associated with large numbers of diatoms occur in the splash zone. A thin film of a unicellular green alga is the only evidence of photosynthetic life in the water. 3 flatworms were the only invertebrates encountered during the survey. The water is always murky and usually has a film of oil and a pungent smell. This site was chosen to investigate changes in the water quality below the second concentration of pollutants.

3.27 Site 7 Lamesley

Map ref: 251 579

Distance from source: 18.6 km

Water sample site: immediately downstream of Lamesley road bridge.

Site description: The river here is 5 - 6 m wide and 10 - 80 cm deep. The bed is mainly rocky, but has some sandy patches. Apart from a brief appearance of Stigeoclonium tenue there were no filamentous algae. No bryophytes are present in the water, and those growing on the banks close to the water exist only as protonema. The moss associated with the protonema higher up the bank was identified as Pohlia delicatula. Growing the protonema from close to the water on zinc free agar plates confirmed that this was the same species. A few chironomid larvae were the only invertebrates found. The water here is always murky and often bears a film of oil and the same pungent smell as site 6. The site was chosen to investigate the extent of recovery before the river enters the Team Valley Trading Estate.

3.28 Site 8 Team Valley Trading Estate

Map ref: 245 605

Distance from source: 22 km

Water sample site: immediately upstream of the
Third Avenue road bridge.

Site description: The river here is 6 m wide and 30 - 60 cm deep. The bed is rocky with a large amount of rubble. Considerable growths of Stigeoclonium tenue occurred near the surface where light could penetrate the constantly murky water. A film of oil was a constant feature of the site during the survey, and raw sewage from storm overflows was evident after heavy rain. Bryophytes are absent from the water, and again occur as protonema on the banks close to the water level. One chironomid larva was the only invertebrate encountered during the survey. This site was chosen to investigate the impact of the Team Valley Trading Estate effluents. This is another site that is sampled regularly by the Northumbrian Water Authority.

3.29 Site 9 The Mouth

Map ref: 232 625

Distance from source: 25.3 km

Water sample site: about 200 m from the confluence with the River Tyne.

Site description: This site is tidal; at high tide the river reaches a maximum width of 23 m , at low tide it is about 7 m wide. The bed consists of a mixture of rocks, rubble and mud containing large quantities of thick oil. One growth of <u>Ulothrix</u> remained for about 10 days, but no other algae were encountered attached to continuously submerged substrates. Extensive films composed mainly of <u>Euglena</u> <u>mutabilis</u> occurred on the mud which is covered at high tide. The water is always extremely murky, and large amounts of oil and raw sewage are visible at all times. The site was chosen to investigate the quality of the water entering the River Tyne.

Plate 1

Site 1 facing upstream.

Plate 2

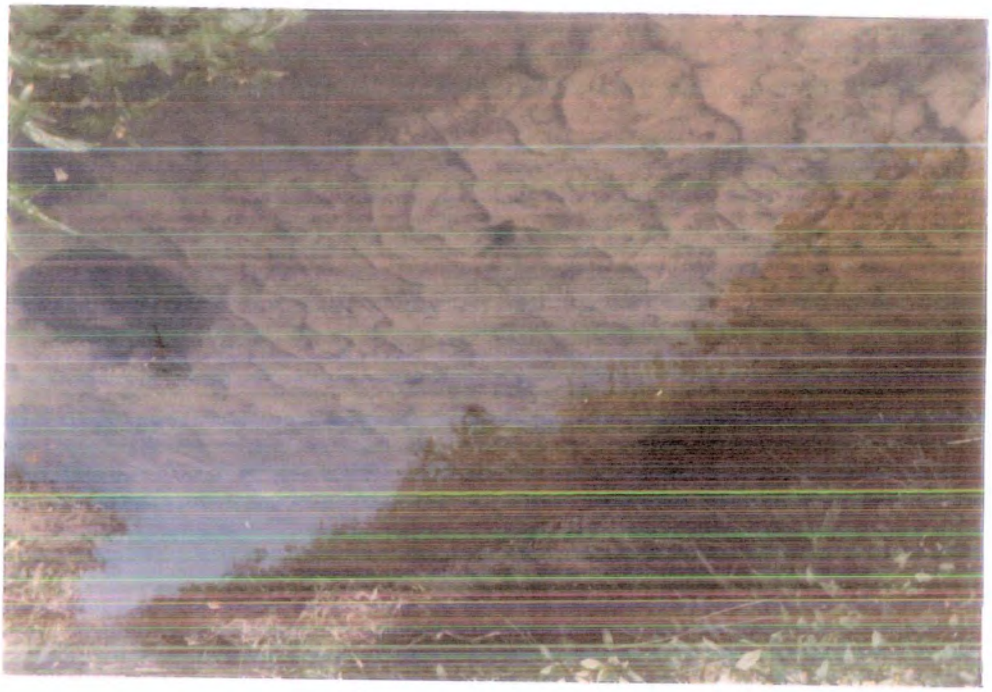
Downstream of site 1, showing almost complete algal cover.

Plate 3

Site 2 facing downstream.

Plate 4

Site 2 showing sandy substrate.



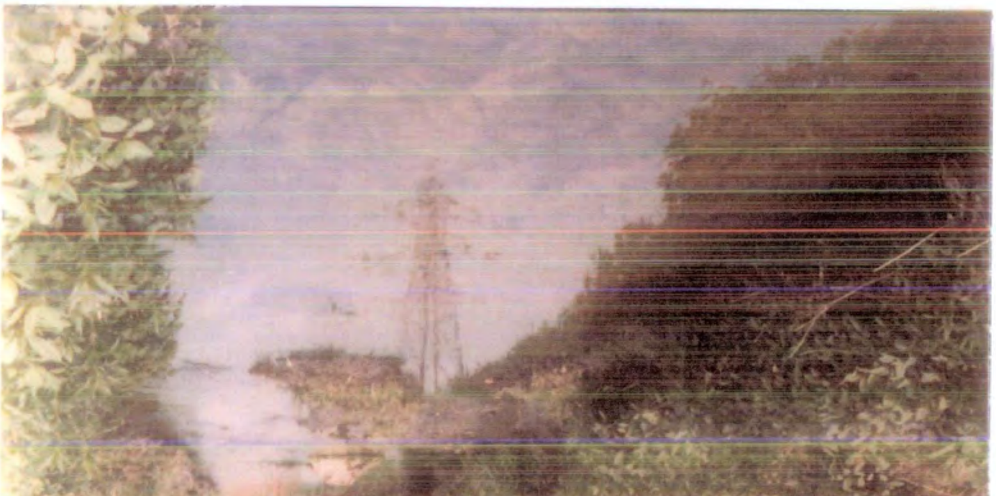


Plate 5

Site 3 facing upstream.

Plate 6

Site 3 facing downstream, showing murky nature of water due to organic pollution.

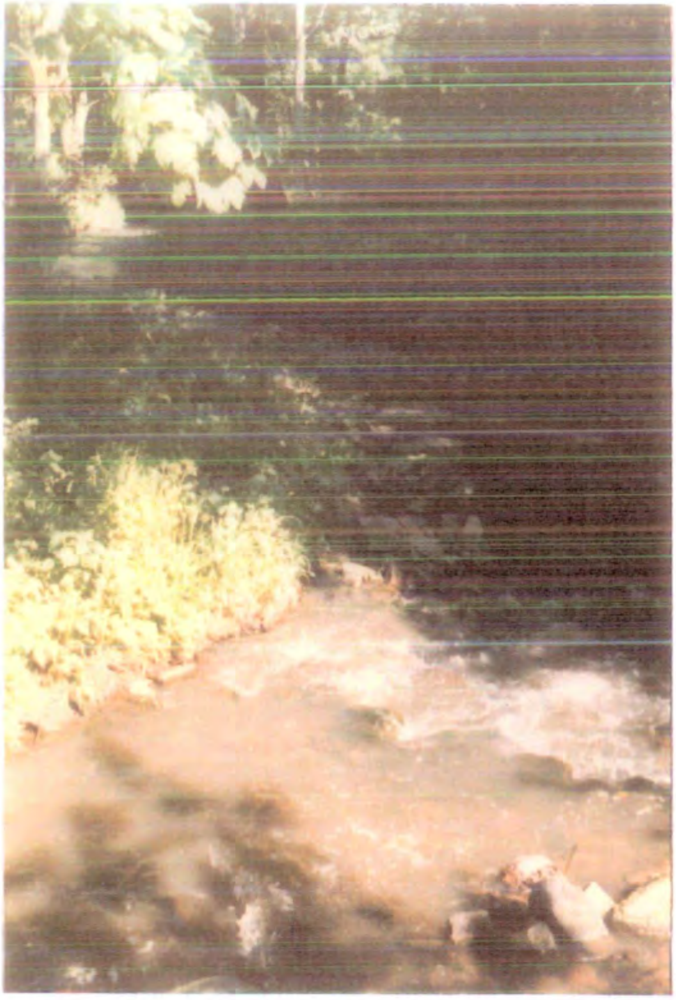


Plate 7

Site 4 facing downstream.

Plate 8

Site 5 facing upstream.

Plate 9

Site 6 facing downstream.

Plate 10

Birtley sewage effluent, upstream of site 6.

Plate 11

Durham Chemicals effluent.

Plate 12

Kibblesworth mine water. The rocks in the foreground show staining due to the iron in the water.

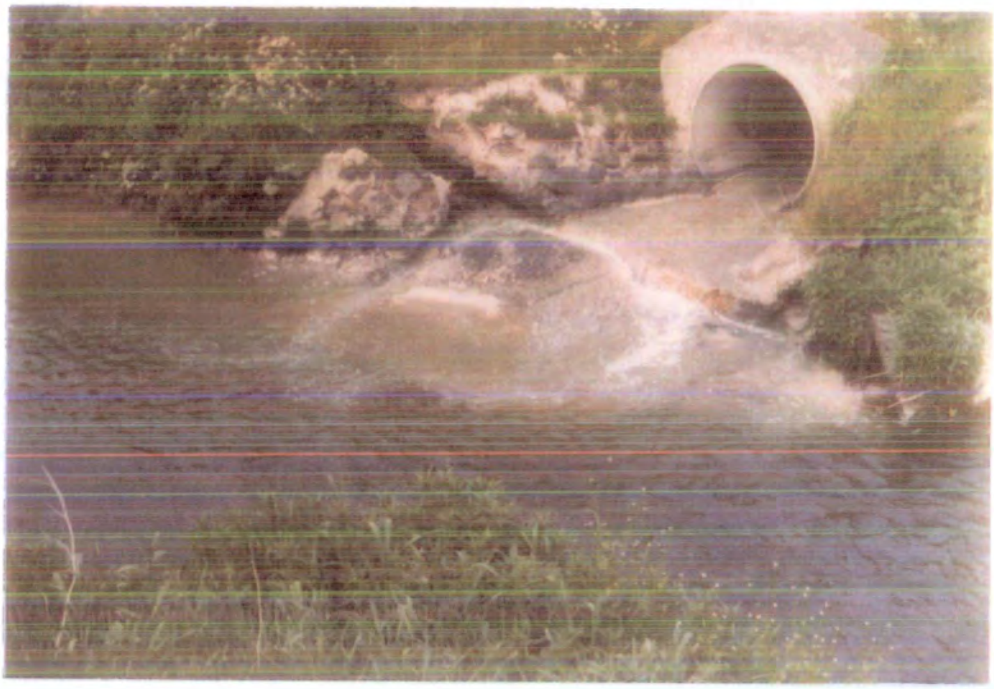


Plate 13

Site 7 facing upstream.

Plate 14

Site 8 facing downstream.
Rubble in the river provided the main substrate for algal growth. The colour of the water is due to the complex mixture of effluents in the Team Valley trading estate.

Plate 15

Site 9 at low tide facing upstream. The green film at the top of the mud bank is composed mainly of *Euglena mutabilis.*

Plate 16

Site 9 at low tide facing downstream. The confluence with the Tyne can be seen through the bridge.

4 WATER CHEMISTRY RESULTS

The results of four complete and two incomplete surveys of the water chemistry of the river are presented, together with the results of one 24 h survey at site 6. Samples of the sediments at all nine sites were analysed for their zinc content, and the results of this analysis are also presented here.

4.1 WATER CHEMISTRY SURVEYS

Although there was high variability in most of the parameters measured, some consistent patterns emerge from the surveys.

