RESEARCH ON THE RAPID BIOLOGICAL ASSESSMENT OF WATER QUALITY IMPACTS IN STREAMS AND RIVERS

by

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EXECUTIVE SUMMARY

Aims of the project

The contract between the CSIR and the WRC stated the aims of the proposed research to be as follows:

1. develop a method to assess the impact of changes in water quality due to effluent on invertebrate communities as key representatives of the living organisms of streams and rivers,
2. express the results of the application of the method in the form of a numerical index,
3. ensure that the index is reliable, rapidly measured and cost-wise competitive with other (chemical) methods for the assessment of changes in water quality,
4. make the method user-friendly through the minimization of the exposure of field workers to water borne diseases such as bilharzia,
5. provide the method in a user-friendly format appropriate to computer-based storage and retrieval of results.

Aim 5 was not addressed in the project, since by the time that this report came to be written two large organistations, the Institute for Water Quality Studies and Umgeni Water had set up their own data bases.

These aims and the execution of the project were strongly influenced by the objective of keeping the method as simple and fast as compatible with user requirements. While this is important in relation to time and staffing costs, it must be appreciated that the simpler and faster a method, the less reliable the results are likely to be. The formal definition of the appropriate balance between cost and reliability in this sort of situation would be difficult. A practical measure of the success of the method is whether or not it is taken up by potential users.

The project did not aim to establish statistical relationships between SASS scores and water quality parameters. The physical and chemical quality of water is defined by so many parameters that it is often impossible to determine which single parameter, or combination of parameters, causes the observed biological response. Moreover, close examination of the relationship between chemical and physical data on the one hand, and biological data on the other, is confounded by the representativeness of the data. Physical and chemical data are, strictly speaking, representative of conditions at the moment the water sample was withdrawn from, or the probe inserted into, the stream. The composition of a biological sample is an integration of the variation in physical and chemical conditions over a period of time. Extreme physical and chemical conditions govern the biology of the stream. Many types of water pollution are periodic, of brief duration and, if detected, tend to be discarded as "outliers" in the analysis of data.

The concept of water quality within the context of this report is that it should be defined in terms of the suitability of the chemical composition, pH, temperature, dissolved gasses (principally oxygen), turbidity and sediment load of the water for the sustained support of natural communities of aquatic invertebrates. It is recognised that the flow regime, particularly of intermittent streams and rivers, has a major impact on the composition of aquatic invertebrate communities. For this reason, intermittently flowing rivers were largely excluded from this study and most of the field studies were conducted in the dry season, when flows may decline, but vary little from day to day.

The conceptual background

World wide it has long been known that the composition of communities of aquatic organisms is responsive to the nature of the physical and chemical environment in which they live. Many attempts have been made to use this fact in detecting water pollution and managing water quality. Most of these attempts have been unsuccessful, mainly on account of the fact that they are unaffordable in terms of time and the highly skilled manpower required to apply the biological knowledge.

In England a simplified method of summarising the meaning of the composition of the aquatic invertebrate community has been developed. In this project the method has been modified, adapted to South African conditions and applied widely to confirm its applicability. It has been re-named SASS (South African Scoring System).

The principle that potential users of the system should be involved in its development to ensure transfer of the technology was applied by inviting such users to sit on the Project Steering Committee. In the event this proved to be almost embarrassingly successful, with users applying SASS while it was still being developed.

The SASS method

The field procedures of the SASS method mimic the BMWP method on which it is based. Collections of invertebrates are made from streams and rivers using a standardised net following defined methods. At the streamside water is placed in a photographic or other large tray and the collected invertebrates are tipped into the tray. The types of invertebrates found are recorded on a score sheet.

The score sheet consists of space to record when and where the sample was collected, instructions for collecting the sample and analysing it and a long list of invertebrate groups, mainly at the family level, and a number between 1 and 15 opposite each name. These numbers have been allocated to each family according to its perceived sensitivity to water quality change, the most tolerant families being scored 1 and the most sensitive 15. The families present at a sampling site are marked on the score: the SASS score which is the sum of the numbers against each taxon present, the number of taxa recorded and the Average Score Per Taxon (ASPT), which is the SASS score divided by the number of taxa. The less altered the water quality, the higher the SASS score and the ASPT. Severe pollution results in very low SASS scores.

The SASS score sheet was modified three times before the final version (called SASS4) was adopted. With a view to technology transfer and to the prevention of a situation arising in which many variations of the score sheet could be developed, users of SASS were invited to take part in meetings of a SASS Forum. During the two meetings of the Forum, scores allocated to taxa were evaluated and altered by consensus, resulting in SASS3 and SASS4. The Forum successfully achieved its objectives. Meetings of the Forum were supported by the Water Research Commission.

The SASS4 scores being selected on the basis of response to changes in water quality, it is hardly surprising that the recorded scores largely followed changes in water quality. However there are other factors which can play major roles in the scores recorded.

The first factor is the available habitats at sampling points. Aquatic invertebrates are specialised in their habitat requirements, so that some families are present only on stones in the current, others only on stones out of the current, others only in marginal vegetation and so forth. The absence of certain habitats can have a major impact on the SASS4 score measured, but has a much lesser impact on the ASPT for reasons explained in the report. Fortunately most of the really tolerant taxa are found in most habitats, so that where there is severe pollution and only the tolerant taxa remain, habitat availability is not a factor in the SASS4 score achieved.

The composition of the aquatic invertebrate community is always modified immediately downstream of dams and weirs. This is also often true downstream of bridges. These changes are very localised, but sampling points should not be sited near dams and weirs and downstream of bridges.

Another factor resulting in changes in the composition of the aquatic invertebrate community is the amount of silt and sand transported by the river. Where this results in the extensive deposition of fine particulate matter, it may be expected to alter SASS4 and ASPT values.

Results

SASS4 data was collected from highly polluted streams in Gauteng, from the Letaba River in Northern Province, from the Crocodile, Sabie and Olifants Rivers in Mpumalanga, from the coalfields, the Mgeni catchment and the Pinetown/ Durban area of Kwazulu-Natal, from the eastern Cape, from the southern Cape, from the Western Cape and from Lesotho. The results are presented in eight appendices addressing each of these areas.

Findings were that the well-known differences between the invertebrate faunas of the strongly acid streams of the southern and western Cape and those of the weakly acid (pH >6) to alkaline waters of the remainder of the country were confirmed by differences in SASS4 scores and ASPT in natural waters in the two regions.

Although SASS4 scores and ASPT often decline in a downstream direction, this was not found to be the case in the Sabie River, which is probably the largest unimpacted river in South Africa.

In all regions where highly polluted waters were sampled SASS4 scores were very low. This was seen in cases of acid pollution, heavy metal pollution, organic pollution, silt and turbidity and increases in the Total Dissolved Solids (TDS). Of these the response to TDS appears to be relatively small up to TDS of about 1000 $mg\ell^{-1}$.

Expectations regarding the effects of missing habitats on sampling point SASS4 scores and ASPT were confirmed, as was the effect of excessive silt loads. Missing habitats at unpolluted sampling points resulted in lower than would be expected SASS4 scores while ASPT remained relatively high. Sites with excessive silt and sand had markedly low SASS4 scores with ASPT relatively high. This change in scores was also found when a river sand recovery operation was started near a sampling point after the first two of four sampling visits had been made.

The interpretation of results

Where southern African surface waters are not naturally acid, (pH >6, that is all parts of the country other than parts of the southern and western Cape), the data presented in this report suggest that guidelines for the interpretation of SASS4 scores should be as follows:

SASS4 >100,	ASPT >6	water quality natural, habitat diversity high
SASS4 <100,	ASPT >6	water quality natural, habitat diversity reduced
SASS4 >100,	ASPT <6	borderline case between water quality natural and some deterioration in water quality, interpretation should be based on the extent by which SASS4 exceeds 100 and ASPT is <6
SASS4 50 - 100,	ASPT <6	some deterioration in water quality
SASS4 <50	ASPT variable	major deterioration in water quality

These boundaries for interpretation are artificial boundaries in a continuum and which is why they should be used as guidelines. For instance one would be far more certain that there was chemically measurable change in water quality were SASS4 to be 60 and ASPT 4, than were SASS4 to be 90 and ASPT to be 5.5.

In Lesotho the impact of high silt loads was to reduce the diversity of taxa found. At the same time a small number of relatively high scoring taxa remained. The outcome was that unusual combinations of SASS4 score and ASPT were frequently recorded, with SASS4 scores between 32 and 56 and ASPT between 4.4 and 5.8 (with an outlier value of 3.0) that is high in relation to SASS4 score. Silt and turbidity are sometimes regarded as components of water quality, in which case these scores would in any case fall into the guidelines between 'some deterioration in water quality' and 'major deterioration in water quality'.

The fact that interpretation of scores has not been varied depending on where (mountains or lower reaches) the sampling point has been located, is due to the lack of substantial variation in either SASS4 score or ASPT along the Sabie River.

In the acid (pH <6) mountain streams of the southern and western Cape it is clear that the scores in unpolluted conditions are higher than those in the rest of the country. There are few results from polluted streams on which to base projections of the impact of water quality deterioration on SASS4 score, so the following guidelines are tentative:

SASS4 >125,	ASPT >7	water quality natural, habitat diversity high
SASS4 <125,	ASPT >7	water quality natural, habitat diversity reduced
SASS4 >125,	ASPT <7	borderline case between water quality natural and some deterioration in water quality, interpretation should be based on the extent by which SASS4 exceeds 125 and ASPT is <7
SASS4 60 - 125,	ASPT <7	some deterioration in water quality
SASS4 <60	ASPT variable	major deterioration in water quality

This guideline is based on the previous guideline for the rest of the country and the fact that SASS4 scores and ASPT were high in naturally acid streams. It requires verification.

Where the measurement of trends in water quality change over a period of time are measured using SASS4, if there is a trend over a number of samples, the results back each other up, and smaller differences in scores than those shown above become credible.

Conclusions

The SASS4 method may be used to assess water quality in broad terms and is therefore useful in water quality monitoring. It is sensitive to all types of water quality change, perhaps less so to increases in TDS than to other types of chemical change. The greatest difficulty in interpreting results arises on the borderline between no water quality impact and slight water quality impact. Places where there is pollution are unambiguously identified using SASS4 and the ASPT value. It must be stressed that ASPT is more important than the sample SASS4 score in interpreting the meaning of the results at intermediate and high ranges of SASS4 scores.

The interpretation of results does require the careful recording of the habitats from which the invertebrate collection has been made at a sampling site. The habitats sampled play a role in the SASS4 score and in the ASPT. The amount of sediment in the river channel is an important modifier of SASS4 results.

It is advisable to record the taxa found in stones in current and stony backwater habitats apart from those found in marginal vegetation and sand/mud habitats when comparisons have to be made between sampling points.

Recommendations

1. If it is intended to use presently available SASS data, modification to the family scores should not be entered into lightly. Converting scores from one version of SASS to another is extremely time consuming and often the resulting change in scores and interpretations is trivial.

2. Means to adjust SASS4 scores and ASPT at sites where a major habitat is missing should be investigated. This could involve building up a data base of separate paired scores for stones in and out of current (on the assumption that where there are stones in the current there will be stones out of the current) and for marginal vegetation. The results could then be compared through regression of one habitat score on the other habitat score. The regression results would then be used to adjust scores where one of these two habitats was missing. The process would have to be done separately for the acid mountain streams of the western Cape and for the remainder of the country.

3. It is recommended that biomonitoring of the impact of water resource use on streams and rivers should be implemented as soon as possible. The results should be used to prioritise river reaches in need of restoration and to track the success of restoration in terms of the biological response. The new water act stresses the priority need to provide water for sustainable river ecosystems. Very obviously the condition of the biota of the river ecosystem is the key measure of the sustainability of the ecosystem.

4. Traditionally water quality management in rivers and the impact of effluents have been based on the chemical quality of the water, usually measured in terms of the major ions and nutrients. It is very strongly recommended that

SASS should also be used, for it reflects water quality over prolonged periods and integrates all water quality impacts.

5. The ability to identify aquatic invertebrates, even to the level required for the application of SASS, is limited to a small number of people in South Africa. There are no readily available and lucid illustrated guides to the aquatic invertebrates of South Africa. The solution to this problem, which will limit the application of SASS and probably cause it to lose credibility due to mis-identifications, is first of all to produce a good written and illustrated guide. Thereafter, using the guide as a tool, people can be properly trained in the identification of aquatic invertebrates. It must however be pointed out that, unless the acquired skills in identification are regularly exercised, they are soon lost. It is recommended that large organisations with regular needs for SASS surveys should use their own personnel. Smaller organisations unable to keep staff occupied with regular SASS work should hire temporary help skilled in the method as needed.

6. There is a major gap in the areas of South Africa covered in the gathering of the SASS4 data on which this report is based. It is the Highveld region falling into Mpumalanga and the Free State which forms the catchment of the Vaal River. It is recommended that the validity of SASS4 should be established in this area.

7. Studies should be undertaken of polluted acid brown water streams to establish confirmed guidelines for the interpretation of SASS4 scores and ASPT in such waters.

General

It is considered that the contract objectives have been achieved and that a new method for evaluating the state of river ecosystems has been successfully developed. An important part of the success of the project is that the technology developed is being widely used. It forms a core element of the Department of Water Affairs and Forestry River Health Programme which is under development at present. SASS4 is extensively used by Umgeni Water and many other organisations responsible for the management of surface water quality. Many consultants are using SASS4 in routine monitoring.

ACKNOWLEDGEMENTS

I have been helped in many ways in the work that has lead up to this report. First of all I was given the opportunity by the Division of Water Technology of the CSIR (now the Division of Water, Environment & Forestry Technology) to develop the SASS approach to the point where a good case could be made for the further development of the method. The Water Research Commission then took up the support, and through its Steering Committee lead and guided the study. Members of the Committee were exceptionally supportive, in particular Dr Mitchell (Chairman), Dr Dickens, Ms H Dallas, Dr A C Uys, Mr D J Roux and Dr P-A Sherman. I gratefully acknowledge the support I received from the CSIR, the Water Research Commission and the Project Steering Committee.

Early versions of the SASS scoring system were taken up by members of the Steering Committee and other interested water scientists almost from the time of the initial Steering Committee meeting. In view of the possibility of the appearance of a plethora of SASS scoring systems, the Water Research Commission entertained and supported a suggestion that a SASS Forum should be formed to agree upon amendments to the SASS score sheet. The Forum held two meetings. I wish to thank the members of the Forum for their enthusiasm and support and the Water Research Commission for its help in this respect.

The Institute for Water Quality Studies of the Department of Water Affairs and Forestry provided water quality and SASS data on the rivers in Mpumalanga at the suggestion of Ms C Thirion and Mr D J Roux. Umgeni Water, through Dr C Dickens, made data from the Mgeni River available for inclusion in the report. Ms H Dallas provided information that she had gathered for her own purposes. Rand Water lead the project leader to their sampling points on the Witwatersrand. Although the vast amounts of data provided caused me mental indigestion, I greatly appreciate the willingness of these people to go out of their way to help the project.

At the field level I was helped by Ms P Scotney, Ms D Savrda, Ms S R Gueppert and Mr P H McMillan of the CSIR. Field work in Natal was undertaken by Mr B K Fowles and Ms T Dor, in the eastern and southern Cape by Dr A C Uys and in the western Cape by Ms H Dallas. Dr F C de Moor collected data from the Baviaanskloof near Port Elizabeth. This help was indispensable and I record my thanks to those named, with whom I spent many happy and productive days in the field.

The final acknowledgement I want to make is to the Water Research Commission, for its great patience in waiting for this report to appear. I hope that the wait has been rewarded by a report which will support the Commission in its activities.

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1. INTRODUCTION

The fact that some components of the aquatic flora and fauna of streams and rivers respond in a predictable fashion to changes in the physical and chemical nature of water has long been known (Cairns & Pratt 1993, Harrison, 1958a,b). In the past many attempts were made to organize this information in a manner which would make it useful to the management of water quality. The literature is littered with descriptions of biological indices of water quality, the majority of which have found little practical application. A major reason for this state of affairs is that, historically, the people who developed the indices were not always the people who had to use them.

The indices usually aimed at a perceived need for scientific levels of accuracy and reliability. In South Africa what little feed-back there was from managers to scientists included the throw away comment "Will it stand up in a court of law?" Real as this question may have seemed at the time, it was driven by the misconception that the only route to successful water quality management lay in the rigid enforcement of standards.

The experience is well illustrated by the Empirical Biotic Index (Chutter 1972). This index for flowing waters was based on the invertebrate fauna of the stones-in-current habitat[1]. It involved the detailed taxonomic analysis and counting of invertebrate samples collected using a fine meshed net. This analysis took about 12 hours per sample and required the attention of technicians with an advanced level of taxonomic expertise. Although it was reported (eg F C Viljoen, Rand Water, personal communication) that the index successfully produced results compatible with known water quality and was adapted in America (Hilsenhoff 1987), it was not regularly used. Twenty years later it is apparent that the reasons were that the method was too costly and stones in current biotopes were not available at every point where water quality information was required. Moreover, the method would not "stand up in a court of law" which was thought to be necessary at the time.

In England simplified approaches to the use of stream biology in stream classification were developed by biologists working for organisations such as River Boards. These people had a sound appreciation of their needs and the role that stream biology could

[1] Habitat is loosely used in this report in place of scientifically correct word "biotope" as it has been found to be more readily understood by non-biologists. The terms have been defined by Macan (1963): *biotope* refers to a given set of conditions which is occupied by a community and *habitat* is applied to the sort of place where a given species is found.

play in the management of water resources. An early approach (Woodiwiss 1964) was not considered suitable for South African conditions as it relied heavily on the occurrence of Amphipoda and Isopoda, two groups of crustacea which have extremely limited distributions (coastal and alpine [>3 000 m amsl] streams) in southern Africa. This was later followed by the BMWP (Biological Monitoring Working Party) scoring system (Chesters 1980, National Water Council 1981) which was described in a report with limited distribution.

The BMWP scoring system is based on the invertebrates and applies to streams and rivers. BMWP scores reflect water quality in broad categories (such as unpolluted, slightly polluted, polluted, highly polluted). The strength of BMWP scores is that they give time-integrated results and thus reveal intermittent pollution. They may also reveal biological change where water quality degradation has not been shown by the chemical analysis of water, due to the omission of critical pollutants from the chemical analysis.

Stream assessment using BMWP is inexpensive when compared to the chemical analysis of water samples. One of the key roles of the BMWP score is to help identify sites where closer chemical investigation of water quality is required. The BMWP score is a powerful tool in monitoring biological responses to the degradation or improvement in water quality.

Recently the Department of Water Affairs & Forestry called for public comment on proposals to review the South African water law (Department of Water Affairs and Forestry, 1995). As regards the biological component of stream ecosystems, it is stated in this document that "The law needs to view the environment as the **resource base** from which all development leads - the foundation on which all else depends". Against this background, it is indeed particularly appropriate to include biological criteria among measures of the effectiveness of management of the quality of water resources.

In the United Kingdom a weakness of the BMWP score is that results from canal-like lowland streams are anomalous. However, the BMWP score has been linked to the RIVPACS prediction of the stream fauna (Wright *et al.* 1988, 1989) so that actual and predicted invertebrate communities may be compared. Conclusions as to water quality may be drawn from the comparison of actual score and predicted score.

This report deals with an attempt to develop a scoring system, derived from the BMWP, suitable for assessing water quality in South African streams and rivers. The initial development of the RIVPACS method required the collection of biological and environmental data from 438 sites distributed through England, Wales and Scotland. In view of this considerable data requirement and the lack of lowland rivers in South Africa, it was decided that the initial approach to adapting the BMWP method to South Africa should be to establish, as far as possible, the variation in scores in natural streams from those parts of the country where streams are perennial. This would reveal whether there was systematic variation in scores following stream and river type and hence the necessity for developing the combined BMWP and RIVPACS approach in South Africa.

