1954

FINAL REPORT ON

INITIAL SURVEYS IN THE INVESTIGATION TO DETERMINE EFFECTS OF TROUT FARM EFFLUENT ON RIVERINE BIOTAS IN THE SOUTH-WESTERN CAPE

by Cate Brown

in liaison with appointed consultants

Dr J.M.King & Dr J.A.Day

Freshwater Research Unit

University of Cape Town

May 1993

The data contained in this report are preliminary and form part of an on-going investigation into the effects of trout farm effluents on rivers in the south-western Cape. For this reason the names of the trout farms listed in Appendix 1 should be treated as confidential. Comments on this draft report are welcomed and should addressed to Ms. C. Brown, Freshwater Research Unit, Zoology Department, University of Cape Town, Rondebosch, 7700, Cape Town.

FINAL INTERIM REPORT

EXECUTIVE SUMMARY

REPORT ON INITIAL INVESTIGATION TO DETERMINE EFFECTS OF TROUT FARM EFFLUENT ON RIVERINE BIOTAS IN THE SOUTH-WESTERN CAPE

Consultants: Dr J.M.King
Dr J.A.Day
Ms C.A.Brown

Introduction

Concern regarding the possible polluting effects of the trout farms on mountain streams and upper rivers in the area resulted in the Department of Water Affairs and Forestry (DWAF), and Cape Nature Conservation (CNC) commissioning an investigation of the effects of trout farms on riverine biota in the south-western Cape which began at the Freshwater Research Unit (FRU), University of Cape Town in August 1991.

Two surveys of several trout farms situated on the upper reaches of rivers in the south-western Cape were undertaken to determine whether there was a common trend in their effect on the rivers, what components of the effluents might be responsible for any observed effects and whether there were any seasonal differences in these impacts on the river.

Summary of main findings

The main findings of the investigation were:

1. The impact of the trout farms on the downstream riverine ecosystems ranged from mild to severe, based on the degree of change in the structure of the bottom-dwelling (benthic) invertebrate communities from upstream to downstream of effluent outlets.
2. Farms situated on mountain streams (complete canopy cover, steep gradient, low annual fluctuations in water temperature, very pure water, highly sensitive endemic fauna) had the greatest impact on the rivers.
3. Farms situated on the downstream foothill zones (open canopy cover, high annual fluctuations in water temperature, moderate gradient, pure water, sensitive, mostly endemic fauna) had a lesser impact than did those situated on mountain streams.
4. The smaller impact of those farms situated in the foothill zone was probably because these reaches were already disturbed by other catchment activities and as a result sensitive components of the riverine community were already missing.
5. Farms that used portapools to house their fish had a greater impact on the downstream river than did farms that used earth dams.

6. There were no significant seasonal differences in the type or degree of impact that the farms had on the downstream rivers. The reduced flow (and therefore reduced dilution) in the river in summer was compensated for by the reduced stocking rates during these hot months.
7. The groups of aquatic invertebrates most likely to disappear below an effluent were the mayfly families Leptophlebiidae, Ephemerellidae, Heptageniidae, beetle families such as the Helodidae and Elmidae and the caddisfly family Glossosomatidae.
8. The midge family Chironominae and the baetid mayflies were found to be good indicators of mild organic pollution.
9. Chemical samples collected at each site suggested that the particulate fraction of the effluent, combined with increased nutrient levels, was the major factor responsible for the recorded reaction of the riverine biota.
10. Finally, apart from minor differences, the trend of impacts recorded in the winter survey were the same as those recorded in the summer survey. The second (summer) survey, therefore, confirmed the results of the first (winter) survey.

Sequence of reports

This is the third report in a series dealing with the investigation of the effects of trout farms on riverine ecosystems in the south-western Cape. The previous two reports were:

1. A preliminary review of Special Effluent Standards, and
2. Report on the initial (winter) survey - Draft.

The final report for the investigation will include the review of Special Effluent Standards, this report on the initial winter and summer surveys and a report on the detailed investigation which followed the initial surveys. It will also include a report on a separate investigation of the effects of trout-farm effluent on algal communities in the downstream rivers. The final report is due in December 1994.

CONTENTS

1. INTRODUCTION

1.1. Background

During the last five years the south-western Cape has been a focal area for growth in the South African trout-farming industry. Concern regarding the possible polluting effects of the trout farms on mountain streams and upper rivers in the area resulted in the Department of Water Affairs and Forestry (DWAF), and Cape Nature Conservation (CNC) commissioning an investigation of the effects of trout farms on riverine biota in the south-western Cape. This investigation began at the Freshwater Research Unit (FRU), University of Cape Town in August 1991. The main aim of the investigation is to provide information on the reaction of the riverine biota to different concentrations of trout-farm effluent which can be translated by the authorities into regulations for controlling the trout-farming industry in the upper reaches of south-western Cape rivers (King, Day & Brown 1991).

This report documents the results of the first stage of the investigation, which comprised two surveys of eight trout farms situated on mountain streams or upper rivers in the south-western Cape.

The surveys had three main objectives:

1. To determine what impacts, if any, trout-farm effluents had on the river ecosystems on which they were situated, and if there were any common trends in the downstream effects;
2. to determine what components of the effluents might be responsible for any observed impacts, and
3. to use the information obtained to select two or three established trout farms for a detailed investigation of the tolerance limits of important components of the riverine ecosystem to pollutants contained in the effluents.

Originally a single survey was proposed (King *et al.* 1991). Because the project began in the winter, the survey was done at the end of winter when low temperatures and high flows minimised the impacts of the farms on the riverine ecosystems. A second survey was thus performed at the end of summer when the impacts were likely to be more severe. Also, as aquatic invertebrate communities in south-western Cape upper rivers change seasonally, the second survey allowed an assessment of the impacts of the farms on two different types of communities. Winter communities appear with the onset of the winter rains and the switch back to summer communities occurs in about November or December (King 1981). Thus, the initial (October-November, winter) survey sampled the winter communities and the second (February-March, summer) survey, the summer communities. The possibility of early rains (March) on the one hand and high river flows (September) on the other prevented the two surveys from being spaced further apart.

This report comprises:

1. an introduction to, and brief explanation of, the potential effects of trout farms on riverine biotas
2. an introduction to the concept of using biological data to monitor impacts on riverine ecosystems;
3. a description of the area under investigation and the work programme;
4. details of data analyses and the statistical procedures used;
5. an explanation of the results;
6. some preliminary recommendations for the control of trout-farm effluent based on the results of the survey and on a preliminary review of Special Effluent Standards (Brown 1991);
7. an outline of the next phase of the investigation.

1.1.1. Definitions

Pollution has been defined by the World Health Organisation as 'the impairment of the suitability of water for some considered purpose' (International Standards Organisation 1980).

Current DWAF policy requires that the effects of pollution on the water quality of a system be evaluated in terms of the requirements of a particular user or category of users and measured in relation to criteria or norms representing the ideal quality for a particular user (DWAF 1991). DWAF has recently recognised the environment as a water user (DWAF 1991), with the result that, in setting effluent standards, the requirements of the natural aquatic biota, in terms of both water quality and water quantity, will in future need to be taken into consideration.

For the purposes of this review, the term *pollutant* is taken to mean 'any entity whose addition to an aquatic ecosystem by humans or their activities actually or potentially changes the characteristics of the system such that the natural biota of that system are adversely affected' (adapted from Hart & Allanson 1984).

Pollutants in waste water may change riverine community structure and species diversity. Apart from aesthetic considerations, these changes may cause

- the appearance, or even increase to pest proportions, of certain nuisance organisms,
- 'rotting' of the river caused by anaerobic conditions, and/or
- a reduction in the self-purifying capacity of the river.

Accumulation of pollutants may also have long-term effects not noticeable in the initial stages (MacDonald *et al.* 1984). Hence, by the time the effects become apparent, severe and long-term damage may already have occurred.

1.2. The nature of the problem

The South African freshwater-aquaculture industry has expanded rapidly since the early 1980s and by 1990 gross production was valued at approximately R72 million (Brink & Bekker 1991). The current commercial production of fresh trout in South Africa is approximately 1023 metric tonnes per annum and, for the past five years, the industry has maintained a 30% growth rate, despite a general economic recession (Brink & Bekker 1991). In 1988, 72% of aquaculture concerns in South Africa were between one and five years old (Brink & Bekker 1991).

The south-western Cape is currently responsible for 45% of the total annual trout production in South Africa (550 tonnes in 1990). Despite an exponential increase in the number of producers in the region over the last five years, the aquaculture industry believes that the natural water courses and support infrastructures (e.g. The University of Stellenbosch; The Department of Agriculture, Elsenburg; & The Council for Scientific and Industrial Research, Stellenbosch) in the region are still under-utilised (Brink & Bekker 1991). Future expansion in the South African trout-farming industry is thus likely to concentrate on the south-western Cape.

A plentiful supply of cool, clean water is the primary requirement for a successful trout farm and the clear water of mountain streams and upper rivers in the south-western Cape is a considerable attraction to the trout-farming industry. These rivers are, however, vulnerable to pollution (Davies, Day & King 1986). The natural biota in the upper reaches is susceptible to disturbances which can also have detrimental effects on the entire downstream ecosystem. Such effects will be worst in summer when low flows result in a reduced dilution capacity of the rivers to dilute effluents, which is an important way of reducing the impact of pollutants.

The potential polluting effects of fish farms have been well documented (e.g. Jones 1990). The most obvious potential impact of a land-based trout farm is over-abstraction of water from a river, which can lead to changes in channel shape and patterns of sedimentation, barriers to migration of fish and alteration of the biological communities (Nature Conservancy Council of Scotland 1990, Jones 1990). Although a matter of some concern, investigation of the effects of over-abstraction did not form part of the initial survey. It will, however, be incorporated into the detailed investigation (King *et al.* 1991).

Potential pollutants in fish-farm effluent include faeces and uneaten food, which settle out on river beds and can result in increased rates of nutrient uptake into the sediments. The quantity and quality of solid wastes in the effluents vary seasonally and diurnally depending on feeding time, stocking rate and other factors.

Dissolved nutrients are also major potential pollutants. The amount of nitrogen in fish-farm effluent varies from time to time, with peaks following feeding and during tank cleaning. Phosphorus concentrations are dependent on feed quality, feed conversion ratios, fish size and fish-farm management (Nature Conservancy Council 1990). Nitrogen and phosphorus in the effluent can result in hypernutrification and increased primary production of macrophytes and algae in downstream rivers, leading to a risk of eutrophication.

The levels of dissolved oxygen in the river may be affected by localised reduction in oxygen levels at the effluent outlet, although this is likely to be minimal. Other factors likely to affect oxygen levels are consumption of oxygen during the breakdown of organic (Biological Oxygen Demand, BOD) and other matter (Chemical Oxygen Demand, COD) contained in the effluent and indirect downstream effects through changes in phytoplankton abundance. The impacts of changes in the level of dissolved oxygen will depend on the characteristics of the receiving waters and of the effluent but would affect the survival of natural riverine fauna and flora (Nature Conservancy Council 1990).

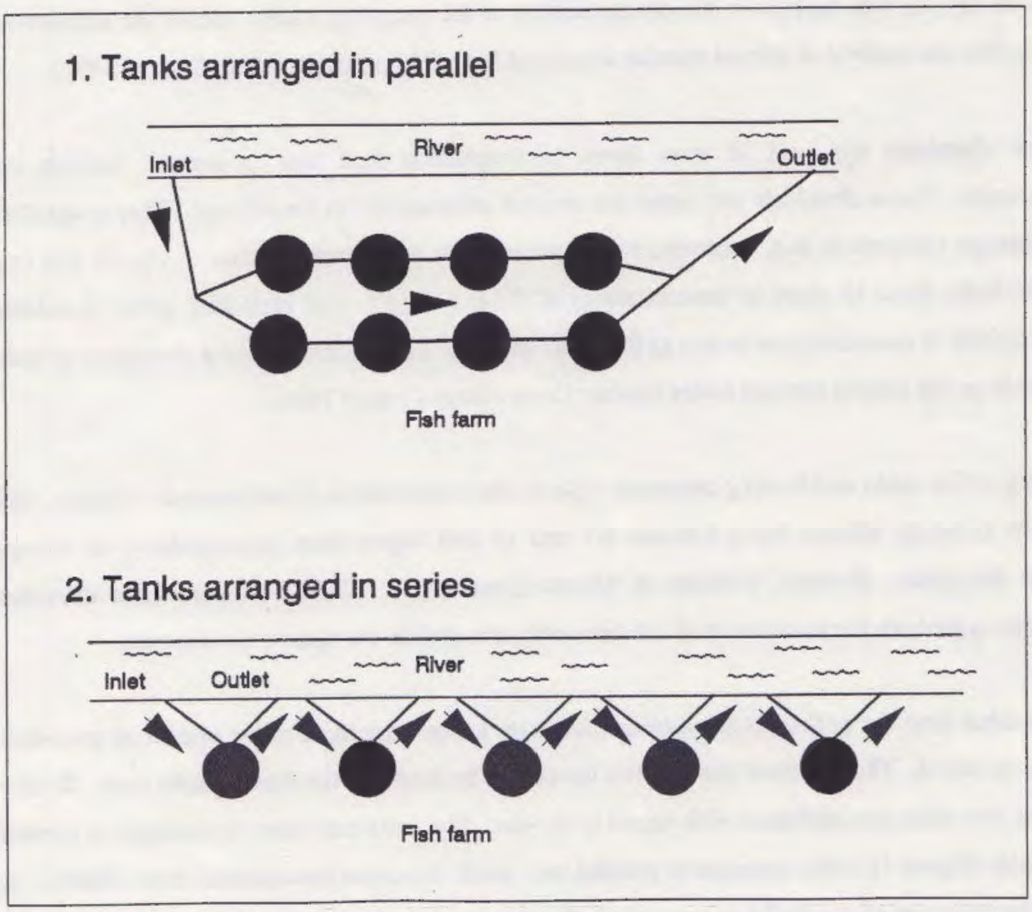
Various chemicals are used in trout farms to supplement feed and to control diseases and ectoparasites. These chemicals may enter the riverine environment in the effluent. They range from fairly benign compounds (e.g. vitamins) to compounds that are extremely toxic to aquatic life (e.g. formaldehyde: toxic to algae at concentrations of 0.3-0.5 $mg.l^{-1}$, and malachite green: sub-lethal effects on fish at concentrations as low as 0.03-0.05 $mg.l^{-1}$). Little is known about the effects of these chemicals on the natural riverine biotas (Nature Conservancy Council 1990).

Cleaning of fish tanks and feeding can cause peaks in the concentration of pollutants in effluents, with peaks in 'cleaning' effluent being between 0.1 and 10 fold higher than concentrations of 'normal' effluent (Bergheim, Hustveit, Kittelsen & Selmer-Olsen 1984). These variations have important implications for both the monitoring of fish-farm effluents and for the natural environment.

Factors other than the pollutants themselves contribute to the magnitude of the impact of trout-farm effluent on rivers. These include the size and lay-out of the farm and the type of tanks used. Briefly, there are two main considerations with regard to lay-out. The tanks can either be arranged in parallel or in series (Figure 1); tanks arranged in parallel may result in a more concentrated final effluent. As far as the structure of the tanks is concerned, there are two types used in land-based farms in the south-western Cape: unlined earth ponds and concrete or plastic-lined tanks. Unlined earth ponds have a slower flow-through rate than concrete or plastic-lined tanks and thus some settlement of solids does occur. The solids in suspension may, therefore, be less concentrated in earth dams than in plastic 'portapools'. The flow-through of water in tank farms is too fast to allow waste food and faeces to decompose before they are discharged into the river.

Many attempts have been made to estimate the size of the human population that would produce an equivalent amount of waste to fish farms. Solbe (1982) estimated that, depending on the parameter measured, the waste produced by 1 ton of fish was equivalent to treated sewage effluent from 122-859 people, referred to here as "the human population equivalent" (HPE). For instance, in Scotland production of trout has increased by two orders of magnitude in the past 20 years (10 % annual growth rate; Nature Conservancy Council 1990) and recent estimates put the HPE of the total amount of effluent produced by fish farming in that country as high as 1.5 million people. A similar estimate for the south-western Cape using 1990 production figures is a HPE of 61 000 (500x122; Solbe 1982; Brink & Bekker 1991) - using Solbe's upper limit the HPE is 426 500. Fortunately, at present, most trout-farming operations in the south-western Cape are relatively small, low-density farms. At its present growth rate, however, South Africa's production of trout will double every three years.

Figure 1. Arrangement of tanks on land-based trout farms



As yet little is known of the effects of pollutants from trout farms on aquatic ecosystems. Furthermore, because pollutant concentrations are usually low and most pollutants are not directly toxic, instances of direct mortality of aquatic life are unlikely. Effects, if any, are likely to be subtle, affecting growth, reproduction or other normal life patterns of the river organisms. Eventually these can lead to changes in community structure and the reduction or elimination of components of a system such that the effects are reflected through more than one trophic level. Often it is only at this late stage that significant changes in ecosystem structure are noticed. Also, although effluent discharged from trout farms is perhaps relatively benign when compared to most industrial pollution (National River Authority of England 1991), the location of the south-western Cape farms, on the sensitive upper reaches of streams, makes them a cause for concern. Changes in conditions induced by effluent outfalls can have quite different consequences in different river zones (Hawkes 1982). In general the higher up the watercourse, the greater the impact of any pollutant. In summary, then, general effects are likely to be subtle, with changes in the oligotrophic upper reaches being both more noticeable and more severe than those in lower sections of the rivers.

1.3. River zonation and its implications

1.3.1. River zones

Streams and rivers change naturally along their length with respect to such properties as temperature, depth, current speed, substratum, turbidity and chemical composition (Hynes 1970). Since these factors are important in determining the distribution of the riverine biota, the longitudinal physical and chemical changes are reflected in changes in species composition of the faunal communities. The result is a longitudinal biotic zonation that can be used to classify reaches of rivers and streams. These zones are not discrete and attempts to define them in terms of a single variable have been unsatisfactory. Generally speaking the rivers in the south-western Cape can be divided into five zones (modified from Nobel & Hemens 1978), namely:

1. Mountain source and cliff water fall

The source of a river, often with sponge vegetation or humic turf and sometimes with waterfalls. Outside the sponges, the flow is usually fast and occasionally torrential. Turbidity is negligible and levels of oxygen saturation high. Summer mean temperatures may be below or about 20°C.

2. Mountain stream

A narrow, defined channel with a very steep gradient, small waterfalls, rapids and little emergent vegetation. There may be occasional rock pools. The substratum is boulders, bed rock and cobble, and flow is generally fast through riffle sections and slow in pools. The riparian trees may or may not form a closed canopy over the stream. Deposition of inorganic sediments is negligible and the surfaces of rocks and vegetation are virtually free of epilithon. Turbidity is negligible except during spates. Summer mean temperatures are around 20°C.

3. Foothill zone

A zone of widening channel and decreasing bed gradient with lower flow velocities. The substratum is boulders, cobbles and some sand. Stony riffles and runs alternate with rock pools. Although there are still riparian trees, the river is wider and, because of this, the canopy is usually open. Turbidity is variable but usually low. Summer mean temperatures are above 20°C.

4. Low and midland stream and river

A zone of reduced gradient with areas of deposition, alternating with stony reaches. The riparian vegetation consists of reedbeds and few trees. Often turbid. Summer mean temperatures are usually well above 20°C.

5. Estuary

Flow is generally very slow and subject to tidal fluctuations. The riparian vegetation is specialised and tolerant of changes in salinity. Summer mean temperatures are well above 20°C.

Since most trout farms in the south-western Cape are situated on or near the upper reaches of rivers, further discussion will be confined to the mountain stream zone (including the source) and the foothill zone.

1.3.2. Aquatic invertebrate community composition of mountain streams and foothill zones

In the south-western Cape, as in other parts of the world, amphipods (non-insect) often account for a considerable portion (*ca* 50%) of the invertebrate fauna at the river source (Hynes 1970). Slightly downstream, the mountain stream invertebrate community is dominated by insects. In the Eerste River, for example, insects accounted for *ca* 99% of total invertebrate numbers (King 1981). During the winter months the Ephemeroptera (mayflies), mainly Leptophlebiidae and Ephemerellidae, usually comprise about 37% of the invertebrates (King 1981). In some streams Blephariceridae (net-winged midges, Diptera) are also numerous, while Trichoptera (caddisflies) and Plecoptera (stoneflies) usually occur in small numbers. Dryopidae, Elmidae, Hydraenidae and Helodidae are all typical mountain stream families of beetles (Coleoptera) and are usually present in small numbers. Chironimidae (midges, Diptera) and Simuliidae (blackflies, Diptera) are always present, usually collectively accounting for *ca* 14% of the overall numbers of invertebrates (King 1981). Non-insect groups, such as Oligochaeta (earthworms and their allies) occur in small numbers, never representing more than 1% of the overall invertebrate fauna.

The invertebrate community in the foothill zone is also dominated by insects (98.8%; King 1981), with the Ephemeroptera again well represented. Within the order, however, the proportion of different mayfly families changes, with Baetidae increasing in prominence. Chironimidae also increase in numbers, as do non-insect groups such as Oligochaeta and the Hirudinea (leeches). Important faunal changes between the winter mountain stream and winter foothill zone communities are the loss or decrease in frequency of the Ephemerellidae, Trichoptera, the mountain stream Coleoptera and the Blephariceridae (King 1981).