1. Dissolved oxygen levels fell substantially at sites 8 and 9;
2. pH always fell at site 6;
3. Substantial increases in conductivity, optical density, chloride, total alkalinity, total and filtered zinc, and total iron, occurred at site 6;
4. Zinc levels also increased at site 3, and then fell off gradually until site 6;
5. Phosphate levels increased at site 3, and then gradually decreased until site 9, where another rise occurred; ? Not sig.
6. Calcium and magnesium levels showed little variability, and were always high at all sites.

4.2 SEDIMENTS

Zinc levels in the sediments increased sharply below the Durham Chemicals effluent, fell back slightly after the entry of the Kibblesworth pumped mine water, and then increased steadily, reaching a peak at site 9.

4.3 24 HOUR SURVEY

This was carried out at site 6 on 26.VI.79 and 27.VI.79. Samples were taken hourly. Dissolved oxygen, pH, O.D., calcium and magnesium all remained fairly constant over the sampling period. Temperature showed the expected diurnal variation.

A sharp rise in conductivity at 2000 h , rising to a peak at 2100 h was followed by a decline to a constant level until 0600 h , when a further drop occurred. This pattern was closely parelleled by chloride levels.

The levels of total manganese showed a similar pattern to those of total iron, rising to a peak at 2000 h and then gradually declining.

Phosphate levels declined steadily from 1200 h to 2100 h and then remained constant during the night, rising sharply to a peak at 0700 h.

Table 2.

Survey of water chemistry 25.1V.79.

Site	No.	km from source	Time	Temp °C	Dissolved O_2 % sat	Dissolved O_2 mg l^{-1}	pH	lab pH	Conductivity (µmhos)	Optical Density 240	Optical Density 254	Total Alkalinity (mg l^{-1} $CaCO_3$)	P (mg l^{-1})	Cl (mg l^{-1})
Above Birtley	5	15.9	1500	7.75	110	12.75	ND	7.8	1210	0.09	0.02	ND	0.3	57
Below Birtley	6	17.4	1445	11	109	11.75	ND	7.0	3500	0.23	0.12	ND	0.21	230
Lamesley	7	18.6	1415	11	101	11	ND	6.9	3400	0.17	0.08	ND	0.17	575
TVTE	8	22	1600	11	102	11	ND	6.8	3310	0.36	0.15	ND	0.24	490

Site	No.	km from source	Time	Zn (mg l^{-1}) Total	Zn (mg l^{-1}) Filtered	Ca (mg l^{-1}) Total	Ca (mg l^{-1}) Filtered	Mg (mg l^{-1}) Total	Mg (mg l^{-1}) Filtered
Above Birtley	5	15.9	1500	0.15	0.13	128	114	42	40
Below Birtley	6	17.4	1445	3.9	3.62	130	130	39.6	40
Lamesley	7	18.6	1415	2.57	2.2	118	140	36.8	42.6
TVTE	8	22	1600	3.02	4.12	144	132	41	40

Table 3

Survey of water chemistry 9.V.79.

Site	No.	km from source	Time	Temp ^{o}C	Dissolved O_2		pH	lab pH	Conductivity (µmhos)	Optical Density		Total Alkalinity (mg l^{-1} $CaCO_3$)	P (mg l^{-1})	Cl (mg l^{-1})
					% sat	mg l^{-1}				240	254			
Beamish	3	7.8	1900	9	103	11.6	7.7	7.6	910	ND		146	0.49	39
Urpeth	4	12.4	1830	9	103	11.6	ND	7.8	790	ND		136	0.3	54
Above Birtley	5	15.9	1750	9	104	11.6	7.9	7.4	760	ND		118	0.2	30
Below Birtley	6	17.4	1515	11	98	10.5	7.4	7.3	2250	ND		253	0.12	227
Lamesley	7	18.6	1445	10	90	9.8	7.3	7.3	2050	ND		230	0.15	295
TVTE	8	22	1300	10	103	11.4	7.6	7.4	1800	ND		221	0.19	550
Mouth	9	25.3	1115	10	84	9.2	7.3	7.3	1410	ND		190	0.18	173

Site	No.	km from source	Time	Zn (mg l^{-1})		Ca (mg l^{-1})		Mg (mg l^{-1})	
				Total	Filtered	Total	Filtered	Total	Filtered
Beamish	3	7.8	1900	0.31	0.29	102	92	29	27.6
Urpeth	4	12.4	1830	0.29	0.23	92	84	28	25.4
Above Birtley	5	15.9	1750	0.24	0.27	86	78	24.4	23
Below Birtley	6	17.4	1515	2.6	2.01	110	104	30.6	29.2
Lamesley	7	18.6	1445	1.95	1.3	106	98	29.8	27.4
TVTE	8	22	1300	1.5	1.15	106	98	27.2	25.6
Mouth	9	25.3	1115	9.73	2.08	94	90	23.6	21.2

Table 4

Survey of water chemistry 19.V.79.

Site	No.	km from source	Time	Temp °C	Dissolved O_2 % sat	Dissolved O_2 mg l^{-1}	pH	lab pH	Conductivity (µmhos)	Optical Density 240 254	Total Alkalinity (mg l^{-1} $CaCO_3$)	P (mg l^{-1})	Cl (mg l^{-1})
Kyo	1	1.1	1130	9	105	11.8	7.8	7.4	950	ND	102	0.02	54
Tantobie	2	4.8	1200	9.5	82	8.9	7.7	7.2	810	ND	104	0.45	75
Beamish	3	7.8	1245	10.5	117	12.2	8.3	8	1280	ND	237	0.14	78
Urpeth	4	12.4	1400	10.0	121	13.2	8.4	8.1	1450	ND	190	0.49	76
Above Birtley	5	15.9	1500	11.5	138	14.6	8.5	8.3	1480	ND	183	0.32	59
Below Birtley	6	17.4	1530	14	115	10.4	7.3	7.1	4400	ND	ND	0.2	600
Lamesley	7	18.6	1615	14	98	9.9	7.6	7.3	4400	ND	ND	0.17	632
TVTE	8	22	1815	14	94	9.3	7.6	7.4	4100	ND	ND	0.13	530
Mouth	9	24.3	1730	13	68	6.9	7.6	7.3	1800	ND	ND	0.43	108

Site	No.	km from source	Time	Zn (mg l^{-1}) Total	Zn (mg l^{-1}) Filtered	Ca (mg l^{-1}) Total	Ca (mg l^{-1}) Filtered	Mg (mg l^{-1}) Total	Mg (mg l^{-1}) Filtered	Fe (mg l^{-1}) Total	Fe (mg l^{-1}) Filtered
Kyo	1	1.1	1130	0.07	0.08	106	106	41	40	1.07	0.23
Tantobie	2	4.8	1200	0.06	0.04	80	70	25	22	0.55	0.18
Beamish	3	7.8	1245	0.25	0.22	134	130	44	43	0.36	0.07
Urpeth	4	12.4	1400	0.12	0.08	128	128	42	43	0.36	0.07
Above Birtley	5	15.9	1500	0.08	0.05	114	112	39	38	0.45	0.11
Below Birtley	6	17.4	1530	1.68	1.35	136	136	42	46	2.6	0.9
Lamesley	7	18.6	1615	1.85	1.3	134	124	44	40	2.6	0.32
TVTE	8	22	1815	1.67	1.2	122	134	41	43	2.1	0.18
Mouth	9	25.3	1730	1.9	1.18	102	98	32	29	0.84	0.16

Table 5.

Survey of water chemistry 1.Vl.79.

Site	No.	km from source	Time	Temp °C	Dissolved O2 % sat	Dissolved O2 mg l^{-1}	pH	lab pH	Conductivity (µmhos)	Optical Density 240	Optical Density 254	Total Alkalinity (mg l^{-1} $CaCO_3$)	P (mg l^{-1})	Cl (mg l^{-1})
Kyo	1	1.1	1200	12	104	11	7.4	7.3	1060	0.04	0.04	86	0.005	41
Tantobie	2	4.8	1245	14	109	11	7.3	7.2	920	0.14	0.11	82	0.065	40
Beamish	3	7.8	1315	13	112	11.6	8.0	7.9	1530	0.12	0.07	200	0.38	57
Urpeth	4	12.4	1415	14	109	11	7.9	7.7	1510	0.15	0.07	180	0.32	60
Above Birtley	5	15.9	1745	14	115	11.5	8.2	7.9	1510	0.17	0.08	196	0.25	57
Below Birtley	6	17.4	1715	15.5	103	10.5	7.2	7.0	4400	0.32	0.19	360	0.11	560
Lamesley	7	18.6	1645	15.5	98	9.5	7.2	7.0	4180	0.23	0.16	352	0.1	475
TVTE	8	22	1600	15.5	102	9.7	7.3	7.1	3900	0.24	0.18	318	0.09	377
Mouth	9	25.3	1430	16.5	67	6.4	7.2	7.2	3750	0.32	0.25	314	0.22	380

Site	No.	km from source	Time	Zn (mg l^{-1}) Total	Zn (mg l^{-1}) Filtered	Ca (mg l^{-1}) Total	Ca (mg l^{-1}) Filtered	Mg (mg l^{-1}) Total	Mg (mg l^{-1}) Filtered	Fe (mg l^{-1}) Total	Fe (mg l^{-1}) Filtered	Mn (mg l^{-1}) Total	Mn (mg l^{-1}) Filtered
Kyo	1	1.1	1200	0.04	0.01	63	69	26	28	0.4	0.08	0.36	0.33
Tantobie	2	4.8	1245	0.01	0.01	62	77	21	22	0.5	0.1	0.27	0.24
Beamish	3	7.8	1315	0.1	0.06	105	100	40	34	0.43	0.1	0.33	0.34
Urpeth	4	12.4	1415	0.06	0.04	102	102	39	35	0.55	0.09	0.5	0.43
Above Birtley	5	15.9	1745	0.04	0.04	102	104	34	35	0.57	0.13	0.42	0.41
Below Birtley	6	17.4	1715	2.65	2.23	135	114	44	39	2.1	0.14	0.64	0.6
Lamesley	7	18.6	1645	12.1	10.2	130	118	41	36	1.75	0.1	0.65	0.61
TVTE	8	22	1600	2.47	1.77	129	119	43	41	3.4	0.13	0.73	0.6
Mouth	9	25.3	1430	1.7	1.33	109	112	36	39	1.75	0.3	0.58	0.5

Table 6.

Survey of water chemistry 5.V1.79.

Site	No.	km from source	Time	°C	Dissolved O_2 % sat	Dissolved O_2 mg l^{-1}	pH	lab pH	Conductivity (µmhos)	Optical Density 240	Optical Density 254	Total Alkalinity (mg l^{-1} $CaCO_3$)	P (mg l^{-1})	Cl (mg l^{-1})
Kyo	1	1.1	1215	12	120	12.5	7.7	7.4	1180	0.12	0.09	100	0.04	55
Tantobie	2	4.8	1130	13	115	11.8	7.6	7.4	1070	0.17	0.14	91	0.08	52
Beamish	3	7.8	1045	13	95	9.7	7.9	7.6	1650	0.19	0.12	199	0.86	73
Urpeth	4	12.4	1330	14	109	10.9	8.1	7.7	1800	0.17	0.11	215	0.39	65
Above Birtley	5	15.9	1430	15.5	136	13.1	8.3	6.8	1750	0.15	0.1	203	0.36	65
Below Birtley	6	17.4	1515	17	103	9.4	7.2	6.9	4850	0.35	0.26	382	0.1	550
Lamesley	7	18.6	1615	17	82	7.7	7.5	7.1	4600	0.31	0.27	345	0.2	522
TVTE	8	22	0930	15	77	7.4	7.3	7.1	5000	0.31	0.27	416	0.18	622
Mouth	9	25.3	1800	17.5	44	4.1	7.6	7.2	3800	0.39	0.33	231	0.36	425

Site	No.	km from source	Time	Zn (mg l^{-1}) Total	Zn (mg l^{-1}) Filtered	Ca (mg l^{-1}) Total	Ca (mg l^{-1}) Filtered	Mg (mg l^{-1}) Total	Mg (mg l^{-1}) Filtered	Fe (mg l^{-1}) Total	Fe (mg l^{-1}) Filtered	Mn (mg l^{-1}) Total	Mn (mg l^{-1}) Filtered
Kyo	1	1.1	1215	0.06	0.04	86	76	34	34	0.42	0.1	0.39	0.4
Tantobie	2	4.8	1130	0.02	0.02	66	67	26	26	0.46	0.1	0.31	0.31
Beamish	3	7.8	1045	0.24	0.17	105	104	38	36	0.49	0.18	0.5	0.44
Urpeth	4	12.4	1330	0.1	0.02	113	111	43	41	0.48	0.12	0.57	0.56
Above Birtley	5	15.9	1430	0.05	0.03	105	113	37	40	0.38	0.14	0.51	0.5
Below Birtley	6	17.4	1515	28.6	25.9	118	115	41	40	2.4	0.12	0.66	0.66
Lamesley	7	18.6	1615	7.4	6.3	128	126	45	41	2.25	0.26	0.72	0.7
TVTE	8	22	0930	1.65	1.4	110	128	36	42	2.7	0.28	0.77	0.74
Mouth	9	25.3	1800	1.95	1.5	118	109	38	40	1.7	0.21	0.63	0.63

Table 7.