Following this introduction, the aims of the project, as agreed between the CSIR and the WRC, are presented and more information on the BMWP method is given. The methods section deals with the approach to the study. Thereafter the protocol (field methods, scoring system and data recording and storage) for the use of SASS (South African Scoring System) is described. Results of field studies from the major areas covered, divided into case studies where appropriate, are presented in eight appendices to demonstrate the level of validity of SASS. The results section of this final report is an overview of the content of the appendices. Guidelines for the interpretation of results are developed in a discussion of the SASS method and its possible future role in the management of water resources for sustained utilisation. The report ends with conclusions and recommendations.

2. THE AIMS OF THE PROJECT

The contract between the CSIR and the WRC stated the aims of the proposed research to be as follows:

2.1 develop a method to assess the impact of changes in water quality due to effluent on invertebrate communities as key representatives of the living organisms of streams and rivers,

2.2 express the results of the application of the method in the form of a numerical index,

2.3 ensure that the index is reliable, rapidly measured and cost-wise competitive with other (chemical) methods for the assessment of changes in water quality,

2.4 make the method user-friendly through the minimization of the exposure of field workers to water borne diseases such as bilharzia,

2.5 provide the method in a user-friendly format appropriate to computer-based storage and retrieval of results.

These aims and the execution of the project were strongly influenced by the objective of keeping the method as simple and fast as compatible with user requirements. While this is important in relation to time and staffing costs, it must be appreciated that the simpler and faster a method, the less reliable the results are likely to be. The formal definition of the appropriate balance between cost and reliability in this sort of situation would be difficult. A practical measure of the success of the method is whether or not it is taken up by potential users.

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The concept of water quality within the context of this report is that it should be defined in terms of the suitability of the chemical composition, pH, temperature, dissolved gasses (principally oxygen), turbidity and sediment load of the water for the sustained support of natural communities of aquatic invertebrates. It is recognised that the flow regime, particularly of intermittent streams and rivers, has a major impact on the composition of aquatic invertebrate communities. For this reason, intermittently flowing rivers were largely excluded from this study and most of the field studies were conducted in the dry season, when flows may decline, but vary little from day to day.

3. THE BMWP METHOD

The BMWP method is based on allocating a score between 1 (highly tolerant of pollution) and 10 (highly sensitive to pollution) to each invertebrate taxon (predominately family) frequently found and readily visible. Samples of invertebrates are collected from the river, using standardised methods. At the stream side the living animals are tipped into a photographic (or other) light coloured tray containing stream water. The taxa present are recorded on a data sheet which shows the taxon names and the scores allocated to each taxon. The end of the identification period is defined and thereafter the scores of the taxa recorded are summed (Sample Score), the number of taxa is counted (Number of Taxa) and the Average Score Per Taxon or ASPT (sample score ÷ number of taxa) is calculated.

Armitage *et al.* (1983) investigated the variability of BMWP sample scores and ASPT at 268 unpolluted sites following season and sampling effort. Most scores and ASPT values fell between 100 and 150 and 5.01 and 6.00 respectively. They found that seasonal variations were relatively low. Sample scores and particularly ASPT were consistent in spring, summer and autumn. Sample replication lead to a rapid increase in sample score, but had little effect on ASPT. This difference in response to increasing sample size is vividly illustrated by the fact that "only 1 sample is needed to obtain an estimate of ASPT which is 97% of the value after 6 samples. In contrast 5 samples are required to obtain a sample score which is 97% of the value after 6 samples". It was concluded that sample score is dependent on sample size, but ASPT is largely independent of sample size at these unpolluted sampling sites. As regards longitudinal changes in BMWP results in single rivers, it was found that high scores were generally more common in the middle reaches, though they could be obtained anywhere along the length of a river. ASPT values were usually highest in the upper reaches of rivers. Rivers which changed little in physical character along their courses did not have a wide range of scores or ASPT. Where a river had a steep upland reach followed by a gently sloping lowland reach, ASPT ranged from 6.6 (top site) to 5.2 (bottom site). The highest score was recorded in the middle reaches and the next highest in the lowland reach.

It is necessary to stress that these results were based on unpolluted sites. As will be shown later, at polluted sites with low scores, ASPT becomes very much more variable and is less reliable than sample score.

4. THE INVESTIGATIONAL APPROACH ADOPTED IN THE STUDY

The initial investigations of the rapid biological assessment of water quality took place under the auspices of the Division of Water Technology of the CSIR. The BMWP scores for families were adapted to local conditions by the addition of taxa found only in South Africa and the deletion of taxa not found here. In some families it was necessary to change scores as the South African representatives are known to have sensitivities to pollution which differ from those in the northern hemisphere. The acronym SASS (South African Scoring System) evolved and successive versions of SASS were named SASS1, SASS2 and so on.

Initial application of SASS took place in moderately to highly polluted streams south of Johannesburg. Chemical water quality is monitored at monthly intervals in these streams by Rand Water. Rand Water sampling points were used so that there was a reasonable knowledge of the chemical nature of the water where the samples were collected. However, chemical and biological samples were not collected simultaneously. As opportunity arose, SASS sampling was undertaken on sampling visits to other less polluted or non-polluted streams and rivers. Results of this work showed that the BMWP approach to biological monitoring was sufficiently promising to warrant further investigation. The Water Research Commission supported the continuation of the investigation through the project which is reported here.

By the time the WRC project commenced, SASS2 was the current version. Both the Project Leader and the Water Research Commission appreciated that the project involved the development of a technology new to South Africa. Prominent among the measures of project success would be the extent to which it was taken up by user agencies. The project Steering Committee therefore included representatives of potential user agencies and interested researchers. Committee members were encouraged to apply SASS2, which soon came to be widely applied in South Africa. (User agencies have made SASS results available to the project leader for inclusion in this report).

Concern arose that due to users initiating modifications, a plethora of SASS2 versions would be generated, so that it would become difficult to compare results. The Water Research Commission therefore supported meetings (known as the SASS Forum) of SASS users. At the SASS Forum ideas on adjustments to SASS scores were discussed and consensus was reached on SASS revisions. In this manner SASS3 and SASS4 (the last version at the time of writing this report) evolved.

The research undertaken was aimed at testing SASS by using it at widely dispersed sites in South Africa. While the sites included polluted streams and rivers in each area, many sites were unpolluted and were chosen to reveal the extent of geographical variation in SASS scores. The sampling programme involved considerable travel. Sampling was therefore limited to the dry season (summer in the south west Cape and winter in the remainder of the country), to obviate undertaking long journeys only to find sampling points inaccessible due to high flows. SASS data provided by user agencies includes sites where year round sampling has been undertaken.

As Armitage *et al.* (1983) had investigated the effect of sample size on BMWP scores and ASPT, the effect of sample size was not investigated in this study. However, an investigation of this type of variation in SASS has been covered in an MSc thesis (Dallas, 1995), in which it was found that SASS4 score increases with sample size, but ASPT is relatively unaffected, confirming the Armitage *el al.* finding.

5. THE SASS METHOD

In this chapter the SASS method for sample collection and analysis is described. The SASS4 score sheet is presented, emphasising how it has been changed from the BMWP score sheet. Comparisons are made between SASS4 and earlier SASS versions and conversion of sample scores from each version to the others is explained.

5.1 Field sampling

The field sampling was undertaken using a net of 1 mm pore size mounted on a square aluminium frame 300 mm x 300 mm. The handle of the net was attached at the middle of one side of the frame and was about 1 m long.

The sampling protocol was described on the left hand side of the field record sheet (**Table 1**). Collections were made from the habitats following instructions and were then tipped into a photographic tray measuring about 250 mm by 350 mm, filled with clear water to a depth of about 20 mm. The taxa present were recorded on the score sheet and the examination of the sample was terminated following the instructions to the left of the score sheet. The sample score, number of taxa and ASPT were readily calculated from the completed score sheet.

By way of further explanation to those unfamiliar with "kick-sampling", the method is that used in the protocol to sample the stones on the bottom of the stream. It consists of kicking and moving the stones with the feet while the net is held downstream, or where there is no current treating the stones the same way, but then sweeping the net through the disturbed area. The stones are sometimes firmly wedged against each other, making the kicking method less effective, often to the point where they have first to be loosened by hand.

Table 1: The SASS4 field record sheet.

SASS4

River. . . . . Date . . . . . . Time . . . .

Sampling point . . . .

Temp °C . . . . . pH . . . . . Cond.(mSm⁻¹) . . . .

Biotopes sampled:

SIC . . . (Type/time . . . .)

Marg veg . . . Dom. sp . . . .

Aq veg . . . Species . . . .

SOOC . . . . Sand . . . . Mud . . . . gravel . . . .

Other . . . .

Procedure Protocols:

1. If stones in current (SIC) all kickable, sample for 2 min., otherwise for maximum of 5 min.
2. Gravel - 1/2 min.
2. Marg/Aq veg, back & forward sweep 2 m.
3. Stones out of current (SOOC) kick +/- 1 m².
4. Sand/mud stir with feet & sweep net over disturbed area for 1/2 minute.
5. Any other biotopes - 1/2 min.
6. Complete top of form.
7. Tip net contents into tray. Remove leaves, twigs & trash.
8. Check taxa present on above list FOR THE LESSER of 15 minutes or 5 minutes since the last taxon was found.
9. Estimate & record taxon abundances on scale: A - 1 to 10; B - 10 to 100; C - 100 to 1000; D - >1000
10. **BEFORE LEAVING THE SAMPLING POINT CHECK THAT THIS FORM HAS BEEN FULLY COMPLETED!**

A* - score allocated to taxon.

Taxon	A*			
Porifera	5			
Coelenterata				
Hydra sp.	1			
Turbellaria				
Planarians	5			
Annelida				
Oligochaeta	1			
Hirudinea				
Leeches	3			
Crustacea				
Amphipoda	15			
Crabs	3			
Shrimps	8			
Hydracarina				
Hydrachnellae	8			
Plecoptera				
Notonemouridae	12			
Perlidae	12			
Ephemeroptera				
Polymitarcyidae	10			
Ephemeridae	15			
Baetidae 1 sp or	4			
2 spp or	6			
> 2 spp	12			
Oligoneuridae	15			
Heptgeniidae	10			
Leptophlebiidae	13			
Ephemerellidae	15			
Tricorythidae	9			
Prosopistomatidae	15			
Caenidae	6			
Odonata				
Chlorolestidae	8			
Lestidae	8			
Protoneuridae	8			
Platycnemidae	10			
Coenagriidae	4			
Calopterygidae	10			
Chlorocyphidae	10			
Zygoptera juvs.	6			
Gomphidae	6			

Aeshnidae	8			
Corduliidae	8			
Libellulidae	4			
Hemiptera				
Notonectidae	3			
Pleidae	4			
Naucoridae	7			
Nepidae	3			
Belostomatidae	3			
Corixidae	3			
Gerridae	5			
Veliidae	5			
Megaloptera				
Corydalidae	8			
Trichoptera				
Hydropsychidae: 1 sp	4			
or 2 spp	6			
or > 2 spp	12			
Philopotamidae	10			
Polycentropodidae	12			
Psychomyiidae	8			
Ecnomidae	8			
Hydroptilidae	6			
Other movable case larvae: case types / score / fam.				
1 / 8 / 1	8			
2 / 15 / 1	15			
3 / 20 / 1	20			
4 / 30 / 2	30			
5 / 40 / 2	40			
>5 / 50 / 3	50			
Lepidoptera				
Nymphulidae	15			
Coleoptera				
Dytiscidae	5			
Elmidae/Dryopidae	8			
Gyrinidae	5			
Haliplidae	5			
Helodidae	12			
Hydraenidae	8			
Hydrophilidae	5			
Limnichidae	8			

Psephenidae	10			
Diptera				
Blepharoceridae	15			
Tipulidae	5			
Psychodidae	1			
Culicidae	1			
Dixidae	13			
Simuliidae	5			
Chironomidae	2			
Ceratopogonidae	5			
Tabanidae	5			
Syrphidae	1			
Athericidae	13			
Empididae	6			
Ephydridae	3			
Muscidae	1			
Gastropoda				
Lymnaeidae	3			
Melaniidae	3			
Planorbidae	3			
Physidae	3			
Ancylidae	6			
Hydrobiidae	3			
Pelecypoda				
Sphaeriidae	3			
Unionidae	6			
Sample score				
No. of families				
Score/taxon (ASPT)				

Other families present/ notes & comments

Depending on the abundance of the fauna and the diversity of habitats available at the sampling point, the various habitats may be sampled one after another into one collection. Alternatively, it is often advantageous to first collect from stones in current and stones out of current and examine the catch and then to collect from the remaining habitats and examine the catch. Advantages of this second approach, which is sometimes more time-consuming than the first, are that the animals are easier to see as there is less debris under which they hide. More important though, is the fact that many sampling points are deficient in either stones in current and stones out of current or in fringing vegetation. When the habitats are separated as suggested, it is possible, if necessary, to compare sampling points habitat by habitat. This is important when comparing results of samples based on differing assemblages of habitats. At the same time the recorded catches in the two groups of habitats may readily be combined to give a sampling site score. The manner in which this should be done is to combine the lists of taxa from the various habitats and to calculate the site score from this combined list. Under no circumstances should the separate habitat scores be summed to give a site score.

5.2 The SASS4 score sheet

The SASS4 score (**Table 1**) sheet is straightforward. It provides three columns for the recording of taxa from different habitats. The protocol includes the recording of the abundance of taxa on a simple scale. This information has yet to be used, though it may become useful at a later date.

5.3 The scoring system

In some respects SASS4 includes radical departures from BMWP. Early in the project it was decided that the range of ASPT values was too narrow. In order to increase this ASPT range, the range of taxon scores was expanded from the 1 to 10 per taxon used in the BMWP method to 1 to 15 used in SASS.

Within the Trichoptera (caddisflies) the larvae of some families are difficult to distinguish from one another in the field using anatomical differences. These families (which construct moveable cases) are found mainly in the southern and western Cape mountain streams and construct moveable cases. The distinct shape of building material is species specific. A sliding scale (driven by the diversity of case types), of scores and number of families to be recorded was therefore drawn up. It is acknowledged that the scale can be somewhat misleading due to the fact that some larvae change building material as they grow. However, the small error in sample score and ASPT due to the false identification of one. or at most two, extra species should be weighed against the time and effort of taking the larvae back to the laboratory for proper identification. Moreover, these animals appear to be sensitive to changes in water quality and are only common and diverse in unimpacted waters.

In the South African aquatic invertebrate fauna, there are two species-rich families in which most of the species are intolerant of water quality change, while there is also a species which is highly tolerant of water quality change. The families are the Baetid Ephemeroptera and the Hydropsychid Trichoptera. The tolerant Baetid is *Baetis harrisoni* and the tolerant Hydropsychids are *Cheumatopsyche thomasseti* and *Amphipsyche scottae*. Fortunately species in these families are readily distinguishable with the naked eye (abdominal pigmentation colour and pattern in the Baetidae and head shape and colour in the Hydropsychidae). In these two families the scores recorded are dependent on the number of species found (**Table 1**). Scoring these families requires specialised identification skills, but again the consequences for the sample score and ASPT of identifying two species when only one is present, or three when two are present, or indeed vice versa in both cases are not overly important.

5.4 Data storage and retrieval

When the project was conceptualized, it was thought that this would be an important component of the work. In the event, two large public organisations, the Institute for Water Quality Studies of the Department of Water Affairs and Forestry and Umgeni Water, have taken up the method and made provision for the inclusion of SASS results in their very large data bases. There is little point to taking the matter further.

For the study reported here, it was found that the data could be handled on spread sheets. The spread sheets were formatted with the taxa in columns and the score applicable to each taxon was entered in the column to the right of the taxon column. The spread sheet was programmed to calculate the sample SASS score, number of taxa and ASPT automatically and to enter the results on the spread sheet as the sample data was entered.

When scores for individual taxa are changed for new versions of SASS, the calculated scores and ASPT are automatically adjusted, simply by changing the number in the score column next to the taxon name. Unfortunately there are several other types of adjustment that may be made to SASS. When these involve adding new taxa or splitting a taxon into more than one component, the automatic conversion of scores is less easily handled.

5.5 Comparisons between SASS1, SASS2, SASS3 and SASS4

Most results to be presented in this report and its appendices are given as SASS4, although the original data from the earlier part of the study were recorded in earlier versions of SASS. The conversion of these results from earlier versions of SASS has sometimes required careful consideration. In order that the conversions may be better understood, the different versions of SASS were compared and then the method of converting SASS results presented.

SASS1 was used for a short time before the contract study with the Water Research Commission started. In SASS1 all scores lay between 1 and 10, following the BMWP scoring system. In SASS2 the range of possible taxon scores was increased to 1 to 15, as previously explained. The taxa included in the SASS1 and SASS2 scoring systems were identical, so that conversion of SASS1 scores to SASS2 scores presented no problem.

SASS2, SASS3 and SASS4 taxa and their scores are shown in **Table 2**. In this table the major differences lie between SASS2 on the one hand and SASS3 and SASS4 on the other. SASS2 did not require the recording of the numbers of Baetid Ephemeroptera or Hydropsychid Trichoptera species. At the same time the method of identifying the case-bearing Trichoptera larvae also changed from SASS2 to SASS3. Eight families were brought into the scoring system in SASS3 and two were omitted, only to be brought back into the scoring system in SASS4. The Leptophlebiidae were handled differently in SASS2 and SASS3. The scores of 23 families were changed between SASS2 and SASS3, but those of only six families were changed from SASS3 to SASS4.

Provided the data on the complete field record sheets are available, it is a simple matter to convert SASS3 scores to SASS4 scores. The only taxon which cannot be accounted for in the conversion is the Hydraenid beetles, which score 8, indicating that they are tolerant of some deterioration in water quality. As will later become apparent, a difference of 8 in a community indicative of moderate or better water quality is unlikely change the interpretation of results.

Several of the taxa first brought into the SASS system in SASS3 were regularly seen during the SASS2 scoring and their presence was recorded on the data sheets among the "other families present". They could thus be included in the SASS4 score. The real difficulties of converting SASS1 and SASS2 results to SASS4 results arise out of the fact that the numbers of Baetid and Hydropsychid species were not recorded in SASS2, although they are required for SASS4. To solve this difficulty, a set of rules was generated for converting SASS1 and SASS2 results to SASS4.

The conversion was a three stage process. Firstly the SASS1 and SASS2 sample data was entered on SASS4 record sheets, with the Baetidae and Hydropsychidae each scored as 1 species present. A first interim sample score was calculated from the SASS4 record sheet. The subsequent adjustment of the first interim score to the second interim score was based on including a Baetidae score, according to the first interim score. The inclusion of the adjusted Baetid score resulted in the second interim score. The full SASS4 sample score was based on the second interim score, using assumptions about the relationship between SASS4 score and Hydropsychid species diversity. The rules followed in adjusting the interim scores are given below:

- if first interim score <50, 1 Baetid species present
- if first interim score 50 to 100, 2 Baetid species present
- if first interim score >100, 3 Baetid species present
- if second interim score <75, 1 Hydropsychid species present
- if second interim score 75-125, 2 Hydropsychid species present
- if second interim score >125, 3 Hydropsychid species present.

The final score consisted of the second interim score adjusted by the inclusion of the Hydropsychid scores from the rules above.