1.4. Biological monitoring

In the past, effluents entering riverine ecosystems have been monitored by chemical analysis of water quality (e.g. Special Effluent Standards, Amendments to the Water Act 1984). Recently, however, more use has been made of biological monitoring programmes, in conjunction with physical and chemical variables, to assess the impacts of perturbations on rivers (Hawkes 1982; Armitage, Furse & Wright 1991). Chemical analysis of water quality provides useful information about the nature of effluents entering a system, but chemical surveillance sampling is usually discontinuous. This can result in underestimates (or overestimates) of daily pollutant loads because of diurnal (or longer) fluctuations in effluent quality, and once-off introductions of harmful wastes into effluent may be missed (Brown 1991). In addition, the number of criteria used to monitor water quality and the number of samples analysed are usually dictated by financial constraints. Serious pollutants may thus simply not be analysed for. Furthermore, the term *water quality* can only be defined relative to a user. For example, it has yet to be determined if fish, plants and humans require the same quality water. Because of the difficulty of analysing for every pollutant likely to be in a sample of water, and of interpreting results in terms of the severity of impact, it makes sense to turn to the aquatic biota for assistance. The main advantage of a biological approach is that it examines organisms whose exposure to the water (and any pollutants therein) is continuous (Ractliffe 1991). Species present reflect the present and past history of the water, allowing detection of disturbances that might otherwise be missed. Changes in the composition of the benthic invertebrate community can often be related to changes in the concentration of pollutant in the water.

Macroinvertebrates, particularly benthic (bottom-dwelling) macroinvertebrates, are most commonly used in biological assessment methods. Since they are relatively sedentary, these animals are exposed to a continuous flow of varying quality water. They are also widespread, easy to sample and, in general, display a rapid response to pollution (Hellawell 1977). In South Africa, most research on benthic macroinvertebrates has concentrated on the stones-in-current, or riffle, faunal communities (e.g. Harrison & Elsworth 1958a; Chutter 1972; King 1981). This is because, in general, the fauna of clean, stony runs and riffles is richer than that of silty reaches and pools, both in number of species and in total biomass (Hynes 1970). Riffles, being shallower, are easier to sample than runs, and are usually favoured for monitoring work. Even so there is a scarcity of hard facts on cause-effect relationships between freshwater communities and pollution.

A potential drawback of most methods of biological monitoring is the necessity to identify organisms to species, since species in the same genus often display markedly different levels of tolerance to pollution (Resh & Unzicker 1975). Species-level data, however, are frequently impossible to attain because of temporal and financial constraints (Armitage, Pardo, Furse & Wright 1990) and there has been some success in the use of family-level identifications (i.e. a coarser level of identification) in Great Britain using the Biological Monitoring Working Party (BMWP) score system (Chesters 1980; Wright, Armitage, Furse & Moss 1988).

One approach to biological monitoring of riverine ecosystems is the use of indicator species and biotic indices. Indicator species are chosen for their sensitivity or tolerance to pollution, and their presence or absence in a river is used to gauge the state of the riverine ecosystem. The use of indicator species is complicated by the fact that they are likely to be specific to particular pollutants and geographic regions. Thus, particular species will indicate particular forms of pollution, and it is unlikely that any species will be equally sensitive to all types of pollution. Additionally, no single indicator species is likely to occur universally and, thus, no biotic index will apply in every region of a country as large and diverse as South Africa without modifications to cater for local conditions.

Biotic indices were evolved as a simple approach for assessing the effects of pollution. There are essentially two types of biotic index: quantitative types based on community diversity, e.g. Shannon-Weiner Index (Krebs 1985) and qualitative types based on levels of abundance, e.g. Chandler Biotic Score (Chandler 1970). The indices compare a 'score' obtained for a known healthy river with another river site of unknown quality in order to assess its condition.

More recently, sophisticated predictive models have been developed for use in biological monitoring of rivers. The most successful of these is RIVPACS (River Invertebrate Prediction and Classification System), a computer-based model currently being used in Great Britain. This enables scientists to predict the probability of capture of species at a site in the absence of environmental stress, using a set of known environmental variables, including substratum composition, oxidised nitrogen, alkalinity, chloride concentration, slope, distance from the source, altitude, air temperature, etc. (Moss, Furse, Wright & Armitage 1987). For an unpolluted site the species actually captured should closely approximate those predicted, and for a polluted site the species found should differ from the predicted composition. The degree of difference between expected and observed is proportional to the severity of the pollution. RIVPACS has also been used with some success when the fauna has only been identified to the family level (Wright *et al.* 1988).

SECTION 2. THE AREA UNDER INVESTIGATION

The investigation was confined to the south-western Cape, South Africa. The locations of trout farms visited during the surveys are provided in Figure 2.

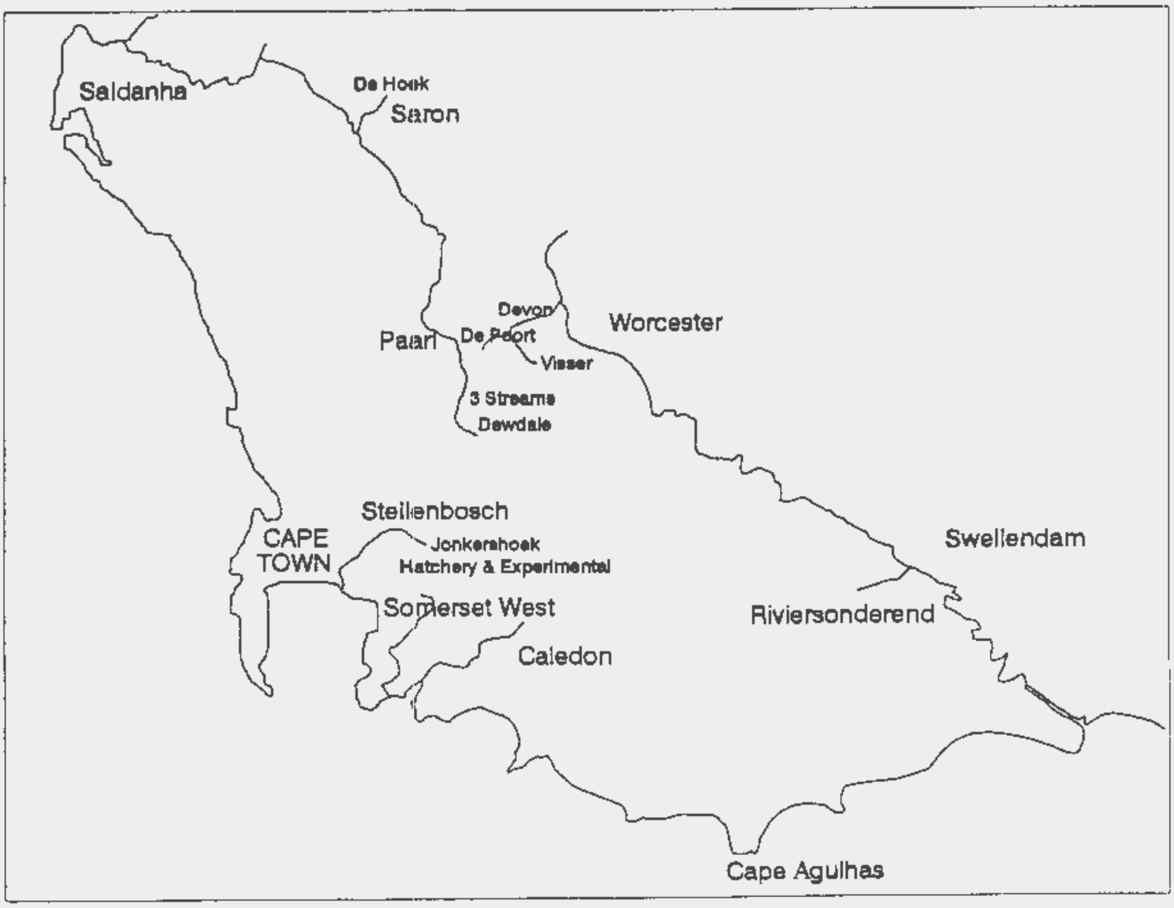
2.1. Trout farms visited during the surveys

The following farms formed part of the initial survey:

De Hoek Estates	Twenty-four & Ewe Rivers
De Poort Trout Farm	Molenaars River
Devon Trout	Molenaars River
Dewdale Trout Farms	Berg River
Jonkershoek Experimental Station	Eerste River
Jonkershoek Hatchery	Eerste River
Three Streams Trout Farm	Franschhoek River
Visser's Trout Hatchery	Kraalstroom River

A detailed description of each farm is provided in Appendix 1. Physical, chemical and biological variables were investigated at each of the trout farms during October and November 1991. A second visit was made to seven of the eight farms in February and March 1992. De Hoek Estates was excluded from the post-summer survey for reasons explained in 2.2.

Figure 2. Map of the south-western Cape, showing the locations of the trout farms visited during the surveys.



2.2. Sampling sites

Most farms drew water from the same river into which they discharged their effluent. In these cases sampling sites were chosen upstream of the farm inlet (control), about 100 metres downstream of the effluent outlet and in the effluent itself (Figure 3). For farms where the water supply was not drawn from the river into which the effluent was discharged, an upstream site was chosen above the outlet (i.e. above the influence of the farm).

Two farms had characteristics which complicated the collection of data:

1. *De Hoek Estates*

   The trout-farming enterprise at De Hoek Estates was divided into two sections, each of which received its water supply from canalised and/or piped sections of the Ewe and Twenty-four Rivers. The effluent from one section of the farm was discharged directly into a farm dam and, from there, to a canalised section of river. Effluent from the second section was discharged into a short (*ca* 200 metres) uncanalised section of the Twenty-four Rivers. Samples were collected from the following sites:

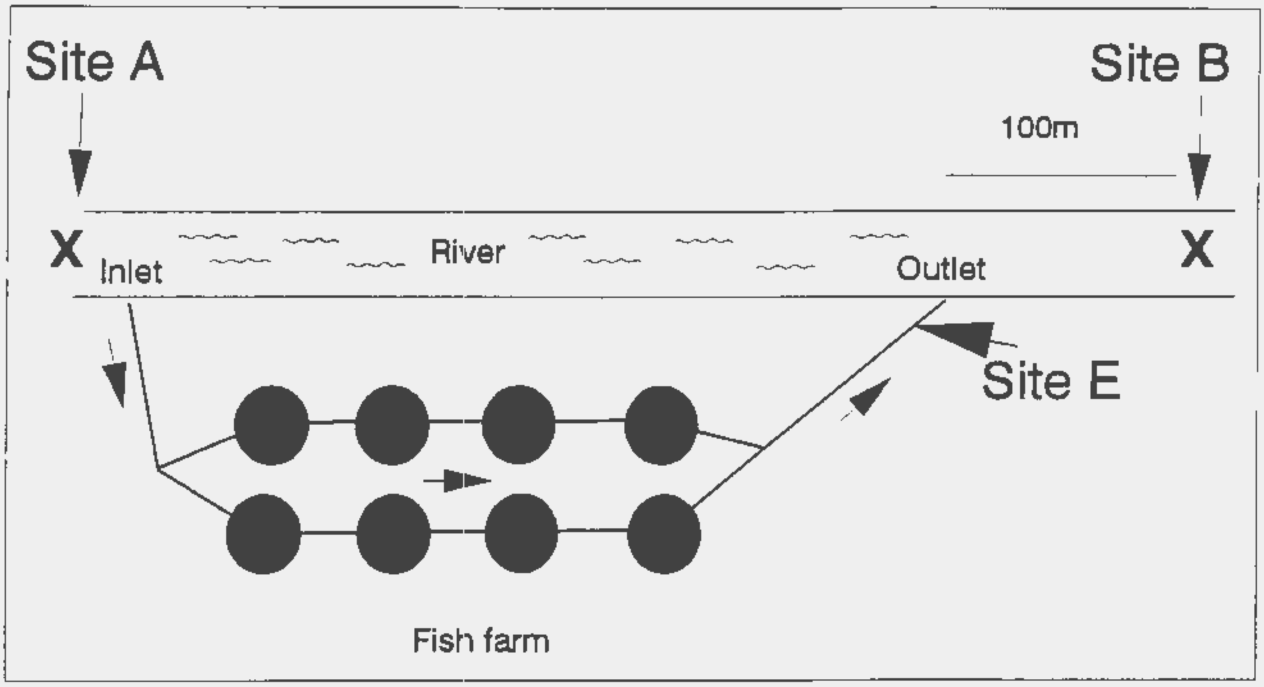
   i. Chemical variables were measured and water samples collected from the piped supply to the first section.
   ii. Chemical variables were measured and water samples collected from the effluent from the first section.
   iii. The full range of samples was collected and measurements (see 3.2.) taken in the uncanalised section upstream and downstream of the outlet of the second section of the farm and chemical variables were measured and water samples collected in the effluent.

   De Hoek Estates was excluded from the second survey and the final analysis because the effects of the canalisation of the river, among other things, made it impossible to assess, in isolation, the impact of the trout-farm effluent on the river ecosystem.

2. *Three Streams Trout Farm*

   The tanks at Three Streams Trout Farm were arranged in series along the banks of the Franschhoek River, near its source. It was not possible to sample the 'total' effluent since the water from each tank was discharged directly into the river, part of which subsequently flowed into the next tank. In only one instance did the water drawn from the river flow through two tanks before being returned to the river. The effluent from the last tank in the series was chosen, since this was as close as possible to the 'total' effluent. Two further complications were (1) that a second stream joined the main river between the tanks, thus contributing to the dilution of the effluent and (2) that at least some of the effects on the river appeared to be a result of pollution from an adjacent stud farm but the extent of this impact on the river could not be quantified.

Figure 3. Sampling sites upstream, 100 metres downstream and in the effluent of a land-based trout farm.



2.3. Uniformity among the sampling sites

Water courses consist of several, well-defined biotopes such as riffles, runs, backwaters, emergent marginal vegetation, submerged vegetation, pools and several types of sediment. Each of these biotopes has a characteristic fauna and can be treated as a separate entity (Hynes 1970). Riffles are shallow, high velocity sections of stream indicated by broken water and the substratum is dominated by cobbles and boulders. Only riffles were investigated in this survey. There were several reasons for this, namely:

- riffles offer the most oxygenated and turbulent conditions in the stream and therefore the best possible environment for recovery following the input of effluent
- when compared with the other biotopes, riffles are relatively easy to sample
- the fauna of riffles is generally rich both in number of species and in total biomass (Hynes 1970),
- riffle invertebrates respond quickly and clearly to pollution (Harrison & Elsworth 1958b), and
- most research on benthic macroinvertebrates in South Africa has concentrated on riffle faunal communities (e.g. Harrison & Elsworth 1958b; Chutter 1972; King 1981) and therefore more literature is available on the riffle communities than on those of the other biotopes.

To ensure as much uniformity as possible between the riffles sampled, substratum composition in each sample riffle was measured according to the percentage cover of sand (1-5 mm diameter particle size), gravel (5-50 mm), cobble (5-50 cm diameter), rock (>50 cm diameter) and bedrock ('sheets' of rock). Each of these, except bedrock, were divided into large, medium and small size classes (after Wright, Moss, Armitage & Furse 1984). A 0.25 m^2 metal grid, subdivided into 36 squares, was used for this process. Estimates of cover were made for each square and then summed to produce an estimate of percentage cover. Three replicate set of measurements were taken at each river site. No significant differences were recorded in percentage composition between the sites or between farms, indicating that the riffle areas chosen were fairly homogeneous with regard to rock size and substratum type.

SECTION 3. EFFECTS OF TROUT-FARM EFFLUENT ON WATER QUALITY AND HABITAT AVAILABILITY

3.1. Introduction

The first (winter) survey took place at the end of winter when the rivers were flowing strongly and water temperatures were low. Since the dilution capacity of a river is proportional to its discharge, the chemical and physical samples collected at that time probably reflect the best water quality likely to be found at any time of the year and the biological samples the best possible condition of the river ecosystem. The second (summer) survey took place at the end of summer when river discharge and hence dilution was low.

The choice of physical and chemical variables was based on the following:

- those determinands appearing in the Special Effluent Standards (Amendments to the Water Act 1984), and
- determinands known to contribute significantly to the impact of trout farms on riverine ecosystems elsewhere in the world (e.g. total suspended solids and total dissolved solids).

In addition, the water samples collected during the winter survey were analysed for a wide variety of trace metals, both acid-extractable and water soluble, to determine which metals, if any, occurred in any appreciable amounts in either the rivers or the effluents.

3.2. Changes in water quality induced by trout-farm effluents

The methods used to determine the physical and chemical variables are provided in Appendix 2 and the results are presented in Table 1. Differences in water quality between sites were investigated for seven trout farms using a paired-sample t-Test (Zar 1984). Where necessary the data were transformed using the following transformation: $X' = X + 0.375$ (Anscombe 1948; cited in Zar 1984) in order to obtain a normal distribution. The results of the paired-sample t-tests are presented in Table 1. The paired-sample T-test gives a good indication of the effect of a general trout-farm effluent because it combines each determinant from each of the farms into a set of paired (upstream/downstream) data.

Despite lower discharge during the summer the concentrations of chemical variables and dissolved and suspended solids in the effluent were not noticeably higher than those recorded in the winter. Part of the reason for this was that the farmers reduced their stock considerably during the summer with the result that differences between the chemical and physical results obtained during the winter survey and those obtained during the summer survey were negligible, in terms both of actual values and of trends. For this reason the results of both surveys are discussed together.

Ref
NO. 27.

Table 1. Physical and chemical variables recorded above, below and in the effluents of the seven trout farms visited during the winter and summer surveys. Major cations and anions were not sampled during the summer survey (n.a. = not available).

	Farm	Site	Season	Oxygen % sat riffles	Temp. °C	pH	Cond. µS/cm	NO_3^{2-}-N mg/l	NO_2^--N mg/l	PO_4^{3-}-P mg/l	NH_4^+ N mg/l	Cl^- mg/l	SO_4^{2-} mg/l	Mg^{2+} mg/l	Na^+ mg/l	Ca^{2+} mg/l	TDS mg/l	TSS mg/l
TF01	De Poort	Above	winter,	71 TF1	16.0	5.5	18.2	0.01	0.003	0.01	0.04	4.36	0.14	0.3	4	0	8.38	0.5
			summer	83	17.5	n.a.	17.5	0.01	0.003	0.01	0.04						0.00	0.4
		Effluent	winter	73	17.7	6.1	43.0	0.04	0.009	0.14	0.36	7.19	0.85	0.5	6	0.1	29.25	5.1
			summer	68	18.7	n.a.	33.3	0.33	0.008	0.09	0.34						12.75	4.8
TF02		Below	winter	94 2	16.0	5.9	22.9	0.04	0.003	0.02	0.14	4.99	0.48	0.3	5	0	8.25	1.6
			summer	100	17.3	n.a.	28.2	0.19	0.007	0.05	0.25						10.75	1.6
TF03	Devon	Above	winter	97 3	19.0	5.9	20.7	0.06	0.003	0.13	0.02	4.68	0.69	0.4	4	0.1	6.88	3.6
			summer	93	24.4	6.6	35.4	0.18	0.005	0.03	0.04						26.91	n.a.
		Effluent	winter	46	21.0	5.9	20.7	0.06	0.007	0.11	0.29	4.89	0.75	0.4	5	0.1	28.13	9.9
			summer	100	23.0	6.5	38.6	0.19	0.003	0.06	0.04						n/a	n.a.
TF04		Below	winter	98 4	19.3	4.9	19.5	0.06	0.005	0.03	0.09	4.85	0.67	0.3	5	0.1	15.50	6.1
			summer	77	25.5	6.6	39.1	0.17	0.005	0.04	0.14						30.27	n.a.
BRG25	Dewdale	Above	winter	95 5	15.3	6.5	34.3	0.07	0.003	0.01	0.07	8.90	1.63	1.0	6	0.1	36.75	3.1
			summer	n.a.	16.5	5.7	72.8	0.06	0.002	0.01	0.03						12.75	0.0
		Effluent	winter	91	17.0	6.2	33.0	0.09	0.005	0.03	0.28	10.5	1.58	0.7	6	0.1	22.50	5.2
			summer	n.a.	18.0	5.3	74.4	0.11	0.002	0.02	0.15						15.75	5.3
BRG03		Below	winter	91 6	17.0	6.4	33.8	0.07	0.008	0.01	0.13	8.88	1.68	1.0	6	0.1	21.00	3.9
			summer	n.a.	18.0	4.8	76.3	0.10	0.002	0.02	0.08						17.25	2.6
TF07	J'Hoek exp.	Above	winter	91 7	17.0	6.9	44.1	0.04	0.020	0.01	0.05	14.0	1.89	0.5	6	0	21.00	1.1
			summer	81	22.3	6.9	68.7	0.15	0.006	0.01	0.07						53.00	2.3
		Effluent	winter	73	17.0	6.4	47.3	0.03	0.010	0.10	0.31	14.0	2.96	1.1	7	0.1	28.88	3.5
			summer	76	21.9	6.2	64.9	0.16	0.009	0.04	0.31						50.28	3.3
TF08		Below	winter	94 8	19.0	7.2	52.5	0.03	0.006	0.02	0.09	n.a.	n.a.	1.0	8	0.1	18.13	1.3
			summer	81	23.2	6.4	68.2	0.10	0.007	0.02	0.03						27.5	3.9
	J'Hoek main	Above	winter	91 9	17.0	6.9	44.1	0.04	0.020	0.01	0.05	14.0	1.89	0.5	6	0	21.00	1.4
			summer	81	22.3	6.9	68.7	0.15	0.006	0.01	0.07						33.00	2.3
		Effluent	winter	82	16.0	5.6	62.4	0.14	0.020	0.04	0.21	16.6	1.69	0.9	9	0.1	41.50	4.8
			summer	87	21.1	6.6	80.3	0.18	0.010	0.01	0.08						45.25	11.4
TF09		Below	winter	88 10	18.5	5.7	37.3	0.10	0.010	0.01	0.08	14.7	1.90	1.0	9	0.1	36.75	2.4
			summer	76	20.9	6.6	68.9	0.12	0.010	0.05	0.14						33.00	2.7
TF10	3Streams	Above	winter	97 11	14.5	6.9	28.4	0.02	0.004	0.01	0.08	6.04	0.53	0.6	6	0.1	18.25	2.3
			summer	82	15.5	6.6	24.4	0.03	0.003	0.01	0.03						12.50	2.4
		Effluent	winter	82	15.5	6.5	31.3	0.08	0.009	0.06	0.26	5.99	0.61	0.6	6	0.1	24.75	5.1
			summer	69	16.0	6.5	43.5	0.35	0.350	0.25	0.41						16.50	4.7
TF11		Below	winter	91 12	16.1	6.5	45.3	0.10	0.010	0.07	0.22	6.63	0.64	0.4	8	0.1	27.75	2.7
			summer	69	16.9	6.3	46.2	0.45	0.450	0.27	0.39						21.00	4.8
TFV01	Visser	Above	winter	79 13	12.0	6.7	23.6	0.01	0.010	0.01	0.03	4.62	0.58	0.4	5	0	0.00	1.0
			summer	87	14.75	6.4	22.9	0.009	0.005	0.01	0.15						0.25	0
		Effluent	winter	58	12.5	6.9	40.0	0.06	0.005	0.10	0.21	5.48	0.74	0.5	5	0.1	14.88	11.6
			summer	70	16.0	6.5	332	0.09	0.007	0.14	0.35						7.75	2.5
TFV02		Below	winter	87 14	13.3	6.8	13.3	0.05	0.007	0.03	0.20	5.46	0.72	0.4	4	0	18.00	4.0
			summer	79	17.1	6.7	35.0	0.12	0.010	0.15	0.35						10.75	1.2
	Special Stds - max.	Value in $mg.l^{-1}$		At least 75% saturation	Max. 25°C	5.5-7.5	< 250 < 15%	1.50		1.00	1.00	Nil	0.05		<0.05 above inlet			10

Table 2. Results of the paired-sample tests performed on the data collected during the winter and summer surveys. Values greater than the critical P-value (2.447) indicate the differences between the determinands at the sites were statistically significant.