Survey of water chemistry 19.V1.79.

Site	No.	km from source	Time	Temp °C	Dissolved O_2		pH	lab pH	Conductivity (µmhos)	Optical Density		Total Alkalinity (mg l^{-1} $CaCO_3$)	P (mg l^{-1})	Cl (mg l^{-1})
					% sat	mg l^{-1}				240	254			
Kyo	1	1.1	1030	12	117	12.4	7.5	7.8	1140	0.04	0.03	126	0.01	60
Tantobie	2	4.8	1100	17	148	14.0	8.1	8.0	1160	0.15	0.14	114	0.03	47
Beamish	3	7.8	1145	15	107	10.6	7.7	8.1	1650	0.14	0.11	254	2.5	63
Urpeth	4	12.4	1215	15	112	10.9	8.2	8.1	2050	0.09	0.08	282	1.06	55
Above Birtley	5	15.9	1300	18.5	158	14.4	8.5	8.7	1600	0.14	0.11	240	0.1	65
Below Birtley	6	17.4	1345	20	122	10.8	8.0	8.1	2250	0.34	0.25	197	0.78	62
Lamesley	7	18.6	1430	20	96	8.5	7.8	7.9	2250	0.26	0.21	203	1.0	65
TVTE	8	22	1515	20	75	6.6	7.8	7.7	2250	0.26	0.21	210	1.1	63
Mouth	9	25.3	1615	21	23	2.0	8.6	8.3	2800	0.32	0.31	323	0.75	145

Site	No.	km from source	Time	Zn (mg l^{-1})		Ca (mg l^{-1})		Mg (mg l^{-1})		Fe (mg l^{-1})		Mn (mg l^{-1})	
				Total	Filtered	Total	Filtered	Total	Filtered	Total	Filtered	Total	Filtered
Kyo	1	1.1	1030	0.08		95	88	46	41	0.36	0.15	0.5	0.48
Tantobie	2	4.8	1100	0.02		77	73	34	30	0.59	0.09	0.32	0.32
Beamish	3	7.9	1145	0.14		119	108	42	40	0.47	0.1	0.34	0.31
Urpeth	4	12.4	1215	0.07		139	116	48	43	0.36	0.1	0.45	0.39
Above Birtley	5	15.9	1300	0.06	0.04	113	104	41	38	0.45	0.14	0.36	0.32
Below Birtley	6	17.4	1345	3.67	0.66	108	93	34	31	0.39	0.08	0.38	0.31
Lamesley	7	18.6	1430	3.4	0.77	112	99	34	30	0.44	0.1	0.46	0.38
TVTE	8	22	1515	2.13	1.0	106	101	33	31	0.46	0.16	0.41	0.41
Mouth	9	25.3	1615	1.6	0.2	98	96	35	34	1.0	0.14	0.41	0.36

Table 8.

Summary of water chemistry surveys.
Data are presented as means and standard deviations.

	Dissolved O_2				Conductivity	Optical density		P	Cl
Site	% sat	(mg l^{-1})	pH	lab pH	(µmhos)	240 nm	254 nm	(mg l^{-1})	(mg l^{-1})
1	112 ± 8.2	11.9 ± 0.69	7.6 ± 0.22	7.5 ± 0.22	1080 ± 101	0.07	0.05	0.019 ± 0.015	53 ± 8.1
2	114 ± 27.1	11.4 ± 2.1	7.7 ± 0.33	7.5 ± 0.38	990 ± 156	0.15	0.13	0.16 ± 0.2	53 ± 15.2
3	107 ± 8.4	11.1 ± 0.99	7.9 ± 0.25	7.8 ± 0.23	1400 ± 315	0.15	0.1	0.87 ± 0.94	62 ± 15.3
4	111 ± 6.6	11.5 ± 0.98	8.2 ± 0.21	7.9 ± 0.2	1520 ± 474	0.14	0.09	0.51 ± 0.32	62 ± 9.0
5	127 ± 20.6	13 ± 1.3	8.3 ± 0.25	7.8 ± 0.66	1385 ± 354	0.14 ± 0.03	0.08 ± 0.04	0.26 ± 0.09	56 ± 13.0
6	108 ± 8.9	10.6 ± 0.76	7.4 ± 0.33	7.2 ± 0.45	3610 ± 1140	0.31 ± 0.05	0.21 ± 0.06	0.25 ± 0.26	372 ± 226.4
7	94 ± 7.0	9.4 ± 1.2	7.5 ± 0.24	7.2 ± 0.36	3480 ± 1109	0.24 ± 0.06	0.18 ± 0.08	0.32 ± 0.39	427 ± 212.2
8	92 ± 13.0	9.2 ± 1.9	7.5 ± 0.22	7.3 ± 0.31	3390 ± 1199	0.29 ± 0.05	0.2 ± 0.05	0.32 ± 0.38	439 ± 200
9	57 ± 23.8	5.7 ± 2.8	7.7 ± 0.55	7.5 ± 0.47	2710 ± 1095	0.34	0.3	0.39 ± 0.23	246 ± 145.4

	total alkalinity (mg l^{-1} ca CO_3)	Zn (mg l^{-1})		Ca (mg l^{-1})		Mg (mg l^{-1})		Fe (mg l^{-1})		Mn (mg l^{-1})	
Site		total	filtered	total	filtered	total	filtered	total	filtered	total	filtered
1	104 ± 16.6	0.06 ± 0.017	0.04 ± 0.03	88 ± 18.3	85 ± 16.0	37 ± 8.9	36 ± 8.9	0.56 ± 0.34	0.14 ± 0.07	0.42	0.4
2	98 ± 14.1	0.03 ± 0.02	0.03 ± 0.02	71 ± 8.6	71 ± 4.3	27 ± 5.3	26 ± 4.3	0.53 ± 0.06	0.12 ± 0.04	0.3	0.29
3	207 ± 41.7	0.21 ± 0.09	0.19 ± 0.08	113 ± 13.5	107 ± 14.3	38 ± 5.8	36 ± 5.8	0.44 ± 0.06	0.11 ± 0.05	0.39	0.36
4	201 ± 53.7	0.13 ± 0.09	0.09 ± 0.08	115 ± 19	108 ± 16.5	40 ± 7.4	37 ± 7.5	0.44 ± 0.09	0.1 ± 0.02	0.51	0.46
5	188 ± 44.5	0.1 ± 0.08	0.06 ± 0.04	108 ± 14.1	104 ± 13.6	36 ± 6.4	36 ± 6.5	0.46 ± 0.08	0.13 ± 0.01	0.43	0.41
6	298 ± 87.8	7.2 ±10.5	5.96 ± 9.8	123 ± 12.5	115 ± 15.9	38.6 ± 5.4	38 ± 6.3	1.87 ± 1.01	0.11 ± 0.03	0.56	0.52
7	284 ± 74.7	4.88 ± 4.1	3.68 ± 3.8	121 ± 11.1	118 ± 16.4	39 ± 5.9	36 ± 6.2	1.76 ± 0.95	0.2 ± 0.11	0.61	0.56
8	291 ± 96.3	2.1 ± 0.59	1.3 ± 0.3	120 ± 15.2	119 ± 15.7	37 ± 6.2	37 ± 7.1	2.17 ± 1.25	0.19 ± 0.07	0.64	0.58
9	264 ± 64.7	3.38 ± 3.6	1.26 ± 0.68	104 ± 9.5	101 ± 9.2	33 ± 5.8	33 ± 7.8	1.32 ± 0.47	0.2 ± 0.07	0.54	0.5

Table 9.

Zinc in samples of sediments.

Zinc in river sediments ($\mu g\ g^{-1}$)

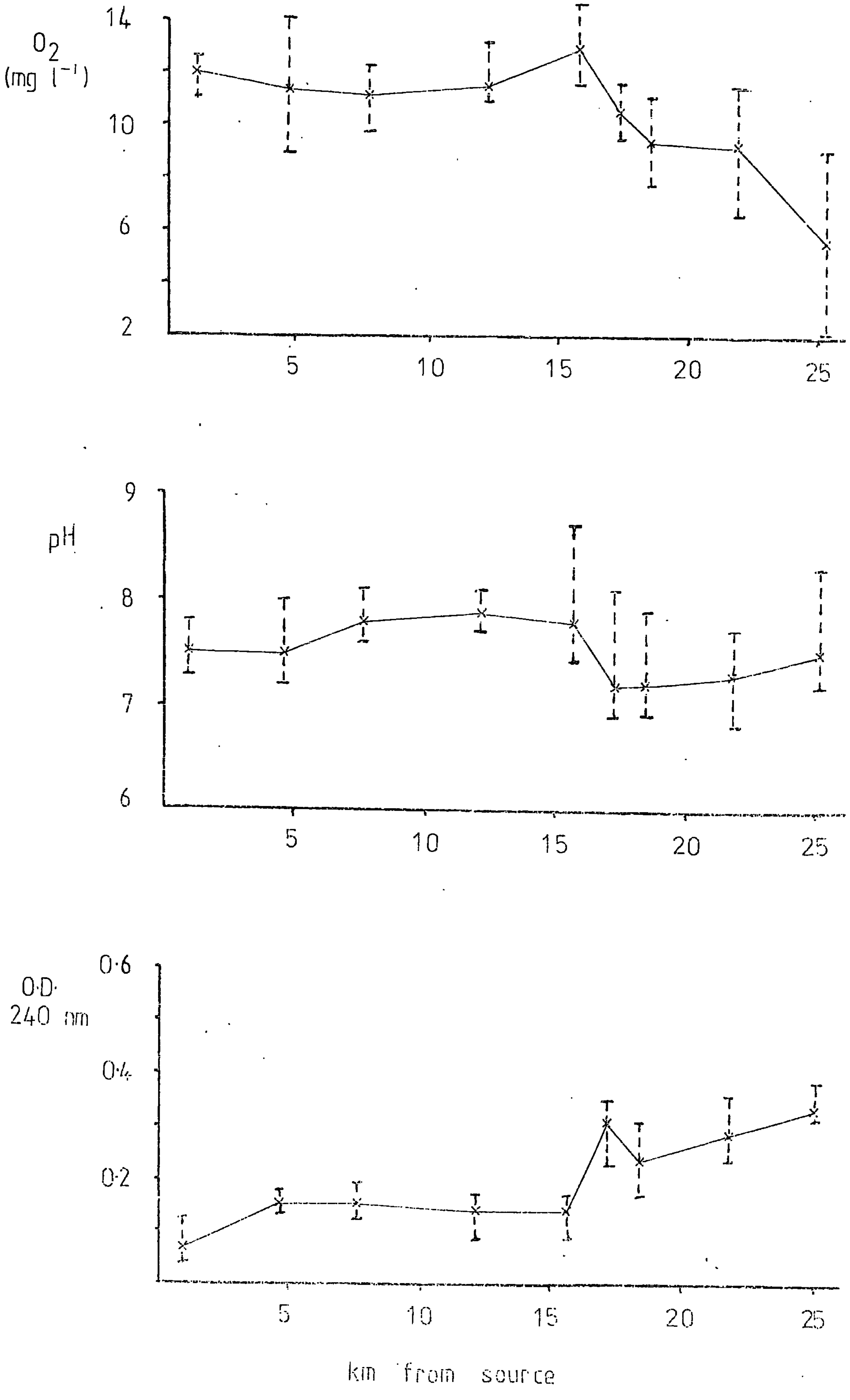
	Replicates					
Sites	A	B	C	D	MEAN	S.D.
1	400	708	363	550	505	158
2	655	500	400	360	479	131
3	1085	950	750	1085	968	158
4	750	550	540	450	573	126
5	625	450	540	550	541	72
6 (Above Kibblesworth)	2136	2318	2750	7364	3642	2495
6	1541	916	3100	2773	2083	1027
7	2200	2050	3150	2800	2550	515
8	1875	1550	2950	5650	3006	1861
9	6500	8166	4590	5300	6139	1564

Means and ranges for surveys from 25.1V.79 to 19.V1.79.