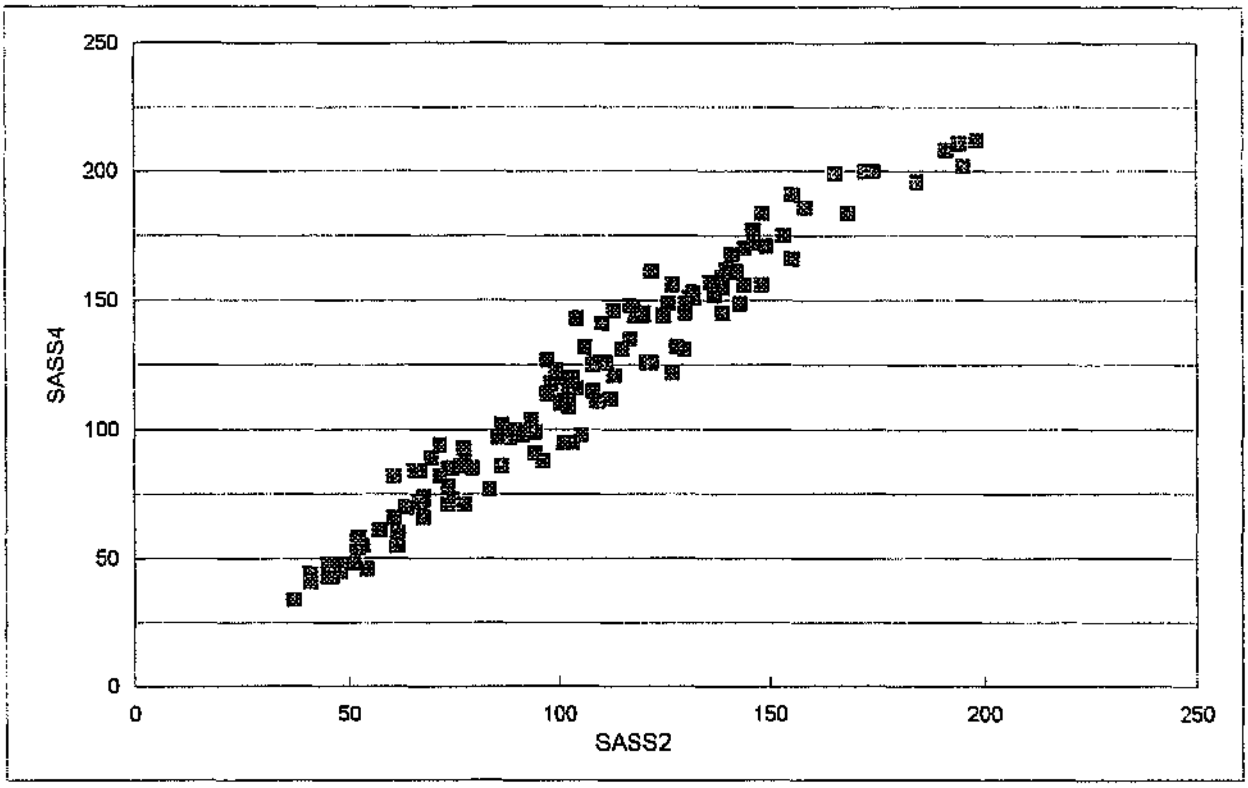
Umgeni Water made a large amount of valuable data available, but provided only sample scores, numbers of taxa and ASPT. The scoring systems used in generating this data were SASS2, SASS3 and SASS4. In order to change all these results to SASS4, original SASS2 and SASS3 results from other parts of the country, which had been converted to SASS4 using the methods described above, were plotted against the synthetic SASS4 results. The plots revealed straight line relationships (**Figures 1** and 2), the regression formulae of which were used to convert the Umgeni Water sample scores from SASS2 and SASS3 to SASS4.

Table 2: Taxa included and the scores allocated to them in SASS2, SASS3 and SASS4.

SASS version	2	3	4
Porifera	5	5	5
Coelenterata			
Hydra sp.	1	1	1
Turbellaria			
Planaria	5	5	5
Annelida			
Oligochaeta	1	1	1
Hirudinea			
Leeches	3	3	3
Crustacea			
Amphipoda	*	15	15
Crabs	3	3	3
Shrimps	5	8	8
Hydracarina			
Hydrachnellae	10	8	8
Plecoptera			
Notonemouridae	7	12	12
Perlidae	12	12	12
Ephemeroptera			
Polymitarcyidae	15	10	10
Ephemeridae	15	15	15
Baetidae any number spp	4	*	*
Baetidae 1 sp	*	4	4
or 2 spp	*	6	6
or >2 spp	*	12	12
Oligoneuridae	15	15	15
Heptageniidae	15	10	10
Leptophlebiidae (pH <6.5)	*	13	*
Leptophlebiidae (pH >6.6)	*	6	*
Leptophlebiidae (any pH)	6	*	13
Ephemerellidae	15	15	15
Tricorythidae	9	9	9
Prosopistomatidae	15	15	15
Caenidae	6	6	6
Odonata			
Chlorolestidae	10	10	8
Lestidae	10	10	8
Protoneuridae	10	10	8
Platycnemidae	10	10	10
Coenagriidae	4	4	4
Calopterygidae	10	10	10
Chlorocyphidae	10	10	10
Zygoptera juvs.	6	6	6
Gomphidae	6	6	6
Aeshnidae	8	8	8
Corduliidae	8	8	8
Libellulidae	4	4	4
Hemiptera			
Notonectidae	3	3	3
Pleidae	4	4	4
Naucoridae	10	10	7
Nepidae	3	3	3
Belostomatidae	3	3	3
Corixidae	3	3	3
Gerridae	5	5	5
Veliidae	5	5	5
Megaloptera			
Corydalidae	*	12	8

SASS version	2	3	4
Trichoptera			
Hydropsychidae present	4	*	*
Hydropsychidae 1 sp	*	4	4
or 2 spp	*	6	6
or >2 spp	*	12	12
Philopotamidae	10	10	10
Polycentropodidae	7	12	12
Psychomyiidae	8	8	8
Ecnomiidae	8	8	8
Hydroptilidae	6	6	6
Other movable case larvae:			
case types score fam.			
1 8 1	*	8	8
2 15 1	*	15	15
3 20 1	*	20	20
4 30 2	*	30	30
5 40 2	*	40	40
>5 50 3	*	50	50
Goeridae	15	*	*
Lepidostomatidae	15	*	*
Leptoceridae	15	*	*
Sericostomatidae	15	*	*
Lepidoptera			
Nymphulidae	15	15	15
Coleoptera			
Dytiscidae	5	5	5
Dryopidae/Elmidae	*	*	8
Dryopidae	5	*	*
Elmidae	5	7	*
Gyrinidae	5	5	5
Haliplidae	5	5	5
Helodidae	*	12	12
Hydraenidae	5	*	8
Hydrophilidae	5	5	5
Limnichidae	*	8	8
Psephenidae	15	15	10
Diptera			
Blepharoceridae	15	15	15
Tipulidae	5	5	5
Psychodidae	1	1	1
Culicidae	1	1	1
Dixidae	*	13	13
Simuliidae	5	5	5
Chironomidae	2	2	2
Ceratopogonidae	*	5	5
Tabanidae	5	5	5
Syrphidae	*	1	1
Athericidae	3	13	13
Empididae	*	6	6
Ephydridae	*	3	3
Muscidae	1	1	1
Gastropoda			
Lymnaeidae	3	3	3
Melaniidae	3	3	3
Planorbidae	3	3	3
Physidae	3	3	3
Ancylidae	6	6	6
Hydrobiidae	3	3	3
Pelecypoda			
Sphaeriidae	3	3	3
Unionidae	6	6	6

* indicates that the taxon was not included in the version of SASS to which it relates

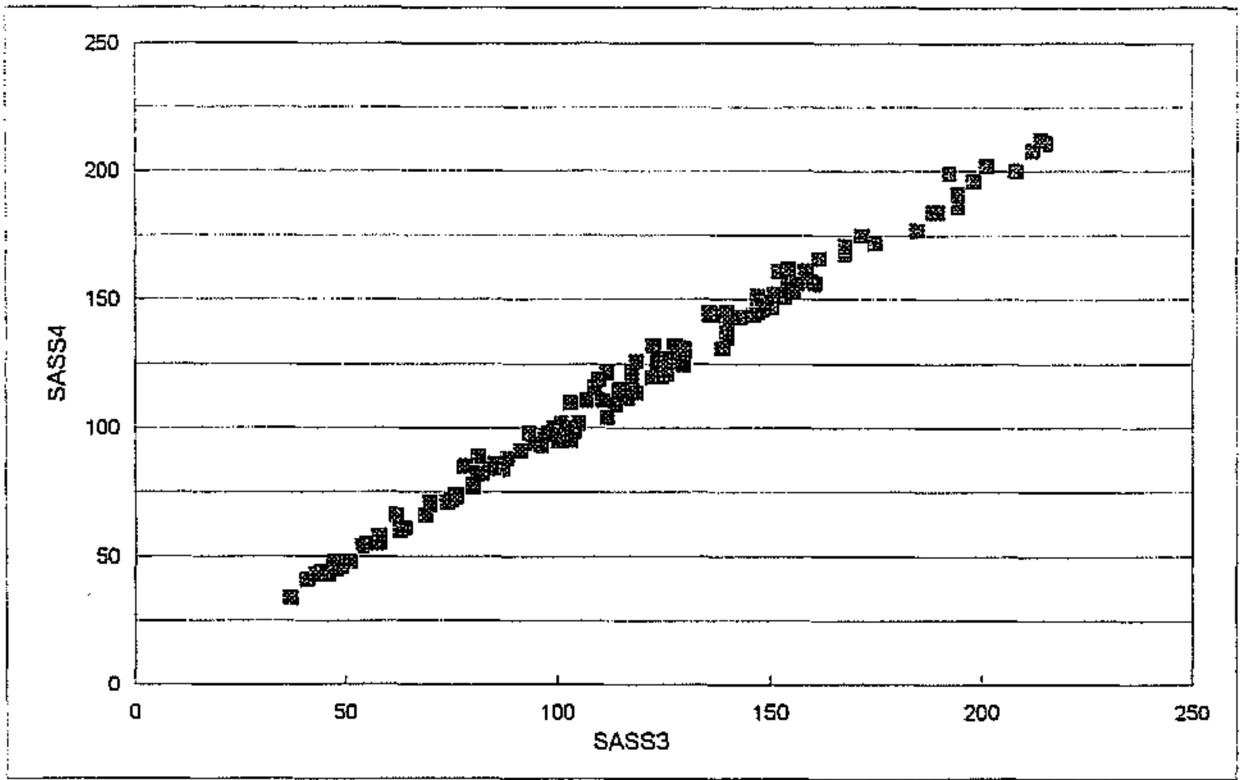


SASS4 on SASS2 131 observations

Regression Output:

Constant		-3.51699
Std Err of Y Est		9.990991
R Squared		0.950215
No. of Observations		131
Degrees of Freedom		129
X Coefficient(s)	1.156033	
Std Err of Coef.	0.023298	

Figure 1: The relationship between SASS2 scores and calculated SASS4 scores



SASS4 on SASS3	131 observations	
	Regression Output:	
Constant		0.094313
Std Err of Y Est		4.102155
R Squared		0.99162
No. of Observations		131
Degrees of Freedom		129
X Coefficient(s)	0.996585	
Std Err of Coef.	0.008066	

Figure 2: The relationship between SASS3 scores and calculated SASS4 scores

5.6 Environmental factors leading to variation in scores

Being formulated according to the perceived response of aquatic invertebrates to water quality deterioration in its broadest sense, SASS4 scores and ASPT do relate directly to water quality (see below, 6. Results). The purpose of this section is to consider other factors which might in practise result in changes in the SASS4 scores.

Many aquatic invertebrates occur only in certain habitats, so that the SASS4 score is considerably influenced by the variety of habitats sampled to provide the data from which the SASS4 score is derived. The most pollution-tolerant taxa occur in almost all habitats, so that scores for places where there is severe pollution are not influenced by habitat diversity. SASS4 scores where water quality is natural are the most sensitive to habitat diversity. There are several examples in the data base of the consequences of restricted habitat diversity for the SASS4 score and ASPT at **unpolluted** sampling points. In each case of restricted habitat diversity, the SASS4 score was low in relation to the ASPT. This is understandable since the community of the missing habitat would decrease the SASS4 score for the site. At the same time the community of the missing habitat would be expected to include taxa with a wide range of taxon scores. The outcome of missing habitats at sampling sites is therefore that the SASS4 score would be more affected by the missing habitat than would be the ASPT.

Low scores tend to be recorded below dams and weirs. In such cases it is suspected that the low scores are responses appropriate to the SASS scoring system, in that they represent localized deleterious changes in water quality due to storage and the occurrence of anaerobic discharges.

Components of the particulate load of rivers, such as silt, are sometimes regarded as being part of water quality, though this is not always the case. The tolerance of aquatic invertebrates to increased silt loads is poorly known, though deposition of silt and sand has obvious consequences for habitat availability. The group of invertebrates most likely to be impacted by excessive silt and sand are the inhabitants of the stones-out-of-the-current habitat. Here the stones can become smothered so that there is no longer space for animals to hide under or between stones, which become embedded in silt and sand.

The implication of these other potential significant impacts on the measured SASS4 score are that it is essential to record the habitats sampled, the proximity of dams and weirs and the general facies of the river channel as regards silt and sand. A weakness in the data base for this report is that these matters were not always recorded.

From an aquatic invertebrate perspective, the diversity of habitats at a point in an unpolluted stream has the overwhelming impact on the numbers of taxa found and therefore on the SASS4 score. Habitat assessment following Platkin *et al.* (1989) is inappropriate to invertebrates as it over-emphasises factors such as channel sinuosity and under-cutting of banks whose relevance is considerable for salmonid fish, but negligible for invertebrate diversity and SASS4 score.

6. RESULTS

The results of the field investigations have been written up in the eight appendices which accompany this report. This section is an overview of the results.

In **Appendix A** results from highly polluted streams draining the Witwatersrand are presented and contrasted with data from the unpolluted Letaba River. The data were the first to be generated using the SASS approach. SASS4 scores and ASPT were very low in the Witwatersrand streams, but they did show expected trends of downstream change. Thus, in the Jukskei/Crocodile River SASS4 scores and ASPT increased in a downstream direction, the greatest water quality impacts being in the upper river. Although the Letaba results were based only on the stones in current community, the lowest Letaba SASS4 scores and ASPT values were higher than the highest Witwatersrand scores and values.

Heavy metal pollution in the Modderspruit upstream of AECI resulted in very low SASS4 scores (< 10) and ASPT (< 1.5). Acid pollution also resulted in a low SASS4 score (24) but, due to the presence of relatively high-scoring acid tolerant Leptocerid caddisflies, in a relatively high ASPT of 4.8. Scores and ASPT were also very low in streams draining an industrial area which was probably a source of pollutants of a diverse nature (TDS, heavy metals, organic matter and acids).

Vleis and wetlands on the river draining the East Rand did result in an improvement of SASS4 scores to 44 and ASPT to 4.9, but these values are nowhere near the values that have been unequivocally associated with unpolluted waters.

Comprehensive data from the Crocodile, Sabie and Olifants Rivers in Mpumalanga are presented in **Appendix B**. This data allowed for the development of guidelines for the assessment of water quality conditions in broad categories from SASS4 results. The behaviour of SASS4 scores and ASPT in the Sabie was particularly relevant, for this is the least disturbed of the Lowveld rivers and must rank as one of the least disturbed rivers of any length in the country. In upper reaches of the Sabie SASS4 scores were initially high, rose higher at two sampling points upstream of Sabie village and then returned to high levels approximating those of the upper reaches all the way down to the lowermost sampling point, 10 km downstream of the Skukuza flow weir in the Kruger National Park. ASPT was about 0.5 lower at the uppermost sampling point than elsewhere, but otherwise evidenced no downstream trend of change. The importance of these observations on the Sabie lie in the fact that in most South African rivers there is a tendency for the SASS4 scores and ASPT to decline downstream of the upper reaches (example given by Dallas 1995). The phenomenon is so frequently observed that it is easy to assume that this is the natural state of affairs. The Sabie data suggest that this is not the case.

SASS4 and ASPT values were similar to those in the Sabie River in Sabie mountain tributaries and in the Olifants and Crocodile Rivers only in the upper catchments, with one exception. SASS4 scores from the Blyde River, after it had entered the lowveld were high, but not as high as in the Sabie. However ASPT at the Blyde River sampling point was as high as in the Sabie. This finding supports the conclusion, based on the Sabie, that the decline in SASS4 results in the lower reaches of South African rivers may be a result of the greater exploitation of the rivers in their lower reaches than in the upper reaches. In the Olifants and Crocodile Rivers, SASS4 and ASPT responded as expected to water quality deterioration.

A feature of 1992 results from many sampling points in the upper and middle reaches of the Crocodile catchment was the very small month to month variation in SASS4 scores and ASPT. The samples were all collected and analysed by the same particularly meticulous worker, which may have a bearing on this constancy in the results.

One sample from the Elands River at Hemlock was collected on the same day as unusually high concentrations of aluminium (12 $mg\ell^{-1}$), iron (25 $mg\ell^{-1}$) and manganese (1.1 $mg\ell^{-1}$) were measured in the water. The invertebrate communities of the sampling point were not affected. High concentrations of these metals were not recorded at the next sampling point. In a water quality monitoring programme this type of occurrence would have been confirmed through taking of more samples.

There was one sampling point on the Kaap River (Crocodile River tributary) where the invertebrate fauna was completely absent on one sampling visit, indicating the temporary occurrence of toxic conditions. This occurrence would have stood a good chance of being missed by conventional sampling of water quality. There was a gradual increase in the diversity of the fauna and hence in SASS4 scores and ASPT in the following months.

At a sampling point on the Upper Crocodile River at Dullstroom low SASS4 scores and ASPT were associated with channel disturbance. Further downstream scores were low downstream of a trout farm.

Appendix B includes data from sampling points of limited habitat diversity. SASS4 scores were lower than would have been the case, should the full range of habitats have been available. At these points ASPT tended to remain at the high levels associated with unimpacted sites.

Both SASS4 scores and ASPT were intermediate, in the ranges SASS4 50 to 100 and ASPT <6, at many sampling points in Mpumalanga where TDS was high and there were elevated heavy metal concentrations.

From the Mpumalanga rivers, combinations of SASS4 scores and ASPT values could be interpreted as follows:

SASS4 >100,	ASPT >6	water quality natural, habitat diversity high
SASS4 <100,	ASPT >6	water quality natural, habitat diversity reduced
SASS4 50 - 100,	ASPT <6	some deterioration in water quality
SASS4 <50	ASPT variable	major deterioration in water quality

When SASS4 scores were low (<50), ASPT became variable for the reason that in a community of low family diversity, the presence of a single moderately scoring family can have considerable influence on the ASPT. ASPT therefore became an unreliable indicator of water quality at low SASS4 scores. When SASS4 scores are very low, the same groups of hardy taxa occupy all habitats and habitat availability has no impact on the SASS4 score.

Data from the Kwazulu/Natal Midlands (**Appendix C**) was collected in both the wet and the dry seasons. Results from the unpolluted sampling points were more variable than had been the case in the Mpumalanga rivers. In certain cases this variability was associated with difficult field sampling under conditions of elevated summer flow. In the Mgeni River results were less variable downstream of Midmar Dam, possibly because flow regulation increased the probability of summer accessibility to the permanently inundated parts of the river bed.

Appendix C was written before **Appendix B**, which is a pity because the findings reported in **Appendix B** have a definite bearing on the interpretation of the results from the Mgeni River. Thus, re-examining Figure 2 of **Appendix C**, it is apparent that the SASS4 >100 and ASPT >6 criterion for unpolluted conditions is confirmed in the Mgeni. The **Appendix C** data base included examples of polluted rivers (Msunduze and Sterkspruit) with low SASS4 scores and variable ASPT.

Appendix D presented results from northern Kwazulu/Natal and from the area in and around Durban and Pinetown. There is a historical record of both chemical and biological conditions at many of the sampling points included in this appendix. It was thus possible to compare SASS4 based results with assessments made using a Biotic Index (Chutter 1972). The comparison confirmed that SASS4 results are similar to Biotic Index results.

SASS4 results were mostly supported by the assessment of water quality made using the Biotic Index (Chutter 1972). Both assessment methods relate in a meaningful way to water quality in most instances, though the boundary between no deterioration in water quality and small deterioration in water quality is blurred in SASS4. In particular the meaning in terms of water quality of samples in which SASS4 is well over 100 (say greater than 120), but ASPT is less than 5.5 is somewhat ambiguous. It is addressed in the discussion.

Two events, whose impact on SASS4 scores is important occurred during the study. The first was the commencement of a river sand extraction operation in close proximity to a sampling point on the Mdloti River during the course of the study, resulted in a drop in SASS4 score and in ASPT. Since the fine particles are washed from the sand back into the river using river water, the impact on the biota may be expected to be similar to the impact of increased silt load due to erosion. A spate at another sampling point had a similar effect. These occurrences raised the necessity for people undertaking SASS4 assessments of water quality always to be on the look-out for happenings which might have an impact on the measured score.

In Lesotho (**Appendix E**) SASS scores were low. Since the chemical nature of the water was unimpacted, this was ascribed to degradation of the fragile terrestrial environment due to both poor land-use practice and development of large infrastructure. Within the rivers this lead to reduction of habitat diversity and habitat modification through siltation.