Variable		Upstream vs effluent	Signif	Upstream vs downstream	Signif
		$t_{0.05(2),7} = 2.447$		$t_{0.05(2),7} = 2.447$	
Oxygen	Winter	0.005 < P(\t\>=0.96) < 0.01	No	0.005 < P(\t\>=0.34) < 0.01	No
	Summer	0.005 < P(\t\>=0.58) < 0.01	No	0.005 < P(\t\>=0.35) < 0.01	No
Temperature	Winter	0.005 < P(\t\>=1.11) < 0.01	No	0.005 < P(\t\>=1.60) < 0.01	No
	Summer	0.005 < P(\t\>=0.72) < 0.01	No	0.005 < P(\t\>=0.57) < 0.01	No
Conductivity	Winter	0.005 < P(\t\>=6.18) < 0.01	Yes	0.005 < P(\t\>=0.07) < 0.01	No
	Summer	0.005 < P(\t\>=0.91) < 0.01	No	0.005 < P(\t\>=1.08) < 0.01	No
Total dissolved solids	Winter	0.005 < P(\t\>=0.87) < 0.01	No	0.005 < P(\t\>=0.35) < 0.01	No
	Summer	-		-	
Total suspended solids	Winter	0.005 < P(\t\>=15.36) < 0.01	Yes	0.005 < P(\t\>=2.98) < 0.01	Yes
	Summer	0.005 < P(\t\>=3.27) < 0.01	Yes	0.005 < P(\t\>=4.58) < 0.01	Yes
Nitrite	Winter	0.005 < P(\t\>=3.00) < 0.01	Yes	0.005 < P(\t\>=1.59) < 0.01	No
	Summer	0.005 < P(\t\>=0.39) < 0.01	No	0.005 < P(\t\>=1.38) < 0.01	No
Nitrate	Winter	0.005 < P(\t\>=5.65) < 0.01	Yes	0.005 < P(\t\>=1.36) < 0.01	No
	Summer	0.005 < P(\t\>=4.87) < 0.01	Yes	0.005 < P(\t\>=9.34) < 0.01	Yes
Phosphate	Winter	0.005 < P(\t\>=16.67) < 0.01	Yes	0.005 < P(\t\>=0.00) < 0.01	No
	Summer	0.005 < P(\t\>=6.60) < 0.01	Yes	0.005 < P(\t\>=9.36) < 0.01	Yes
Ammonia	Winter	0.005 < P(\t\>=19.25) < 0.01	Yes	0.005 < P(\t\>=17.00) < 0.01	Yes
	Summer	0.005 < P(\t\>=3.81) < 0.01	Yes	0.005 < P(\t\>=17.41) < 0.01	Yes

3.2.1. Oxygen

Oxygen saturation levels in the mountain stream and foothill zones of rivers are normally in excess of 80% (FRU unpublished data). The oxygen levels in the riffle sections of the river downstream of the effluent outlets were not significantly different from those above the farm. The levels of oxygen saturations in the slow-flowing areas downstream of the farms, however, were seldom above 40% (FRU unpublished data). Organic material, suspended in the effluent, tended to settle out in the slow-flowing sections below the outlet and, for the most part, did not affect the riffle areas sampled. Where settlement had occurred decomposition of the solids could have resulted in an increase in Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD), which might account for the reduction in available oxygen in the slow-flowing areas.

3.2.2. Temperature and pH

Natural differences in pH occur between different rivers in the same region. In some instances trout farmers deliberately raised the pH of the inlet water by adding lime (M. Kruger, De Hoek Estates, *pers. comm.*). This, however, did not have an appreciable effect on the pH in the effluent or in the downstream river. Temperatures did not differ significantly above, below or in the effluent of any of the farms.

3.2.3. Conductivity, total dissolved solids (TDS) and total suspended solids (TSS)

Conductivity was greater in the effluents and in the downstream river than in the upstream river (Figure 4). There were also statistically significant increases in TDS and TSS concentrations in both the effluent and the downstream river compared with the upstream control sites (Figure 5 & 6; Table 1). In all instances TSS was elevated in the downstream site and in most instances TSS concentrations in the effluent were more than double those upstream. In the case of J.B.Visser Hatchery, the TSS concentrations in the effluent were two orders of magnitude greater than those upstream (Table 1).

The solids suspended in the effluent appeared to consist mainly of uneaten fish food and faeces. Instead of settling out in sediment ponds or being removed by filtering, these solids remained in suspension in the effluent and settled out in the river immediately below the outlet (hence the reduction in suspended solids downstream compared with in the effluent), where they decomposed (see 3.2.1.).

It has been demonstrated that much of the nutrient input from trout-farm effluent into rivers is associated with the organic suspended solid fraction of the effluent (Clark, Harman & Forster 1985). In this survey, however, the nutrient content of the suspended and settled solids was not analysed.

When solids, suspended in the effluent, settle out on the river bottom they reduce the habitat available for the clean-bottom macroinvertebrate fauna normally found in the upper reaches of rivers. Settling solids fill up the interstices between the stones, depriving cryptic animals of their refuges (Hynes 1960). They also coat the stones and impair the attachment mechanisms and normal feeding activities of the stony-bed fauna (Wiederholm 1984). If there is a corresponding increase in nutrient concentrations this problem is compounded by algal growth (see 3.3.). While still in suspension, the material may reduce light penetration, clog the gills and feeding apparatus of riverine animals, and hamper their vision (Ractliffe 1991). In serious cases of pollution, the typical fauna disappears and is replaced by burrowing or tube-dwelling animals, such as worms and chironomid midge larvae, the numbers depending on the availability of food (Hynes 1960).

Figure 4. Changes in recorded conductivity above (upstream), below (100m downstream) and in the effluents of the seven farms sampled during the surveys.

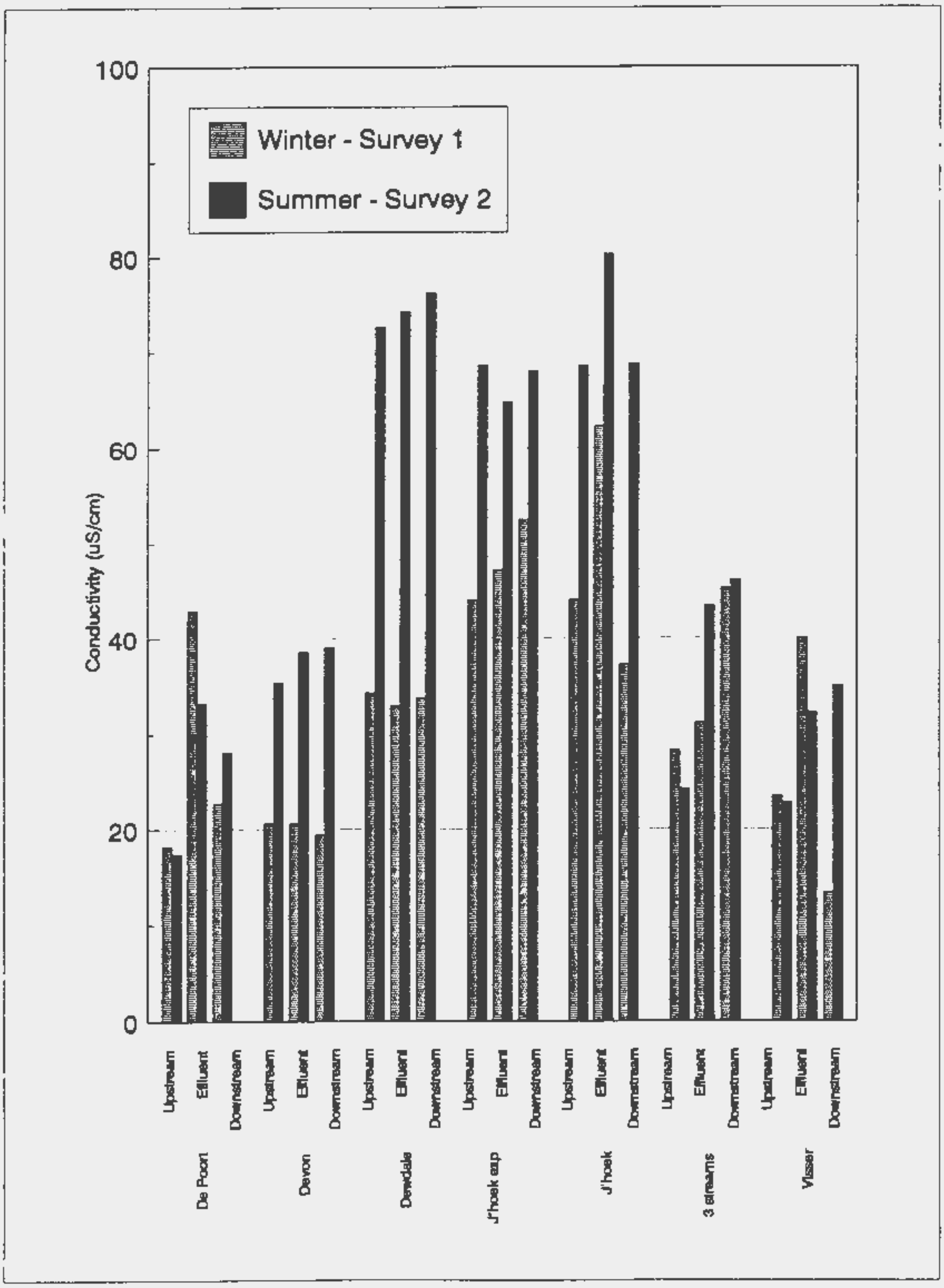


Figure 5. Changes in total dissolved solid concentrations (TDS) above (upstream), below (100 m downstream) and in the effluents of the seven farms sampled during the surveys.

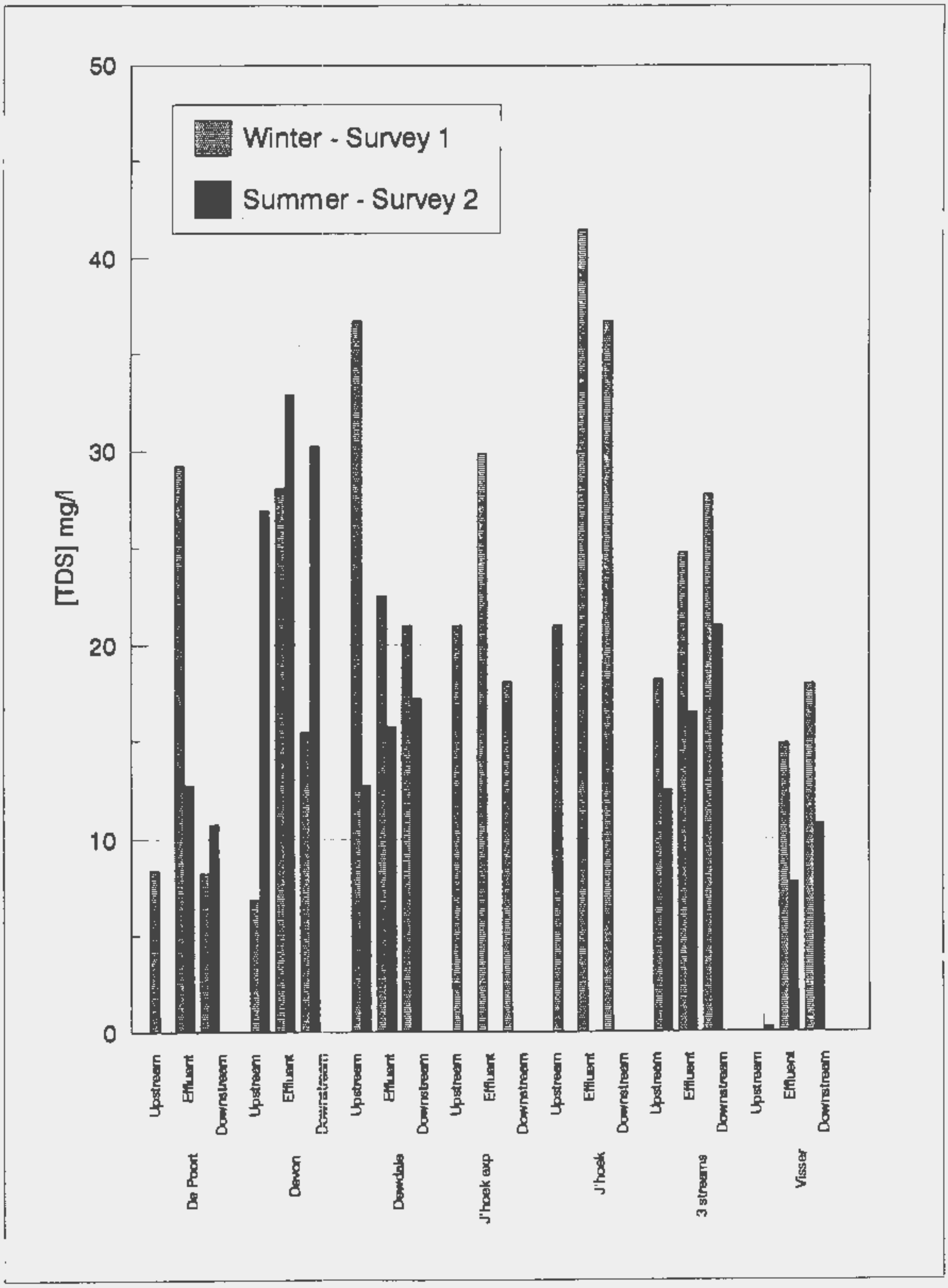
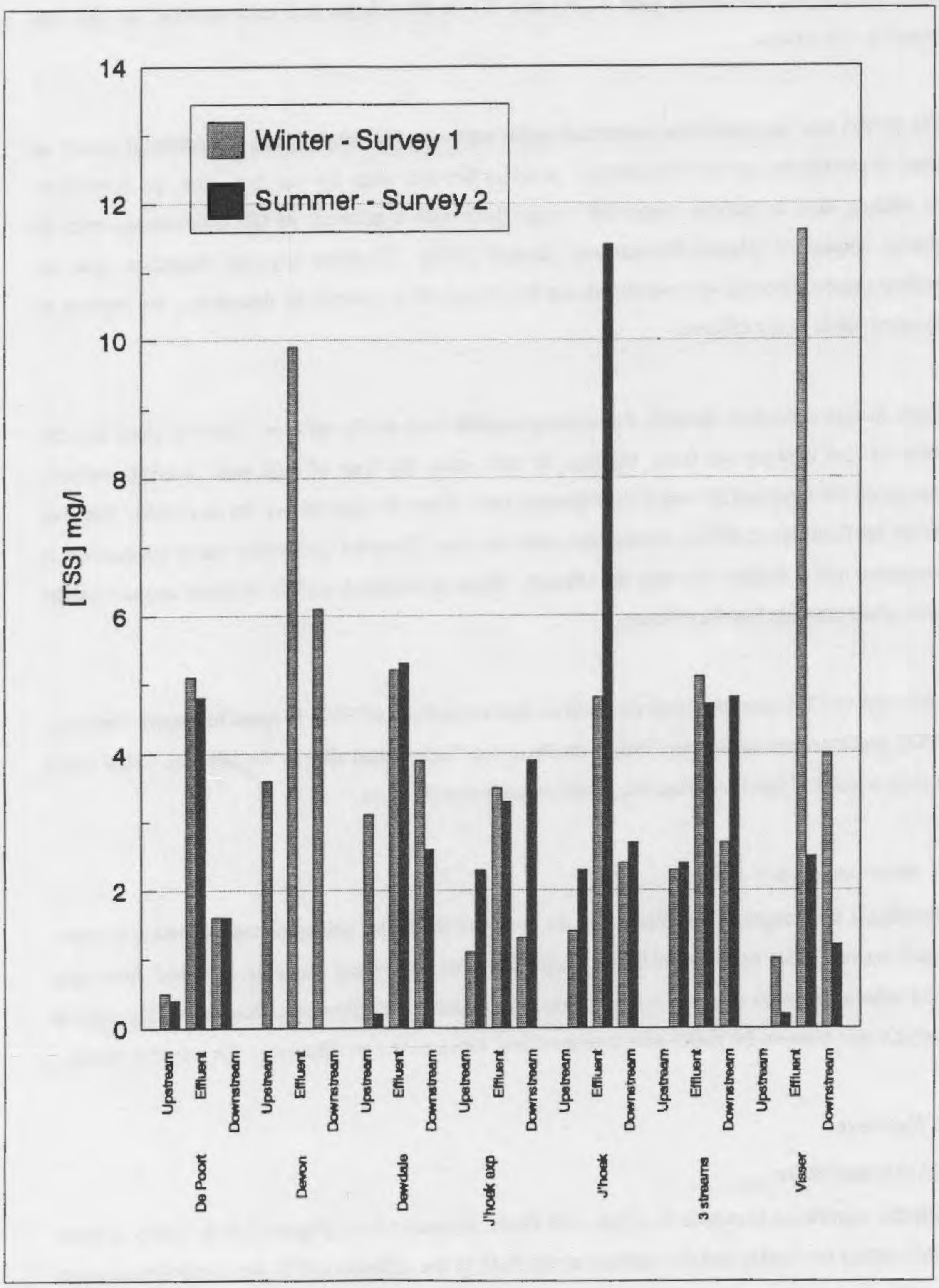


Figure 6. Changes in total suspended solid concentrations (TSS) above (upstream), below (100 m downstream) and in the effluents of the seven farms sampled during the surveys.



The areas of natural deposition in a fast-flowing river, often at the head of a riffle area or the downstream end of a pool, usually have a gravel substratum and are the natural spawning areas for salmonid fishes (Hunter 1991). Deposition of fish-farm wastes in these areas disturbs the spawning cycle of both trout and indigenous fish. It can smother fish eggs laid amongst cobbles and pebbles, reduce the oxygen availability (see 3.2.1.) and fill in deep holes and bury cobbles, in this way destroying fish habitat.

Solbe (1982) has suggested that suspended solids represent the most significant potential source of impact of trout farms on river ecosystems. A recent Scottish study showed that, after the installation of a settling tank to remove suspended solids, there was a recovery of the downstream river to upstream conditions (Nature Conservancy Council 1990). Evidence suggests, therefore, that the overall pollution potential of trout farms can be considerably lessened by decreasing the amount of suspended solids in the effluent.

Various factors contribute towards the suspended-solid load in the effluent. Among them are the number of fish kept on the farm, the type of tank used, the type of feed used, feeding methods employed on the farm and the water flow-through rate. Trout in captivity are fed on pellets. The fish will only eat food that is falling through the water column. Once the food settles out of suspension, it disintegrates and is flushed out with the effluent. Thus, economical feeding methods can reduce the amount of uneaten food in the effluent.

The increase in TDS concentrations were not as marked as those of TSS. In some instances, however, the TDS concentration in the river below the farm was higher than that in the effluent. This could have been a result of leaching from the solids settled below the farm.

3.2.4. Major anions and cations

No significant differences in the concentrations of any of the major anions or cations measured were recorded between sites or between farms (Table 1). The data were, however, obtained from spot samples which can miss once-off introductions of pollutants. Furthermore, because of the cost of analysing water samples for major anions and cations, these were not collected in the summer survey.

3.2.5. Nutrients

3.2.5.1. Nitrate/Nitrite

Statistically significant increases in nitrate and nitrite concentrations (Figure 7 & 8; Table 1) were recorded during the winter and the summer survey both in the effluents and in the rivers downstream of the effluent outlets.

Elevated nitrate levels are detrimental, particularly when phosphate levels are also high, since this leads to eutrophication (Ng, Sim, Ong, Kho, Tay & Goh 1990). Nitrite is the highly toxic ionised form of nitrous acid, a weak acid. Generally, however, low pH, coupled with low temperatures, such as found in south-western Cape rivers, favours the non-toxic form of the nitrate.

3.2.5.2. Ammonium

Ammonium concentrations were statistically significantly higher in the effluents and the downstream sites than in the upstream rivers (Table 1). The average ammonium concentration in the effluent was approximately eight times higher than in the upstream river during the winter and approximately five times higher during the summer (Figure 9).