Figure 3 - dissolved oxygen.

Figure 4 - pH (laboratory value).

Figure 5 - optical density at 240 nm.

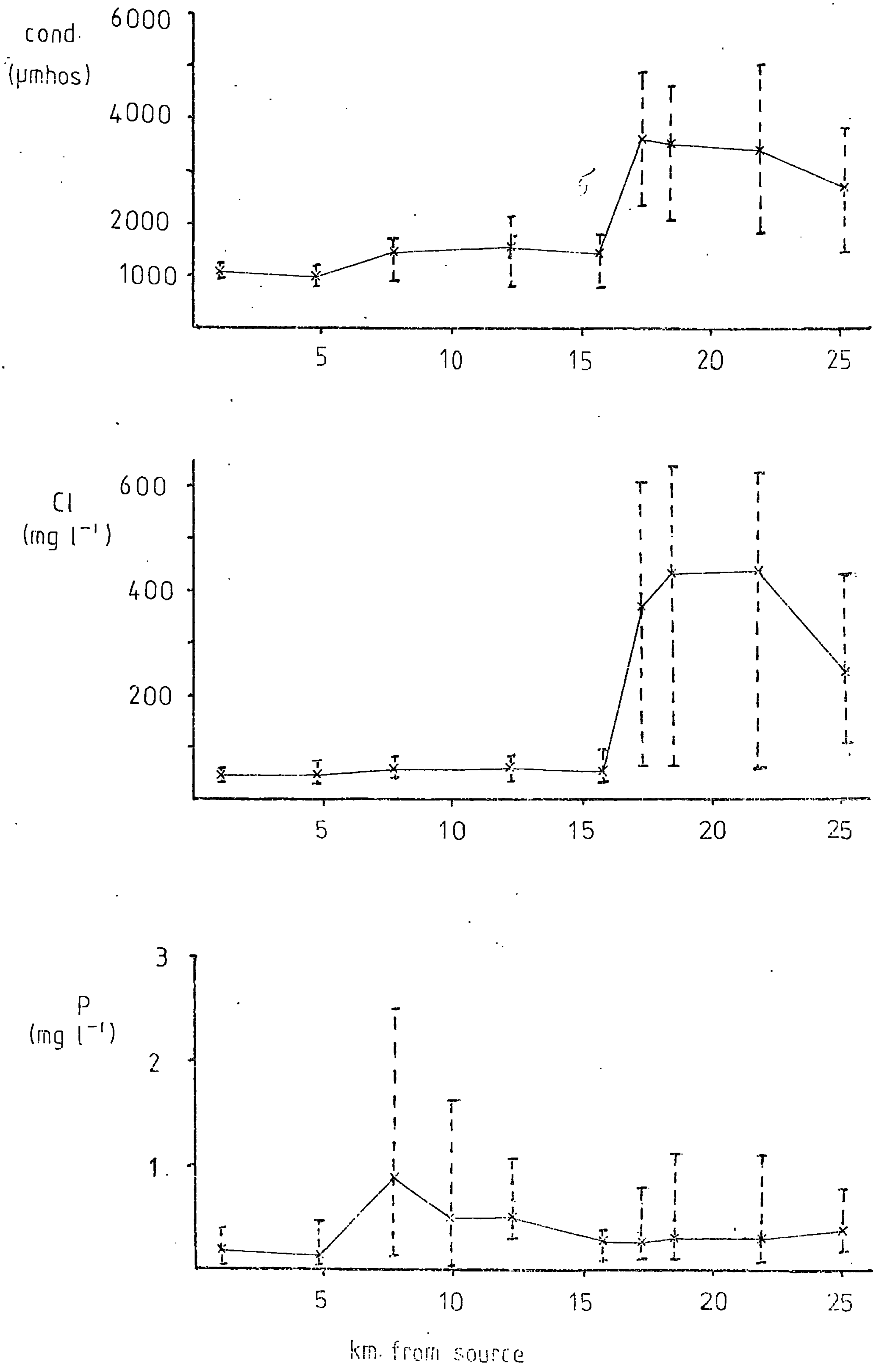

O2 (mg l-1)
14
10
6
2
5
10
15
20
25
pH
9
8
7
6
5
10
15
20
25
O·D· 240 nm
0·6
0·4
0·2
5
10
15
20
25
km from source

Means and ranges for surveys from 25.lV.79 to 19.Vl.79.

Figure 6 - conductivity.

Figure 7 - chloride.

Figure 8 - soluble reactive phosphorus.



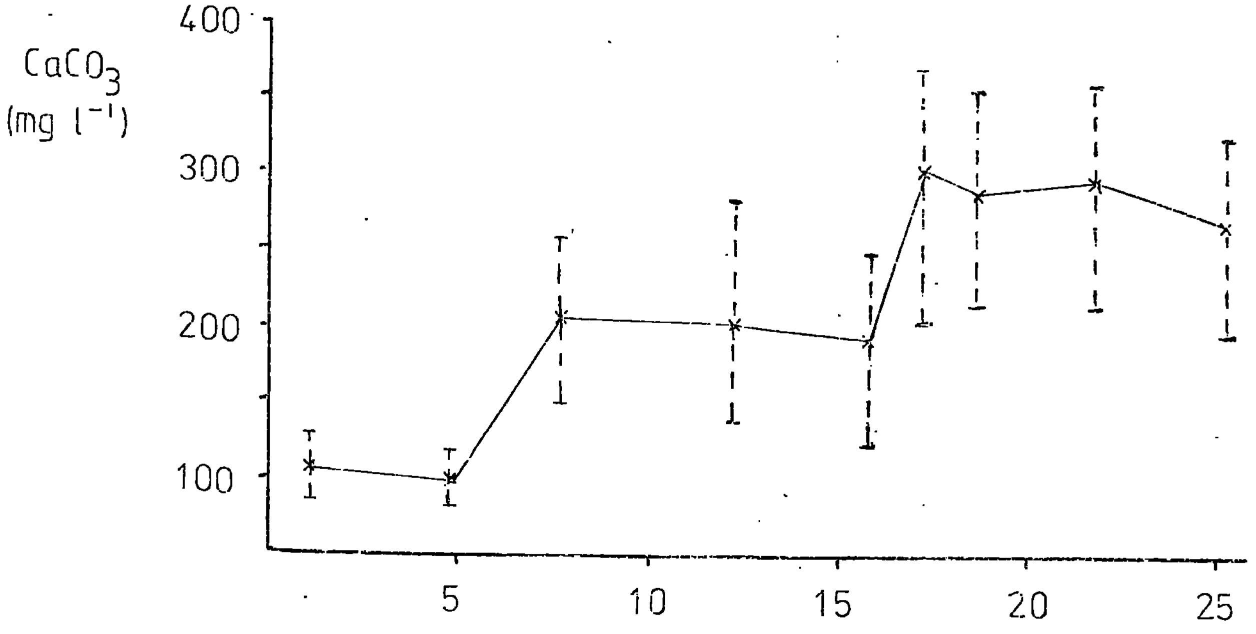
cond
(μmhos)
6000
4000
2000
1000
5
10
15
20
25
Cl
(mg l⁻¹)
600
400
200
5
10
15
20
25
P
(mg l⁻¹)
3
2
1
5
10
15
20
25
km from source

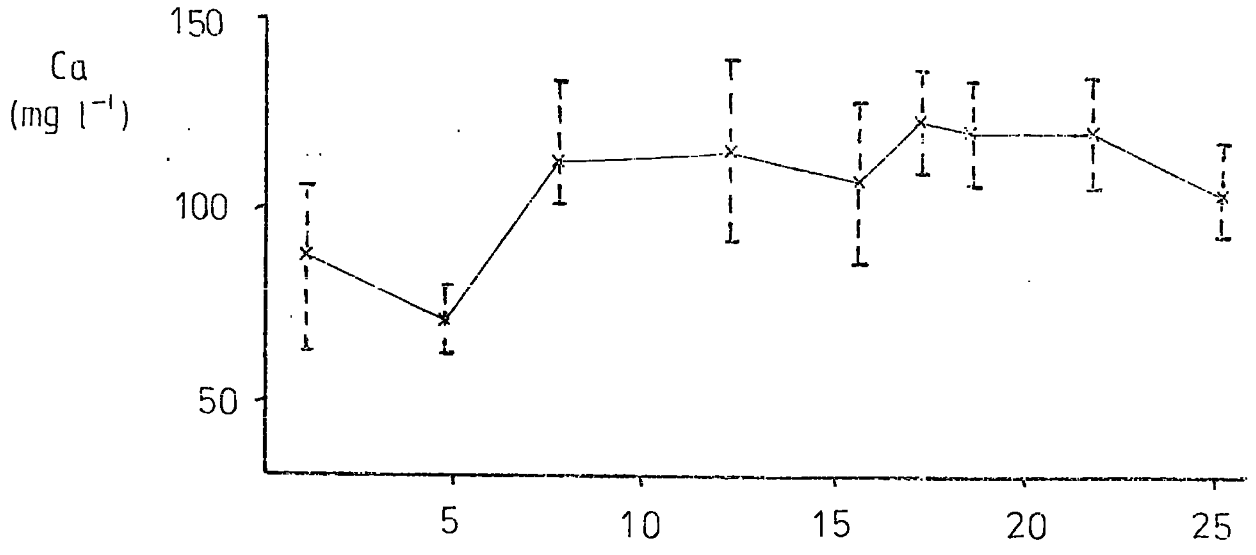
Means and ranges for surveys from 25.1V.79 to 19.V1.79.

Figure 9 - total alkalinity.

Figure 10 - "total" calcium.

Figure 11 - "total" magnesium.


CaCO$_3$ (mg l^{-1})
400
300
200
100
5
10
15
20
25


Ca (mg l^{-1})
150
100
50
5
10
15
20
25

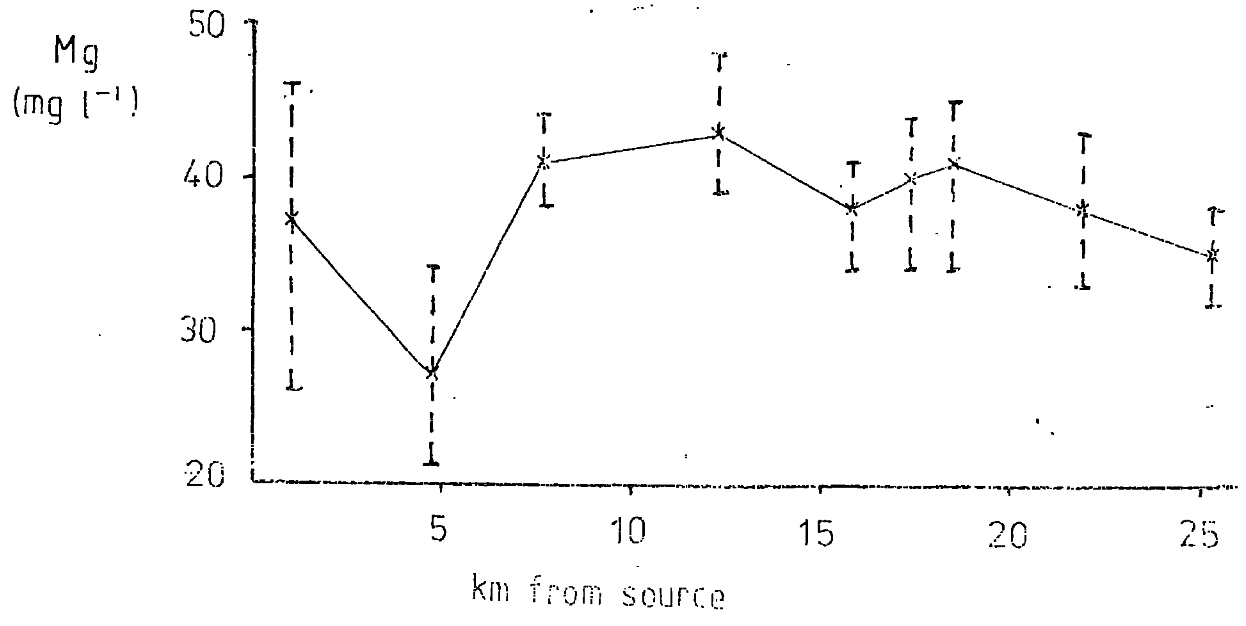

Mg (mg l^{-1})
50
40
30
20
5
10
15
20
25
km from source

Figure 12.

a) Total zinc in water samples - mean values for surveys from 25.1V.79 to 19.V1.79.

b) Zinc in sediments.