Results from the eastern Cape are presented in **Appendix F**. Most of the sampling points evidenced impaired water quality which is hardly surprising, since they were located on the Buffalo River from King Williams Town downstream and on the Bloukrans River at Grahamstown. Water quality is poor in parts of these rivers. SASS4 scores in the unpolluted stream at the bottom of Howiesonspoort outside Grahamstown (yet another Palmiet River!) were high. SASS4 scores and taxon diversity were lower in the Great Fish River than would be associated with the quality of the water. This seems likely to be due to the fact that until the arrival of the water transferred from the Orange River, the Great Fish River stopped flowing for up to 9 months on some occasions. The aquatic invertebrate fauna is limited in diversity due to the loss of many species under no flow conditions. It is said (F C de Moor, personal communication) that the process of re-colonisation by species previously absent continues.

The streams and rivers sampled in the southern Cape (**Appendix G**) included both clear water and humic acid impacted brown water streams. Scores in the clear water streams were similar to those in Natal, Gauteng and Mpumalanga. The unpolluted acid brown water streams had SASS4 scores similar to the higher part of the range found in Natal, Gauteng and Mpumalanga, but ASPT was exceptionally high, 90% of the observed values exceeding 7 and ranging up to 9.1. Unfortunately insufficient incidence of water quality impairment could be found for the evaluation of the impact of pollution on SASS4 scores in acid brown water streams. A major deleterious impact on the invertebrate community of the Swart River was associated with the Garden Route Dam near George.

SASS scores in the Western Cape are described in **Appendix H**. As in the case of the acid brown water streams of the southern Cape, the SASS4 scores and ASPT were extremely high in the mountain streams of the western Cape. The highest ASPT of 11.6 was recorded in the upper catchment of the Berg River, while the highest SASS4 score was 231 from the Elandspad River. The data base includes a case of the pollution of a mountain stream by a trout farm and its recovery. Assessing the relationship between SASS4 and water quality was impeded by a lack of water quality data and by the fact the once the streams leave the mountains in this area water quality is invariably modified.

7. DISCUSSION

7.1 The role of SASS in water quality management

The SASS4 method is intended to be a rapid and inexpensive technique for the detection of water quality degradation or for revealing trends of water quality change over periods of time. It is not intended to categorise the degree of degradation in any detail, nor to identify the nature of the degradation. The role of SASS4 should be to guide chemical water quality investigations to the places where there is biological evidence of water quality deterioration. In view of the relative costs of the two types of investigation, use of SASS4 should lead to savings. For this use of SASS, interpretation of results need only be based on the broad categories of scores described in the next section.

While the speed and convenience of SASS-based monitoring are attractive features, it must not be assumed that interpretation of results is necessarily simple. Proper interpretation requires information about the habitats sampled, the proximity of dams, weirs and bridges and the channel characteristics, particularly the embeddedness of stones in silt and sand.

7.2 Interpretation of results

SASS4 scores respond to many types of change in water quality such as of pH from alkaline to acid in naturally alkaline streams (and vice versa), heavy metal pollution, organic pollution, silt and turbidity and increases in the TDS. Of these the response to TDS appears to be relatively small in the range of TDS found in this study (Appendix D, page 7, Mzinyatshana River for example). In fact SASS4 is sensitive to all forms of pollution which are recognised as having an impact on aquatic invertebrates.

Where southern African surface waters are not naturally acid, (pH >6, that is all parts of the country other than parts of the southern and western Cape), the data presented in this report suggest that guidelines for the interpretation of SASS4 scores should be as follows:

SASS4 >100,	ASPT >6	water quality natural, habitat diversity high
SASS4 <100,	ASPT >6	water quality natural, habitat diversity reduced
SASS4 >100,	ASPT <6	borderline case between water quality natural and some deterioration in water quality, interpretation should be based on the extent by which SASS4 exceeds 100 and ASPT is <6
SASS4 50 - 100,	ASPT <6	some deterioration in water quality
SASS4 <50	ASPT variable	major deterioration in water quality

These boundaries for interpretation are artificial boundaries in a continuum and which is why they should be used as guidelines. For instance one would be far more certain that there was chemically measurable change in water quality were SASS4 to be 60 and ASPT 4, than were SASS4 to be 90 and ASPT to be 5.5.

The fact that interpretation of scores has not been varied depending on where (mountains or lower reaches) the sampling point has been located, is due to the lack of substantial variation in either SASS4 score or ASPT along the Sabie River.

Turning now to the acid (pH <6) mountain streams of the southern and western Cape it is clear that the scores in unpolluted conditions are higher than those in the rest of the country. There are few results from polluted streams on which to base projections of the impact of water quality deterioration on SASS4 score, so the following guidelines are tentative:

SASS4 >125,	ASPT >7	water quality natural, habitat diversity high
SASS4 <125,	ASPT >7	water quality natural, habitat diversity reduced
SASS4 >125,	ASPT <7	borderline case between water quality natural and some deterioration in water quality, interpretation should be based on the extent by which SASS4 exceeds 125 and ASPT is <7
SASS4 60 - 125,	ASPT <7	some deterioration in water quality
SASS4 <60	ASPT variable	major deterioration in water quality

This guideline is based on the previous guideline for the rest of the country and the fact that SASS4 scores and ASPT were high in naturally acid streams. It requires verification.

Where the measurement of trends in water quality change over a period of time are measured using SASS4, and if there is a trend over a number of samples, the results back each other up, and smaller differences in scores than those shown above become credible.

The alternative to setting guidelines for the interpretation of SASS4 data, is that which has been adopted by the National Rivers Health Programme. It is to select the site with the highest score in a region and to use this as a reference against which scores from other sites are compared. The greatest problems associated with this approach are the selection of reference sites, the variation of results from single reference sites and the possibility of reference sites being lost due to events such as changes in land use or the building of dams. It is presumed that reference sites will be chosen to include all habitat types. The non-reference sites may include sites without a full site of habitat types. If SASS results are recorded by habitat, comparisons between monitoring and reference sites may be made on the basis of comparisons between shared habitats, omitting those habitats that occur only at the reference site.

In any case in a long term monitoring programme each sampling point will gradually build up a track record which can be examined for trends of change. One is uncertain as to how relevant reference points will be over this longer term.

7.3 Extraneous impacts on SASS4 scores

The extraneous impacts on SASS4 scores that have been recorded during this study have been described in Section 5.6. It is important to appreciate that these factors are important and should be recorded whenever they are encountered. It is only when the field conditions are properly recorded that proper interpretation of the scores measured may be made.

These impacts include the habitats sampled. Ideally there should be stones in and out of the current, marginal vegetation, and sand or mud at a sampling point. If, in natural streams, either stones or marginal vegetation are absent at a sampling point, SASS4 scores often drop to levels indicative of some water quality impact, while ASPT remains in the range for no impact. The worse the water quality, the less important the absence of habitats becomes. In polluted waters only the hardy taxa remain and they are found in both the stones habitats and the marginal vegetation.

The invertebrate communities of streams and rivers immediately downstream of dams and large weirs are modified by the proximity of these structures. Downstream recovery of the invertebrate communities is rapid, but it is suggested that sites for monitoring using SASS should not be placed within five kilometres of a dam or weir with a height greater than four metres. If sampling is to be done at easily accessible bridges, sampling should always be done upstream of the bridge.

It would seem from sites reported in this study, that a high silt load does result in low SASS4 scores. In Lesotho the impact of high silt loads was to reduce the diversity of taxa found. At the same time a small number of relatively high scoring taxa remained. The outcome was that unusual combinations of SASS4 score and ASPT were frequently recorded, with SASS4 scores between 32 and 56 and ASPT between 4.4 and 5.8 (with an outlier value of 3.0).

Rainy season sampling was for the most part avoided in this study, but results provided by Umgeni Water which included summer samples, showed that the quality of the information obtained in summer was often poor, due to the inaccessibility of those parts of the river bed permanently inundated. It is also quite probable that in high flow conditions the invertebrates tended to be swept away or made their way deeper into the bottom material.

7.4 Habitat evaluation

There are two scales on which the quality of the stream or river habitat may be assessed. The large scale evaluation depends on criteria such as the slope of the river, its sinuosity, the shape of the channel, the nature of the channel bottom, the riparian vegetation and so forth. The small scale evaluation is based on the habitats available, but one cannot isolate habitat availability from the community of organisms under consideration. In SASS4 the habitats are small because the invertebrates are small. Of all the extraneous impacts on SASS4, invertebrate habitat diversity has the greatest impact after water quality on the score measured. Where ever the impact of small scale habitat variation on SASS or BMWP has been considered (this report, Dallas 1995, Armitage *et al.* 1983) it has been found that there is little change in ASPT. Indeed this is the ground for interpreting relatively low SASS4 scores and simultaneously relatively high ASPT scores as indicating a limitation in habitat diversity, rather than a deterioration in water quality.

It is as well that as water quality deteriorates, differences between invertebrate communities of the various habitats tend to disappear, so that habitat diversity no longer plays a role in the interpretation of results.

The cases where the large scale properties of the river habitat have an apparent direct impact on the SASS4 scores are limited, and indeed may be picked up through their impact on small scale habitat diversity. In this report the scores measured in Lesotho have been ascribed to what might be regarded as river-scale habitat changes (erosion and sedimentation), but these river scale changes have contributed to the elimination of the fringing vegetation and stones out of current habitats in most places.

In a conference proceedings (Chutter 1994), an index to evaluate habitat diversity has been developed. It has not obviously been used in this report, but where the information was recorded in the data base, it has alerted the writer to refer to the field sheets where habitats scores were low. Dr C Dickens (Umgeni Water - personal communication) has reported that he has found that SASS4 scores can be related to the habitat diversity index.

8. CONCLUSIONS

The SASS4 method may be used to assess water quality in broad terms and is therefore useful in water quality monitoring. It is sensitive to all types of water quality change, perhaps less so to increases in TDS than to other types of chemical change. The greatest difficulty in interpreting results arises on the borderline between no water quality impact and slight water quality impact. Places where there is pollution are unambiguously identified using SASS4 and the ASPT value. It must be stressed that ASPT is more important than the sample SASS4 score in interpreting the meaning of the results at intermediate and high ranges of SASS4 scores.

The interpretation of results does require the careful recording of the habitats from which the invertebrate collection has been made at a sampling site. The habitats sampled play a role in the SASS4 score and in the ASPT. The amount of sediment in the river channel is an important modifier of SASS4 results.

It is advisable to record the taxa found in stones in current and stony backwater habitats apart from those found in marginal vegetation and sand/mud habitats when comparisons have to be made between sampling points.

Southern Africa would appear to be divisible into two regions as far as SASS4 scores and ASPT values in unpolluted waters are concerned. The greater part of the country appears to support invertebrate communities in which SASS4 scores greater than 100, combined with SASS4 scores of greater than 6, indicate unaltered water quality. In the southern and western Cape acid water mountain streams SASS4 scores and ASPT are higher than in the rest of the country. Here the lower limits of scores associated with unaltered water quality are higher. It was concluded that the natural condition in a South African river is for there to be no significant change in SASS4 scores or ASPT along the length of the river.

9. RECOMMENDATIONS

1. Experience with changing scores associated with individual taxa, as occurred with changing SASS2 to SASS3 and SASS3 to SASS4, is that it is very time-consuming to update sample scores. It would appear that the SASS scoring system (and presumably the BMWP too) is very robust in the sense that it is necessary to change the scores associated with many taxa before changes in the interpretation of results become meaningful. The largest change in taxon scores was from SASS2 to SASS3 and involved changing the scores of 23 taxa. Moving on to SASS4 the scores of a further six taxa were changed (**Table 2**). It is recommended that users of SASS4 refrain from changing SASS4 scores until such time as there are suggestions to change more than 20 scores. Then if change is wanted it should be based on a very careful consideration of the impact of the new scoring system on the results obtained and their interpretation.

2. Means to adjust SASS4 scores and ASPT at sites where a major habitat is missing should be investigated. This could involve building up a data base of separate paired scores for stones in and out of current (on the assumption that where there are stones in the current there will be stones out of the current) and for marginal vegetation. The results could then be compared through regression of one habitat score on the other habitat score. The regression results would then be used to adjust scores where one of these two habitats

was missing. The process would have to be done separately for the acid mountain streams of the western Cape and for the remainder of the country.

3. It is recommended that biomonitoring of the impact of water resource use on streams and rivers should be implemented as soon as possible. The results should be used to prioritise river reaches in need of restoration and to track the success of restoration in terms of the biological response. The new water act stresses the priority need to provide water for sustainable river ecosystems. Very obviously the condition of the biota of the river ecosystem is the key measure of the sustainability of the ecosystem.

4. Traditionally water quality management and the impact of effluents in rivers has been based on the chemical quality of the water usually measured in terms of the major ions and nutrients. It is very strongly recommended that SASS should also be used, for it reflects water quality over prolonged periods and integrates all water quality impacts.

5. The ability to identify aquatic invertebrates, even to the level required for the application of SASS, is limited to a small number of people in South Africa. There are no readily available and lucid illustrated guides to the aquatic invertebrates of South Africa. The solution to this problem, which will limit the application of SASS and probably cause it to lose credibility due to mis-identifications, is first of all to produce a good written and illustrated guide. Thereafter, using the guide as a tool, people can be properly trained in the identification of aquatic invertebrates. It must however be pointed out that, unless the acquired skills in identification are regularly exercised, they are soon lost. It is recommended that large organisations with regular needs for SASS surveys should use their own personnel. Smaller organisations unable to keep staff occupied with regular SASS work should hire temporary help skilled in the method.

6. There is a major gap in the areas of South Africa covered in the gathering of the SASS4 data on which this report is based. It is the Highveld region falling into Mpumalanga and the Free State which forms the catchment of the Vaal River. It is recommended that the validity of SASS4 should be established in this area.

7. Studies should be undertaken of polluted acid brown water streams to establish confirmed guidelines for the interpretation of SASS4 scores and ASPT in such waters.

11. POSTSCRIPT - JUNE 1998

The draft of this report was written in November 1995 and approved with revision by the Project Steering Committee in December 1995. The author would like to apologise to both the Water Research Commission and the community of aquatic scientists for the delay in revising the report. To those who have been using SASS and have published scientific papers including SASS information, I plead for your forbearance. I made a conscious decision that it was more important to complete this report than to take account of more recent data.

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* not seen in the original

Appendix A

SASS assessment of the condition of streams and rivers in the Witwatersrand and the Letaba River

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EXECUTIVE SUMMARY

This appendix presents the results of the earliest applications of the SASS method to streams and rivers. The work was carried out mainly on highly polluted streams draining urban and industrial areas and receiving point sources of pollution. Data from the unpolluted Letaba River in the Lowveld are included in the appendix and provide a good measure of the differences in SASS4 scores between polluted and unpolluted rivers.

In the polluted streams conditions ranged from the absence of invertebrates through to mean SASS4 scores of 50 in the least impacted parts of the Jukskei/Crocodile River system. The highest single score from this river was 70 (ASPT 3.5). In the Letaba River the lowest single score was 64 (ASPT 7.1) and mean SASS4 scores ranged between 70 and 125. The Letaba results were based on sampling only the stones in current habitat (which would result in low scores compared to the full range of available habitats), whereas all available habitats were sampled in the other rivers.

The manner in which SASS4 scores varied with water quality showed that the assessment method does yield results which follow water quality changes, provided that when SASS4 scores are less than 50, little attention is given to ASPT. ASPT proved itself to be variable when SASS4 scores were low. Under conditions of mild acid pollution, most taxa disappeared, but relatively high-scoring Leptocerid Trichoptera tolerate such conditions, so that the anomalous low SASS4, relatively high ASPT combination occurs.

ACKNOWLEDGEMENTS

I would like to acknowledge the company and help of Pearl Scotney and Dana Savrda in the field and laboratory studies reported here and to thank them.

1. INTRODUCTION

In this appendix results of the initial use of SASS in South Africa are presented. The method was applied to polluted streams in the Witwatersrand using SASS1 and later SASS2. In all cases SASS1 has been converted directly to SASS2, since identical lists of taxa were used in SASS1 and SASS2, the only changes made in developing SASS2 being the alteration of the scores allocated to many taxa (see main report section 5.4). All results are presented in SASS4, SASS2 scores being converted to SASS4 scores following the methods given in the main body of the report.

In the Letaba River SASS sampling was restricted to only the stones in current biotope. This means that the recorded SASS4 scores and numbers of taxa are not as great as they would have been had all habitats been sampled. ASPT values were probably not as much affected as SASS4 scores (see main report). The Letaba results contrast with the Gauteng area results and make a useful comparison.

At the time these studies were carried out, the intensity of field sampling effort was left to the discretion of the person doing the sampling. This was partly to gain some idea of whether the SASS method was sufficiently robust to be immune to reasonable variation in sampling effort. It is suspected that results were effected by sampling effort at some sampling points where stream conditions made for difficult sampling. Attention is drawn to results which were considered to be unreliable for this reason.

2. RESULTS

Results from the Modderfontein/Jukskei/Crocodile River (which drains the northern Witwatersrand watershed), streams on the East Rand, the Apies River (which drains central and western Pretoria) and from the Letaba River in the Lowveld are presented in this report. Sampling points in the Witwatersrand/Pretoria area were mainly on polluted rivers, while the water quality in the Letaba River was good.

In this Appendix all histograms are plotted with Y axes appropriate to SASS scores obtained in unpolluted streams and rivers. In the case of many of the results from the Witwatersrand and Pretoria, this has resulted in short histograms which may appear wasteful of space, but which serve to illustrate that scores were nowhere near as high as frequently encountered in unpolluted streams.

2.1 The Modderfontein/Jukskei/Crocodile River

Sampling points on the Modderfontein/Jukskei/Crocodile River were numbered and located as shown in **Table 1.** **Figure 1** is a schematic diagram of the position of the sampling points in relation to one another.

Table 1. Modderfontein/Jukskei/Crocodile River. Sampling point numbers and description of sampling points.

Station number	River and Locality	
M0	Modderfontein Stream:	Kelvin Power Station outflow
M1		Above AECI, in Illiondale
M3		Below AECI, just above Jukskei confluence
J2	Jukskei River:	Below Alexandra Sewage Works
J4		Above Modderfontein confluence
J5		Below Modderfontein confluence
J6		Kyalami Ranch, below Midrand
J7		Lone Hill road
J8		Indaba Hotel road
J9		Woodmead School
J10		Below Northern Sewage Works
C11	Crocodile River:	Above Jukskei confluence
C12		Below Jukskei confluence, (Winsome Valley)

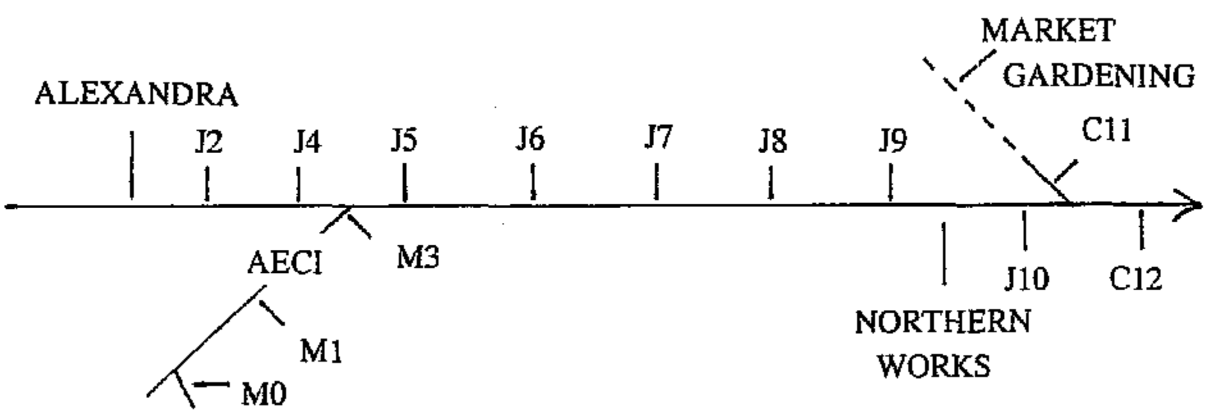

Figure 1. A schematic diagram of the sampling points on the Modderfontein/Jukskei/Crocodile River, showing the location of sampling points and places mentioned in the text.