The ammonium ion (NH_4^+) is non-toxic but exists in dynamic equilibrium with free ammonia (NH_3) which is highly toxic to aquatic life. The species depends on pH: NH_4^+ occurs exclusively at low pH (< 6; acid conditions) and NH_3 predominates at high pH (alkaline conditions). In natural waters in the south-western Cape the non-toxic ammonium ion predominates.

3.2.5.3. Phosphate

Concentrations of soluble phosphate in the effluents and in the downstream river were statistically significantly higher (Table 1) than those in the upstream river (Figure 10), in both winter and summer.

Phosphates are indicative of organic pollution, and their presence is nearly always associated with the presence of other, less desirable, pollutants (Kempster, Hattingh & van Vliet 1982). An increased concentration of phosphate enhances algal, bacterial and fungal growth, which in turn alters habitat availability in the river resulting in the loss of biotic species normally found there.

3.2.6. Trace metals

The results of the trace metal analyses (dissolved metals) are presented in Table 3. No trends were evident (in either dissolved metals or acid extractable metals), although, once again, the data were obtained from spot-sampling which can miss once-off introductions of pollutants.

3.3. Changes in epilithon growth induced by trout-farm effluents

The mixed growth of algae, fungi and micro-organisms on submerged rocks, together with any trapped inorganic particles, is commonly called epilithon. An increase in epilithon is indicative of an increase in productivity of a water body as a result of elevated nutrient (mainly phosphates and nitrates) levels.

Figure 7. Changes in nitrate concentrations above (upstream), below (100m downstream) and in the effluents of the trout farms visited during the surveys.

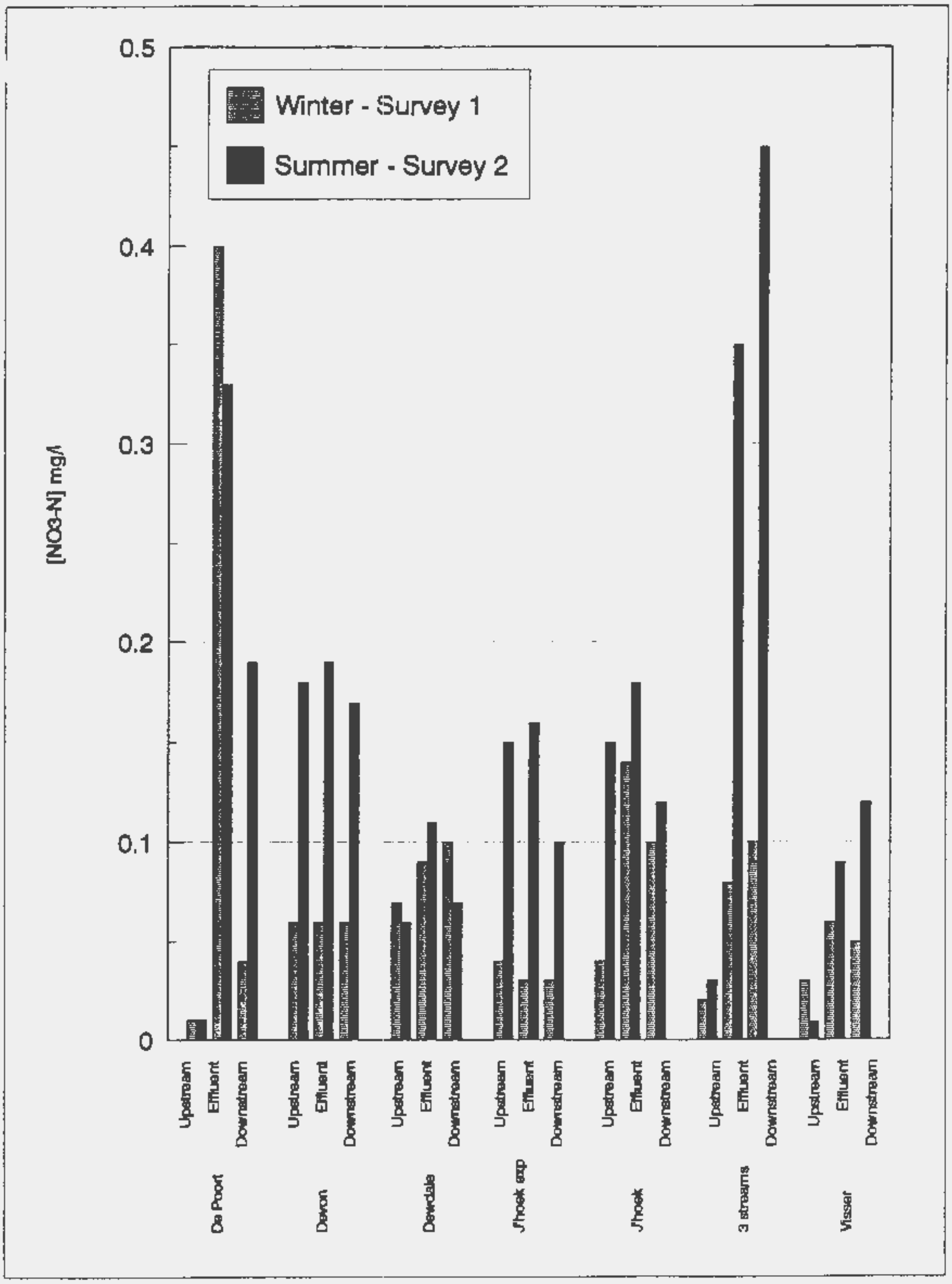


Figure 8. Changes in nitrite concentrations above (upstream), below (100m downstream) and in the effluents of the trout farms visited during the surveys.

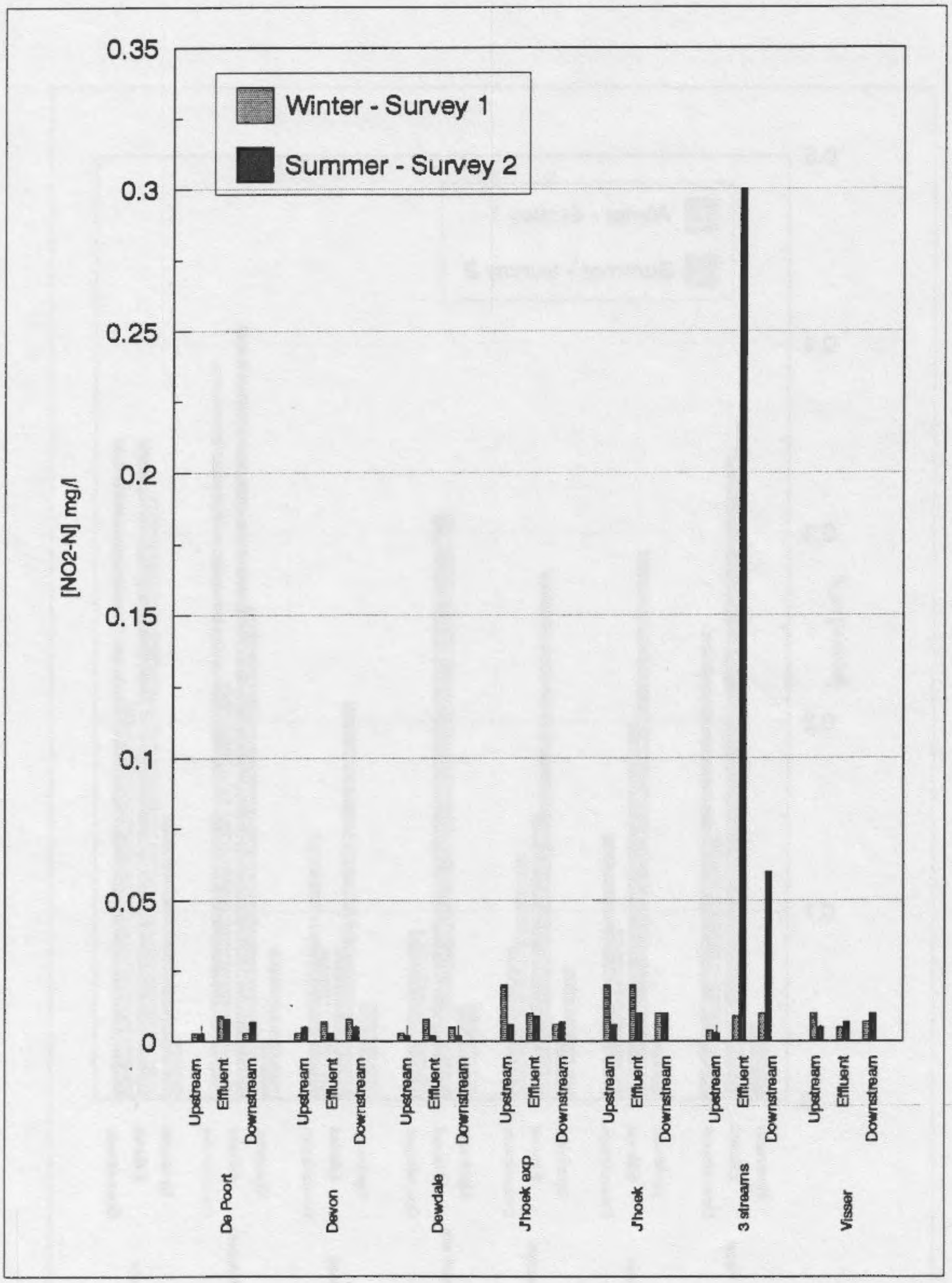


Figure 9. Changes in ammonium concentrations above (upstream), below (100m downstream) and in the effluents of the trout farms visited during the surveys.

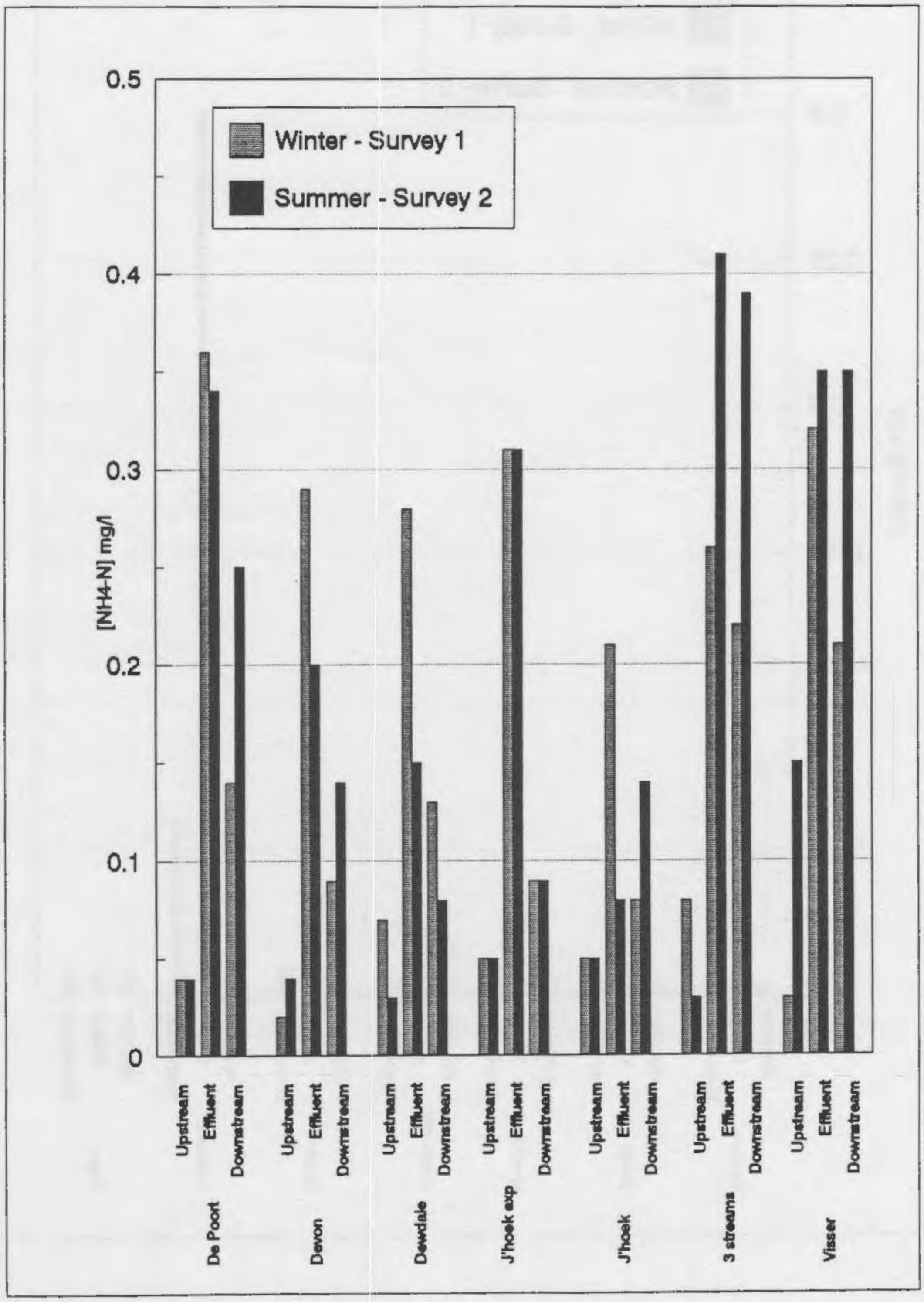


Figure 10. Changes in phosphate concentrations above (upstream), below (100m downstream) and in the effluents of the trout farms visited during the surveys.

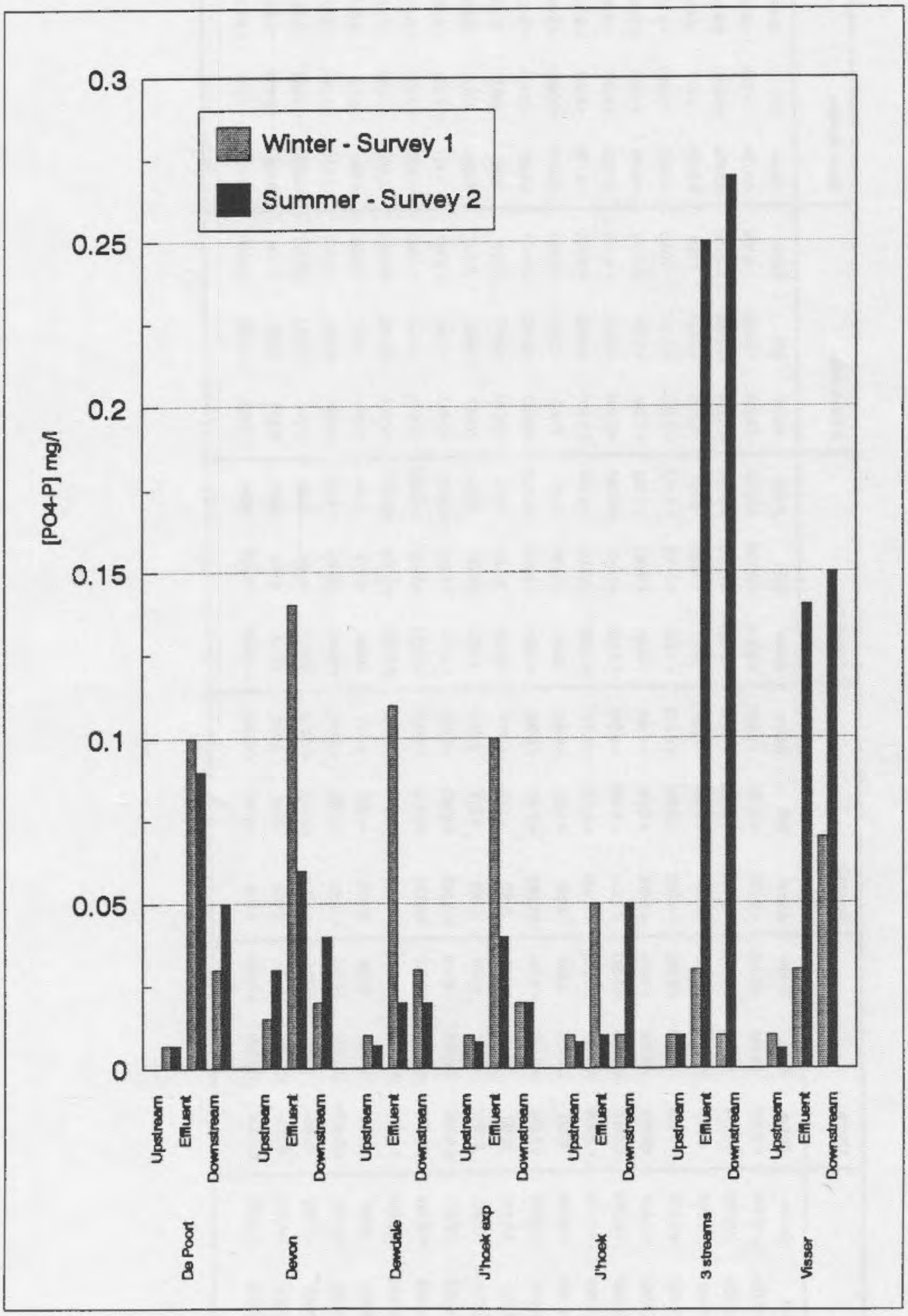


Table 3. Results of the trace chemical analyses (dissolved metals, mg.l^{-1}) of water samples collected during the winter survey, above (upstream), below (downstream) and in the effluents of the seven trout farms that formed part of the survey (analyses done by HRI, DWAF).

Trace metal	**De Poort**			**Devon**			**Dewdale**			**J'Hoek Exp.**			**J'Hoek main**			**Three Streams**			**J.B. Visser**		
	Above	Effl	Below	Above	Effl	Below	Above	Effl.	Below	Above	Effl.	Below	Above	Effl	Below	Above	Effl.	Below	Above	Effl.	Below
Aluminium	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
Aresenic	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100	< 0.100
Barium	< 0.004	0.009	< 0.004	0.010	< 0.004	0.004	0.004	< 0.004	0.004	0.008	< 0.004	0.007	0.008	< 0.004	0.006	< 0.004	0.017	0.005	< 0.004	0.006	0.009
Boron	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Beryllium	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Cadmium	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Cobalt	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020
Chromium	< 0.005	< 0.005	< 0.005	0.005	< 0.005	0.005	0.005	< 0.005	< 0.005	0.007	< 0.005	0.008	0.007	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Copper	< 0.005	0.009	< 0.005	< 0.030	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Iron	0.144	0.031	< 0.020	0.251	0.168	0.097	0.008	0.128	0.127	< 0.020	0.126	0.013	< 0.020	0.097	0.206	0.082	0.072	0.568	0.043	0.042	< 0.020
Manganese	0.003	0.001	0.002	0.006	0.002	0.004	0.003	0.013	0.016	0.002	0.003	0.004	0.002	0.005	0.002	0.006	0.004	0.019	0.005	0.001	< 0.001
Molybdenum	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Nickel	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020
Lead	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050
Strontium	0.009	0.013	0.012	0.010	0.008	0.018	0.015	0.002	0.010	0.006	0.010	0.006	0.006	0.007	0.010	0.004	0.013	0.013	0.006	0.001	0.006
Titanium	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Vanadium	< 0.002	0.003	< 0.002	0.006	0.006	0.005	< 0.002	< 0.002	< 0.002	0.006	0.006	0.006	0.006	< 0.002	< 0.002	< 0.002	< 0.002	0.004	< 0.002	< 0.002	< 0.002
Zinc	< 0.004	0.026	< 0.004	0.299	< 0.004	0.007	0.008	0.022	0.014	0.004	0.005	0.006	0.004	0.009	0.026	0.008	< 0.004	0.012	< 0.004	0.021	< 0.004
Zirconium	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	0.025	< 0.020	< 0.020	< 0.020	< 0.020	0.036	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020

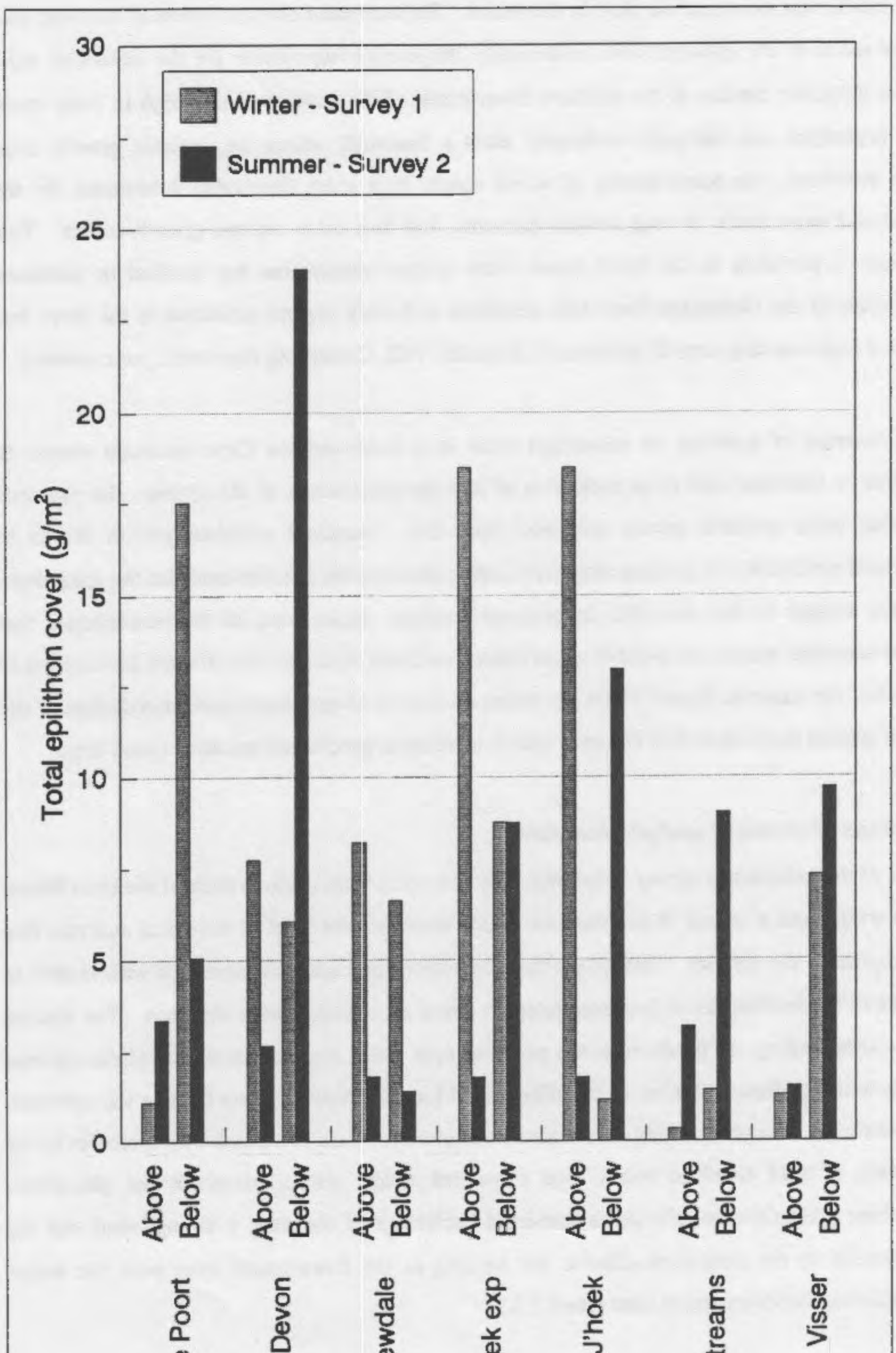
Despite high flow conditions before and during the winter sampling, a greater standing crop of epilithic algae and associated fungi and micro-organisms (organic fraction of the epilithon) occurred at sites downstream of all effluent outlets (Figure 11), except those on the Eerste River (Jonkershoek) where the upstream concentrations of epilithon were high. In the summer algal growth below the effluent outfalls was more marked than in the winter. *The increased concentrations of nutrients and suspended solids in the effluents were undoubtedly the factors responsible for the enhanced algal crop.* The inorganic content of the epilithon downstream of the farms was also high in most cases. Epilithic organisms and inorganic sediments show a 'snowball' effect, i.e. organic growth traps inorganic sediments, the accumulation of which results in a more favourable substratum for the organisms and more ability to trap nutrient particles, and thus more organic growth occurs. This phenomenon is prevalent in Du Toit's Kloof where bridge construction has resulted in increased sediment loads in the Molenaars River and, combined with mild organic pollution in the river, has resulted in a high standing crop of epilithon (G.Ractliffe, VKE Consulting Engineers: *pers. comm.*).