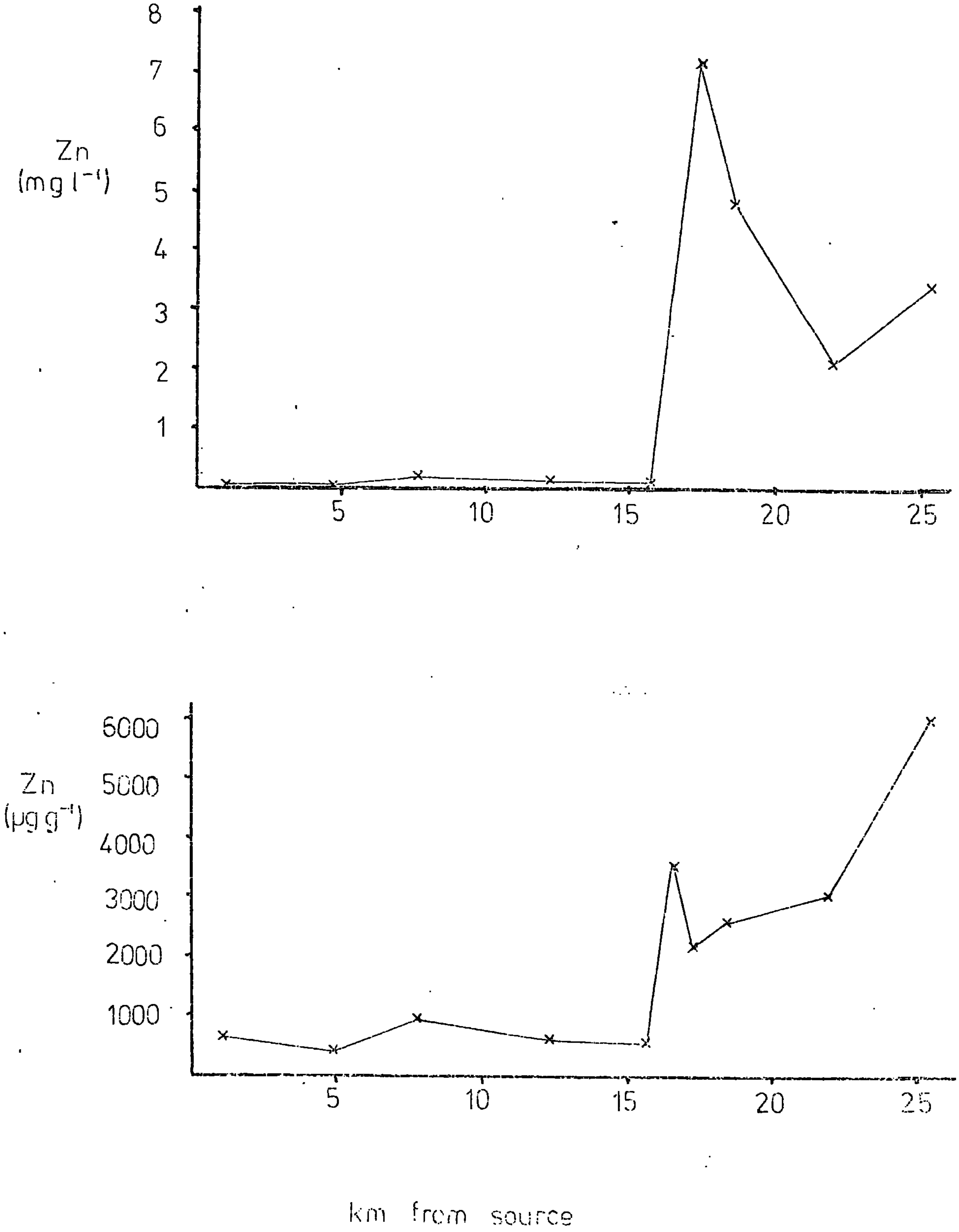

Zn
(mg l^{-1})
8
7
6
5
4
3
2
1
5
10
15
20
25
Zn
(µg g^{-1})
6000
5000
4000
3000
2000
1000
5
10
15
20
25
km from source

Table 10.

Results of 24 h survey at site 6,
26.V1.79 and 27.V1.79.

Time	Temp ^{o}C	Dissolved O_2		pH	lab pH	Conductivity (μmhos)	Optical Density		Total Alkalinity (mg l^{-1} $CaCO_3$)	P (mg l^{-1})	Cl (mg l^{-1})
		% sat	mg l^{-1}				240	254			
1200	16	98	9.4	7.4	7.35	4300	0.31	0.25	432	0.315	630
1300	16	102	9.7	7.25	7.35	4000	0.4	0.27	432	0.25	545
1400	16.2	101	9.6	7.25	7.3	4200	0.33	0.26	412	0.25	634
1500	16.2	96	9.2	7.4	7.3	4200	0.35	0.3	435	0.3	593
1600	16.5	96	9.1	7.4	7.3	4000	0.4	0.32	427	0.24	630
1700	16.4	98	9.3	7.35	7.35	3900	0.37	0.29	429	0.17	630
1800	16	97	9.3	7.25	7.35	4100	0.32	0.22	430	0.125	605
1900	16	100	9.5	7.1	7.35	3900	0.38	0.32	442	0.17	637
2000	16	105	10.1	7.1	7.2	5200	0.35	0.29	565	0.06	910
2100	16	104	10.0	7.0	7.2	5500	0.34	0.3	546	0.04	950
2200	16	105	10.1	6.9	7.25	4600	0.29	0.27	550	0.09	845
2300	15.5	104	10.1	7.0	7.2	4600	0.3	0.28	567	0.1	725
2400	15	107	10.4	7.2	7.2	4800	0.35	0.29	564	0.1	755
0100	15	105	10.3	7.25	7.25	5000	0.35	0.28	573	0.13	749
0200	15	104	10.2	7.25	7.2	4800	0.32	0.29	580	0.07	749
0300	15	106	10.3	7.5	7.25	5100	0.35	0.27	596	0.12	749
0400	15	107	10.4	7.4	7.2	4800	0.32	0.26	604	0.07	755
0500	15	105	10.3	7.9	7.25	5000	0.28	0.27	586	0.04	745
0600	15	105	10.3	7.9	7.15	5100	0.3	0.24	604	0.08	780
0700	14.5	103	10.4	7.8	7.2	4300	0.3	0.23	492	0.11	660
0800	14.75	103	10.4	7.6	7.25	4300	0.32	0.25	482	0.13	610
0900	15	102	9.9	7.6	7.25	4200	0.31	0.27	428	0.43	575
1000	15	107	10.4	7.6	7.35	4200	0.31	0.26	454	0.225	630
1100	16	97	9.3	7.55	7.25	4600	0.37	0.27	452	0.28	620

Table 10 (cont.).

24 h survey.

Time	Zn (mg l^{-1}) Total	Zn (mg l^{-1}) Filtered	Ca (mg l^{-1}) Total	Ca (mg l^{-1}) Filtered	Mg (mg l^{-1}) Total	Mg (mg l^{-1}) Filtered	Fe (mg l^{-1}) Total	Fe (mg l^{-1}) Filtered	Mn (mg l^{-1}) Total	Mn (mg l^{-1}) Filtered
1200	2.2	1.75	130	128	44	42	2.35	1.25	0.73	0.70
1300	2.0	1.65	136	122	45	41	2.35	1.6	0.71	0.60
1400	2.0	1.6	133	119	48	40	2.3	1.35	0.70	0.62
1500	1.7	1.2	126	125	42	41	2.3	1.3	0.67	0.60
1600	1.7	1.4	128	133	44	43	2.3	1.5	0.66	0.65
1700	1.75	1.45	128	120	44	43	2.4	1.45	0.70	0.64
1800	1.8	1.5	126	120	48	41	2.4	1.55	0.74	0.69
1900	1.6	1.3	122	114	46	42	2.25	1.6	0.64	0.60
2000	1.4	1.15	140	128	50	47	3.9	2.7	0.85	0.80
2100	1.2	0.98	134	127	48	47	3.75	2.6	0.74	0.78
2200	1.2	1.1	136	129	55	46	3.65	2.4	0.82	0.75
2300	1.3	1.1	134	142	49	46	3.4	2.4	0.84	0.77
2400	1.15	1.0	142	144	49	49	3.3	2.4	0.84	0.82
0100	1.2	1.0	140	132	50	50	3.25	2.1	0.78	0.77
0200	1.4	1.2	140	133	50	50	3.15	2.15	0.84	0.79
0300	1.2	1.05	140	129	47	44	3.1	2.15	0.85	0.81
0400	1.25	1.1	142	128	49	44	3.25	2.25	0.78	0.82
0500	1.1	0.9	138	125	53	43	3.1	2.2	0.79	0.80
0600	1.15	0.98	133	126	48	45	3.1	2.25	0.80	0.80
0700	3.6	3.0	131	120	44	44	2.35	1.4	0.76	0.70
0800	2.2	1.9	125	137	50	44	2.4	1.6	0.75	0.74
0900	1.9	1.5	116	114	40	43	2.25	1.7	0.68	0.68
1000	2.1	1.7	132	115	44	40	2.4	1.6	0.74	0.69
1100	1.9	1.5	128	112	43	45	2.6	1.4	0.70	0.68

Results of 24 h survey at site 6

on 26.V1.79 and 27.V1.79.

Figure 13 - "total" zinc.

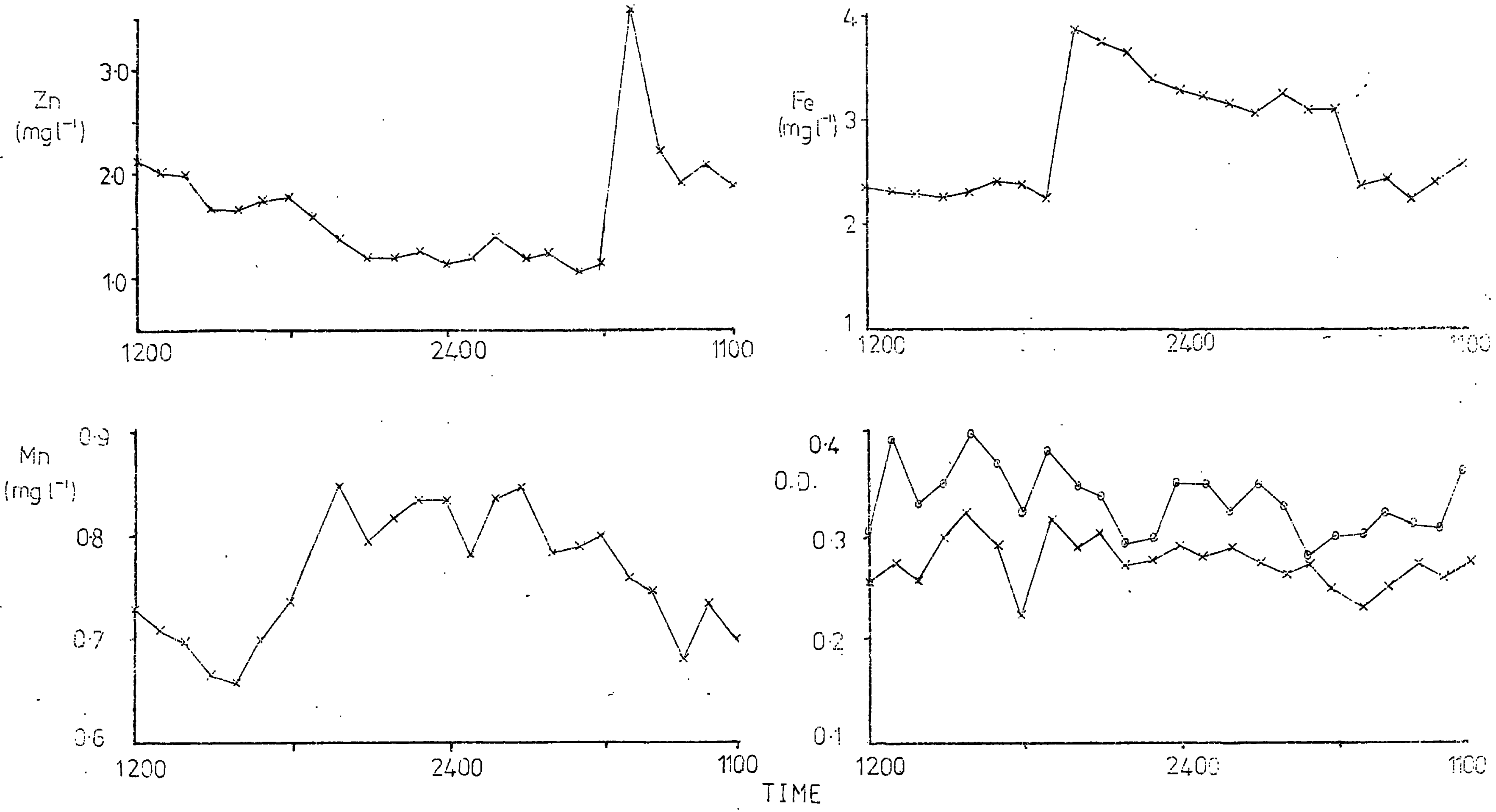
Figure 14 - "total" iron.