Station M0 was in the power station effluent stream where it leaves the power Station property, Station M1 was upstream of the AECI plant (a large chemical industry plant through whose property the stream flows) and Station M3 was just upstream of the Jukskei confluence. Drainage from the Sebenza light industrial area reaches the Modderfontein stream between Stations M0 and M1. The treated effluent from AECI is discharged through a series of dams into the Modderfontein stream between M1 and M3. Features of the chemistry of this stream are that heavy metal pollution has been measured upstream of the AECI property (R E M Archibald - personal communication) and that the ammonia and nitrate nitrogen concentrations above the Jukskei confluence can be high (about 20 $mg\ell^{-1}$).

Station J2 was on the Jukskei River downstream of the effluent discharge from the Alexandra Sewage Treatment Works, Station J4 was just upstream of the Modderfontein confluence and Station J5 was downstream of the confluence. During the study it was observed on several occasions that there was an obvious difference in the turbidity and suspensiods in the Jukskei River between Stations J2 and J4. Whereas the water at Station J2 was clear, that at Station J4 was cloudy grey and included a lot of shredded paper. The origin of this material is unexplained. The effluent from the Johannesburg Northern Sewage Treatment Works entered the Jukskei River between Stations J9 and J10.

Station C11 was on the Crocodile River just upstream of the Jukskei confluence and C12 was downstream of the Jukskei confluence. The Crocodile River rises in the Krugersdorp area and its valley is used for intensive market gardening and agricultural small holdings.

The cooling water origin of the stream at Station M0 is reflected in the elevated mean temperature of the water (**Table 2**). Station M0 was characterized by the presence of a chemical precipitant covering all substrata in the stream. In addition the sodium, sulphate, chloride, nitrite + nitrate and orthophosphate concentrations were high at Station M0, due most probably to the fact that sewage works effluent is used as cooling water. Concentrations of these determinands (with the exception of orthophosphate) remained high at all three sampling points on the Modderfontein stream. Mercury and heavy metal toxicity has previously been found at Station M1 (L. Slabbert - personal communication). At Station M3, downstream of AECI, there were exceptionally high concentrations of all forms of bound nitrogen.

There were minor differences in water quality between Stations J2 and J4. At both points the concentration of bound nitrogen in all forms was very much higher than would be expected in a natural stream, probably due to the fact that there is a small sewage works upstream of Station J2 (the Alexandra Works). Nevertheless, bound nitrogen concentrations rose between these two stations, which is contrary to the expectation that they would decline

Table 2. Mean values for physical and chemical water quality determinands in the Modderfontein, Jukskei, Crocodile River system. Based on monthly grab samples in June, July, August and September 1991.

River and Sampling Point	Modderfontein stream			Jukskei River								Crocodile River	
	M0	M1	M3	J2	J4	J5	J6	J7	J8	J9	J10	C11	C12
Temperature ^{0}C (footnote 1)	19	16	13	14	15	16	17	17	12	14	15	13	14
pH (footnote 2)	8.9	8.8	7.8	7.7	7.6	7.6	7.7	7.8	7.8	8.0	8.1	8.2	8.2
Conductivity mSm^{-1}	162	162	206	65	66	97	105	90	96	70	75	64	73
Sodium $mg\ell^{-1}$	174	158	157	55	55	83	97	81	84	77	75	31	68
Potassium $mg\ell^{-1}$	16	15	15	6	5	7	8	7	6	7	7	2	6
Calcium $mg\ell^{-1}$	72	80	80	41	42	63	65	57	59	41	44	53	45
Magnesium $mg\ell^{-1}$	18	22	39	18	18	23	24	21	21	14	14	28	17
Kjeldahl N $mg\ell^{-1}$ (footnote 3)	0.8	0.8	29.1	4.5	4.7	10.5	10.4	6.7	5.6	2.2	1.0	0.5	0.9
Ammonia N $mg\ell^{-1}$	0.1	0.2	24.1	3.9	4.1	7.9	8.7	5.9	4.7	1.6	0.3	0.2	0.2
Nitrite + nitrate N $mg\ell^{-1}$	11.0	11.0	17.7	7.0	8.1	9.8	11.9	9.4	13.0	8.2	6.8	4.7	6.3
Sulphate $mg\ell^{-1}$	300	256	387	77	75	169	190	143	152	100	97	96	99
Orthophosphate P $mg\ell^{-1}$	1.0	0.4	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.9	0.1	0.4
Chloride $mg\ell^{-1}$	136	132	140	83	83	108	117	107	114	87	85	49	78
Alkalinity as $CaCO_3$ $mg\ell^{-1}$	187	25	162	133	126	136	133	141	118	124	135	178	144

Footnotes:

1. Temperatures measured in the field are reported above.
2. pH measured in the laboratory.
3. Confirming that nitrogen and orthophosphate are reported in $mg\ell^{-1}$ and NOT $\mu g\ell^{-1}$.

in a downstream direction, were there to be no additional pollution. From this observation and the behaviour of the SASS4 scores (see below) it is evident that there was an undetected source of pollution between Stations J2 and J4.

Water quality at Station J5 reflected the impact of the Modderfontein stream water on the Jukskei River (**Table 2**). The recorded values for many determinands rose slightly from Station J5 to Station J6, but then, with the exception of a few determinands which rose slightly at Station J8, declined down to Station J10. The Northern Works effluent enters the river between Stations J9 and J10. Its main impact on measured water quality determinands would appear to be on the orthophosphate concentration which rose from 0.3 to 0.9 $mg\ell^{-1}$.

Some 40 to 50 km upstream of Station C11 the Crocodile River receives a sewage works effluent. For about 10 km above the sampling point the river flows through a valley in which there is extensive market gardening. These facts probably account for the relatively (in relation to natural streams) high nitrite + nitrate, sodium, calcium, magnesium, chloride and sulphate concentrations recorded at Station C11. Water quality at Station C12 reflected the mixing of the Jukskei and Crocodile waters. Due to the relative flow volumes of the two rivers, Station C12 was more similar to Station J10 than to Station C11 in water quality.

Sampling conditions were difficult and variable at Station J7 where current speeds were high in a narrow channel. At times there was fringing vegetation suitable for sampling and at other times there was none. The river flowed in deep narrow channels incised in bedrock leading into deep pools at Station C11.

SASS4 scores in the Modderfontein/Jukskei/Crocodile system are shown in **Table 3** and **Figure 2**. The general trend (**Figure 2**) was for SASS4, number of taxa and ASPT to increase in a downstream direction, following the broad trend of improvement in water quality. Points of particular interest include the considerable biological improvement in the Modderfontein stream as it passed through the AECI property from Station M1 to Station M3. (It should however be noted that the fauna was nevertheless far from natural, as can be seen by comparison with SASS4 scores at Stations J10, C11 and C12, which are again far lower than scores from the Letaba River - see **Table 12**). It is also of interest that SASS4 scores showed that, although considerably degraded, conditions at Station J2 were better than at Stations J4 and J5. This reinforces the somewhat tentative conclusion arrived at from the chemical data from these points.

The mean numbers of taxa mirrored the SASS4 scores in many respects. Lowest numbers of taxa were recorded from the Upper Modderfontein stream and there were more taxa at J2 than at J4. The mean number of taxa recorded increased steadily from J4 to J10, whereafter there was a small decline in the number of taxa at C11 and C12.

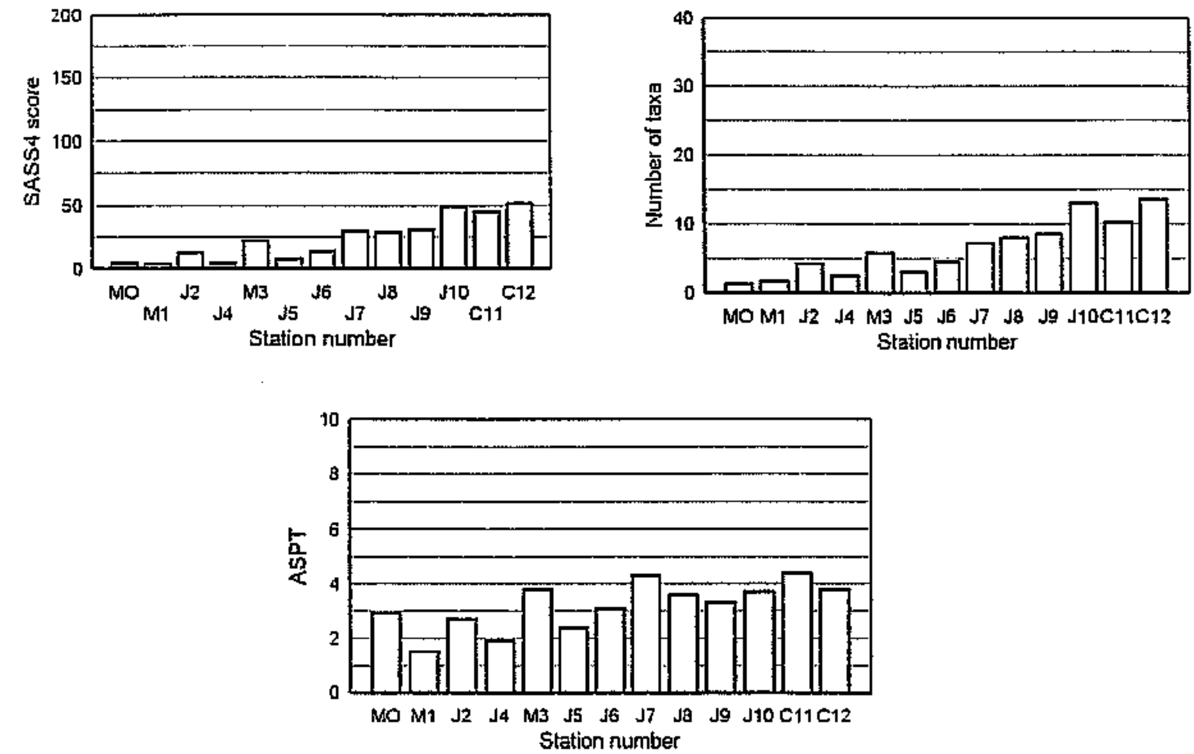

Figure 2. Mean SASS4 scores, numbers of taxa and ASPT values from sampling points in the Jukskei/Crocodile River.

ASPT results show that mean ASPT was not well related to mean SASS4 score with relatively high ASPT values at M0, J2 and M3. Broadly speaking, however, ASPT increased down the length of the river system as water quality improved.

Considering the month to month variation in SASS4 data, the most stable results came from Station C12, where SASS4 scores varied between 49 and 54, numbers of taxa between 13 and 14 and ASPT was always 3.8 (**Table 3**). J8 was another sampling point where the range of SASS4 scores was narrow. Stations where results were very variable were M0, M1, J2, J4, and J5. These stations were those exposed to the poorest water quality and had the lowest SASS4 scores. ASPT was rather variable at these sampling points. The reason for this was that with numbers of taxa being low, the impact of the presence of one moderately scoring taxon on SASS4 and ASPT was disproportionally large. At J7 (a "difficult" sampling point which has a bearing on representative sampling) there was a great variation in ASPT. At J10 and C11 single high SASS4 scores were recorded.

The variability of SASS4 results as related to the variability of ASPT in polluted streams is illustrated in **Figure 2**, where it may be seen that the mean values for ASPT show greater sampling point to sampling point variability than do the SASS4 mean values. On an individual sampling point basis this difference is illustrated by both the month to month variation in ASPT at single sampling points and by the month to month variability from station to station (**Table 3**). Month to month ASPT variability was high at Stations J4 and J5. The highest ASPT in June and July were at Station C11, in August at J10 and in September at J7. The second highest ASPT values in August and September were at the highly polluted Station M0. As will be confirmed by data sets which include a wide range of chemical conditions presented in other appendices, ASPT is an increasingly unreliable indicator of water quality as SASS4 scores drop below 50.

Table 3. SASS4 scores, numbers of taxa and ASPT values for sampling points on the Modderfontein, Jukskei and Crocodile Rivers in 1991.

Station	SASS4 Score				Number of taxa				ASPT			
	Jun	Jul	Aug	Sep	Jun	Jul	Aug	Sep	Jun	Jul	Aug	Sep
M0	11	0	4	4	3	0	1	1	3.7	0	4.0	4.0
M1	3	2	10	0	2	1	4	0	1.5	2.0	2.5	0
M3	13	20	23	23	5	6	6	6	2.6	3.3	3.8	3.8
J2	16	13	10	7	6	4	4	3	2.7	3.2	2.5	2.3
J4	7	2	7	3	3	1	4	2	2.5	2.0	1.7	1.5
J5	15	7	3	7	4	3	2	3	3.7	2.3	1.5	2.3
J6	19	10	14	13	6	3	5	4	3.2	3.3	2.8	3.2
J7	31	38	23	26	8	10	6	5	4.5	3.8	3.8	5.2
J8	32	28	29	27	9	8	8	7	3.5	3.5	3.6	3.8
J9	35	31	32	25	10	11	10	7	3.5	2.8	3.2	3.6
J10	47	48	70	32	13	13	17	9	3.6	3.7	4.1	3.5
C11	64	44	33	39	14	8	9	10	4.6	5.5	3.7	3.9
C12	49	54	49	53	13	14	13	14	3.8	3.8	3.8	3.8

2.2 Streams on the East Rand

Sampling points in the East Rand coincided for the most part with the routine water quality monitoring points used by the Rand Water Board. The points used are shown in **Table 4**, where the descriptions given in the Rand Water Board (1992) are repeated. The record of chemical quality in these streams is particularly comprehensive and is often indicative of considerable episodic pollution.

Table 4. Sampling points used on the East Rand.

Sampling Point	River and Locality	
B1 B2	Blesbokspruit:	Outflow from New Kleinfontein Dam Outflow from Van Ryn Dam
R1 R2 R5	Rietspruit:	Rietspruit from Sallies Withokspruit Rietspruit at Heidelberg-Klip River road
N8A N8	Natalspruit:	Immediately upstream of Boksburg Sewage Works Outfall Natalspruit at Heidelberg-Klip River road
K10	Klip River:	Klip River at Everite
E7 E8 E12	Elsburgspruit:	Elsburgspruit at Elsburg Town, Brug St. Stream at Elspark Stream from Elandsfontein at Moores Road

Data (**Tables 5 and 6**) on the chemical quality of the streams studied in this area have been abstracted from the 1991 results published by the Rand Water Board (Rand Water Board, 1992). Bound nitrogen concentrations were high at Stations B1 and B2, moderate at Stations N8, K10 and E7 and low elsewhere (**Table 5**). Generally, the higher the bound nitrogen concentrations, the nearer an upstream sewage effluent discharge. Sulphate concentrations were very high at sampling points R1, R5 (downstream of R1), E7 and E8.

In addition, mean pH was below 7 at Stations E7 and E8. The ERGO mine dump re-processing plant lies upstream of Station R1. Station E12 drains the industrial area of Wadeville and it is suspected, but by no means proved, that there are waste spills into this stream.

The maximum recorded concentrations of determinands not shown in **Table 5** (**Table 6**) show that there was heavy metal pollution of the Elsburgspruit and of the Rietspruit at Station R1 and R2. COD and DOC maxima were extremely high at Station E7.

The invertebrate communities in the East Rand streams (**Figure 3**) all have low SASS scores and few taxa. ASPT was particularly variable where SASS4 scores were low as has been commented on in the description of the results from the Modderfontein/Jukskei/Crocodile River. Mean SASS4 scores in East Rand streams were lowest in the Elsburgspruit (**Figure 3**), with Station E12 results no different from those from E7 and E8; despite the fact that maximum recorded values for heavy metals (**Table 6**) were lower at E12 than those recorded from E7 and E8. This supports the hypothesis (made above) that there are likely to be unrecorded waste spills from Wadeville.

Table 5. Mean annual values for water chemistry determinands at sampling points on the East Rand, taken from Rand Water Board (1992).

River system	Blesbokspruit		Rietspruit			Natalspruit		Klip R.	Elsburgspruit		
Sampling Point	**B1**	**B2**	**R1**	**R2**	**R5**	**N8A**	**N8**	**K10**	**E7**	**E8**	**E12**
Temperature °C (footnote 1)	12	12	9	11	13	12	13	12	13	11	11
pH (footnote 2)	7.4	7.7	7.6	8.0	8.1		7.8	7.8	6.3	6.7	7.7
Conductivity mSm^{-1}	69	65	245	74	215		125	76	195	145	57
Sodium $mg\ell^{-1}$	77	55	200	72	140	N	100	63	125	79	28
Potassium $mg\ell^{-1}$	17	13	18	16	13	O	16	18	16	7.7	3.6
Calcium $mg\ell^{-1}$	34	38	345	41	275		110	50	395	155	51
Magnesium $mg\ell^{-1}$	10	12	110	22	110	S	32	18	60	60	22
Kjeldahl N $mg\ell^{-1}$ (footnote 3)	3.5	5.1	< 1.0	< 1.0	< 1.0	A	3.3	< 1.0	1.8	< 1.0	1.0
Ammonia N $mg\ell^{-1}$	1.1	3.2	0.19	0.36	0.18	M	1.3	< 0.05	0.90	0.27	0.23
Nitrite + nitrate N $mg\ell^{-1}$	5.7	5.7	1.5	0.7	0.71	P	3.0	3.5	3.4	0.93	1.1
Sulphate $mg\ell^{-1}$	140	130	1310	72	980	L	350	120	1280	680	80
Orthophosphate P $mg\ell^{-1}$	.8	0.08	< 0.03	0.18	<0.03	E	0.97	0.45	0.03	< 0.03	0.71
Chloride $mg\ell^{-1}$	62	59	220	66	165	S	105	75	110	64	31
Alkalinity as $CaCO_3$ $mg\ell^{-1}$	63	52	115	200	175		110	100	27	23	140

Footnotes:

1. Temperatures measured in the field are reported above.
2. p*H* measured in the laboratory.
3. Confirming that nitrogen and orthophosphate are reported in $mg\ell^{-1}$ and NOT $\mu g\ell^{-1}$.

Table 6. Maximum annual values for water chemistry determinands at sampling points on the East Rand, taken from Rand Water Board (1992).

River system	Blesbokspruit		Rietspruit			Natalspruit		Klip R.	Elsburgspruit		
Sampling Point	**B1**	**B2**	**R1**	**R2**	**R5**	**N8A**	**N8**	**K10**	**E7**	**E8**	**E12**
Cadmium	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05		< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Chromium	< 0.05	< 0.05	0.20	0.07	1.1		< 0.05	< 0.05	0.05	0.53	0.10
Cobalt	0.12	< 0.10	0.67	0.48	0.22	N	< 0.10	0.28	0.41	0.18	< 0.10
Copper	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	O	< 0.10	< 0.10	< 0.10	< 0.10	0.11
Iron	5.2	1.1	1.1	4.0	3.3		1.6	3.0	6.4	2.4	5.6
Manganese	0.49	0.51	15	2.4	0.41		1.3	0.58	5.7	5.9	1.1
Lead	< 0.30	< 0.30	< 0.30	0.35	< 0.30	S	0.67	< 0.30	< 0.30	< 0.30	< 0.30
Zinc	0.20	< 0.10	0.53	0.12	< 0.10	A	< 0.10	< 0.10	0.52	1.4	0.31
Nickel	< 0.10	< 0.10	2.4	2.9	0.22	M	< 0.10	0.21	0.60	2.2	< 0.10
Aluminium	3.2	0.86	1.4	4.3	3.7	P	2.1	3.3	5.9	0.69	0.94
Boron	0.34	0.38	0.49	0.23	0.26	L	0.30	0.16	0.25	0.42	0.14
Fluoride	-	-	-	-	-	E	0.49	0.33	-	-	-
M.B.A.S.	0.81	0.60	1.0	1.2	0.64	S	3.0	0.69	1.7	1.4	2.4
C.O.D.	120	80	34	305	50		63	53	1950	68	79
D.O.C.	17	11	4.1	20	7.5		11	11	670	6.0	14

Footnotes: all results in mg\l

< results less than the indicated detection limit

After the Elsburgspruit, the lowest individual (as opposed to mean) SASS4 scores recorded occurred at Stations B2 and K10. In this respect the K10 result was aberrant and very probably due to very difficult field sampling conditions which could lead an inexperienced person to greatly under-sample. B2 water appeared on at least one occasion to be undiluted effluent from a very rich oxidation pond (phytoplankton was super-abundant).