A visible covering of epilithon on submerged rocks in a south-western Cape mountain stream or foothill zone is abnormal and is an indication of nutrient enrichment of the system. Its presence suggests that some sensitive species may have been lost. Increased epilithon growth results in increased food availability for grazing and filter-feeding insect larvae but also modifies the substratum in a similar manner to that described for suspended solids. Since many of the invertebrates that inhabit the mountain stream and foothill zones depend on clean stones for the efficient functioning of their hold-fast mechanisms (Hynes 1960), the increased growth of epilithon results in a decline in the numbers of species characteristic of the zone and an increase in species not normally found there.

3.4. Synthesis of chemical and physical data

The nature of the preliminary survey meant that only two visits were made to each of the trout farms, one in the winter and a second in the summer, which restricted the level of statistical analyses that could be applied to the data set. This means that conclusions on causal relationships with respect to the changes in the benthic fauna presented later are based on circumstantial evidence. The limited data set notwithstanding, the results from the paired-sample T-test showed that several chemical were consistently and significantly higher in the effluent and the downstream rivers than in the upstream river. Downstream changes in benthic invertebrate communities were correlated with increases in the concentrations of total dissolved solids, total suspended solids, nitrate, ammonia and phosphate. Based on these preliminary results and a first-hand knowledge of the sites, it is suggested that the solids suspended in the trout-farm effluent and settling in the downstream river were the major pollutant effecting the downstream river (see 3.2.3.).

Figure 11. Changes in epilithon above (upstream) and below (100m downstream) of the farms visited during the winter and summer surveys.



3.5. Special Effluent Standards

In 1981 the Department of Water Affairs and Forestry (DWAF) adopted a Receiving Water Quality Objectives approach to managing water quality in South Africa (DWAF 1991). This approach involves specification of the desired quality of the receiving water environment and the control of sources of pollution. The Receiving Water Quality Objectives as applied by DWAF amounts to a policy that can be formulated thus:

> *"Effluent producers have to comply with minimum effluent standards, namely the uniform General and Special Effluent Standards (Amendments to the Water Act 1984). If satisfactorily motivated on technological and/or economic grounds and justified by the Receiving Water Quality Objectives approach, exemptions to the Standards may be granted by substituting site-specific effluent standards. This policy also makes provision for site-specific standards that may be stricter than the General and Special Effluent Standards"* (DWAF 1991).

Several of the trout farms in this survey were situated on so-called Special Standards rivers, viz. the Berg River, the Eerste River, the Elands River and the Molenaars River. Special Effluent Standards (Water Act 1956, Amendments to the Water Act 1984) are quality standards for waste water or effluent arising in the catchment area draining water to any designated Special Standard river. A summary of relevant water quality criteria and their required level of purification in terms of the Special Standards is provided in Table 1 and allows for comparison between the concentrations of the determinands in the trout-farm effluents and those stipulated by Special Effluent Standards. For most trout farms, the concentrations of the chemical variables in their effluents were much lower than stipulated by Special Effluent Standards. Yet despite this, the changes in downstream water quality, induced by trout-farm effluents, resulted in considerable changes in the downstream riverine ecosystems (see Section 4).

SECTION 4. EFFECTS OF TROUT-FARM EFFLUENTS ON THE AQUATIC INVERTEBRATE FAUNAS

4.1. Introduction

4.1.1. Levels of information obtainable from the aquatic biota

Plants and animals are taxonomically identified according to an hierarchical system of classification. This allows for a progressively detailed identification of an individual plant or animal through the levels of phylum, class, order, family, subfamily, tribe, genus and, finally, species. At the finest level of identification the name of any organism consists of a generic and a specific name. For example, the common mayfly (*Baetis harrisoni*), is a member of the genus *Baetis* and the species *harrisoni*. Identification of benthic macroinvertebrates to the species level, although often desirable because this is the level at which ecosystem changes are best detected, is, however, extremely difficult, time-consuming and, at times, unnecessary.

In the case of the Chironomidae (midges), for instance, identifying the larvae to the level of tribe provided sufficient information for this investigation because of the clarity of the distribution at the tribe level, i.e. members of each tribe are found in different kinds of conditions. Within the Chironominae, the tribe Chironomini as a whole appeared only below the effluent outlets, with very few or no individuals recorded above the farms. The Chironomini consisted almost entirely of *Polypedilum* spp. (A.D.Harrison, Chironomid taxonomist, *pers. comm.*) which increase in numbers in the presence of severe organic pollution in mountain streams (Berhe, Harrison & Hynes 1989). Likewise, the chironomid subfamily Tanypodinae was virtually eliminated at the downstream sites. Thus a clear picture emerged without the need for identification to a generic or specific level.

With other groups, however, comparing changes at the family/tribe level masked the picture. For example, more information could possibly be gained by identifying the chironomid subfamily Orthocladiinae to species level, since no clear trends were evident at a higher level. Within-family differences in pollution tolerance were also clearly illustrated by the Baetidae (mayflies). Considerable numbers of baetids occurred at both the upstream and downstream sites. However, in the pristine rivers above J.B.Visser Hatchery and Three Streams Trout, the dominant baetid was *Acentrella capensis*, while downstream of the effluent outfalls, the more hardy (Harrison & Elsworth 1958b) *Baetis* spp. predominated. Thus pollution-induced changes in the composition of the Baetidae occurred at the generic level.

Some groups are more useful than others as tools for assessing the impact of trout-farm effluent on riverine faunas. In many instances a group's usefulness stems from the fact that it is reasonably well-known and well-studied. The Ephemeroptera (mayflies) are such a group: their taxonomy and distribution have received considerable attention from biologists in the past and, consequently, their responses to different conditions are fairly well documented.

Sometimes a group is useful because its members respond to pollution at a higher taxonomic level than other groups as, for example, the Chironomidae. This reduces the amount of time and effort required to identify the animals, thereby reducing the cost of monitoring and also allowing information to become available quickly.

Groups restricted to the mountain stream zone are generally considered to be sensitive to environmental fluxes and are therefore particularly useful in pollution studies. Such groups include the immature forms of some coleopterans (beetles), Ephemerellidae (spiny-crawler mayflies), some Leptophlebiidae (prongill mayflies) and some Trichoptera (caddis flies).

Plecopteran nymphs (stoneflies), despite being characteristic of the mountain stream zone, are an example of a group that may not be good indicators of organic pollution. These animals only occur in the upper reaches of rivers and are generally thought to be sensitive to any changes in their micro-environment. Past studies have suggested that Plecoptera are among the last group to recover from organic pollution (Wiederholm 1984). The preliminary results of this survey, however, suggest that their restricted distribution is not a result of an intolerance of high nutrient levels. Another recent study indicated they were also tolerant of increased turbidity (Ractliffe 1991) and it is possible that a sensitivity to high temperatures, rather than obvious pollutants, may dictate their distribution (Sprules 1947, cited in Hynes 1970).

Groups whose members are solitary (e.g. Megaloptera: dobsonflies) or have patchy distributions (e.g. Simuliidae: black flies) have limited value in monitoring programmes since a greater sampling effort is required to determine their true distributions and abundances.

4.1.2. Zonal siting of farms

The farms visited during the survey were situated on one of three different river zones, namely the source, the mountain stream or the foothill zone. Each zone has characteristic benthic faunal components. For example, the presence of amphipods is indicative of the source area. Generally, however, the differences in the species composition of macroinvertebrates between the zones are subtle. The sensitive macro-invertebrates in each of the zones are gradually replaced by more tolerant, wide-spread elements downstream.

The sensitive species are most affected by an impact on the river, often being completely eliminated by an impact that had little effect on the other species, some of which may even benefit by the absence of the eliminated species. Thus, after an initial elimination of sensitive, or stenoic, species, subsequent impacts may have little noticeable effect on the macroinvertebrate species composition until conditions deteriorate to the extent that another species is affected. To describe this phenomenon we have used the terms "*impacted mountain stream*" and "*impacted foothill zone*". These are zones in the river where the natural invertebrate communities have lost some of their sensitive species as a result of disturbance of one kind or another. This was determined by comparing the macroinvertebrate community structure in the upstream river with historic data on community structure (e.g. Harrison and Elsworth 1958a, King 1981).

Although benthic invertebrates are good indicators of pollution, they are by no means the only group affected. Benthic macroinvertebrates serve as a primary food source for many fish. The alteration of benthic community structure may lead to the reduction of those species that are the predominate food for fish. For example, a system may be numerically rich in oligochaetes but, since these animals live buried in the substratum, they are unavailable as food for the fish that would ordinarily live there. Hence, higher (vertebrate) predators may be eliminated from the system because of a lack of quality and quantity of prey rather than because of directly toxic effects (Sheehan 1984). The demise of the fish or crab population would, in turn, lead to a reduction in animals higher up the food chain, e.g. otters. Thus an elimination of organisms at the base of the food chain will eventually affect other organisms higher up the food chain.

4.1.3. Analysis of the faunal data

The level of statistical analysis that could be applied to the data set was limited by the once-off nature of the surveys. The type of data collected during the survey did not, however, preclude the use of multivariate analysis. Hierarchical clustering and multi-dimensional scaling (MDS) were therefore used to detect similarities and differences in community composition between all the sites and between the seasons sampled during the surveys. The details of the procedure performed are provided in Appendix 2.

Sensitive multivariate methods of the type used on this data set are only capable of detecting *differences* in the composition of collected samples. Multivariate methods alone do not indicate whether or not the change is deleterious (Clarke & Warwick 1990), although differences in species composition of the invertebrates can be correlated with measured levels of pollutants in the effluents in the rivers. When combined with a knowledge of the tolerances of benthic invertebrates, however, the combination of multivariate analysis of the benthic samples and statistically significant changes in measured chemical variables becomes a powerful technique for assessing the impact of pollutants on a system.

The results of the analysis are presented in two ways: a dendrogram (Figure 12) and an ordination plot (Figure 13). The results of the hierarchical clustering are represented by the dendrogram, with the x-axis representing the invertebrate community present at each of the river sites during each of the two surveys, as represented by the samples collected, and the y-axis defining the level of similarity of two or more sets of samples. The order in which the samples are presented on the x-axis is optional (within defined limits) in that each group can swing around on its common axis, and, in Figure 12, they have been ordered to facilitate the explanation of the relationships between them.

MDS creates a 'map' or ordination plot of the samples in a specified number of dimensions, in this case three, which attempts to satisfy all the conditions imposed by a ranked similarity matrix (Clark & Warwick 1990). The placing and the *relative* distance apart, on a two-dimensional plot (depicting only the x-axis and the y-axis, not the z-axis), of the samples gives an idea of the relationships between them, i.e. those closest are most similar (Figure 13). Although both of these techniques have shortcomings, when the same relationships between samples are clearly shown by both methods, then the patterns provide a good representation of the degree of similarity of invertebrate communities collected at different places and times. These results were combined with information on the specific tolerances to various water quality variables of the benthic invertebrate groups present in each sample to appraise the relative degree of impact at each site and season.

The relationships between the sites and seasons can be determined by referring to the Figures 12, 13 & 14.. For example, the sites upstream of the farms situated in the mountain stream zone in the Molenaars River catchment (De Poort A2, Vis A1, Vis A2) cluster together in Figure 12. These sites have similar aquatic communities and are less than 60% similar to any of the other sites. Their downstream sites also cluster together (DePoort B2, Vis B1, Vis B2), and with the downstream sites of Three Streams Trout Farm (3Stream B1 & 3Stream B2), indicating that their downstream communities were also alike but dissimilar to their upstream sites. Thus, the farms had similar effects on the rivers on which they were situated. Three Streams Trout Farm had the greatest effect on the river on which it was situated in that its downstream sites were only 40 % similar to the pristine upstream control sites, while De Poort and Visser's were 60% similar to their upstream sites. The remaining farms showed between 75% and 90% similarity between their upstream and downstream sites.

Figure 13 depicts the results of MDS in an ordination plot. In Figure 13, sites that clump together had benthic communities that were similar to one another and the distance by which sites are separated reflects the distance between them. For instance, the pristine mountain stream sites upstream of the farms, cluster together. One exception, DePoort A1, the river upstream of which had been bulldozed shortly before the winter samples were collected (A.Coetzer CNC pers. comm.). The sites downstream of the farms situated on mountain streams are far away in a separate cluster,

Figure 12. Dendrogram depicting the results of the hierarchical clustering, based on macroinvertebrate community structure of the river sites sampled during the surveys. A = above (upstream of the farm) site), B = below (downstream of the effluent outlet) site, 1 = winter survey and 2 = summer survey.

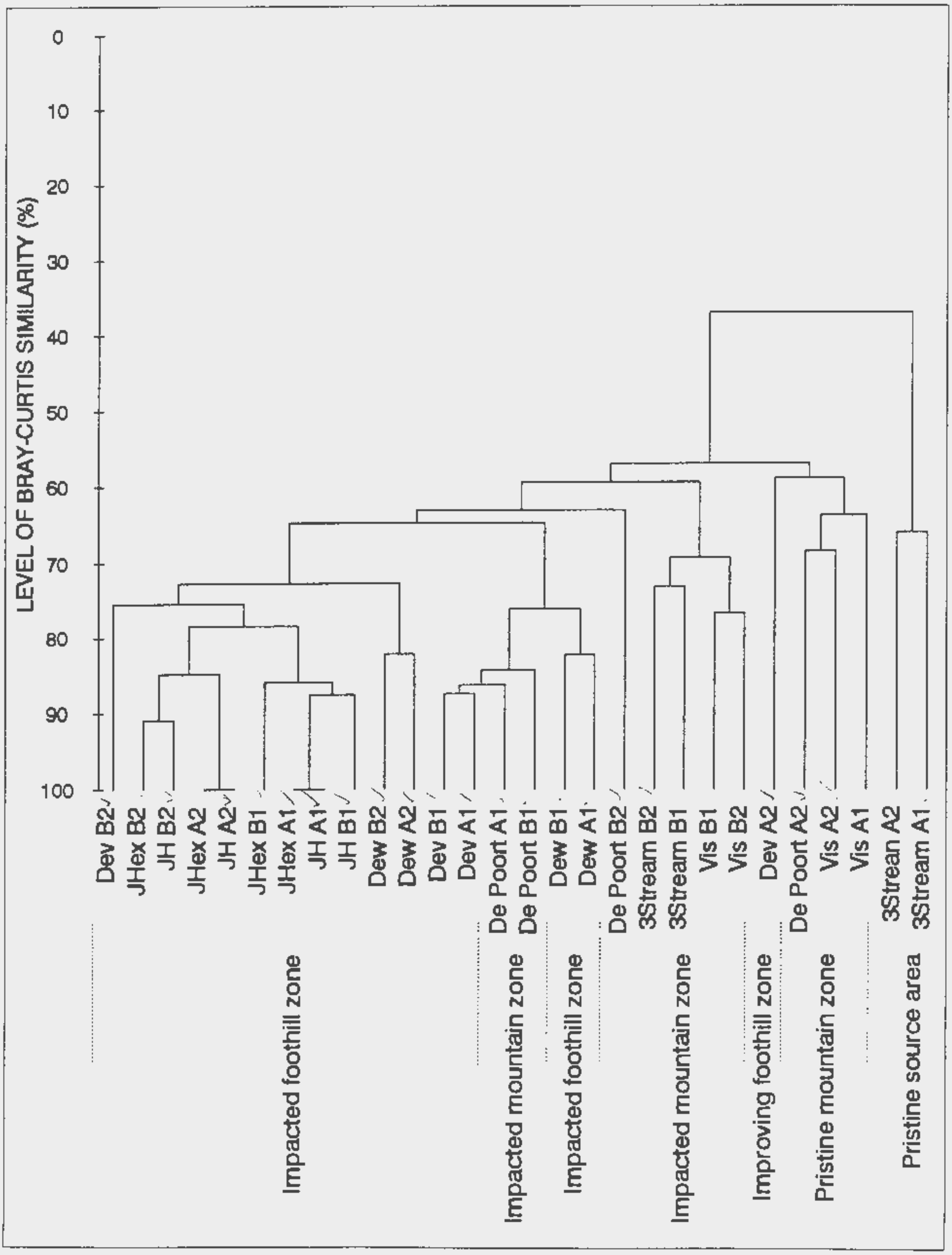
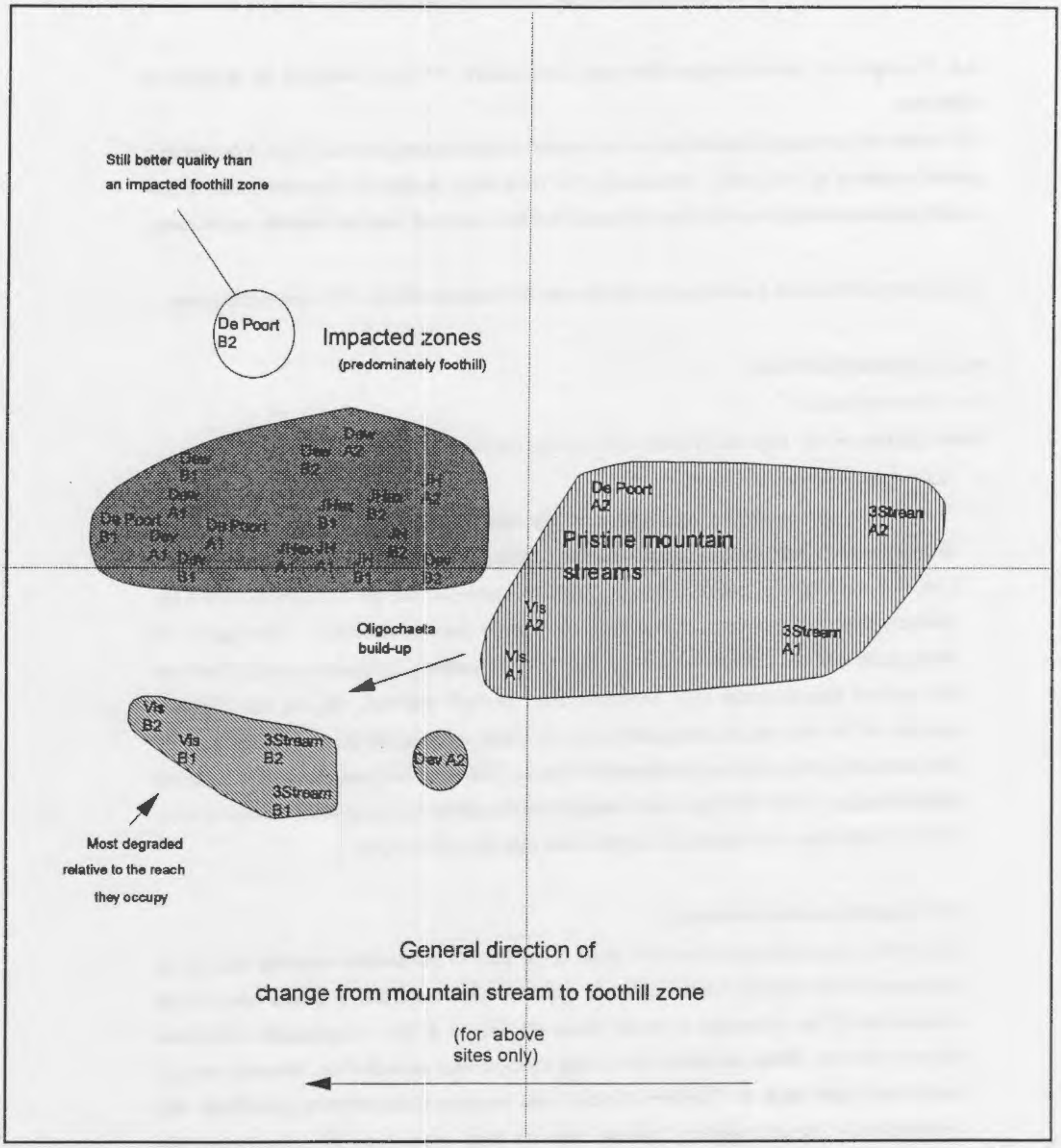


Figure 13. Ordination plot depicting the results of the multidimensional scaling of the differences in community structure between the sites sampled during the survey. A = above (upstream of the farm) site, B = below (downstream of the effluent outlet) site, 1 = winter survey and 2 = summer survey.



indicating the farms have a large impact on the community structure in the river. The sites upstream of the farms situated on foothill zone cluster to the left of the axis along which degradation is shown, indicating they are more degradated with respect to the pristine mountain streams. Sites downstream of these farms cluster close to their upstream control sites, indicating that the farms have less impact on their downstream rivers than do those farms situated on mountain streams.