Figure 15 - "total" manganese.

Figure 16 - optical density

× - at 254 nm.

o - at 240 nm.


Zn
(mg l⁻¹)
3·0
2·0
1·0
1200
2400
1100
Fe
(mg l⁻¹)
4
3
2
1
1200
2400
1100
Mn
(mg l⁻¹)
0·9
0·8
0·7
0·6
1200
2400
1100
O.D.
0·4
0·3
0·2
0·1
1200
2400
1100
TIME

Results of 24 h survey at site 6

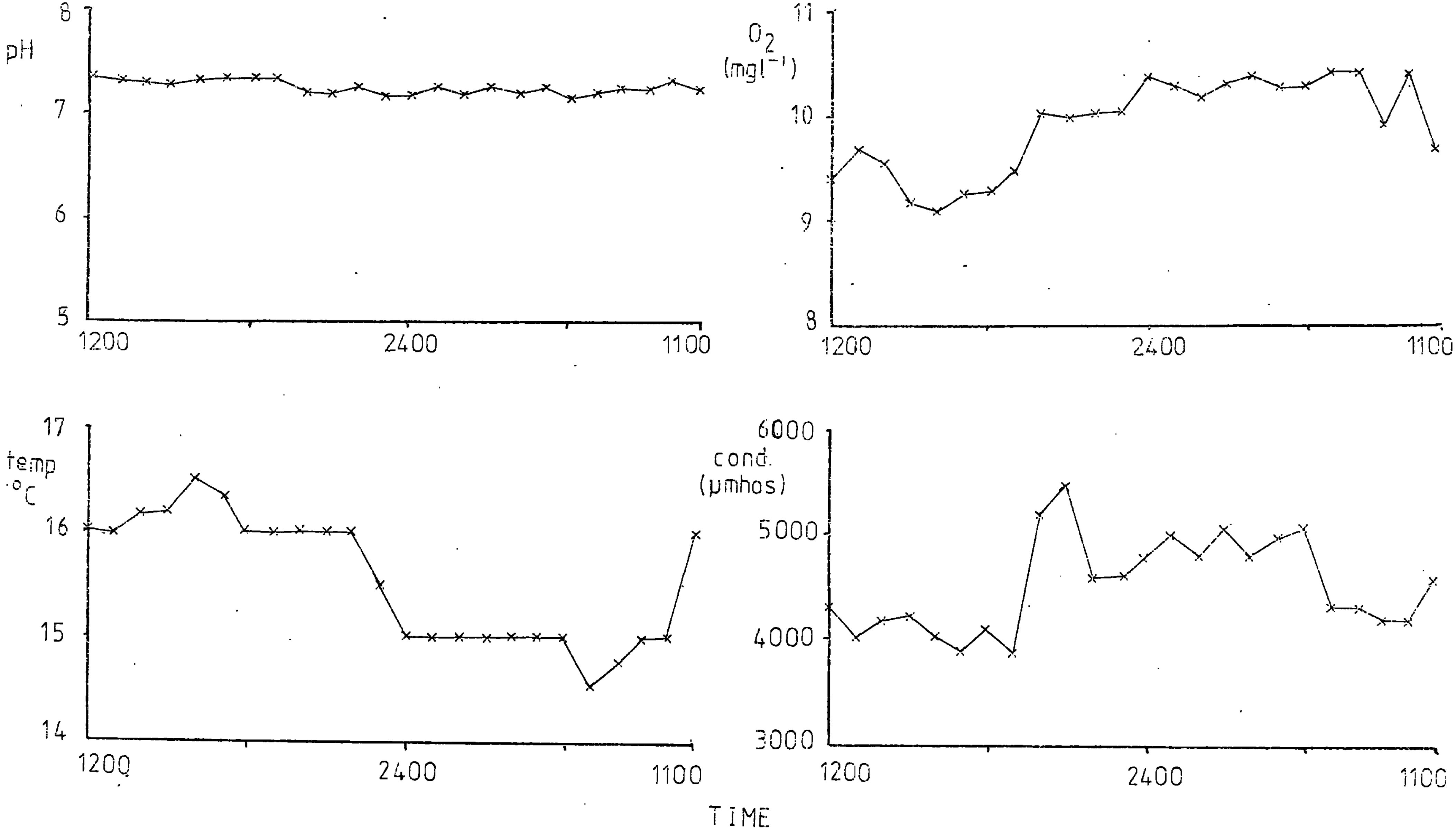
on 26.V1.79 and 27.V1.79.

Figure 17 - pH (laboratory values)

Figure 18 - dissolved oxygen.

Figure 19 - temperature.

Figure 20 - conductivity.


8
pH
7
6
5
1200
2400
1100
11
O_2
(mgl^{-1})
10
9
8
1200
2400
1100
17
temp
°C
16
15
14
1200
2400
1100
6000
cond.
(µmhos)
5000
4000
3000
1200
2400
1100
TIME

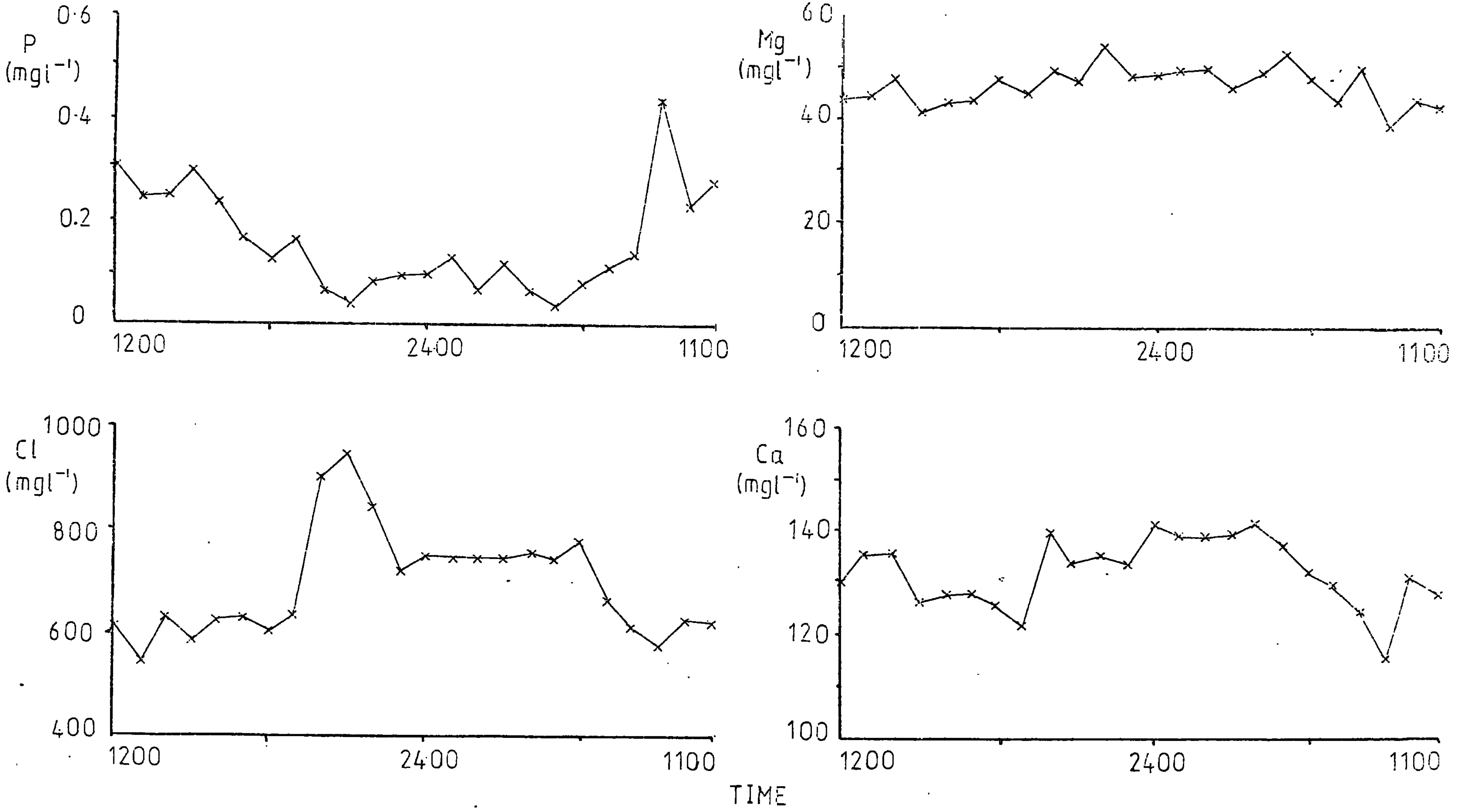
Results of 24 h survey at site 6
on 26.V1.79 and 27.V1.79.

Figure 21 - soluble reactive phosphorus.

Figure 22 - "total" magnesium.

Figure 23 - chloride.

Figure 24 - "total" calcium.


P
(mgl⁻¹)
0·6
0·4
0.2
0
1200
2400
1100
Mg
(mgl⁻¹)
60
40
20
0
1200
2400
1100
Cl
(mgl⁻¹)
1000
800
600
400
1200
2400
1100
Ca
(mgl⁻¹)
160
140
120
100
1200
2400
1100
TIME

5 BIOLOGICAL RESULTS

5.1 PLANT ANALYSES

The zinc levels in the algae and bryophytes studied are shown in Figs. 25 - 29 and in Table 11. All figures are based on limited numbers of samples, so results must be treated with caution.

All species analysed except *Brachythecium rivulare* showed highest enrichment ratios where zinc levels in the water were lowest. In all species where samples were taken from more than one site, enrichment ratios between sites were extremely variable. The high standard deviations in Table 11 show that variation within each site was also considerable. These results are discussed in greater detail in 6.4.

Table 12 shows that zinc levels in older parts of mosses are considerably higher than in the tips. This emphasizes the need to standardize the sampling technique.

5.2 INVERTEBRATES

Table 14 shows the main groups of invertebrates encountered during the survey. The most important feature of the table is the severely restricted fauna at sites 6 - 9. The reasons for this and for the lack of some groups at site 2 are discussed in 6.1.

Table 11.

Zinc levels in plant samples.

		Zn in filtered water ($mg\ l^{-1}$)			Zn in plant ($\mu g\ g^{-1}$)			Enrichment Ratio
Species	Site	$\bar{x}$	S.D	n	$\bar{x}$	S.D	n	
Stigeoclonium tenue	1	0.04	0.03	4	732	72	4	18300
	3	0.19	0.08	5	790	-	1	4850
	4	0.09	0.08	5	440	188	4	4888
	5	0.06	0.04	5	407	190	4	6783
	8	1.3	0.28	5	9795	1246	4	7535
Ulothrix sp	1	0.04	0.03	4	545	214	4	13625
	9	1.26	0.68	5	8000	-	1	6349
Cladophora glomerata	3	0.19	0.08	5	752	235	4	3960
	4	0.09	0.08	5	657	-	3	7300
	5	0.06	0.04	5	1062	237	5	17700
Brachythecium rivulare	1	0.04	0.03	4	505	-	2	12625
	3	0.19	0.08	5	2160	-	2	11368
	4	0.09	0.08	5	1242	205	4	13800
	5	0.06	0.04	5	1177	240	4	19616
Rhynchostegium sp	1	0.04	0.03	4	775	-	1	19375
	3	0.19	0.08	5	1532	196	4	8063
	4	0.09	0.08	5	465	-	2	5166
	5	0.06	0.04	5	1090	478	4	18166
Fontinalis antipyretica	5	0.06	0.04	5	640	-	3	10666

Table 12.