Station R1 provided a good example of a fauna typical of mild acid pollution. The number of taxa found was very low but the ASPT was moderately high, mainly due to the presence of Leptocerid Trichoptera. Leptocerids are associated with high quality streams and rivers but are tolerant of low pH, evidenced by their abundance and diversity in the naturally acid brown-water streams of the southern and western Cape mountains. They have therefore been allocated high scores. They are, however, known worldwide to tolerate acid pollution.

None of the streams in the East Rand supported a fauna as diverse as would be expected in unpolluted streams with natural channels. The highest individual SASS4 score occurred at Station R5, which is below one of the very large riverine vleis. Station N8 was also below a large vlei, but in this case the Boksburg Sewage Works effluent is discharged into the vlei.

As was the case for the Modderfontein/Jukskei/Crocodile River, results from the East Rand included sampling points where month to month results were relatively constant (B1, R2, N8A) and others which were very variable (B2, K10, N8) (**Table 7**).

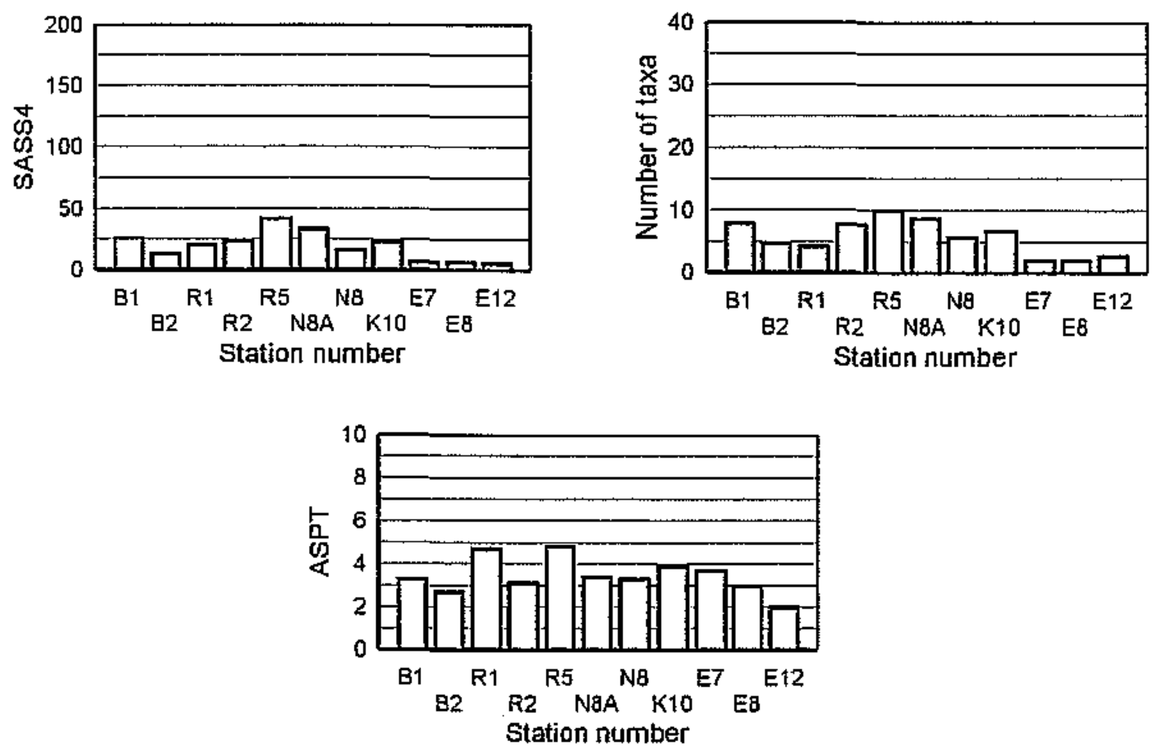

Figure 3. Mean SASS4 scores, number of taxa and ASPT values in East Rand streams.

Table 7. SASS4 scores, numbers of taxa found and ASPT values for sampling points on the East Rand in 1991. Rand Water Board station numbers.

Station number		SASS4			Number of Taxa			ASPT		
		Jul	Aug	Sep	Jul	Aug	Sep	Jul	Aug	Sep
Blesboksp't	B1	26	26	27	8	8	8	3.3	3.3	3.4
	B2	7	23	10	3	7	4	2.3	3.3	2.5
Rietspruit	R1	33	11	18	7	3	3	4.5	3.7	6.0
	R2	23	22	26	9	7	7	2.5	3.1	3.7
	R5	41	26	59	7	10	13	5.9	3.9	4.5
Natalspruit	N8A	30	39	31	8	8	10	3.7	3.3	3.1
	N8	32	18	9	8	6	3	4.0	3.0	3.0
Klip River	K10	30	7	32	7	2	11	4.3	3.5	2.9
Elsburgsp't	E7	1	9	11	1	2	3	1.0	4.5	3.7
	E8	-	4	8	-	2	2	-	2.0	4.0
	E12	8	2	6	4	2	2	2.0	1.0	3.0

2.3 The Apies River - Pretoria

Sampling points on the Apies River in and north of Pretoria are shown in **Table 8**. This stream is canalised with concrete-lined banks from Station A2 almost to Station A4. Factors having a potential impact on water quality include Daspoort Sewage Treatment Works effluent and the tributary which drains the ISCOR steel mill area, which both enter the Apies River between Stations A1 and A2. Bon Accord Dam, which serves as a mixing basin and therefore tends to reduce rapid fluctuations in water quality, lies between Stations A5 and A7. The abattoir effluent goes to the Rooiwal Sewage Treatment Works whose effluent is used as cooling water in the Rooiwal Power Station. Water quality data indicates that some sewage works effluent is discharged directly into the river. Cooling water enters the Apies River between Stations A8 and A9.

Table 8. Sampling points on the Apies River, in downstream order.

Station number	Locality
A1	Downstream of zoo, above Daspoort Sewage Works
A2	Downstream Sewage Works, Flowers St., Capital Park
A3	At Fred Nicholson St.
A4	At Wonderboom water park
A5	Bridge at Onderstepoort road, upstream of Bon Accord Dam
A6	NO SAMPLING POINT
A7	Honingsneskrans near Sphinx Station, downstream B.A.Dam
A8	Downstream of abattoir, above Rooiwal Sewage Works
A9	Downstream Rooiwal Power Station, below discharge
A10	Near Petronella railway station, Lusthof road

The impact of the Daspoort Sewage Works effluent on the quality of the Apies river was evidenced by the increases in bound nitrogen, sodium, sulphate and chloride concentrations from Stations A1 to A2 (**Table 9**). Thereafter there was little change in recorded water quality down to Station A5. Bon Accord Dam lies between Stations A5 and A7 and resulted in some expected (lower nutrient concentrations) and unexpected (higher sodium, calcium, magnesium, sulphate and chloride concentrations) changes. These unexpected changes might in fact be due to irrigation return flows, for Station A7 is not immediately below the dam which supplies irrigation water to market gardens.

Station A8 water was similar to that at Station A7, but between Stations A8 and A9 there was a considerable increase in the nutrient content of the water. This, together with an increase in the sodium concentration and major decreases in the calcium, magnesium and sulphate concentrations, suggests a large inflow of water between Stations A8 and A9, possibly from the Rooiwal Sewage Works. There was little change in water quality from Station A9 to Station A10.

In the Apies River, mean SASS4 scores and numbers of taxa were highest at Station A8 and lowest at Station A4 (**Figure 4**). There is no apparent reason why the scores should have been lowest at Station A4, but from **Table 9**, it is apparent that water quality at Station A8 was less degraded than at nearly all other sampling points. The least impacted water quality was recorded at Station A1, but from the SASS4 scores the representativeness of the analyzed water samples might reasonably be questioned.

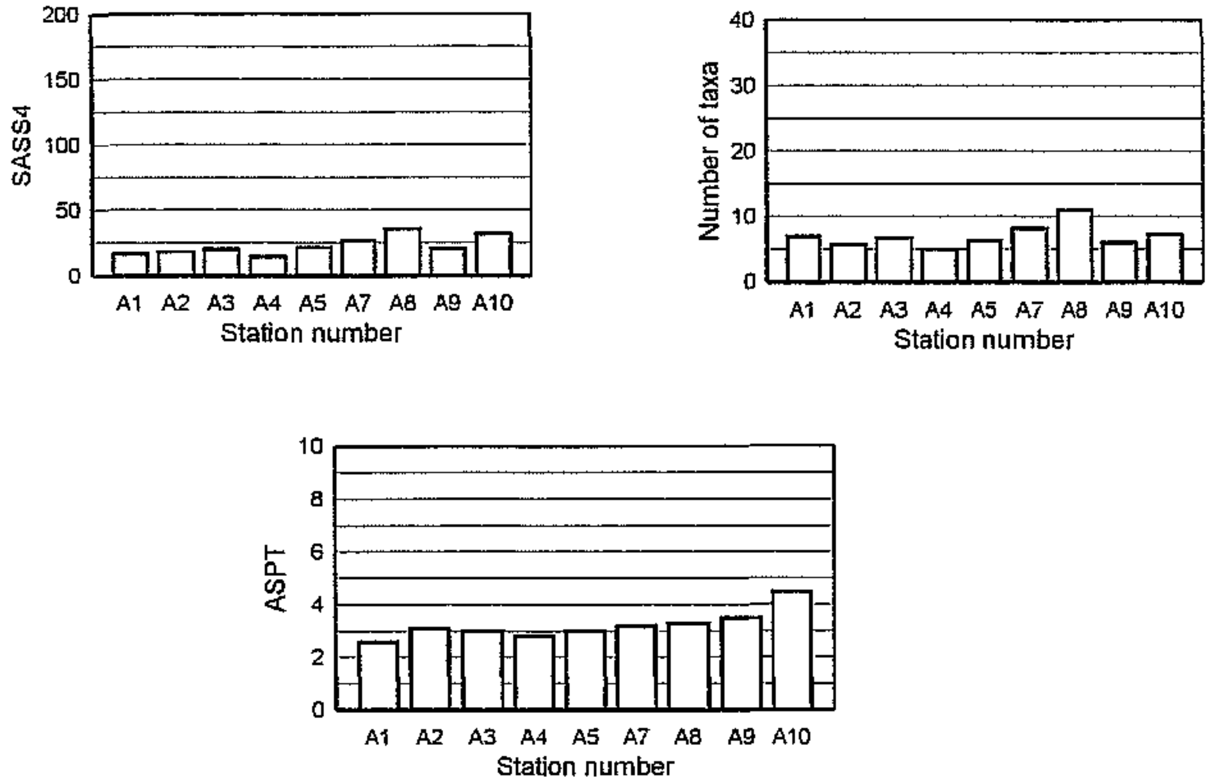

Figure 4. Mean SASS4 scores, numbers of taxa and ASPT values in the Apies River.

The change in water quality between Stations A8 and A9 coincided with a sharp decline in the SASS4 score, but there was reason to believe that stream channel conditions played some role in this decline (note the relatively high ASPT at Station A9). Station A10 had the second highest mean SASS4 score and the highest ASPT.

In general all scores recorded from the Apies River were intermediate, as were numbers of taxa recorded and average scores per taxon. Various degrees of variation in monthly scores at single sampling points were found as was the case in the Modderfontein/Jukskei/Crocodile River and in the East Rand streams (**Table 10**).

Table 9. Mean values for physical and chemical water quality determinands in the Apies River system. Based on monthly grab samples in July, August and September 1991.

Sampling Point	A1	A2	A3	A4	A5	A7	A8	A9	A10
Temperature ^0C (footnote 1)	17	17	17	17	17	16	16	19	17
pH (footnote 2)	7.9	7.9	8.0	8.0	7.9	7.9	7.9	7.9	7.9
Conductivity mSm^{-1}	59	71	73	67	74	100	104	87	87
Sodium $mg\ell^{-1}$	35	54	53	50	56	68	73	98	101
Potassium $mg\ell^{-1}$	2	4	4	4	4	3	3	6	6
Calcium $mg\ell^{-1}$	44	47	48	42	52	72	79	47	45
Magnesium $mg\ell^{-1}$	22	21	20	19	25	43	42	21	20
Kjeldahl N $mg\ell^{-1}$ (footnote 3)	1.1	2.3	1.6	1.6	1.4	0.5	0.7	1.1	0.9
Ammonia N $mg\ell^{-1}$	0.8	1.8	1.2	1.2	0.9	0.3	0.4	0.5	0.2
Nitrite + nitrate N $mg\ell^{-1}$	1.7	6.9	6.7	6.7	7.1	2.9	3.2	6.6	8.2
Sulphate $mg\ell^{-1}$	42	71	74	52	80	182	185	117	119
Orthophosphate P $mg\ell^{-1}$	0.6	0.6	0.6	0.6	0.6	0.2	0.3	1.7	1.7
Chloride $mg\ell^{-1}$	46	63	65	61	66	86	105	91	95
Alkalinity as $CaCO_3$ $mg\ell^{-1}$	198	192	188	181	202	235	215	149	208

Footnotes:

1. Temperatures measured in the field are reported above.
2. pH measured in the laboratory.
3. Confirming that nitrogen and orthophosphate are reported in $mg\ell^{-1}$ and NOT $\mu g\ell^{-1}$.

Table 10. SASS4 scores, numbers of taxa found and ASPT values for sampling points on the Apies River in 1991.

Sampling Point	SASS4 Score			Number of taxa			ASPT		
	Jul	Aug	Sep	Jul	Aug	Sep	Jul	Aug	Sep
A1	14	17	19	6	6	7	2.3	2.8	2.7
A2	10	22	23	4	7	6	2.5	3.1	3.8
A3	22	13	26	7	5	8	3.1	2.6	3.2
A4	13	10	20	5	4	6	2.6	2.5	3.3
A5	10	23	33	4	7	8	2.5	2.3	4.1
A7	19	28	34	7	9	9	2.7	3.1	3.8
A8	38	37	33	12	11	10	3.2	3.4	3.3
A9	15	24	24	5	6	7	3.0	4.0	3.4
A10	37	34	26	8	9	5	4.6	3.8	5.2

2.4 The Letaba River

The Letaba River was studied between Tzaneen and the Western border of the Kruger National Park. Sampling points were numbered in ascending order downstream. There are several large weirs in this river and many small ones. Of the sampling points reported here, Station L4 was below Prieska Weir and Station L7 about 100 m below the weir at The Slab. In the studied stretch of Letaba River there are no known direct discharges of effluent into the river. Agriculture in the river valley is very intensively developed and biocides, which may on occasion drift into the river, are extensively used on the citrus and sub-tropical fruit orchards and vegetable fields.

Water quality in the Letaba River is not subject to point source modification. There was a downstream increase in concentration in all non-nutrient determinands within the range of values shown in **Table 11**. For many of the determinands shown in **Table 11**, the maximum value was lower than the mean values in the streams which have thus far been described in this appendix. Nutrient concentrations in the Letaba (shown in $\mu g \ell^{-1}$ in **Table 11**) were particularly low.

Table 11. Minimum and maximum values for physical and chemical water quality determinands in the Letaba River.

	Minimum	Maximum
Temperature °C (footnote 1)	17	31
pH (footnote 2)	6.9	8.6
Conductivity mSm^{-1}	4	69
Sodium $mg\ell^{-1}$	4	63
Potassium $mg\ell^{-1}$	< 1	3
Calcium $mg\ell^{-1}$	2	33
Magnesium $mg\ell^{-1}$	1	19
Kjeldahl N $\mu g\ell^{-1}$ (footnote 3)	169	628
Ammonia N $\mu g\ell^{-1}$	21	222
Nitrite + nitrate N $\mu g\ell^{-1}$	57	563
Sulphate $mg\ell^{-1}$	4	39
Orthophosphate P $\mu g\ell^{-1}$	19	117
Chloride $mg\ell^{-1}$	6	81
Alkalinity as $CaCO_3$ $mg\ell^{-1}$	19	203

Footnotes:

1. Temperatures measured in the field are reported above.
2. pH measured in the field
3. Confirming that nitrogen and orthophosphate are reported in $\mu g\ell^{-1}$ and NOT $mg\ell^{-1}$.

Compared with the streams and rivers which have been previously described in this appendix, the Letaba stones in current invertebrate community was diverse and included many taxa with high SASS4 scores. Consequently, mean SASS4 scores (**Figure 5**) were far higher than in these other polluted rivers, to the extent that the lowest mean SASS4 score and the lowest mean ASPT recorded in the Letaba exceeded the highest mean SASS4 scores and ASPT from these other rivers (cf **Figures 2, 3, 4 and 5**).

The lowest SASS4 scores on the Letaba were at Station L4 which was immediately downstream of Prieska Weir (**Table 12**). Benthic samples from the Letaba River, collected and analyzed to species in a conventional manner, showed that species diversity was reduced immediately below this and other weirs. Despite this lower SASS4 score the ASPT was little different from that recorded at other sampling points.

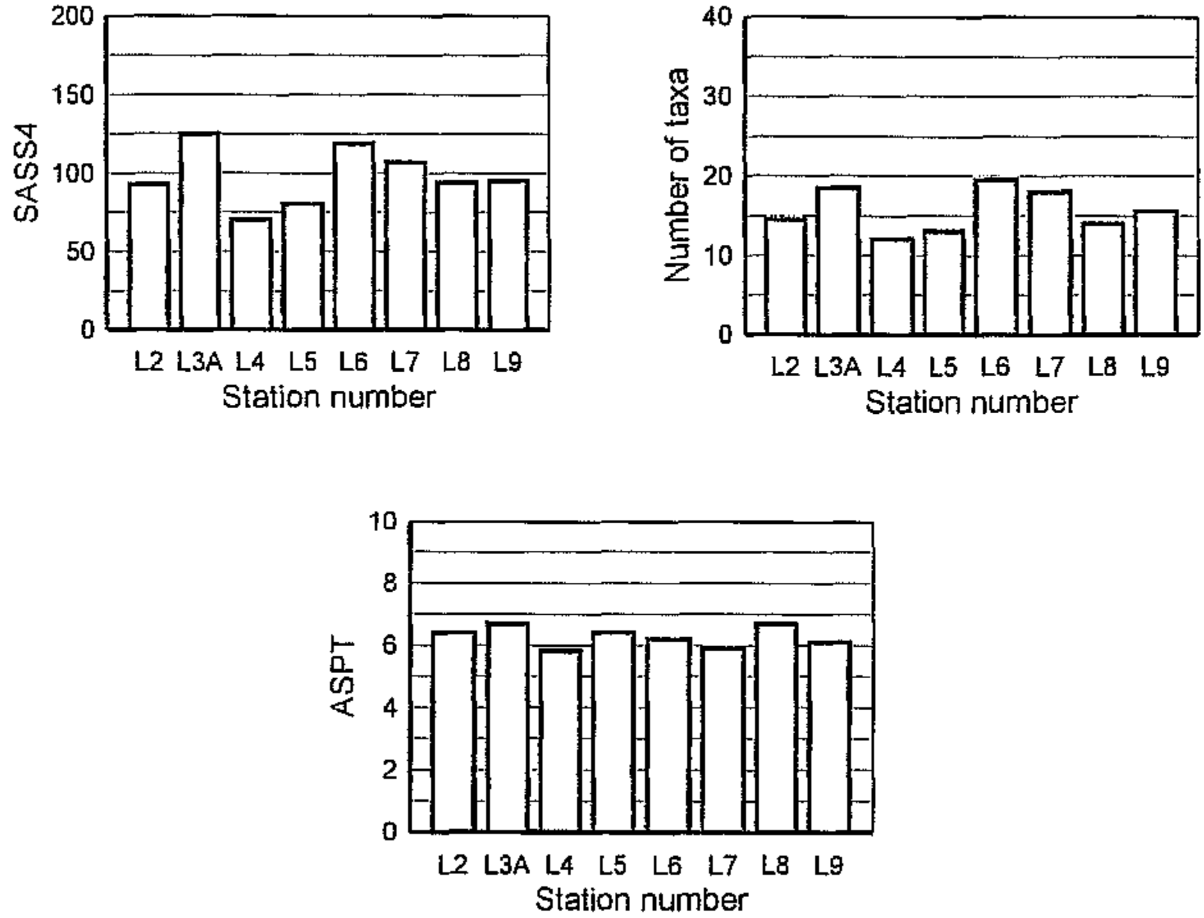

Figure 5. Mean SASS4 scores, numbers of taxa and ASPT values for sampling points in the Letaba River.