4.2. Changes in species composition and community structure induced by trout-farm effluents

The results of the biological investigations are presented alphabetically for each farm, followed by a general summary of the trends. Additionally, for those farms located on impacted rivers, a site-specific explanation is given of the type of impacts that have occurred, and their possible implications.

Note. Refer to Tables 4 & 5 and Figure 14 for the data that accompanies the following explanations.

4.2.1. De Poort Trout Farm

Zone: Mountain stream

Status of upstream site: Impacted (winter) / Unimpacted (summer)

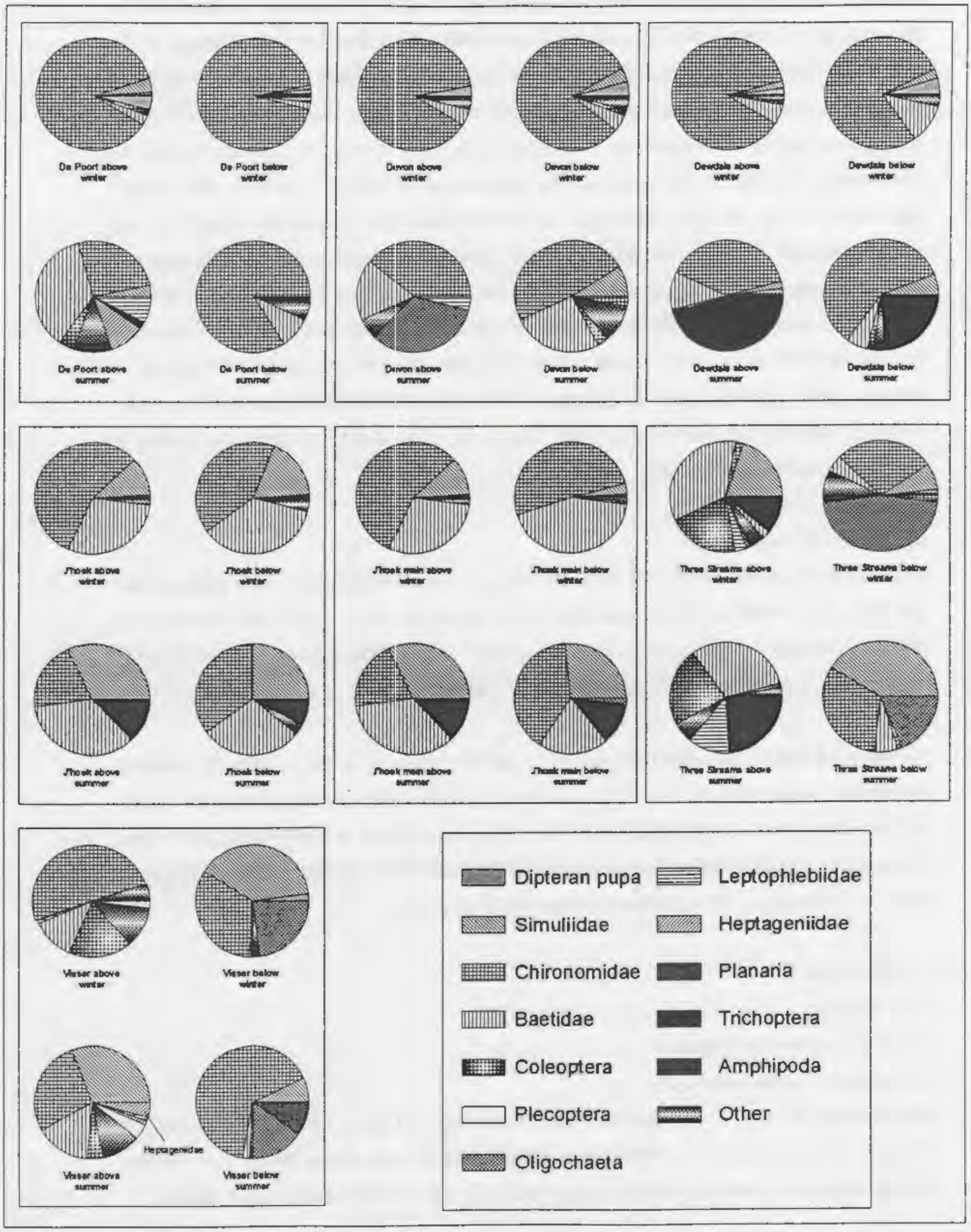
ii) Changes to winter community

The changes in the species composition of the benthic fauna between the upstream and downstream sites were minimal despite the loss of some groups (see below & Figure 14). This farm was situated on a mountain stream. Both the upstream and the downstream sites were, however, poor in abundance and diversity of aquatic macroinvertebrates. The paucity of representatives of the Coleoptera (beetles), Plecoptera (stoneflies), Trichoptera (caddis flies) and the sensitive Ephemeroptera (e.g. Leptophlebiidae: prongill mayflies) suggests that the river upstream of the farm was, or had recently been, disturbed, masking the impact of the farm itself. Some sensitive groups, such as the ephemerellid genus, *Ephemerellina*, and members of the beetle family Elmidae, present upstream, were missing from the samples collected at the downstream site (Table 4), indicating some additional impact on the river by the trout-farm.

(ii) Changes to summer community

The benthic community upstream of De Poort at the time of the summer sampling showed no indications of the impacts registered in the previous winter and had a species composition characteristic of an undisturbed mountain stream (Figures 12 & 13). Consequently, the direct effects of the farm effluent on benthic community structure were more obvious. Mountain-stream macroinvertebrates such as Coleoptera (beetles) and sensitive Ephemeroptera (specifically the Leptophlebiidae: prongill mayflies), present above the farm, were absent from the downstream sites. The trichopteran (caddis fly) family, Glossosomatidae, a common component of summer mountain-stream communities in the south-western Cape, was also absent below the effluent

Figure 14. Pie Diagrams showing the changes in benthic invertebrate communities between sites above (upstream of the farms) and below (downstream of the effluent outlets) sites of the trout farms visited during the survey.



outlet. Another trichopteran family, Hydropsychidae, which is indicative of mild organic pollution (Wiederholm 1984), increased in number below the outlet, however. The different responses of these two families can be attributed to differences in feeding habits. The Glossosomatidae have mouthparts that are specialised for scraping minute organic particles from rock surfaces, while the Hydropsychidae construct fine nets that strain particulate matter from the water (Pennak 1978). Hence the increase in hydropsychid larvae below the farm was probably a response to increased suspended material in the water column below the effluent outlet. Another component of the mountain-stream summer community, the Heptageniidae (*Afronurus* sp.) was less abundant at the downstream site than at the upstream site (abundances of 463m^{-2} upstream and 143m^{-2} downstream). Like the Glossosomatidae, the Heptageniidae feed on particles attached to rock surfaces (Pennak 1978), and the reduction of both these groups suggests that the farm adversely affected the animals utilising this food source. This could mean that, for some reason, the food source is not available below the farm or that an increase in another group resulted in the more specialised groups being out-competed. There were few changes among the other groups of animals. Among the Baetidae (mayflies) there was a slight decrease in the *Acentrella capensis* : *Baetis* sp. ratio but this was not significant. There was also a slight increase in the number of chironomid larvae below the farm.

(iii) Site specific explanation

Although no degradation of the upstream site was apparent at the time the winter samples were collected, later enquiries revealed that the reaches upstream of De Pooort had recently been bulldozed to create trout ponds (A.Coetzer, Cape Nature Conservation, *pers. comm.*), which would explain the lack of sensitive invertebrate species upstream of the farm.

An important feature was that there was not a marked increase in the numbers of naidid or lumbriculid worms below the farm either in winter or summer. This phenomenon occurred below both the other farms sampled during this survey that were situated in a mountain stream zone. The primary difference between the farms was that De Poort used earth dams while the other two farms used portapools. This is discussed in more detail in 4.3.1..

4.2.2. Devon Trout

Zone: Foothill

Status of upstream site: Impacted

(i) Changes to winter community

The changes between the upstream and downstream sites at Devon Trout appeared minimal. There were minor changes in community structure among the chironomid (midge) sub-families, with a reduction in the number of Tanypodinae and an increase in Chironominae (particularly

Chironomini), indicating organic pollution. No Plecoptera (stoneflies) were located at the downstream site and only a single individual was found in the upstream samples, which suggests that some upstream disturbance may have had an impact on the abundance of Plecoptera in this river reach.

(ii) Changes to summer community

The impact of Devon Trout on the fauna in the downstream river was greater in summer than in winter, although the community below the farm had more representatives of some of the sensitive species characteristic of the foothill zone than did that above the farm. There was, however, a large increase in the numbers of filter-feeders (Simuliidae) and detritivores (Naididae) below the effluent outlet. A possible explanation is given below.

(iii) Site specific explanation

At the time of these surveys the stretch of the Molenaars River on which Devon Trout was situated formed part of an extensive sampling programme to monitor the effects of bridge construction upstream of the farm. The results of this monitoring programme (Ractliffe 1992) and a knowledge of the topography of the area, provide an explanation for the finding described above.

The site upstream of Devon Trout was adjacent to where the Pos Stroom flowed into the Molenaars. Before its confluence with the Molenaars, Pos Stroom flowed through a compound of farm-labourers' cottages where it received a cetain amount of pollution (G.Ractliffe, VKE Consulting Engineers, *pers. comm.*). The result was that the site upstream of Devon Trout was impacted. In addition, between the upstream and downstream sampling sites, several pristine mountain streams flowed into the Molenaars River from the mountains on its western bank. Downstream drift from these streams of benthic invertebrate species associated with unpolluted waters could account for the increase in sensitive species below the farm.

Results from the sampling programme monitoring bridge construction showed that the overall health of this section of the Molenaars River improved from the start of the programme, August 1991, through to April 1993 (Ractliffe 1993), with an accompanying increase in the numbers of sensitive species present in the river. This improvement may account for the increased impact of Devon Trout in the summer samples collected in February 1992, compared with the winter samples collected in August 1991 (Figures 12 & 13).

4.2.3. Dewdale Trout Farm

Zone: Foothill

Status of upstream site: Impacted

(i) Changes to winter community

Species richness and abundance were generally low, both upstream and downstream of the farm. Apart from an increase in the abundance of dipteran (fly) larvae in the river downstream of the farm, there were few noticeable differences between the two sites.

(ii) Changes to summer community

Apart from an increase in the numbers of Trichoptera (caddisflies) upstream and downstream of the farm (i.e. relative to the point of impact), similar patterns existed in the summer as in the winter. Species richness and abundance were generally low both upstream and downstream of the farm and the effects of the farm on the benthic invertebrate community were muted by impacts upstream of the farm inlet (see site specific explanation). There were slight downstream increases in the numbers of chironomid (midge) larvae and hydracarinids (water mites) but these were insufficient for conclusions to be drawn. There was also a slight decrease in the numbers of the trichopteran family Hydropsychidae which is tolerant of organic pollution (see 4.2.1.ii.). The pollution-sensitive baetid, *Acentrella capensis*, which made up 29% of the Baetidae above the farm, was absent below the outlet.

(iii) Site specific explanation

The farm was situated on the Berg River, just below the Theewaterskloof Tunnel. In addition to abstracting water from the perennial Berg River, Dewdale received water from the Theewaterskloof Dam scheme via the tunnel, which it drew from the river channel approximately 500 metres from the point at which the tunnel empties into the river. Although the impact of the Theewaterskloof scheme on the Berg ecosystem is, as yet, poorly known, large numbers of planktonic Crustacea, characteristic of an impoundment, and Chaoborinae (ghost midges), which feed on the Crustacea, were present in both the upstream and downstream samples. The tunnel, therefore, obviously had an impact on the river. Furthermore, the river had been bulldozed at the inlet to Dewdale to facilitate flow into the inlet channel and during the summer the flow between the farm inlet and outlet was almost nonexistent (A.von Felewski, Franschhoek landowner, *pers comm.*). Since the upstream samples were collected slightly downstream of the inlet of the trout farm (high flow conditions prevented entry into the river at a higher point) it was not clear whether the low numbers and diversity recorded at the upstream site were a result of the tunnel, of bulldozing of the river bed at the inlet or of insufficient flow between inlet and outlet during the summer months.

4.2.4. Jonkershoek Experimental Farm

Zone: Foothill

Status of upstream site: Impacted

(i) Changes to winter community

Many sensitive groups such as the leptophlebiid genera *Choroterpes*, *Aprionyx* and *Adenophlebia* were absent from the upstream site, suggesting that the river above the farm was already disturbed (King 1982). Chironomid community structure at the downstream site differed from that upstream: there was a higher abundance of pollution-tolerant groups, specifically Chironomini (*Polypedilum* sp.) in the downstream samples than in the upstream ones. In addition, the predatory tanypodine chironomids were absent from the downstream site. The ephemerellid *Ephemerellina* sp. and a trichopteran (Philopotamidae), which are sensitive to pollution, were present at the upstream sites in low numbers but were absent from the downstream site. The leptophlebiid genus *Castanophlebia*, which is generally regarded as being more tolerant to organic pollution than some of the other species, was also absent from the downstream site. Plecopteran (*Aphanicerca* complex) and baetiid numbers were higher below the farm. The downstream increase in Baetidae was accompanied by a shift in species composition from a predominance of *Acentrella capensis* to a predominance of *Baetis* sp. The reasons for the slight increase in plecopteran numbers below the effluent outlet is not clear. Finally, there was a slight increase in the numbers of lumbriculid worms downstream of the effluent outlet.

(ii) Changes to summer community

Apart from slight changes in the number of chironomids and hydropsychids below the outlet there were no noteworthy differences in the composition of the benthic fauna above the inlet and below the farm effluent outlet. The fauna above the farm was, however, highly impacted and lacked virtually all the sensitive species characteristic of the summer foothill benthic fauna in the south-western Cape, e.g. *Afronurus harrisoni* (Heptageniidae), *Adenophlebia peringueyella* (Leptophlebiidae) and members of the Plecoptera and Coleoptera (King 1981).

(iii) Site specific explanation

The Jonkershoek Experimental Farm was situated on the Eerste River. Upstream of the farm there were a number of perturbations, including the inter-basin transfer scheme from the Theewaterskloof Dam, the Kleinplaas Dam (the site of trout-farming operations) and the Jonkershoek State Forest (logging activities). Since the last detailed survey of the Eerste River in 1975/76 (King 1981), one or a combination of these perturbations had resulted in the elimination of sensitive benthic invertebrate species, recorded during that survey, from the foothill section of this river.

4.2.5. Jonkershoek Hatchery

Zone: Foothill

Status of upstream site: Impacted

(i) Changes to winter community

The results were much the same as described for Jonkershoek Experimental Farm (see 4.2.4.), with the exception of a slight increase in naidid worms, *Nais* sp., below the effluent outlet.

(ii) Changes to summer community

Similar to those described for Jonkershoek Experimental Station (see 4.2.4.).

(iii) Site specific explanation

This farm was situated approximately 500 metres below the experimental farm discussed above and the same explanation of the impacts applies here. Added to this is the fact that the farm was not a commercial concern and generally had low stocking rates.

4.2.6. Three Streams Trout Farm

Zone: Mountain stream

Status of upstream site: Pristine

(i) Changes to winter community

The river immediately upstream of the inlet to Three Streams Trout Farm had a benthic faunal community characteristic of a pristine mountain stream as described by Harrison & Elsworth (1958b) and King (1982). The high numbers of Amphipoda are characteristic of source areas and are common in unpolluted, clear waters (Pennak 1978). Trichopteran (caddis fly), plecopteran (stonefly), and coleopteran (beetle) larva and the leptophlebiid and emphemerellid ephemeropterans were all present in the upstream samples. In contrast, all of these groups, with the exception of the plecopterans (*Aphanicerca* complex), were either absent, or considerably reduced in number, in the samples from the downstream site. Baetid numbers were also low in the downstream samples. Furthermore, there was a decrease in the absolute numbers of *Acentrella capenis* between the upstream and downstream sites. The upstream baetid population was composed of approximately 84% *A. capensis* and 16% *Baetis* spp., while the situation was reversed at the downstream site (*ca* 61% *Baetis* spp.; *ca* 38% *A. capensis*). The numbers of Planaria (flatworms) increased below the farm, as did the numbers of lumbriculid worms (*Lumbriculus* sp.: 0 worms.m^{-2} upstream to 1520 worms.m^{-2} below the effluent outlet) and naidid worms (*Nais* sp.: 180 worms.m^{-2} upstream to 11 260 worms.m^{-2} below the effluent outlet). These aquatic worms obtain their food by ingesting quantities of the substratum and digesting the organic component, in much the same way as do earthworms. They are normally common in the organically rich mud and debris on the bottom of stagnant pools and ponds, and occur in large numbers in the presence of organic pollution (Pennak 1978).

(ii) Changes to summer community

The situation in the summer was similar to that recorded in the winter. The benthic fauna collected upstream of the farm was characteristic of that of a pristine mountain stream and the effect of the farm effluent on this fauna appeared to be equally evident. Many species present above the farm were absent below the effluent outfall. These included amhipods and beetles, as well as the ephemeropteran families Leptophlebiidae and Heptageniidae. There was also a considerable decline in baetid numbers from $1960m^{-2}$ above to $447m^{-2}$ below. On closer examination, as in the winter, this reduction was at least partly the result of the elimination of *Acentrella capensis*. There was an accompanying increase in the number of Simuliidae ($216m^{-2}$ above; $2970m^{-2}$ below) and Chironomidae ($110m^{-2}$ above; $2863m^{-2}$ below). In the case of the chironomids the predatory sub-family Tanypodinae was completely eliminated below the farm. There was also an increase in the numbers of naidid worms ($30m^{-2}$ above; $1340m^{-2}$ below) but, in contrast to the situation if the winter, this was not accompanied by an increase in large Lumbriculiidae.

(iii) Site specific explanation

The river below the effluent outfall of Three Streams was heavily coated with settled organic matter which almost completely covered the stony river bed. How much of this pollution was attributable to the near-by stud farm was, however, not quantified. The influence of stud farm notwithstanding, the trout farm appeared to have a substantial effect on the river on which it was situated.

4.2.7. J.B.Visser Trout Hatchery

Zone: Mountain stream

Status of upstream site: Pristine

(i) Changes to winter community

The benthic invertebrates at the upstream site were indicative of an undisturbed mountain stream (King 1981). The absence of Amphipoda from the samples is consistent with the farm being situated some distance from the source. The faunal composition of the samples collected downstream of the effluent outlet differed considerably from those of the upstream site. There was an increase in simuliid (blackflies) larvae suggesting increased particulate material in the water column. The pollution-sensitive, predatory tanypodine chironomids were absent from the downstream site. In addition, the ratio of the two tribes comprising the Chironominae swung in favour of the Chironomini *(Polypedilum* sp.), which benefit from organic pollution (Berhe *et al.* 1989). The second tribe, the Tanytarsini, which was present in moderate numbers in the river above the influence of the farm, was absent from the downstream samples. The numbers of Coleoptera, Plecoptera and Ephemeroptera (including Baetidae) were all considerably lower below the effluent outlet than above. These were replaced by a large population of naidid worms *(Nais* sp.: 1630 worms.m^{-2}) at the downstream site.

(ii) Changes to summer community

The situation above the farm was similar to that in the winter except for expected seasonal changes in the species composition. The changes in species composition as a result of the effluent from the farm were almost identical to those recorded at Three Streams Trout Farm and many species present above the farm were absent below the effluent outfall. These included all the representatives of the Coleoptera, Trichoptera and the Plecoptera (Plecoptera fill a niche similar to that occupied by the Amphipoda nearer the source), as well as the ephemeropteran families, Leptophlebiidae and Heptageniidae. There was a similar decline in baetid numbers, which was in part a result of the elimination of *Acentrella capensis*, and an accompanying increase in the number of Simuliidae and Chironomidae. Finally, as at Three Streams, there was an increase in the numbers of naidid worms (103 worms.m^{-2} upstream to 2340 worms.m^{-2} below the effluent outlet).

(iii) Site specific explanation

There were large deposits of grey organic matter below the outfall and for some distance downstream of the effluent outlet of Visser's Trout Hatchery. These were particularly evident in the slow-flowing areas, especially pools where no faunal samples were collected. It should be stressed that all the samples collected from this and other farms were collected in the fast-flowing riffle areas where comparatively little deposition occurred and yet the change in the composition of the benthic fauna was still marked. The change between upstream and downstream pools must have been even more marked.