Zinc levels in 2 cm tips of mosses, and in older parts of the plants.

	Zn ($\mu g\ g^{-1}$)	
	2 cm tips	Older parts
Brachythecium rivulare	550	2350
	1380	2200
	820	3900
	830	2200
Rhynchostegium sp	1690	2560
	1710	3120
	470	2160
	630	2850
Fontinalis antipyretica	580	1100
	420	1150

Table 13.

Enrichment ratios of mosses and algae.

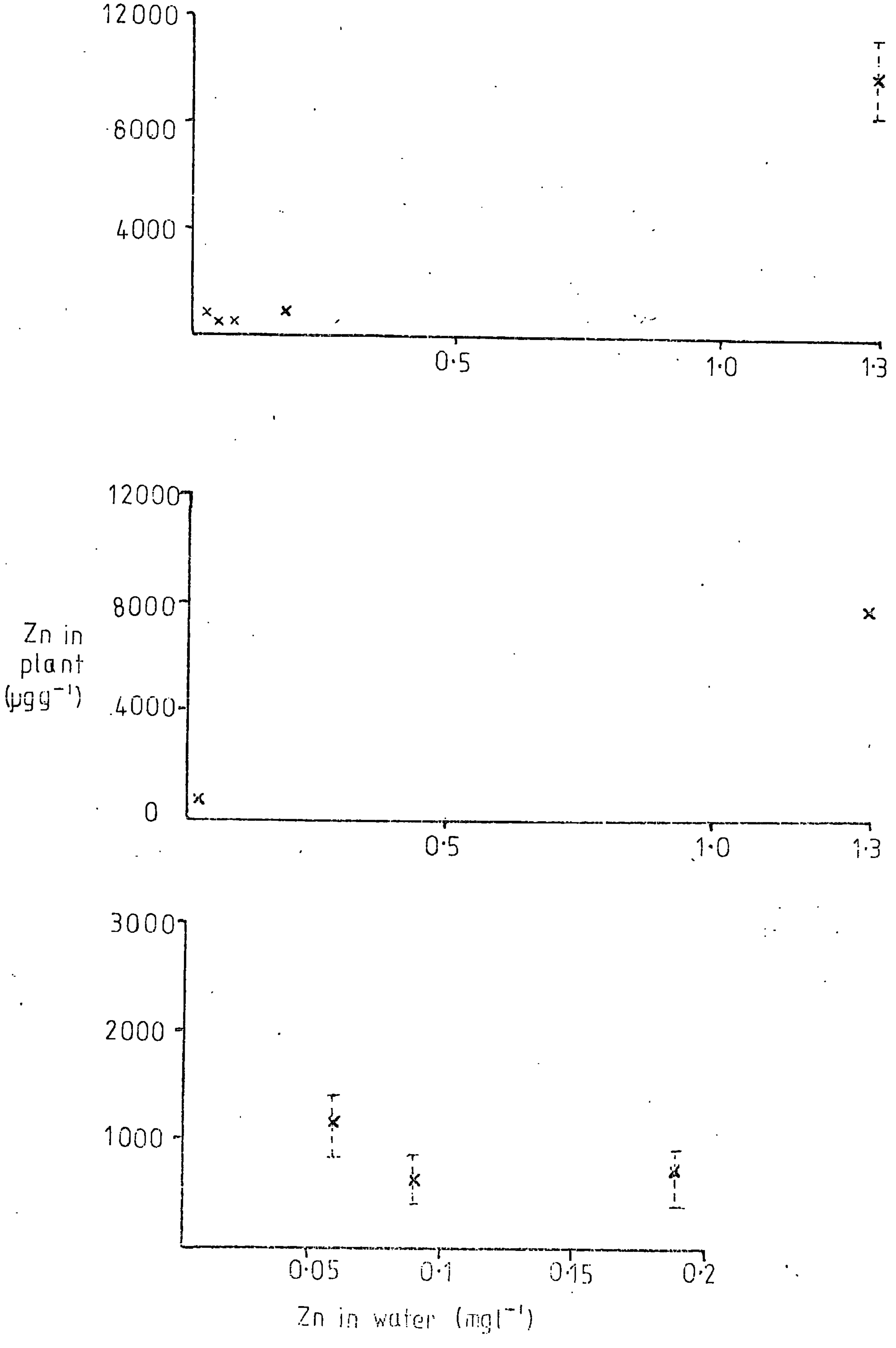
	Mean filtered zinc in water (mg l^{-1})					
	0.04	0.06	0.09	0.19	1.26	1.3
Stigeoclonium tenue	18300	6783	4888	4850		7535
Ulothrix sp	13625				6349	
Cladophora glomerata		17700	7300	3960		
Brachythecium rivulare	12625	19616	13800	11368		
Rhychostegium sp	19375	18166	5166	8063		
Fontinalis antipyretica		10666				

Zinc in algal populations living in waters with different mean "filtered" zinc levels.

Figure 25 - *Stigeoclonium tenue*.

Figure 26 - *Ulothrix sp*.

Figure 27 - *Cladophora glomerata*.


12000
8000
4000
0·5
1·0
1·3
12000
8000
Zn in plant (μgg⁻¹)
4000
0
0·5
1·0
1·3
3000
2000
1000
0·05
0·1
0·15
0·2
Zn in water (mgl⁻¹)

Zinc in bryophyte populations living in waters with different mean "filtered" zinc levels.

Figure 28 - *Brachythecium rivulare*.

Figure 29 - *Rhynchostegium sp*.

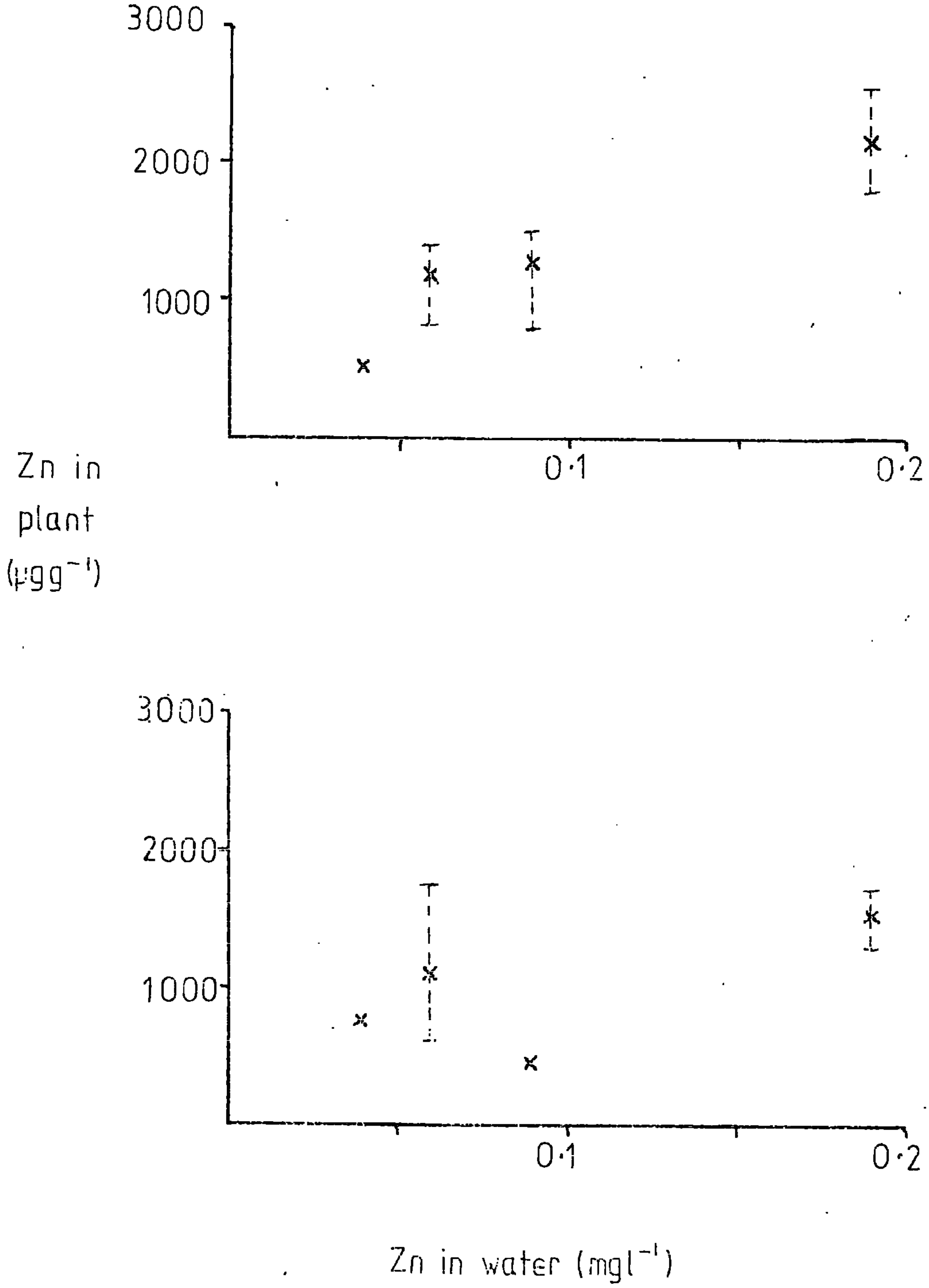

3000
2000
1000
0·1
0·2
Zn in plant (μgg⁻¹)
3000
2000
1000
0·1
0·2
Zn in water (mgl⁻¹)

Table 14.

The main groups of invertebrates encountered during the survey.

	Site								
	1	2	3	4	5	6	7	8	9
Ephemeroptera	+	+	+	+	+				
Plecoptera	+				+				
Tricoptera	+		+	+	+				
Simulidae	+		+	+	+				
Chironomidae	+	+	+	+	+		+	+	
Mollusca (Limnaea)		+	+	+	+				
Platyhelmia						+			
Dipteran larvae	+		+	+	+				
Oligochaetes		+							

6 DISCUSSION

6.1 THE RIVER

The picture to emerge from the surveys of water chemistry is of a river divisible into four sections, the three points of concentrations of pollutants (3.12) being responsible for the transitions between sections.

6.11 Section 1

The first section, represented by sites 1 and 2, shows no signs of severe organic or metal pollution. Zinc levels did not exceed 0.08 mg l^{-1} (total Zn), a value consistent with a stream draining a heavily mineralized area.

Phosphate levels, which may be regarded as a rough guide to the degree of organic pollution, did not exceed 0.08 mg l^{-1} except on one occasion (site 2, 19.VI.79), when the high value was associated with large amounts of suspended solids, apparently due to a sewage discharge from one of the factories on the Tanfield Lea Industrial Estate.

The invertebrate fauna at site 1 was diverse and abundant (Table 14), and the algal cover was almost complete during the first half of the survey. At site 2, the paucity of plant and animal life is probably due to the lack of suitable substrates (3.22 PL 4) rather than to any feature of the water chemistry.

It therefore seems reasonable to regard this first section of the river as a control, against which the effects of pollution in the lower part of the river may be assessed.

6.12 Section 2

The second section, represented by sites 3, 4 and 5, receives both organic and metal pollution derived from the first major concentration of pollutant sources (3.12).

The East Tanfield sewage treatment works is the source of the organic pollution. Below this effluent, gradual recovery of the river is apparent both from the appearance of the water, and from the water chemistry. Phosphate levels fall progressively at sites 3, 4 and 5, and by site 5 there are no visible signs of the pollution that is clearly evident at site 3 (3.23 PL 6). The phosphate levels, however, do not return to those in the control section.

A similar pattern is seen in the case of zinc levels. The steady reduction of levels between sites 3, 4 and 5 does not seem to be prevented by the large number of small mine drainages entering the river in this section (3.12). Since the collieries at Marley Hill and Blackburn Fell no longer pump water into the river (3.12), the small amount of water draining from these workings probably no longer contributes significantly to the elevated zinc levels found at site 3. Bobgin's Burn was sampled on two occasions (25.1V.79, 9.V.79) and the low levels of zinc found, lend weight to this view. Samples from the main stream above and below the confluence with Bobgin's Burn would be useful to confirm this. In the past, zinc from this source was probably more important at night, since that is when pumping of minewater occurred (Carslake pers. comm.). However, there is no longer any reason to suspect such a pattern, so that daytime values from Bobgin's Burn may be considered as representative of the total load of metals carried. It therefore seems that the main sources of zinc in this section are the Ever-Ready waste tips and pumped minewater from East Tanfield colliery.