Table 12. SASS4 scores, numbers of taxa found and ASPT's for sampling points on the Letaba River between Fanie Botha Dam and the Kruger National Park in 1991.

Sampling Point	SASS4 Score		Number of Taxa		ASPT	
	May	Aug	May	Aug	May	Aug
L2	97	89	16	13	6.1	6.8
L3A	113	137	17	20	6.6	6.9
L4	74	65	12	12	6.2	5.4
L5	64	96	9	17	7.1	5.8
L6	118	120	17	22	6.9	5.5
L7	118	96	18	18	6.5	5.3
L8	96	92	13	15	7.4	6.1
L9	101	89	16	15	6.3	5.9

Another particularly low SASS4 score was recorded at Station L5 in May (**Table 12**). Here channel conditions, with stones in current restricted to narrow chutes in bedrock, were not ideal for collecting invertebrates. Having experienced this problem in the May sampling, a smaller circular hand net, which could reach the stones, was used in August. Collecting with the smaller net resulted in a large increase in SASS4 score and number of taxa collected. At Station L5 ASPT was very high in May and below average for the Letaba River in August.

The Letaba River bed becomes more sandy the further downstream the river flows. Also during extreme droughts the lowermost part of the river is the first to experience flow cessation. These facts may have something to do with the slightly lower SASS4 scores recorded from Stations L8 and L9, but it should be pointed out that this decline was not evident in the ASPT.

3. DISCUSSION AND CONCLUSIONS

The streams and rivers reported in this Appendix illustrate a variety of conditions. Firstly, the Letaba River is an example of a river in which water quality is, to the best of our present knowledge, more or less natural. It supports a high diversity of invertebrate life and neither the SASS4 scores nor the ASPT values reveal any systematic trend of change along the course of the river. However, it is necessary to recall that opportunity to sample this river arose when studies on the Rapid Biological Monitoring using invertebrates was in its infancy.

An emphasis of this discussion is that neither SASS4 score, number of taxa nor ASPT is alone adequate to interpret the water quality implications of the SASS method results. All three measures must be taken into account.

In conclusion, the data presented in this report has revealed that SASS4 scores were very low in the polluted streams of the Witwatersrand/ Pretoria area. In the Jukskei/Crocodile System SASS4 scores increased with increasing distance from the sources of pollution in the Johannesburg area, until the river received the effluent from Johannesburg Northern Works. ASPT scores were more variable. The study reach of the Apies River in Pretoria received repeated point and other sources of effluent and showed virtually no downstream recovery. Conditions in East Rand streams varied in degree of impact of water quality change. It was particularly interesting to observe the unusual impact of acid conditions on SASS4 and ASPT. The results from these streams differ greatly from the scores measured in only the stones in current in the unpolluted Letaba River. Results from the Letaba suggested that immediately downstream of large weirs (6m) the number of taxa present may be reduced.

4. REFERENCE

Rand Water Board (1992) Analyses of water in the catchment area of the Vaal Dam and the Vaal River Barrage. Forty-first Report. Rand Water Board, Johannesburg.

Appendix B

SASS assessment of the condition of the Crocodile, Sabie and Olifants Rivers in Mpumalanga, based mainly on information provided by the Institute for Water Quality Studies, Department of Water Affairs and Forestry.

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EXECUTIVE SUMMARY

In this appendix the relationships between SASS4 derived data and water quality in the Crocodile, Sabie and Olifants Rivers and their tributaries are described. The river basins are adjacent to one another in Mpumalanga Province, but the Olifants river rises considerably further to the west than do the other two rivers.

In the Sabie River, often regarded as the most natural river in north-east South Africa, ASPT evidenced no systematic trend of change over the length of the river. SASS4 was initially high, rose at sampling points upstream of Sabie Village and returned to levels similar to those at the uppermost sampling point down to the most downstream sampling point within the Kruger National Park. In contrast, most other rivers in South Africa show declining SASS4 scores and ASPT values downstream from the upper reaches. SASS4 and ASPT values were similar to those in the Sabie River only in the upper catchments of the Olifants and Crocodile Rivers.

There is reason to believe that at some sampling points of limited habitat diversity, SASS4 scores were lower than would have been the case, should the full range of habitats have been available. At these points ASPT tended to remain at the high levels associated with unimpacted sites. From the Mpumalanga rivers, combinations of SASS4 scores and ASPT values could be interpreted as follows:

SASS4 >100,	ASPT >6	water quality natural, habitat diversity high
SASS4 <100,	ASPT >6	water quality natural, habitat diversity reduced
SASS4 50 - 100,	ASPT <6	some deterioration in water quality
SASS4 <50	ASPT variable	major deterioration in water quality

When SASS4 scores were low (<50), ASPT became variable for the reason that in a community of low family diversity, the presence of a single moderately scoring family had considerable influence on the ASPT. ASPT therefore became an unreliable indicator of water quality at low SASS4 scores. When SASS4 scores are low, habitat availability has no impact on the SASS4 score, since the communities of all habitats are made up of the same tolerant taxa.

ACKNOWLEDGEMENTS

Considerable parts of this Appendix are due to data provided by the Institute for Water Quality Studies of the Department of Water Affairs. The Institute is gratefully thanked for making the data available. Mr D J Roux of the Institute has been an enthusiatic advocate and applier of the SASS method and I thank him for his support.

Much of the field work in the Crocodile River catchment was conscientiously undertaken by Ms S R Geuppert of the Division of Water Technology, frequently assisted by Mr P H McMillan of the same organisation. I thank them for their help.

1. INTRODUCTION

This appendix is an expanded version of that part of the annual report to the Project Steering Committee for 1992 which described results from the Crocodile River in Mpumalanga. The report was based on data gathered under the project auspices, supplemented by data released by the Institute for Water Quality Studies (IWQS), Department of Water Affairs and Forestry, which was simultaneously making SASS assessments of the invertebrates in the same river system. SASS2 was the version of SASS current at the time the report was written.

The expansion of the Steering Committee annual report has involved the addition of results gathered in 1993 by the IWQS. These results cover not only the Crocodile River but also the nearby Sabie and Olifants River systems.

The annual report included maps of the Crocodile River with bar charts showing SASS2 scores superimposed on them at the sampling points. Rather than attempt to revise these maps, figures have been prepared in which charts for SASS2 and SASS2 derived ASPT results are juxtapositioned with SASS4 and SASS4 derived ASPT results. These data are all for 1992. The 1993 data for the fewer sampling points have also been added to the figures. In addition to allowing close comparison of SASS2 and SASS4 data from the same samples, the figures allow the reader to compare 1992 and 1993 results.

2. THE MPUMALANGA CROCODILE RIVER SYSTEM

2.1 General description

The Crocodile River (**Figure 1**) rises in the Highveld in the Dullstroom area and descends rapidly to the intermediate altitude open valley in which the Braam Raubenheimer Dam lies. Immediately downstream of the dam the river enters Schoemanskloof in which the channel gradient again increases. It emerges from Schoemanskloof at the Montrose Falls whereafter the gradient is low all the way to Krokodilpoort, which begins at Nyamazaneni and continues almost to Kaapmuiden (**Figure 1**). From Kaapmuiden to Komatipoort the Crocodile River is in the Lowveld. The river bed is extensively sandy.

There is extensive afforestation of the high lying parts of the catchment approximately to the west of a line from Barberton to White River. Sampling points were chosen to be representative of land use types, possible water quality changes and climatic zones. The

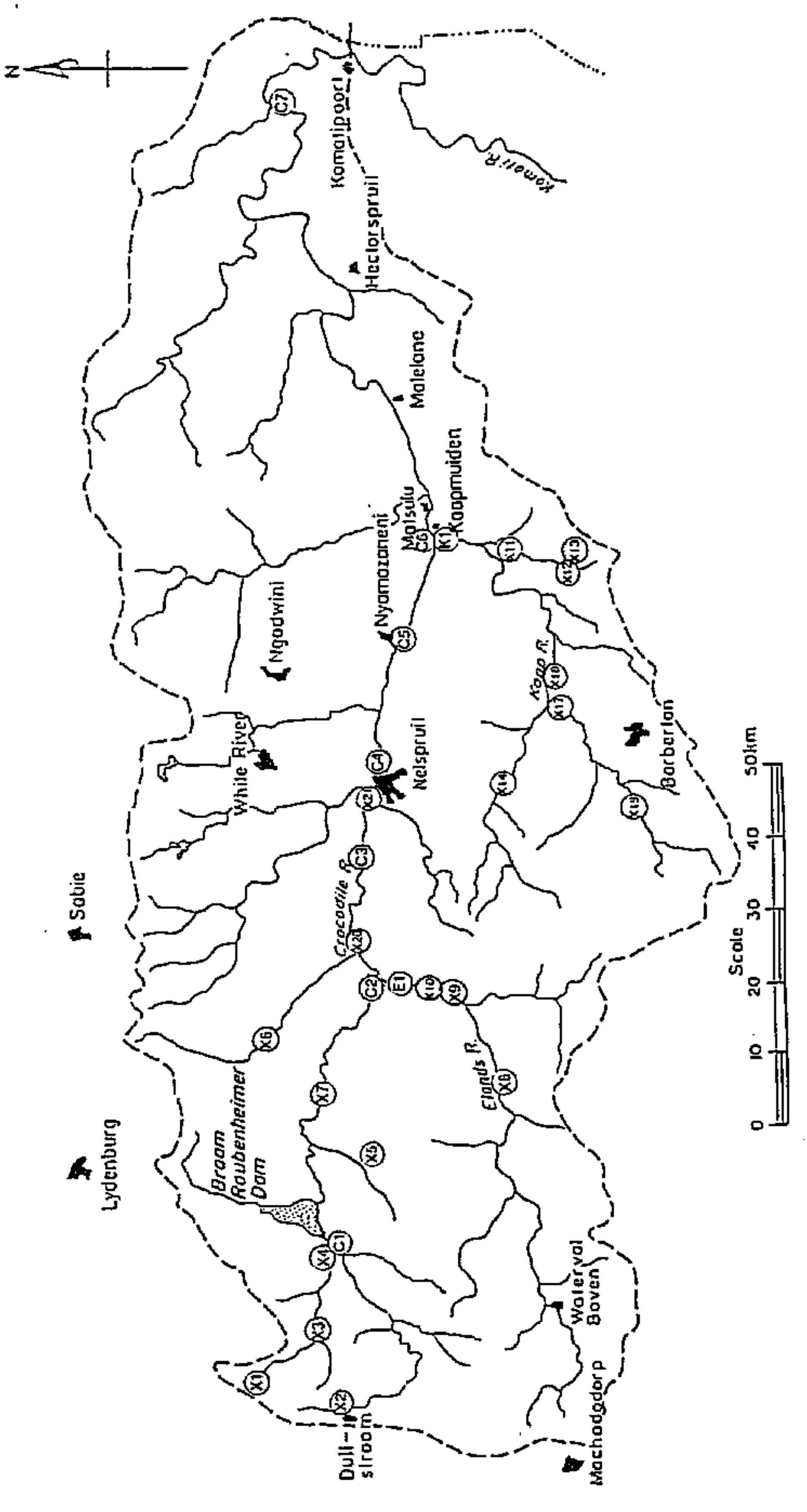


FIGURE 1: A map of the Crocodile River catchment showing sampling points used in 1992.

climate of the catchment ranges from temperate (the highest point in the Transvaal is in the Steenkampsberg approximately between Dullstroom and Lydenburg) to the hot sub-tropical low veld. Trout farming is practised extensively in dams built in streams in the Machadodorp/Dullstroom area. In the Lowveld much of northern bank is within the Kruger National Park, while there are extensive areas of irrigated sugar cane on the southern bank.

2.2 Sampling points

Figure 1 shows the sampling points used by IWQS (C1 to C10, E1 and K1) and the sampling points used in this research project (X1 to X14 and X17 to X20). X15 and X16 coincided with IWQS sampling points and sampling by the project team was discontinued when this was recognised.

Sampling points were chosen for the following reasons:

X1 - source stream in undisturbed grassland in nature reserve - Verloren Vallei. Stream gradient not torrential.

X2 - source stream in Dullstroom with trout dams and 30 m upstream a trampled muddy drift. Stream gradient low.

X3 - lower altitude than X1 in an area where the stream valley is extensively invaded by black wattle.

X4 - some arable agriculture and a large trout farm about 3 km upstream.

X5 - stream source at intermediate altitude, flowing through natural bush.

X6 - stream (Houtbosloop) in valley bottom with natural vegetation, but upper catchment heavily afforested.

X7 - Possible impacts due to river regulation and intensive agricultural development in the narrow Schoemanskloof.

X8 - A foothills stream with a known very diverse fauna; control sampling point for impacts of Sappi Ngodwana pulp mill further downstream.

X9 - Downstream of area irrigated by Sappi Ngodwana and of factory.

X10 - About 5 km further downstream.

X11 - Louws Creek downstream of gold mining operations (which are upstream of stations X12 and X13) and downstream of a highly populated area.

X12, X13 - Upper Louws Creek and tributary both of which had gold mines upstream and nearby.

X14 - Noord Kaap River upstream of Suid Kaap confluence. Here the valley vegetation was undisturbed sub-tropical bushveld with a canopy over most of the stream.

X17 - Suid Kaap above confluence with Kaap River, there are upstream mining activities.

X18 - Kaap River downstream of confluence - gold mines upstream.
X19 - Representative of a Barberton area river without active gold mining in its catchment.
X20 - Crocodile River - start of sub-tropical agriculture.
X21 - Bestersspruit, draining Nelspruit and adjacent to the Manganese Metal Company Factory.

The Institute for Water Quality Studies' sampling points were chosen to monitor impacts of towns and effluent and of tributaries on the Crocodile River. They were as follows:
C1 - Similar to X4, but no trout farm.
C2 - Crocodile River above confluence with Elands.
C3 - Between C2 and Nelspruit.
C4 - Immediately downstream of Nelspruit.
C5 - Downstream of Nyamazaneni sewage works effluent.
C6 - Downstream of Kaap River confluence.
C7 - Crocodile Bridge, impacts of extensive cane farming on south bank from between Kaapmuiden and Malelane.
E1 - Elands above Crocodile confluence.
K1 - Kaap above Crocodile confluence.

In 1993, when the project team moved on to other parts of the country, the IWQS biomonitoring team continued monitoring in the Crocodile catchment. They continued to use the above sampling points together with points X1 and X18 sampled by the project team in 1992. The IWQS has carefully documented the sampling points (**Table 1**).

2.3 Water Quality

Water samples were collected by IWQS from Stations C1 to C7 on each of the five occasions when the fauna was sampled in 1992. A very comprehensive analysis of the water was undertaken. Summarised results are shown in **Table 2** together with mean biological assessment results. Water quality was good at Stations C1 and C2 and thereafter there was an increase in the concentrations of most major ions in a downstream direction. Downstream of Nelspruit (C4) there were increases in nutrient concentrations (the mean ammonium concentration is noteworthy) and the manganese concentration was high at this station. **Table 3** shows that the quality of Elands River water was good. The deterioration of the water quality in the Kaap River is shown by the sporadic occurrence mercury, lead, vanadium and zinc (**Table 4**). The conductivity was high, compared to the Crocodile River. It is known that there are intermittent discharges of arsenic and zinc into the Kaap River (P J Ashton - personal communication).

TABLE 1: Sampling points in the Mpumalanga Crocodile River catchment, used by IWQS in 1993.

Station number this report	DWAF Station number	Locality	River	Coordinates					
				Longitude			Latitude		
CROCODILE RIVER									
C1	ZCROC-GOE	Goedehoop, upstream of Lunsklip confluence	Crocodile	25	24	32	30	18	58
C2	X2H013.Q02	Montrose, 30 m upstream of flow weir	Crocodile	25	26	50	30	42	41
C3	ZCROC-SSP	Bridge at Sterkspruit, upstream of Nelspruit	Crocodile	25	26	30	30	53	15
C4	ZCROC-LCB	Lion's Club Bridge in Nelspruit	Crocodile	25	27	47	30	59	53
C5	ZCROC-KRP	Bridge at Crocodile Poort	Crocodile	25	30	00	31	10	44
C6	ZCROC-KPM	Bridge at Kaapmuiden	Crocodile	25	32	10	31	18	42
C7	X2HO5O.Q02	Crocodile Bridge (KNP)	Crocodile	25	21	37	31	53	40
TRIBUTARIES									
X8	ZELAN-HEM	Bridge at Hemlock	Elands	25	36	00	30	33	34
E1	X2H015.Q02	Elandshoek, 1 km downstream of flow weir	Elands	25	29	37	30	42	11
X1	ZLUNZ-VVL	Lunsklip in Verlorenvlei Nature Reserve	Lunsklip	25	17	49	30	07	48
X18	ZSKAA-JOE	Joe's Luck, downstream of confluence of North & South Kaap Rivers	Kaap	25	39	52	31	07	26
K1	X2H022.Q02	Just upstream of Crocodile confluence	Kaap	25	32	34	31	19	02

TABLE 2: Mean biological (SASS2 sampling) and chemical quality of the Crocodile River in 1992. Data provided by the IWQSt, DWAF. All results in mgℓ^{-1}.

Site	C1	C2	C3	C4	C5	C6	C7
SASS2	87	136	109	42	95	111	106
No. taxa	17	20	17	9	19	21	22
ASPT	5.1	6.7	6.3	4.6	5.1	5.2	4.9
O2	9.3	9.6	9.9	8.7	9.6	8.6	9.2
Al	0.168	0.697	0.263	0.326	0.064	0.021	0
B	0.017	0.016	0.008	0.038	0	0.016	0.1
Ba	0.03	0.04	0.03	0.03	0.02	0.021	0.053
Be	0	0	0	0	0	0	0
Cd	0	0	0	0	0	0	0.018
Cr	0.018	0.032	0.001	0.001	0.002	0.039	0.01
Cu	0.001	0.002	0	0.001	0.001	0	0
Fe	1.11	1.93	0.93	0.75	0.1	0.351	0.157
Hg	0	0	0	0	0	0	0
Mn	0.037	0.101	0.097	1.978	0.061	0.065	0.56
Mo	0	0	0.001	0	0.001	0.001	0.001
Ni	0	0.013	0	0	0	0	0
Pb	0.26	0.071	0	0.063	0.165	0.036	0
Sr	0.034	0.099	0.035	0.049	0.058	0.067	0.176
Ti	0.007	0.025	0.008	0.008	0.001	0	0
V	0	0.001	0	0	0	0	0
Zn	0.013	0.032	0.03	0.021	0.009	0.001	0.007
Zr	0	0	0	0.01	0	0	0
Ca	8	10	14	15	16	16	27
Cl	3	3	7	8	10	10	36
EC	16	16.5	20.8	23.5	24.7	25.1	65.3
F	0.2	0.2	0.2	0.2	0.2	0.2	0.5
Hardness	61	62	77	83	85	88	187
K	1	1	0.9	1	1.2	0.8	1.6
Mg	10	9	10	11	11	12	29
Na	2	2	4	5	8	9	67
NH4-N	0.01	0.03	0.11	1.16	0.21	0.35	0.2
NO2-N	0	0	0	0		0	0
NO2 + NO3-N	0.12	0.24	0.21	0.52	1.52	1.19	0
pH	8.1	7.9	8.1	7.9	8.1	8	8.6
PO4-P	0.01	0.01	0.008	0.009	0.064	0.023	0.014
SAR	0.1	0.1	0.2	0.2	0.4	0.4	2.1
SO4	5	5	8	18	18	20	32
Si	9	4.5	5.2	5.4	5.2	4.8	10.2
CaCO3	65	62	72	69	66	69	249
TDS	110	110	134	146	152	157	497

TABLE 3: Water quality in the Elands River at Station E1 in 1992. Data provided by the IWQS, DWAF. All results in mgℓ^{-1}.