4.3. Synthesis of faunal results

4.3.1. The significance of location and infrastructure of trout farms with respect to their impact on river ecosystems

The impacts of the trout-farm effluent on the rivers, judged purely on their impact on the invertebrate community structure, were to eliminate some of the sensitive species and, in the worst cases, to provide the ideal habitat for worms. Three main conclusions can be drawn from the data. The first is that the responses of the benthic communities in the foothill zone to the release of trout-farm effluent were less marked than were the responses of those in the mountain stream zone. This can be related to the condition of the river upstream of the inlets of the individual farms: the foothill zones were already impacted. Associated with this, it appears that farms that used earth-pools had less impact on the river than farms that housed their fish in plastic portapools (discussed in 4.2.1.). Finally, there was little difference between summer and winter impacts of most of the trout farms (see Figures 12 &

13), which may have been because lower stocking rates in the summer counteracted the low flows and high temperatures.

4.3.1.1. Location

Of the farms sampled during this preliminary survey, two farms were situated on pristine mountain streams, namely Three Streams Trout Farm (near the river source) and Visser's Trout Hatchery. The faunal community composition of the sites upstream of these two farms were most different from other sites sampled (Figure 12). The site upstream of Three Streams, in particular, had a species composition 60% different from all other sites because of its location near a stream source.

The aquatic invertebrate communities downstream of Visser's and Three Streams differed considerably in composition from their respective upstream (control) communities. Hence, the effluent from these farms had the effect of displacing the species normally found in a mountain stream in the region with species tolerant of organic pollution. The composition of the downstream communities also differed from those found at the other farms (Figure 12 & 13). The main reason for this was that the downstream samples from these two farms were dominated by oligochaetes (not normally found in large numbers in mountain streams), which inhabited deposits of organic material below the effluent outfalls. The appearance of such taxa in areas where they do not normally occur is recognised as a response by the fauna to organic pollution (Chutter 1972).

A third farm situated on a mountain stream, namely De Poort Trout, was also included in the investigation. This farm differed from the other two in that the samples collected above this farm in the winter had a species composition similar to that of an impacted foothill zone. Although no degradation of the upstream river was apparent at the time of winter sampling, later enquiries revealed that reaches upstream of the control site had been bulldozed shortly before the samples were collected. This had the effect of masking the impacts of the fish farm on the river biota. The benthic community upstream of De Poort at the time of the summer sampling, however, showed no indications of the impacts registered in the previous winter. The community had a species composition characteristic of a mountain stream and in the hierarchical clustering grouped with the upstream site from Visser's, which was situated in the same catchment (Figure 12). As a result, the farm appeared to have a far greater impact on the river in the summer months that it had in the winter (Figures 12 & 13). This was misleading, since the apparently small impact of the farm in the winter was a consequence of the sensitive species having already been eliminated upstream of the farm (see explanation in *Zonal siting of farms:* 4.1.).

The other farms sampled during the survey were situated on impacted foothill zones (an explanation of the impacts upstream of each of these farms was provided in 4.2.). The degradation of the rivers upstream of these farms meant that the sensitive benthic invertebrates normally found there had already been eliminated by some impact other than that of the trout farm. As a result each farm had very little additional effect on the community structure of the biota inhabiting the river into which it discharged it's effluent but did prevent recovery from the upstream impacts.

The information in this report indicates that farms situated on mountain-stream zones had a greater impact on benthic invertebrate community structure than did farms situated on foothill zones. Generally the impact of the farms on foothill zones appeared small. This was mostly because sensitive components of their benthic invertebrate fauna had already been eliminated by some upstream perturbation. The foothill zone, although its fauna is slightly more tolerant to organic pollution than is the fauna in the mountain-stream zone, is still naturally oligotrophic, with low buffering capacity and sensitive faunal species. In the absence of any upstream disturbance, these species would have been present in the river upstream of the trout farms. Had this been the case, the change in species composition after the addition of the effluent to the downstream river would undoubtedly have been far more marked.

4.3.1.2. Infrastructure

The sampling programme provided evidence to suggest that farms using plastic portapools to house their fish had a greater impact on the downstream river ecosystem than those using earth-pools. In explanation, of the three farms that were situated on mountain streams, two used plastic portapools (Three Streams and Visser's) and the third earth pools (De Poort). There was a substantial increase in the number of oligochaetes below both 'portapool' farms and yet, despite being situated in the same sensitive river zone, this did not occur below the farm that used earth pools. Oligochaetes derive most of their nutrition from bacteria and are found in stony streams when sufficient organic matter is introduced to maintain a thick bacterial slime on the substratum (Brinkhurst & Cook 1974). The oligochaetes below Three Streams and Visser's occurred in organic deposits not evident below the earth pool farms.

Of the farms situated on foothill zones, only one used portapools (Jonkershoek Experimental Farm) while all the others used earth pools. In contrast to the 'portapool' farms on mountain streams, there was no significant build-up of oligochaetes in the river below Jonkershoek Experimental Farm, although *Nais* sp. were found below ($0m^{-2}$ above; $63m^{-2}$ below). The effluent from that farm, however, was not discharged directly into the river but into an earth-lined canal that flowed for approximately 60m before entering the river. Organic deposits, as below the two mountain stream farms, occurred in this canal but not in the downstream sampling site, 100m downstream of the point where the canal flowed into the river. It thus appears that the canal was acting as a type of settlement facility.

Unlined earth ponds provide for a certain amount of settlement for solids and, thus, the solids in suspension in the effluent are often lower than for a corresponding weight of fish kept in portapools (Drummond 1990). The interchange of water in portapool systems is too fast to allow waste food and faeces to breakdown before being discharged into the river. Portapools, however, have some advantages over earth dams. For example, the rapid interchange of water reduces heat build-up in the summer. This reduction can prevent the type of stock losses experienced by Devon Trout in January 1993 (The *Argus* Newspaper January 6, 1993). There are also several other factors which ensure that greater settlement of solids occur in earthpool farms. One of these is that the ponds are gravity fed, each pond being filled by spill-over from the pond before it. Hence, the water that is finally discharged is surface water and the more laiden, deeper water remains in the pond. In a portapool system, on the other hand, the water is released from the bottom of the pools, where the water is richest in suspended solids.

The total number of farms sampled during the surveys was, however, small. The conclusions presented on the different impacts of portapool versus earthdam facilities are therefore only suggested and have not been conclusively proven.

In conclusion, while farms in the mountain stream zones appeared to have a greater impact on the river than do those in the foothill zones, this was probably because of the sensitive components of the benthic fauna had already been eliminated by upstream disturbances. It is likely that a fish farm situated on a *pristine* foothill zone would have as severe an effect on the benthic invertebrate fauna as a fish farm situated on a pristine mountain stream. There were, however, marked differences in the severity of impacts of farms using plastic portapools and those using earth pools, with portapool farms having a greater effect on the biota in the downstream river.

SECTION 5. CONCLUSIONS

Trout farming in South Africa, as in many other parts of the world, has experienced rapid growth and has attracted much attention from groups claiming that the industry is responsible for pollution of the rivers. Trout farmers, on the other hand, contend that they have less of an impact on rivers than have other types of agriculture. The importance of the impact of trout farms relative to other threats to rivers in the south-western Cape is not the subject of this investigation, which was designed specifically to assess the impacts of trout farms on rivers. Two clear conclusions can be reached as a result of this investigation: (1) the position of the trout farms, on the relatively undisturbed upper reaches of rivers in the south-western Cape, is at least partly the reason for the attention the industry receives and (2) the farms have a detrimental effect on the downstream river ecosystems, relative to their pristine situation.

Reaches downstream of effluent outlets of trout farms showed signs of organic enrichment and the loss, to a greater or lesser extent, of pollution-sensitive species. This was accompanied by the appearance of other pollution-tolerant and pollution-loving species and, for some farms, the complete dominance of the downstream community by a pollution-loving species, such as naid worms. Enrichment of the river by the trout farms almost certainly provided the food for the organisms, e.g. Oligochaeta (aquatic worms) and Simuliidae (blackfly larvae), that were abundant downstream of the effluent outlets.

Clearly, the magnitude of the impacts of the farms on the rivers on which they are situated differ. Three Streams Trout Farm, J.B.Visser Hatchery and De Poort Trout Farm (summer) had the greatest impacts on the downstream rivers, probably because they are situated in the mountain stream zone and because the reaches upstream of the farms were completely undisturbed. Farms situated lower down the rivers, in the foothill zone, had less impact, mostly because sensitive components of their benthic invertebrate fauna had already been eliminated by other upstream perturbations. Waters of the foothill zone are naturally similar to those of the mountain stream zone (oligotrophic, with low buffering capacity and sensitive faunal species) and, in the absence of any upstream disturbance, rare and sensitive species would have been present in the river upstream of the trout farms on that zone. Had this been the case, the impact of the farms on the foothill zone would have been much greater.

The preliminary results indicate that farms that use plastic portapool systems with a high flow-through rate have a more detrimental effect on their dowsntream rivers than do those that use earth ponds. Plastic pools, however, have advantages over earth ponds in that the high flow-through rates reduce the heat build-up which can lead to stock losses. This may prevent occasional 'shock' pollution loads associated with sudden stock loss entering the river.

SECTION 6. REDUCTION OF ENVIRONMENTAL IMPACTS AND CONSIDERATIONS FOR FUTURE MANAGEMENT PLANS

The results of this preliminary survey clearly show that effluents from land-based trout farms are having a deleterious effect on the upper reaches of rivers in the south-western Cape. There is little doubt that the rapid growth of the trout-farming industry in South Africa has outstripped existing legislation designed to protect the streams. For instance, the Water Act (1956) does not require that freshwater resources remain in a pristine state *except where this can be justified by the requirements of one of the recognised water users* (DWAF 1991). Department of Water Affairs and Forestry has recently recognised the environment as a water user (DWAF 1992), however, with the result that the requirements of the natural aquatic biota, in terms of both water quality and water quantity, will in future need to be taken into consideration to an extent never before attempted.

6.1. Reduction of environmental impacts

Data collected during the surveys showed a significant correlation between changes in benthic invertebrate community structure downstream of trout farms and increases in the concentrations of the following determinands in the trout-farm effluents:

- Total suspended solids
- Total dissolved solids
- Nitrate/Nitrite (NO_3^{2-}/NO_2^{-}-N)
- Ammonia (NH_4^{+}-N)
- Phosphate (PO_4^{3-}-P)

The preliminary results suggest that the solids suspended in trout-farm effluent were responsible for the major impact on the downstream ecosytems. These solids consist mainly of uneaten fish food and faeces. Various factors contribute towards the suspended-solid load in the effluent. Amoung them are the number of fish kept on the farm, the type of tanks used, the type of feed used, feeding methods employed on the farm and the water flow through rate. Trout in captivity are fed on pellets. The fish will only eat food that is floating or falling through the water column. Once the food settles out of suspension, it disintegrates and, in the absence of a settlement or filtering facility, is flushed into the river with the effluent.

Studies in other parts of the world have indicated that the reduction or removal of suspended solids in trout-farm effluent will result in a marked reduction in nutrient levels and the dissolved solid concentration in the effluents (Nature Conservancy Council of Scotland 1990). Stricter control of the amount of suspended solids in trout farm effluent thus seems a sensible starting point for reducing the impact of trout-farm effluents on the river ecosystems. Solids in suspension can be reduced by:

6.1.1. Improving the quality of fish food available in South Africa.

Recent experiences in Finland have shown that increases in production are possible without significant increases in nutrient loading, through the use of improved diets and management techniques (Nature Conservancy Council 1990). "Low-pollution" diets would considerably reduce the loads placed on rivers and, in addition, would benefit the farmers by improving feed conversion ratios. Overfeeding also contributes to the amount of pollution produced since it decreases digestibility and increases production of faeces.

There have been recent advances in low-pollution feed in South Africa and a new 'floating' pellet is currently being developed in the south-western Cape.

6.1.2. Sieving supplied fish food.

Pellets that crumble easily contribute dust and soluble material to the water, increasing the amount of waste in the effluent. One trout farm in the south-western Cape which sieves supplied pellets before feeding, extracts five tons of dust per annum (M.Coxhill, J.B.Visser Trout Hatchery, *pers. comm.*). This provides some idea of the amount of waste that may be entering rivers from farms that do not sieve supplied pellets.

6.1.3. Settlement treatment of effluents.

Solids suspended in trout-farm effluent can be reduced by using settlement ponds before the effluent enters the river (Clark, Harman & Forester 1985). The effectiveness of a settlement tank in removing solids in suspension is, however, dependent on both the velocity of the water flowing through the pond/tank and the surface area available for settling (Bromage, Henderson & Watret 1989). Removal efficiencies for settlement treatment range from 16 to 69% for suspended solids, from 8 to 80% for biological oxygen demand (BOD) and 47% for total phosphorus depending, among other things, on the retention time of the settlement pond (various authors cited in Nature Conservancy Council 1990). In order to maintain the efficiency of such settlement ponds, accumulated sludge must be removed at regular intervals to minimise resuspension of the settled solids and leaching of nutrients into the effluent water.

6.1.4. Filtration treatment of effluents.

Solids may also be removed by filtering or sieving the effluent. Although single, stationary filters tend to clog quickly, self-cleaning filters are employed elsewhere in the world (Nature Conservancy Council 1990). Depending on the model and screen size used, the removal efficiencies of one of these filters, Triangelfilter (TM), ranged from 40 to 90% for suspended solids, from 20 to 80% for total phosphorus, from 33 to 82% for BOD, from 27 to 40% for total nitrogen, 75% for COD, 26% for dissolved organic carbon and 55% for dissolved reactive phosphorous (various authors cited in Nature Conservancy Council 1990). The filters are, however, expensive and require considerable maintenance.

The majority of land-based trout farms in the south-western Cape have no form of waste-treatment system.

More information on the reduction of environmental impacts of trout-farm effluent through improved trout-farm design is summarised in Fish Farming and the Scottish Freshwater Environment (Nature Conservancy Council 1990).

6.2. Future considerations

The evidence at this early stage suggests that it is the suspended solids in trout-farm effluent that are most damaging to the downstream river ecosystem and that trout farms situated on undisturbed mountain streams have the greatest impact. Since there are several viable trout farms situated further downstream in the usually already disturbed foothill zone, the production of trout clearly is not dependent on water quality of the calibre found in pristine mountain streams.

It is suggested that the authorities controlling present and future permits for the operation of trout farms should consider the following points when developing management plans for guiding and controlling trout farms on rivers in the south-western Cape.

1. Should such developments be allowed on mountain streams?
2. Should developments on mountain streams have more stringent effluent controls than similar developments on foothill zones?
3. Should the fact that most foothill zones are already subject to other disturbances be sufficient reason for less stringent effluent controls than those implemented in undisturbed sections of rivers?
4. Should pressure be placed on fish-food manufactures to provide low-pollution, floating pellets?

8. ACKNOWLEDGEMENTS

This report was prepared under contract to the Department of Water Affairs and Forestry, and to Cape Nature Conservation.

We gratefully acknowledge the contribution of:

- Members of the project Steering Committee, Dr J.J.Barnard (DWAF), Mr J.van der Westhuizen (DWAF), Dr J.Lusher (DWAF), Mr G.M^{c}Conkey (DWAF), Ms S.Pithey (DWAF), Dr K.Hamman (CNC) and Mr A.Coetzer (CNC) for their comments and guidance.
- Mr D.Grobler and Mr G.Quibel of the Hydrological Research Institute (DWAF) for trace metal analyses.
- Mr M.Coxhill of the J.B.Visser Hatchery for information on the management of fish farms.
- Ms C.Coulson for laboratory assistance.
- C.Coulson, S.Eekhout, D.Gould, S.Harris, G.Ractliffe, C.Peckham, C.Smith and W.Steele for field assistance.

Finally, we thank Cape Nature Conservation, the Department of Water Affairs and Forestry, D.Brink, M.Kruger, G.Stubbs, B.Smal, J.Visser and G.Watson for their help and for allowing us access to the trout farms and rivers.

9. REFERENCES

AMENDMENTS TO THE WATER ACT. 1984. Special Effluent Standards. Section 15 of Act No.96. of 1984. Government Gazette.

ARMITAGE,P.D., FURSE,M.T. & WRIGHT,J.F. 1991. Environmental quality and biological assessment in British rivers - past and future perspectives. Journadas sobre la Gestion Integral de Ecosistemas Acuaticos. Direccion de Investigacion y Formacion Agropesqueras: Gobierno Vasco.

ARMITAGE,P.D., PARDO,I., FURSE,M.T. & WRIGHT,J.F. 1990. Assessment and prediction of biological quality. A demonstration of a British macroinvertebrate-based method in two Spanish rivers. Limnetica 6:147-156.

BERGHEIM,A., HUSTVEIT,H., KITTELSEN,A. & SELMER-OLSEN,A.R. 1984. Estimated pollution loadings from Norwegian fish farms. II. Investigations 1980-1981. Aquaculture, 36:157-168.

BERHE,T., HARRISON,A.D. & HYNES,H.B.N. 1989. The degradation of a stream crossing the city of Addis Ababa, Ethiopia. Tropical Freshwater Biology, 2:112-120.

BRAY,J.R. & CURTIS,J.T. 1957. An ordination of the upland forest communities of southern Wisconsin. Ecological Monographs 27:325-349.

BRINK,D. & BEKKER,H. 1991. 'n Verslag oor die potential van akwakultuur in die Winterreenstreek. Departement Landbou-ontwikkeling. Winterreenstreek, Elsenburg; 22pp.

BRINKHURST,R.O. & COOK,D.G. 1974. Aquatic earthworms (Annelida: Oligochaeta). In: Pollution ecology of freshwater invertebrates. Hart,C.W.Jr., Fuller,S.L.H. (Eds.). Academic Press, Inc. London.

BROMAGE,N., HENDERSON,J.P. & WATRET,R. 1989. How to design a settlement pond. Fish Farmer, 12(3).

BROWN,C. 1991. A preliminary review of Special Effluent Standards. Unpublished report to the Department of Water Affairs and the Chief Directorate of Nature and Environmental Conservation. 42pp.

CHANDLER,J.R. 1970. A biological approach to water quality management. Water Pollution Control. 69:415-421.

CHESTERS,R.K. 1980. Biological Monitoring Working Party. The 1978 national testing exercise. Department of the Environment, Water Data Unit, Technical Memorandum 19:1-37.

CHUTTER,F.M. 1972. An Empirical biotic index of the quality of water in South African streams and rivers. Water Research 6:19-30.

CLARK,E.R., HARMAN,J.P. & FORSTER,R.M. 1985. Production of metabolic waste products by intensively farmed rainbow trout, *Salmo gairdneri* Richardson. Journal of Fish Biology, 27:381-393.

CLARKE,K.R. & WARWICK,R.M. 1990. Statistical analysis and interpretation of marine community data. IOC Manuals and Guides No.22. Unpublished draft Sept (1990). Intergovernment Oceanographic Commission, GEEP. Plymouth Marine Laboratory, UK.

DAVIES,B.R., DAY,J.A. & KING,J.M. 1986. Riverine ecosystems. In. O'Keefe,J.H. Ed. The conservation of South African rivers. South African National Programmes Report. No. 131.

DEPARTMENT OF WATER AFFAIRS. 1985. 16th Edition of Standard Methods for the examination of water and wastewater.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY. 1991. Water quality management policies and strategies in the RSA. April 1991.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY. 1992. Water for managing the natural enviroument. Draft Policy. Report no. DF\\R-ENVIRO-POLICY-00192.

DRUMMOND,S. 1990. Trout farming handbook. Fishing News Books, Oxford.

HARRISON,A.D. & ELSWORTH,J.F. 1958a. Hydrobiological studies on the Great Berg River, Western Cape Province. Part 1. General description, chemical studies and main features of the flora and fauna. Trans. Roy. Soc. S.Afr. 25:125-226.

HARRISON,A.D. & ELSWORTH,J.F. 1958b. Hydrobiological studies on the Great Berg River, Western Cape Province. Part IV. The effect of organic pollution on the fauna of parts of the

Great Berg River system and of the Krom Stream, Stellenbosch. Trans. Roy. Soc. S.Afr. 25:125-226.

HART,R.C. & ALLANSON,B.R.(Eds). 1984. Limnological requirements for the management of water quality in the southern hemisphere. South African National Scientific Programmes Report No. 93. Council for Scientific and Industrial Research, Pretoria.

HAWKES,H.A. 1982. Biological surveillance of rivers. Water Pollution Control 1982: 329-342.

HELLAWELL,J.M. 1977. Biological surveillance and water quality monitoring. In: Biological Monitoring of Inland Fisheries. Alabaster,J.S. Ed. 69-88. Applied Science Publishers, London.

HUNTER,.J. 1991. Better trout habitat. A guide to stream restoration and management. Montana Land Reliance, Island Press, Washington D.C.

HYNES,H.B.N. 1960. The biology of polluted waters. Liverpool University Press, Liverpool.

HYNES,H.B.N. 1970. The ecology of running waters. Liverpool University Press, Liverpool.

INTERNATIONAL STANDARDS ORGANIZATION. 1980. Report No. 6107/1 - 1980 (E/F/R).

JONES,J.G. 1990. Pollution from fish farms. Journal of IWEM 4:14-18.

KEMPSTER,P.L., HATTINGH,W.A.J. & VAN VLIET,H.R. 1980. Summarized water quality criteria. Department of Water Affairs, Forestry and Environmental Conservation. Technical report 108.

KING,J.M. 1981. The distribution of invertebrate communities in a small South African river. Hydrobiologia 83:43-65.

KING,J.M. 1982. An ecological study of the macro-invertebrate fauna of the Eerste River, Western Cape Province, South Africa. Unpublished PhD Thesis, University of Cape Town.