The brief survey of flora and fauna that was carried out does not show many differences between this section and the control (Table 14). The only major changes seem to be the replacement of Ulothrix as the dominant alga by Cladophora glomerata, and the increase is the amount of Stigeoclonium tenue. The affinity of both these algae for organic pollution has been noted (McLean 1974, Whitton 1975).

Consequently it would seem that although the organic pollution in the upper part of this section may produce an unsightly and occasionally smelly river, the biological effects of organic and zinc pollution are not severe. A more detailed survey of flora and fauna would be required to detect any subtle effects of these pollutants.

6.13 Section 3

The most significant changes in water chemistry and biology occur at the transition between the second and third sections of the river. This transition occurs at the second major concentration of pollutants. The mean total zinc level rose to 7.1 mg l^{-1} with a maximum of 28.6 mg l^{-1}.

Chloride, conductivity, total iron, total alkalinity and optical density all show considerable rises, while pH drops (4.1). Phosphate levels continue the steady decline seen in section 2, although the water here shows clearly visible signs of organic pollution from the Birtley sewage works. However, this seems to be unimportant biologically, compared with the effect of the Durham Chemicals effluent.

Below this effluent there are no bryophytes or macroscopic algae in the water, although moss protonema and films of Stigeoclonium tenue associated with large numbers of diatoms were found in the splash zone. 3 flatworms of unidentified species were the only invertebrates encountered during the survey. The Rowletch Burn effluents do not seem to be responsible for this severe reduction in the biota, since healthy growths of Cladophora glomerata, which has been noted by Whitton (1970) as being sensitive to metal pollution, occur between Rowletch Burn and the Durham Chemicals effluent. The fauna of this stretch seems to be similar to that at site 5, but again, a more detailed survey would be needed to detect any subtle effects of this group of effluents.

The recovery of the river between site 6 and the Team Valley Trading Estate is represented by site 7. Mean total zinc levels by this point have fallen to 4.88 mg l^{-1}. However, it must be remembered that the mean zinc values at sites 6, 7 and 8 are biased by one particularly large value, so that the drop in zinc between sites 6 and 7, and between 7 and 8 may not be as large as these figures suggest. It seems from the zinc levels in the sediments (Fig. 12b) that at least part of the observed fall in zinc in the water is due to binding to the sediments. The large increase in total iron values due to Kibblesworth pumped minewater (Table 8 PL 12) may have a role to play in immobilizing zinc in this way (1.12)

The biological recovery by this site does not appear to be great. The only observed differences in the biota between this site and site 6 were the presence of an extensive although stunted and short lived growth of <u>Stigeoclonium</u> <u>tenue</u> in the water, and the presence of a few chironomid larvae.

Although the river has received a number of effluents from the Team Valley Trading Estate upstream of site 8, the water chemistry at this site shows great similarities to sites 6 and 7, so that this site may be regarded as being part of the third section of the river. The only major differences between this site and the previous two are a further drop in zinc levels and a drop in dissolved oxygen. However, the situation here is so complex that there may be other important differences which are not reflected in the water chemistry parameters chosen for this survey.

Possibly due to the drop in zinc at this site, there is limited biological recovery. Extensive growths of <u>Stigeoclonium</u> <u>tenue</u> were found during most of the survey at this site. There is, however, no sign of a recovery of the fauna, a few chironomid larvae being the only invertebrates encountered.

6.14 Section 4

The fourth section is tidal. The rise in zinc levels here seems to be due to the Norwood coke works (km 23). The other main changes at this site are the drop in dissolved oxygen levels and the constant presence of large amounts of raw sewage.

6.2 THE ROLE OF ZINC

It seems from 6.11 and 6.12 that zinc probably has little effect on the first 16.5 km of the river. This may be at least in part due to the high levels of phosphate, calcium and magnesium, all of which are known to reduce the toxicity of zinc (1.21).

However, the effects of the Durham Chemicals effluent, containing very high levels of zinc, are very serious, incolving the almost complete elimination of fauna and macrophytic flora. Detailed analysis of this effluent would be useful to determine whether it is the zinc levels or another constituent of the effluent that is responsible for this effect.

Whatever the precise cause, there is only very limited recovery of the river from the effects of this effluent before the complex combination of Team Valley effluents are added to its burden.

In every section of the river, the high variability in zinc levels makes it hard to draw conclusions from isolated results.

6.3 GRADING OF THE RIVER

The Northumbrian Water Authority classification of the river together with the criteria involved were mentioned in 3.13. The present survey raises certain points concerning the relationship between classifications based primarily on chemical criteria, and the biological state of the river.

The section classed in July 1977 as grade 4 begins at the East Tanfield sewage works, and includes site 3 of the present survey. This classification appears to be based entirely on the severity of the organic pollution, which periodically becomes a nuisance to local inhabitants due to the appearance and smell of the river. The flora and fauna at site 3, however, is much more abundant and diverse than that below the Durham Chemicals effluent (3.23, Table 14), a reach classed as grade 3. Grading on restricted chemical criteria does not, therefore, necessarily reflect the biological health of the river.

6.4 MONITORS

6.41 Advantages and requirements

The two main reasons for using the technique of biological monitoring were mentioned in 1.24. In the present study, zinc levels in the water were always easily measurable, so that the first of these reasons does not apply. It can be seen from Table 8, however, that there is great variation in zinc levels at all sites. Monitoring would therefore be useful in order to smooth out short term fluctuations in the environmental level, thereby providing an integrated figure for the zinc concentration over a period of time.

The examples quoted in 1.24 give an indication of some of the features a plant requires if it is to be of use as a monitor. Firstly the plant should ideally be independent of the substratum for its nutrition. Secondly, there should be a consistent relationship between levels of the metal in the water and in the plant. The plant should be widespread, occuring in all parts of the river under study. In view of the conclusions of Harvey and Patrick (1.23) it is desirable that growth form of the plant should be consistent between samples. Difficulties in cleaning the material (2.21) make it impossible to be certain that a result is not due to contamination. Ease of cleaning is therefore another important requirement. If monitoring is to be carried out all the year round, the plant should have a long growing season. Finally, identification of the species should be easy if monitoring is to be used as a regular indication of the state of the river.

In addition to these requirements for the plant, there should be clearly defined limits for important variables of water chemistry such as phosphates (1.21) and other metals (1.24), which may modify the uptake of zinc by the plant.

6.42 Monitoring in the Team

In view of these considerations, do the results in chapter 5 suggest a likely candidate for a monitor species in the Team? The first problem is that of distribution. No aquatic bryophytes were found downstream of the Durham Chemicals effluent, so that any use they may have is restricted to the upper 16 km of the river. Pohlia delicatula occurs on the banks of several sites, growing only as protonema where it is closest to water bearing high (≥ 1 mg l^{-1}) levels of zinc. Variations in water level, however, result in irregular inundation, making it extremely hard to interpret the zinc levels in this plant.

The only macroscopic alga found throughout most of the river was Stigeoclonium tenue. It was absent only at site 9. This alga, however, falls short of the requirements mentioned in 6.41 on several grounds. Firstly, it has a short growing season. In the present study it had almost completely disappeared from sites 1 - 6 by late July, remaining well into August at sites 7 and 8, possibly due to reduced grazing pressure.

Secondly, the growth form of the samples from above and below the Durham Chemicals effluent were very different. The Stigeoclonium from sites 1 - 5 grew in clean dark green tufts of up to about 2 cm in length and often completely covered areas of the substrate, while that at sites 7 and 8 was sparse, pale green, associated with a large amount of silt and debris, and never exceeded a few mm. in length. At site 6, apart from one short lived growth in the river itself, this alga was restricted to the splash zone, and showed even less development of filaments than at sites 7 and 8.

Samples from sites 6, 7 and 8 were also found to be unsuitable for monitoring due to very great difficulties in cleaning, making it hard to be sure that the results were unaffected by contamination.

The enrichment ratios at different sites range from 4850 to 18300, and although there is a great difference between zinc levels in samples from site 8 and from the cleaner sites (1, 3, 4 and 5) there does not appear to be a close enough relationship between levels in the water and in the plant to enable detection of subtle changes.

In summary, there are many reasons why biological monitoring of zinc levels does not appear to be viable in the lower part of the Team: no bryophytes occur in this part of the river; the algae are sparse, hard to clean and have a short growing season; the stunted growth form of Stigeoclonium makes it hard to compare with samples of the same species from higher reaches of the river; the water chemistry above and below the Durham Chemicals effluent shows many differences which may alter zinc uptake rates. Furthermore, it could be argued that attempts to monitor the exact levels in this stretch are a waste of time, since the almost complete absence of invertebrates gives a clear indication of the health of the river.

It therefore seems clear that any use for biological monitoring of zinc in the River Team is restricted to the first 16 km. In this section, a marked increase in zinc levels consistently occurs at site 3 (4.1). This rise is reflected by the zinc levels in Stigeoclonium tenue, Brachythecium rivulare and Rhynchostegium, the magnitude of the increase being highly variable (Table 11). All three plants show higher enrichment ratios at site 1 than at site 3. In the case of Brachythecium, however, this difference is slight, and the levels of zinc in the moss appear to reflect those in the water far more closely than either Rhynchostegium or Stigeoclonium. The zinc levels in Cladophora show no clear relationship to zinc levels in the water (Fig. 27).

A drop in zinc levels in the water occurs between sites 3 and 4 and between 4 and 5 (4.1). The zinc levels in Stigeoclonium and Brachythecium show a similar drop, but in the case of Rhynchostegium site 4 shows much lower levels than sites 3 and 5.

Moreover, considerable problems of identification were encountered in the case of Rhynchostegium. Under conditions of high organic pollution, this plant has a growth form very similar to that of Amblystegium, which also occurs in the river.

Stigeoclonium, although reflecting the water quality of this section of the river, has the disadvantages of a short growing season, and being more difficult to clean than the mosses. Of the plants studies, therefore, Brachythecium rivulare appears to offer greatest potential as a monitor of zinc in the upper part of the Team. It must be emphasised, however, that the number of samples analysed was very small, so that much more work would be required to confirm this.

In view of the conclusions in 6.2, it seems questionable that such a monitor would be of much practical value in this stretch. It was, however, suggested earlier (6.2) that one possible reason for the apparent low toxicity of zinc in this section of the river might be the high levels of phosphate. If attempts to reduce the degree of organic pollution from East Tanfield sewage works are successful, then it is possible that the resulting drop in phosphate levels might increase the toxicity of the zinc to levels where monitoring would be desirable. Surveys of the second section between the Ever-Ready effluent and site 3 would be useful to determine whether zinc produces a more serious problem there.

6.43 Conclusion

In conclusion, this study shows that biological monitoring of zinc levels in the upper 16 km of the River Team is a clear possibility, but casts doubts upon the usefulness of such an operation at present.

6.5 TOXICITY AND ACCUMULATION

The parellel MSc project carried out by C.S. Craggs on the resistance of Stigeoclonium tenue populations from the Team to varying levels of zinc, showed that populations from high zinc sites were adapted to tolerate higher levels of zinc than those from low zinc sites. The present study found that the populations from high zinc sites had lower enrichment ratios than those from low zinc sites (Table 13). This raises the possibility that low accumulation might be the mechanism of increased tolerance. There are, however, two main reasons why this must be regarded as no more than a tentative suggestion for further investigation.

Firstly, the reduced enrichment ratio may be a result of the differing water chemistry in the different sections of the river, rather than being due to any property of the algal populations.

Secondly, it is possible that uptake of zinc is not constant at all levels, but that there is a saturation point for zinc uptake, and that the enrichment ratio drops as this is approached. Transplant experiments would enable the enrichment ratios of different populations to be more easily compared, and would do much to clarify the situation.

SUMMARY

The River Team was found to be severely affected both by organic and by metal pollution. Organic pollution was the main problem in the upper part of the river, while zinc pollution was found to have serious effects in the lower part. Both forms of pollution were severe in the tidal stretch of the river.

The use of plants to monitor zinc levels was found to be feasible only in the first 16 km of the river. It is suggested that Brachythecium rivulare shows the greatest potential as a zinc monitor, although the value of such a procedure is questioned.

The Stigeoclonium tenue populations found by Craggs to be most resistant to zinc were found to have lower enrichment ratios than less tolerant populations. It is suggested that this may point towards low uptake being the mechanism of high tolerance, but reasons are presented why this conclusion must be regarded as very tentative.

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