KING,J., DAY,J. & BROWN,C. 1991. Proposal to investigate the effects of trout farms on riverine biotas. Unpublished Research Proposal. 10pp.

KREBS,C.J. 1985. Ecology: The experimental analysis of distribution and abundance. 3rd Ed. Harper, New York.

M^{C}CAFFERTY,W.P. 1990. A preliminary guide to the Ephemeroptera of southern Africa. In: Aquatic Entomology; M^{C}Cafferty,W.P., Jones & Barlett Publ.,Inc. Boston, U.S.A.

MACDONALD,R.J., SCOTT,W.E., HATTINGH,W.H., KEMPSTER,P.L., SARTORY,D.P., TOERIEN,D.F., VAN VLEIT,H.R. & VILJOEN,F.C. 1984. Pollutants. In: Hart,R.C. & Allanson,B.R. (Eds.). Limnological requirements for the anagement of water quality in the southern hemisphere. South African National Scientific Programmes Report No. 93. Council for Scientific and Industrial Research, Pretoria.

MOSS,D., FURSE,M.T., WRIGHT,J.F. & ARMITAGE,P.D. 1987. The prediction of the macroinvertebrate fauna of unpolluted running-water sites in Great Britain using environmental data. Freshwater Biology 17:41-52.

NATIONAL RIVERS AUTHORITY (England). 1991. Proposed scheme of charges in respect of discharges to controlled waters. Report. 19 pp.

NATURE CONSERVANCY COUNCIL (Scotland). 1990. Fish farming and the Scottish freshwater environment. NCC. Contract No. HF3-03-450.

NG,W.J., SIM,T.S., ONG,S.L., KHO,K. HO,L.M., TAY,S.H. & GOH,C.C. 1990. The effect of *Elodea densa* on aquaculture water quality. Aquaculture, 84:267-276.

NOBEL,R.G. & HEMENS,J. 1978. Inland water ecosystems in South Africa - A review of research needs. South African National Scientific Programmes Report No. 34.

PENNAK,R.W. 1978. Fresh-water invertebrates of the United States. Second Edition. John Wiley & Sons, New York.

RACTLIFFE,G. 1991. The effects of suspended sediments on the macroinvertebrate community structure of a river ecosystem. Unpublished Honours Project. Freshwater Research Unit, Department of Zoology, University of Cape Town.

RACTLIFFE,G. 1992. Du Toit's Kloof National Road Construction. Impacts of activities on Molenaars River. Unpublished report to Department of Transport. Report No. 2: February 1992.

RACTLIFFE,G. 1993. Du Toits Kloof Environmental Report. Unpublished Report to Hill Kaplan Scott Consulting Engineers.

RESH,V.H. & UNZICKER,J.D. 1975. Water quality monitoring and aquatic organisms: the importance of species identification. Journal of the Water Pollution Control Federation. 47:9-19.

SHEEHAN,P.J. 1984. Functional changes in the ecosystem. In: Sheehan,P.J., Miller,D.R., Butler,G.C. & Bourdeau,P. (Eds.). Effects of pollutants at the ecosystem level. SCOPE. John Wiley & Sons, Toronto.

SPRULES,W.M. 1947. An ecological investigation of stream insects in Algonquin Park, Ontario. Univ. Tortonto Stud. biol. ser. 56:1-81.

SOLBE,J.F.DE L.G. 1982. Fish-farm effluents - Cause for concern? Water. March 1982.

WIEDERHOLM,T. 1984. Responses of aquatic insects to environmental pollution. In: The Ecology of Aquatic Insects. V.Resh & D.M.Rosenberg. eds. Praeger Publishers, Conneticut.

WRIGHT,J.F., ARMITAGE,P.D., FURSE,M.T. & MOSS,D. 1988. A new approach to the biological surveillance of river qnality using macroinvertebrates. Verh. Internat. Verein. Limnol. 23:1548-1552.

WRIGHT,J.F., MOSS,P.D., ARMITAGE,P.D. & FURSE,M.T. 1984. A preliminary classification of running water sites in Great Britain based on macro-invertebrate species and the prediction of community type using environmental data. Freshwater Biology. 14:221-256.

ZAR,J.H. 1984. Biostatistical analysis (2nd Ed.) Prentice-Hall, Inc., New Jersey.

APPENDIX 1:
TROUT FARMS VISITED DURING THE SURVEY (alphabetical order)

De Hoek Estates - Tulbagh

Owner:	Mr F.Langenhoven
Contact person:	Mr Mike Kruger
Location:	Saron
Address:	P.O.Box Saron 6812
Telephone:	0236-400300 (Main farm) 0236-400333 (Mr Kruger)
Fax:	0236-400335
Water supply:	Water is supplied from a *ca* 5km long pipeline which takes water from the Uwe and 24 rivers. This supply is shared 50/50 with Saron. The division is just above the first set of tanks (4). The second set of tanks (10) take their water from the extensive canal system in the area.
Effluent destination:	1. The first set of tanks empties into a settlement dam and then into a canal system, which feeds Voelvlei Dam. 2. The second set of tanks empties directly into a short uncanalized stretch of the Uwe River (*ca* 200 m).
Tanks	
Arrangement:	The operation is divided into two parts: one of four tanks (round) and the other of ten tanks (long, see below). The tanks are arranged in parallel.
Number:	1. 4 2. 10
Type:	1. Round, concrete ponds (portapool size). In parallel. 2. Long, narrow tanks (ca 10m x 2m). In parallel.
Stocking rate:	Winter - 1. 35 kg m^{-3} h^{-1} per tank - 2. 35 kg m^{-3} h^{-1} per tank Summer - 1. 15-18 kg m^{-3} h^{-1} per tank - 2. 15-18 kg m^{-3} h^{-1} per tank

APPENDIX 1:
TROUT FARMS VISITED DURING THE SURVEY (cont.)

De Poort - Smalblaar

Owner: Mr B.Smal
Contact person: Mr J.J Smal
Location: Du Toit's Kloof
Address: De Poort
Rawsonville
6845
Telephone: 0231-91285

Water supply: Three springs on the property. Mr Smal also uses the Molenaars River to augment his water supply during the summer.
Effluent destination: Molenaars River

Tanks
Arrangement: Ponds are divided into two sections.
Near the main house 5 ponds in series are supplied by one spring.
Near the river, some distance from the main house, 10 ponds are linked in series with the first section but are also supplied by 2 additional springs.
There are no settlement tanks before the effluent enters the river.
Number: 10 in all (5 & 5)
Type: Earth ponds, *ca* 25x10m.
Stocking rate: *ca* 20 tons per annum (winter)

Devon Trout - Du Toits Kloof

Owner: Mr G.Watson
Contact person: Mr G.Watson
Location: Du Toit's Kloof
Address: P.O.Box 69
Paarl
7622
Telephone: 0231-91676

Water supply: Molenaars River
Effluent destination: Molenaars River

Tanks
Arrangement: Two sets in series near the Protea Hotel in Du Toit's Kloof. Also four portapools at Mr. Watson's home *ca* 2 km upstream. The area at his house utilizes the water from a small tributary of the Molenaars but empties directly into the Molenaars River. No settlement tank.
Number: 10
Type: Earth ponds (ca 50x10m).
Stocking rate: Unknown.

APPENDIX 1:
TROUT FARMS VISITED DURING THE SURVEY (cont.)

Dewdale Trout Farms - Berg River, Franschhoek

Owner: Mr G.Lubner
Contact person: Mr Dexter Leite (in Cape Town)
Location: Franschhoek
Address: P.O.Box 2215
Cape Town
8000
Telephone: 021-248040 (Dexter Leite)
02212-2044/5 (Brian Leite on the farm)
Water supply: Berg River
Effluent destination: Berg River

Tanks
Arrangement: Earth tanks arranged in parallel.
Type: Earth ponds.
Stocking rate: Capacity for 1000 tons per annum.

Jonkershoek - Stellenbosch

Including the experimental farm and the main hatchery (sampled separately).

Owner: Cape Nature Conservation (C.P.A.). Experimental farm leased to University of Stellenbosch.
Contact person: Dr. Danie Brink
Location: Jonkershoek Valley, Stellenbosch
Address: c/o Department of Genetics
University of Stellenbosch
Stellenbosch
7600
Telephone: 02231-774772
Fax: 02231-774336

Water supply: The experimental farm is supplied by the Eerste River and the 'main' farm by a small tributary of the Eerste (no name).
Effluent destination: Eerste River

Tanks
Arrangement: Exp: 10 earth ponds in parallel before entering the experimental farm proper. Within the experimental fram there are a further 40 portapools arranged in series of 20 each. There is no settlement tank and the effluent in discharged into a small channel which runs directly into the Eerste River.
'Main': Five large earth pools arranged in series. Effluent dsicharged into a small channel that runs into the Eerste River.
Number: 40 & 10 in experimental farm
5 in 'main' farm
Type: 15 earth, 40 portapools
Stocking rate: Portapools - Winter *ca* 60kg per pool/40 pools.
Summer *ca* 20kg per pool

Earth ponds -Only brood fish *ca* 300kg max.

APPENDIX 1:
TROUT FARMS VISITED DURING THE SURVEY (cont.)

Three Streams Trout Farm - Franschhoek

Owner: Mr D.Stubbs
Contact person: Mr G.Stubbs
Location: Franschhoek
Address: P.O.Box 233
Franschhoek
7690
Telephone: 02212-2692

Water supply: The three streams making up the source of the Franschhoek River.
Effluent destination: Franschhoek River.

Tanks
Arrangement: Pools are arranged in three sets along the banks of the river. A second stream joins the first just below the second set of pools. The groups are in series and the pools within each set in parallel. There are no settlement tanks.
Number: First set - 2 tanks
Second set - 4 tanks
Third set - 2 tanks
Type: Portapools
Stocking rate: *ca* 50000 tons in winter

Vissers Trout Hatchery - Elandspad

Owner: Mr J.B.Visser
Contact person: Mr Guy Masson
Location: Du Toit's Kloof
Address: P.O.Box 107
Paarl
7622
Telephone: 0231-91133/91275
Fax: 0231-91973

Water supply: Kraalstroom River (tributary of Elands River) and a small spring which flows through the hatchery/juvenille ponds to the side of the main farm.
Effluent destination: Kraalstroom - Elands - Molenaars.

Tanks
Arrangement: *ca* 16 tanks in one area and approximately 14 more scattered around the farm. There is a single settlement tank.
Number: *ca* 30
Type: Portapools ($20m^3$ & $30m^3$), 2 earth pools further downstream stocked with brown trout.
Stocking rate: Summer - *ca* 20 kg m^{-3} h^{-1}
Winter - *ca* 40 kg m^{-3} h^{-1}

APPENDIX 2: ANALYTICAL METHODS

1. Analysis of chemical and physical variables

Measurements of conductivity (Crison CDTM-523 Conductivity Meter, standardized to 25°C), pH (Crison 506 Portable pH Meter), dissolved oxygen (Yellow Springs Institute Portable Oxygen Meter, compensated for altitude and temperature) and temperature (mercury thermometer) were taken in the field. Probes were placed in the stream for a 30-minute equilibration period before the readings were taken.

Spot water samples, collected in the field, were filtered and cooled *in situ* to below 4°C and, on return to the laboratory, frozen for later analysis. Chemically cleaned (Contrad and acid) polyethylene bottles and vials were used for the collection of all water samples, with the exception of the ammonia samples, which were collected in acid-washed glass vials, and of trace metal samples, which were collected in plastic bottles supplied by the Hydrological Research Institute (HRI). All analyses were from single spot samples.

Total dissolved solids (TDS) and total suspended (TSS) solids

One litre of water was filtered through a pre-ashed, pre-weighed Watmann GF/F (0.45 µm pore-size) glass microfibre filter. A known quantity of the filtrate was placed in a pre-weighed beaker and evaporated. The beaker was then re-weighed to obtain TDS. The filter papers were dried at 60°C for 48 hours and weighed to determine TSS. They were then placed in a muffle furnace for four hours at 450°C and then re-weighed to determine the ratio of organic to inorganic suspended solids (OSS:ISS).

Major anions and cations

The major cations Na^+, K^+ and Ca^+, were analyzed in the Department of Chemical Engineering and the major anions SO_4^{2-} and Cl^-, in the Department of Geochemistry, University of Cape Town.

Nutrients

Soluble reactive phosphate (PO_4^{3-}-P), nitrite (NO_2^- -N) and nitrate (NO_3^- -N) and ammonium (NH_4^+-N) were analyzed using a Technicon Autoanalyser by EMATEK, CSIR, Stellenbosch.

Trace Metals

500ml water samples were collected in bottles provided by the Hydrological Research Institute (HRI, Department of Water Affairs and Forestry) in Pretoria and returned to them for analysis. The samples were analyzed for both dissolved trace metals and cold water acid extractable trace metal content (DWA 1985).

2. Epilithon

The layer of epilithon on rocks in riffles was sampled using a plastic area measurer, laid over a rock. The organic and associated inorganic materials were removed with a stiff-bristled brush, placed in a container with some river water and kept cool at about 4^{o}C. Three replicate samples were taken at each site. Immediately on return to the laboratory the samples were filtered through pre-ashed, pre-weighed Watmann GF/F (0.45 µm pore-size) glass microfibre filters. The filter papers were dried at 60^{o}C for 48 hours and weighed to determine the total amount of material removed from the cleaned rock surface. They were placed in a muffle furnace for four hours at 450^{o}C and re-weighed to determine the ratio of organic to inorganic material.

3. Aquatic benthic invertebrates

Sampling of the benthic (bottom-dwelling) macroinvertebrates was restricted to those inhabiting stony riffles. A square-framed sampler (King 1981) with a 0.1 m^2 sample area was used to collect the animals. The downstream (collecting) side of the box was fitted with a funnel of 80 µm mesh netting and a detachable collecting jar. The frame was placed on the bed of the river and all the moveable stones inside the frame were lifted and gently brushed to remove the animals. The substratum was then agitated to a depth of *ca* 10 cm to disturb buried animals, which were carried downstream by the current into the collecting jar. The samples were placed immediately in 5% formalin and were transferred to 70% alcohol within seven days of collection. Three replicate samples per survey were collected at each site and averaged for each site in each season.

Measurements of flow and depth were taken at each point where benthic fauna were collected using a "*Pygmy*" Flow Meter and a top-setting wading rod (Scientific Instruments Inc.).

The faunal samples were sorted under a Nikon dissecting microscope, and all animals were identified and counted. The following keys were used in the identification of the faunal: de Moor (in prep.); M^c^Cafferty (1990), Pennak (1978), Wilmot (in prep.). The abundance of individuals in each group is expressed as the number per square metre of river bed.

4. Statistical analysis of results

The relationship between sites, according to the chemical composition and species composition of aquatic invertebrate communities, was investigated using procedures compiled by M.R.Carr (Plymouth Marine Laboratory, United Kingdom), using the Bray-Curtis index of similarity (Bray & Curtis 1957) calculated as:

$$BCI = \frac{2w}{u + v}$$

where BCI = Bray-Curtis Similarity Index

u = the sum of all taxa present in sample A

v = the sum of all taxa present in sample B

w = the sum of the lesser values of the taxa common to both samples A and B.

Data on abundance of species and physical/chemical characteristics from each of the river sites were pooled and averaged, and log-log transformed before analysis. Results of the classification were summarized by group-average sorting, and depicted on dendrogram (Figure 12) and an ordination plot (Figure 13) for the species composition.

08.'91

Table 4. List of taxa and mean numbers (per metre square of river bed) of benthic macroinvertebrates upstream and downstream of each trout farm sampled during the winter survey. Pollution-sensitive groups are indicated by a thick double border and pollution-loving groups by a single thick border.

TF01 TF02 TF03 TF04 BRG25 BRG03 TF07 TF08 TF09 TF10 TF11 TFV01 TFV02

			De Poort		Devon		Dewdale		J'hoek exp.		J'hoek main		Three Streams		J.B. Visser	
			Above	Below	Above	Below	Above	Below	Above	Below	Above	Below	Above	Below	Above	Below
Diptera	Simuliidae		210	40	70	35	30	230	870	1470	870	290	2480	2060	420	278
	Ceratopogonidae		0	0	0	0	0	0	0	0	0	0	0	0	10	0
	Rhagionidae		10	0	0	10	0	0	0	0	0	0	0	30	20	0
	Chironomidae	Orthocladinae	4070	4130	4060	6130	1310	4710	3690	303	3690	2430	290	4790	3890	2380
		Tanypodinae	30	0	60	20	30	50	120	30	120	90	70	60	60	0
		Chironominae	0	0	0	10	0	70	10	90	10	70	0	1480	0	10
		Tanytarsini	10	20	40	120	40	1330	620	250	620	1500	0	470	20	0
		Chaoborinae	0	0	0	0	10	70	0	0	0	0	0	0	0	0
Ephemeroptera	Leptophlebiidae	Aprionyx sp.	0	0	0	0	0	0	0	0	0	0	20	0	0	0
		Choroterpes sp.	0	0	0	40	0	0	0	0	0	0	0	0	20	0
		Adenophlebia sp.	0	0	0	0	0	0	0	0	0	0	0	10	0	0
		Castanophlebia sp.	10	0	10	20	0	0	0	10	0	10	600	310	60	0
	Baetidae		230	10	240	420	150	380	2480	2030	2480	3520	6800	1360	1460	50
		Baetis sp.	-	-	-	-	-	-	-	-	-	-	16%	61%	56%	100%
		Acentrella capensis	-	-	-	-	-	-	-	-	-	-	84%	38%	43%	0%
	Ephemerellidae	Lestagella sp.	10	10	0	20	0	0	0	0	0	0	60	0	0	10
		Ephemerellina sp.	10	0	0	10	0	10	10	0	10	0	10	0	30	10
Plecoptera			10	0	10	0	0	0	0	10	0	1	240	220	180	10
Trichoptera			10	10	0	0	0	0	20	0	20	0	290	50	10	0
Coleoptera	All Adults		0	0	0	0	0	0	0	0	0	0	0	0	270	0
Coleop. larva	Helodidae		10	10	0	10	10	0	0	0	0	0	170	10	580	10
	Elimidae	Species a	20	0	0	10	0	0	0	10	0	1	980	60	150	0
		Species b	10	0	0	0	0	0	0	10	0	0	40	10	0	0
		Species c	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	DRYOPIDAE =	Species d	0	0	0	0	0	0	0	0	0	0	190	0	340	0
Megaloptera	Corydalidae		0	10	0	0	0	0	0	0	0	0	0	0	20	0
Planaria			0	0	0	0	0	0	0	0	0	0	60	270	20	30
Oligochaeta	Lumbriculidae		10	10	10	10	0	0	0	10	0	0	0	1520	10	10
	Naididae	Nais sp.	10	30	40	230	0	0	0	0	0	60	180	11260	0	1630
Amphipoda			0	0	0	10	0	0	0	0	0	0	1580	0	0	0

02.92

Table 5. List of taxa and mean numbers (per square metre of river bed) of benthic macroinvertebrates upstream and downstream of each trout farm visited during the summer survey. Pollution-sensitive groups are indicated by a thick double border and pollution-loving groups by a single thick border.

Order	Family	Subfamily, Tribe or Genus	De Poort		Devon		Dewdale		J'hoek exp.		J'hoek main		Three Streams		J.B. Vissers	
			Above	Below	Above	Below	Above	Below	Above	Below	Above	Below	Above	Below	Above	Below
Diptera	Simuliidae		193	187	37	1093	167	687	3310	1483	3310	2240	217	2790	2690	1007
	Ceratopogodnidae		0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Rhagionidae		47	13	227	93	3	17	0	7	0	3	0	3	0	3
	Chironomidae	Orthocladinae	1497	1173	3180	4203	2980	5703	1900	1840	1900	1840	17	1353	2390	9460
		Tanypodinae	163	160	2397	383	77	73	0	20	0	7	27	0	393	7
		Chironominae	53	0	403	43	67	213	0 ✓	10	0	0	0	740	450	17
		Tanytarsini	950	14055	2410	960	827	583	130	227	130	360	30	770	87	213
		Chaoborinae	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ephemeroptera	Leptophlebiidae		557	17	1087	447	0	0	0	3	0	0	830	10	83	3
	Baetidae	%	1447	1540	2770	2030	827	393	2440	1387	2440	1317	1447	1540	983	273
		Baetis sp.	42%	55%	100%	100%	32%	100%	100%	84%	100%	96%	45%	94%	54%	87%
		Acentrella capensis	58%	45%	0%	0%	68%	0%	0% ✓	16%	0%	4%	55%	6%	46%	13%
	Heptageniidae		463	143	0	0	3	13	0	0	0	3	36	0	440	3
Plecoptera			63	3	0	0	0	0	0	0	0	0	30	30	390	10
Trichoptera			147	183	90	303	4480	2660	1370	467	1370	607	30	13	93	0
Coleoptera	Adults		0	3	63	177	0	0	0	0	0	0	0	3	0	0
	Helodidae		540	20	20	40	0	0	0	3	0	3	383	0	70	3
	Elimidae	Species a	110	30	223	400	30	60	0	20	0	7	47	10	23	0
		Species b	0	0	0	0	0	0	0	0	0	0	707	33	117	0
		Species c	37	47	0	0	17	143	0	0	0	0	200	13	217	0
	DRYOPIDAE =	Species d	40	0	0	0	0	0	0	0	0	0	0	0	83	0
Megaloptera	Corydalidae		7	23	3	7	7	3	10	3	10	0	0	0	10	0
Planaria			0	0	0	0	0	0	0	0	0	0	0	13	20	1443
Oligochaeta	Lumbriculidae		7	0	0	0	0	7	0	0	0	3	0	3	10	0
	Naididae	Nais sp.	47	7	7757	107	0	0	0	63	0	7	30	1340	103	2350
Amphipoda			0	0	0	0	0	0	0 ✓	0	0	0	1293	10	0	0