	May	June	July	Sept	Oct
O2	9.5	11	11.1	8.8	7.8
Al	0	0	0	0	0
B	0.034	0	0.008	0	0
Ba	0.018	0.037	0.012	0.021	0.011
Be	0	0	0	0	0
Cd	0	0.03	0	0	0
Cr	0	0.023	0	0	0
Cu	0	0	0	0	0
Fe	0.308	0.269	0.047	0.053	0
Hg	0	0	0	0	0
Mn	0.039	0.031	0.019	0.02	0.037
Mo	0	0	0	0	0
Ni	0	0	0	0	0
Pb	0	0	0	0	0
Sr	0.04	0.033	0.043		
Ti	0.001	0	0	0	0
V	0	0	0	0	0
Zn	0.019	0	0.01	0	0
Zr	0	0	0		
Ca	21	25	25	26	27
Cl	26	28	22	30	29
EC	30.2	33.1	32.7	35	34.3
F	0.2	0.2	0.3	0.3	0.2
Hardness	105	128	126	132	135
K	0.4	0.5	0.5	0.5	0.5
Mg	13	16	15	16	16
Na	9	7	9	12	11
NH4-N	0.62	0.12	0.05	0	0.15
NO2-N	0				
NO2 + NO3-N	0.19	0.04	0.29	0.3	0.23
pH	7.9	8.1	8.3	8.5	8.8
PO4-P	0.01	0.014	0.012	0.022	0.029
SAR	0.4	0.3	0.4	0.5	0.4
SO4	12	12	16	18	23
Si	7.5	0.8	5.9	7.4	6.5
CaCO3	76	94	88	93	98
TDS	177	203	198	218	228

TABLE 4: Water quality in the Kaap River at Station K1 in 1992. Data provided by the IWQS, DWAF. All results in mgℓ⁻¹.

	May	June	July	Sept	Oct
O2	8.5	9	9	6.4	7
Al	0	0	0	0	0
B	0.03	0	0.029	0	0.062
Ba	0.03	0.163	0.029	0.042	0.032
Be	0	0	0	0	0
Cd	0	0	0	0	0
Cr	0.03	0	0	0	0
Cu	0	0	0	0	0
Fe	0.316	0.19	0.124	0	0.357
Hg	0.125	0	0	0	0
Mn	0.045	0.047	0.035	0.122	0.134
Mo	0	0	0	0.013	0
Ni	0	0	0	0	0
Pb	0	0.928	0	0	0
Sr	0.147	0.166	0.159		
Ti	0	0	0	0	0
V	0.005	0.007	0	0.005	0
Zn	0	0.078	0.0005	0	0
Zr	0	0	0		
Ca	42	44	47	55	55
Cl	26	20	22	29	27
EC	63.8	73.8	74.4	80.4	86.6
F	0.5	0.3	0.2	0.3	0.3
Hardness	310	339	332	376	391
K	0.5	0.5	0	0.5	0.3
Mg	50	55	52	58	61
Na	31	31	332	41	38
NH4-N	0.07	0.08	0.07	0.05	0.47
NO2-N	0				
NO2 + NO3-N	1.85	2.14	2.24	1.96	1.38
pH	8	8.1	8.2	8.2	8.3
PO4-P	0.013	0.013	0.008	0.012	0.011
SAR	0.8	0.7	0.8	0.9	0.8
SO4	44	42	44	45	87
Si	23	22.2	20.9	26.1	23.3
CaCO3	304	321	310	358	329
TDS	571	594	586	674	678

Water samples for chemical analysis were collected by IWQS in 1993 and 1994 at quarterly intervals (**Table 5**), though sampling intensity was very much greater at C2 and K1 than elsewhere. **Table 5** confirms findings made the previous year that the total dissolved salts (TDS) increased in a downstream direction. TDS concentrations were greater in the Kaap River than elsewhere. Since the major impact of water quality on life in streams is due to high concentrations and the rate of change of concentrations, rather than to mean concentrations, the data for water samples in which concentrations of determinands greater than arbitrarily defined levels were abstracted from the water quality data base and are shown in **Table 6**. All data in this table come from the Crocodile River at Komatipoort, the Kaap River at Kaapmuiden and the Kaap River downstream of the Noord/Suid Kaap confluence.

Selected results from the analysis of heavy metals in water samples are shown in **Table 7**. In this case the criteria for inclusion of sample data in the table were, with the exception of Ti, B and Sr, based on half the maximum (or median where no maximum is given) concentration given by Kempster *et al.* (1980) in their table of water quality criteria for the protection of aquatic life in river/dam water. The table confirms the previous finding regarding sporadic high concentrations of manganese in the Crocodile River downstream of Nelspruit. In single samples zinc concentrations were high in the lower river at sites C6 and C7. It is quite probable that the zinc originated in the Kaap River catchment. The most surprising result, with very high concentrations of aluminium, iron and manganese, came from the Elands River at Hemlock (Station X8). This stream is known to support a very great diversity of aquatic organisms and is generally regarded as "pure".

2.4 SASS2 scores, numbers of taxa and ASPT. The 1992 results

Results have been initially presented as histograms on three maps covering the Crocodile catchment. Unfortunately it has been necessary to split the Crocodile catchment into three sections, covering the western part, the central part and the eastern part.

The Western Catchment

Figures 2, 3 and 4 show respectively the SASS2 scores, the numbers of taxa and the average scores per taxon. Features of the scores shown in **Figure 2**, are that the three smallest streams (X1, X2 and X5) had low SASS2 scores, that the score was low at X4 below the trout farm, and that the score was variable at C1, ranging from 40 to 140. Scores were high and sometimes remarkably constant (X8) at the remaining sampling points. The numbers of taxa (**Figure** 3) were very low at X5, intermediate at X1, X2 and X4 and usually high at the

TABLE 5: The Crocodile River System. Water quality; mean concentrations (mgℓ^{-1}) of macro-determinands from water samples collected in 1993 and 1994. IWQS data.

SITE	n*	pH	EC	TDS	Na	K	Ca	Mg	Cl	SO4	TAL	F	PO4-P	NH4-N	NO3 + NO2 - N	Si
CROCODILE RIVER																
C1	5	7.7	14.0	111	3	1.2	8	10	4	6	64	0.2	0.012	0.04	0.15	7.8
C2	22	7.8	14.2	112	4	1.3	10	8	4	7	63	0.2	0.017	0.04	0.08	5.4
C3	5	7.7	19.9	143	6	1.0	15	11	9	12	72	0.2	0.015	0.05	0.17	5.4
C4	5	7.6	22.7	157	7	1.3	17	11	9	23	70	0.2	0.011	0.86	0.50	5.4
C5	5	7.6	23.3	161	10	1.4	18	11	11	18	71	0.2	0.153	0.08	1.21	5.2
C6	5	7.6	23.8	165	11	1.1	18	12	11	19	72	0.3	0.110	0.05	1.05	4.6
C7	14	8.1	44.8	359	47	2.5	22	20	30	31	168	0.4	0.032	0.06	0.15	9.2
TRIBUTARIES OF THE CROCODILE RIVER																
X8	5	7.6	17.1	125	7	1.0	11	9	5	9	67	0.2	0.013	0.04	0.16	6.1
E1	5	7.9	33.2	220	14	0.6	26	16	31	18	93	0.2	0.024	0.05	0.31	6.0
X1	4	7.2	3.6	24	2	0.6	2	1	3	3	9	0.1	0.008	0.03	0.17	3.4
X18	5	7.9	58.8	449	29	1.3	38	39	22	82	194	0.3	0.011	0.06	0.19	11.1
K1	36	8.1	75.8	619	62	1.4	43	46	31	107	267	0.4	0.021	0.07	0.64	14.2

n* = number of samples

TABLE 6: The Crocodile River System. Water quality; concentrations ($mg\ell^{-1}$) of macro-determinands in samples in which specified concentration levels were exceeded. IWQS data.

Determinand High-lighted concentration		pH	EC	TDS	Na	K	Ca	Mg	Cl	SO4	TAL	F	PO4-P	NH4-N	NO3-N	Si
		<6.8 >8.9	>70	>500	>100	>10	>40	>50	>100	>60	>220	>1	>0.05	>0.1	>0.5	>10
SITE	DATE															
CROCODILE RIVER																
C7	Jy93	8.4	64.0	636	92	1.9	29	35	36	106	275	.6	.019	.09	.07	9.6
C7	Au93	8.1	74.9	572	83	1.0	30	33	52	35	276	.4	.007	.05	.04	9.5
TRIBUTARIES OF THE CROCODILE RIVER																
K1	Ja93	8.0	66.4	488	47	1.7	41	37	23	160	146	.3	.006	.05	.19	12.4
K1	Ja93	7.5	74.3	541	54	1.7	42	40	26	158	178	.4	.030	.05	.28	14.9
K1	Ma93	8.3	47.7	388	36	1.4	29	26	20	77	158	.3	.028	.06	1.37	14.6
K1	Ap93	8.3	75.7	645	70	1.2	42	45	31	100	290	.5	.025	.07	.61	16.7
K1	My93	8.2	81.4	676	81	1.7	44	42	35	113	294	.6	.020	.12	.08	10.1
K1	My93	8.3	78.0	674	79	1.5	43	45	34	113	293	.6	.021	.07	.22	11.6
K1	My93	8.1	86.0	714	85	1.2	46	47	35	117	312	.4	.022	.06	.54	14.7
K1	My93	8.3	85.8	690	81	1.2	44	45	37	111	301	.5	.018	.10	.53	13.6
K1	Ju93	8.0	86.0	689	77	1.0	44	46	32	103	313	.5	.015	.05	.57	14.1
K1	Ju93	7.9	80.4	713	82	1.0	42	48	35	106	324	.5	.029	.08	.66	14.0
K1	Ju93	8.4	92.1	728	81	.8	44	54	38	101	332	.6	.014	.11	1.01	15.6
K1	Jy93	8.1	87.5	770	92	1.0	44	56	35	117	345	.6	.012	.07	.75	13.4
K1	Jy93	8.4	87.8	769	93	.9	45	53	38	116	343	.6	.012	.07	.87	14.5
K1	Jy93	8.1	76.7	777	95	1.1	43	54	51	104	347	.6	.025	.10	.90	13.3
K1	Jy93	8.3	96.5	787	92	.7	44	55	42	112	358	.6	.007	.06	.95	14.8
K1	Au93	7.8	90.7	733	61	.5	51	62	34	69	365	.3	.008	.10	2.22	18.0
K1	Oc93	7.7	80.4	645	40	.2	53	56	29	44	340	.3	.015	.10	1.86	21.3
X18	Oc93	8.0	63.4	499	34	1.5	43	42	24	101	206	.2	.019	.10	.21	12.6

TABLE 7: The Crocodile River System. Water quality; concentrations (mgℓ⁻¹) of heavy metals in water samples in which specified concentration levels were exceeded. IWQS data.

Metal		Ti	B	Sr	Cu	V	Al	Cr	Fe	Mn	Ni	Cd	Pb	Zn	Ba	Co
Kempster max*		12	5	200	0.200	0.500	1.5	0.100	1.000	1.000	0.050	0.030	0.100	0.100	5.000	1.000
High-lighted conc >		0.250	0.250	1.000	0.100	0.250	0.750	0.050	0.500	0.500	0.025	0/015	0.50	0.050	2.000	0.500
SITE	DATE															
CROCODILE RIVER																
C1	Jy93	.002	.014	.035	0.000	0.000	.041	0.000	**.875**	.020	.004	0.000	0.000	.029	.044	0.000
C1	Oc93	.002	0.000	.034	0.000	.002	.076	0.000	**.582**	0.000	.017	0.000	0.000	.010	0.000	0.000
C2	Au93	.005	0.000	.028	0.000	0.000	.157	0.000	**.660**	0.000	.002	0.000	0.000	0.000	0.000	.002
C2	Oc93	.013	0.000	.033	0.000	.004	.376	0.000	**1.206**	.030	.010	0.000	0.000	.024	0.000	0.000
C3	Oc93	.006	0.000	.035	0.000	.004	.269	0.000	**.956**	.042	.016	0.000	0.000	.032	0.000	0.000
C4	Jy93	.001	.025	.048	0.000	0.000	.030	0.000	.147	**1.471**	.007	0.000	0.000	0.000	.081	.003
C4	Oc93	.005	0.000	.048	0.000	.004	.166	0.000	**.622**	**1.323**	.013	0.000	0.000	.015	0.000	0.000
C5	Oc93	.006	0.000	.061	0.000	.002	.349	0.000	**.712**	.456	**.035**	0.000	0.000	.015	0.000	0.000
C6	Jn93	0.000	.026	.067	0.000	0.000	0.000	0.000	.038	.006	0.000	0.000	0.000	**.069**	.020	0.000
C7	Jy93	0.000	.152	.199	0.000	.001	0.000	0.000	.079	.003	.004	0.000	0.000	**.271**	.112	.002
TRIBUTARIES OF THE CROCODILE RIVER																
X8	Jy93	.004	.010	.046	0.000	0.000	0.000	0.000	**.716**	.008	.004	0.000	0.000	0.000	0.000	.003
X8	Oc93	.073	0.000	.047	.056	.098	**12.174**	**.053**	**24.973**	**1.105**	**.050**	0.000	0.000	**.088**	.176	0.000
E1	Jy93	.002	.017	.045	0.000	0.000	0.000	0.000	**.776**	.112	.007	0.000	0.000	0.000	0.000	.005
E1	Oc93	.005	0.000	.039	0.000	.003	.175	0.000	**.573**	.026	.011	0.000	0.000	.022	0.000	0.000
X18	Au93	0.000	.002	.245	0.000	0.000	0.000	0.000	0.000	0.000	.003	0.000	0.000	0.000	0.000	.013

Measured - not detected in the samples included in this table: Hg Be Mo Zr As

*see text

other sampling points. The range of ASPT values (from about 3.7 to 7) was narrow. ASPT at Station X4 was low, at X1 and X5 usually above 5, but each included an ASPT of 4, X2 was never above 5 and the ASPT at the remaining stations (X3, X6, X7 and X8) was usually above 6.

To review the content of these three figures, SASS2 scores were low in small streams (X1, X2 and X5) but provided that the streams were not disturbed (X1, X5) ASPT scores were high. At Dullstroom (X2), the score was low and ASPT was intermediate, indicating that deterioration in river conditions. It has been pointed out that there was obvious disturbance of the river channel just upstream of the sampling point, but without a comprehensive investigation of water quality, it is impossible to pin point the cause of the low SASS2 and ASPT scores. Station X4 shows the impact of the nearby trout farm - low SASS2 score, intermediate number of taxa and consequently a low ASPT. From the nature of the pollution of streams by trout farms - increased organic load and nutrient load, low dissolved oxygen at night - the result is not at all unexpected. At X6 where there was no reason to expect deterioration of water quality, SASS2 scores tended to be intermediate, but the ASPT was as high as anywhere else. Sampling conditions - a stony bed with large stones and no fringing vegetation - were difficult at X6.

The content of **Figures 2**, **3** and 4 clearly shows that the ASPT has a major role to play in the interpretation of results.

The Central Catchment

Results for this area are shown in **Figures 5**, **6** and 7 where it is obvious that there were considerable differences in all SASS2 scores, numbers of taxa and ASPT along the course of the Elands/Crocodile River. From X9 down to C3 and including C2, SASS2 scores, numbers of taxa and ASPT values were high and it is noteworthy that ASPT fell below 6 in only 4 of the thirty samples collected at these points. The Bestersspruit (X21) was almost devoid of fauna, resulting in an extremely low SASS2 score, a limited number of taxa recorded and an ASPT that was surprisingly high in relation to the SASS2 score. SASS2 scores were all low at C4 downstream of Nelspruit and increased at C5. ASPT scores at C4 and C5 were a little lower than the ASPT scores of the upper river.

SASS2 results from the Noord Kaap River at X14 showed that the fauna was diverse in May, reduced in June, totally eliminated in July and that it showed some recovery by October. This would be expected were there intermittent toxic pollution as suspected in the Kaap basin. At the other sampling points in the Kaap basin SASS2 scores and ASPT were intermediate to high.

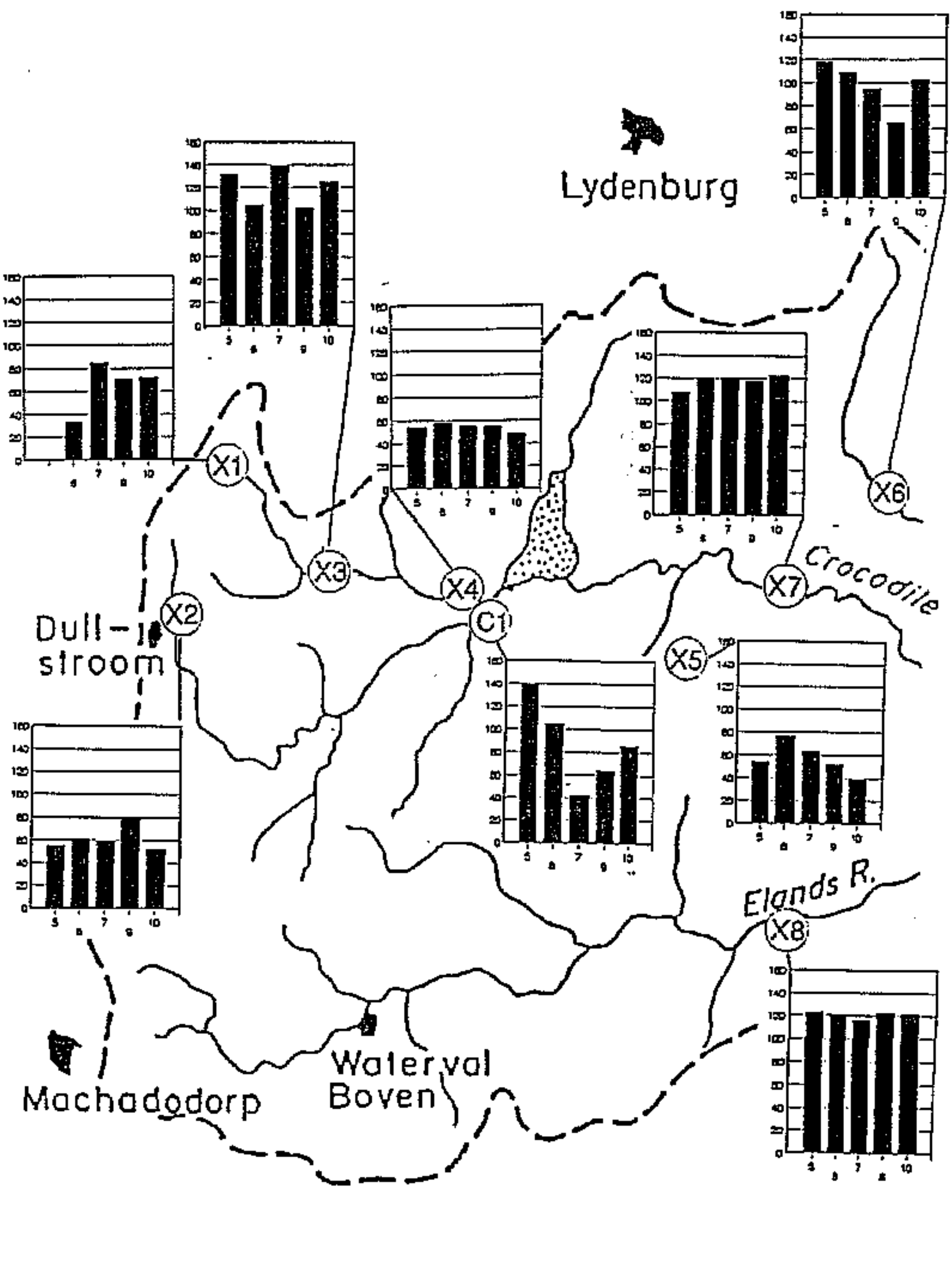


FIGURE 2: SASS2 scores from sampling points in the Western part of the Crocodile catchment in 1992. Horizontal axis months when samples were collected, vertical axis score.

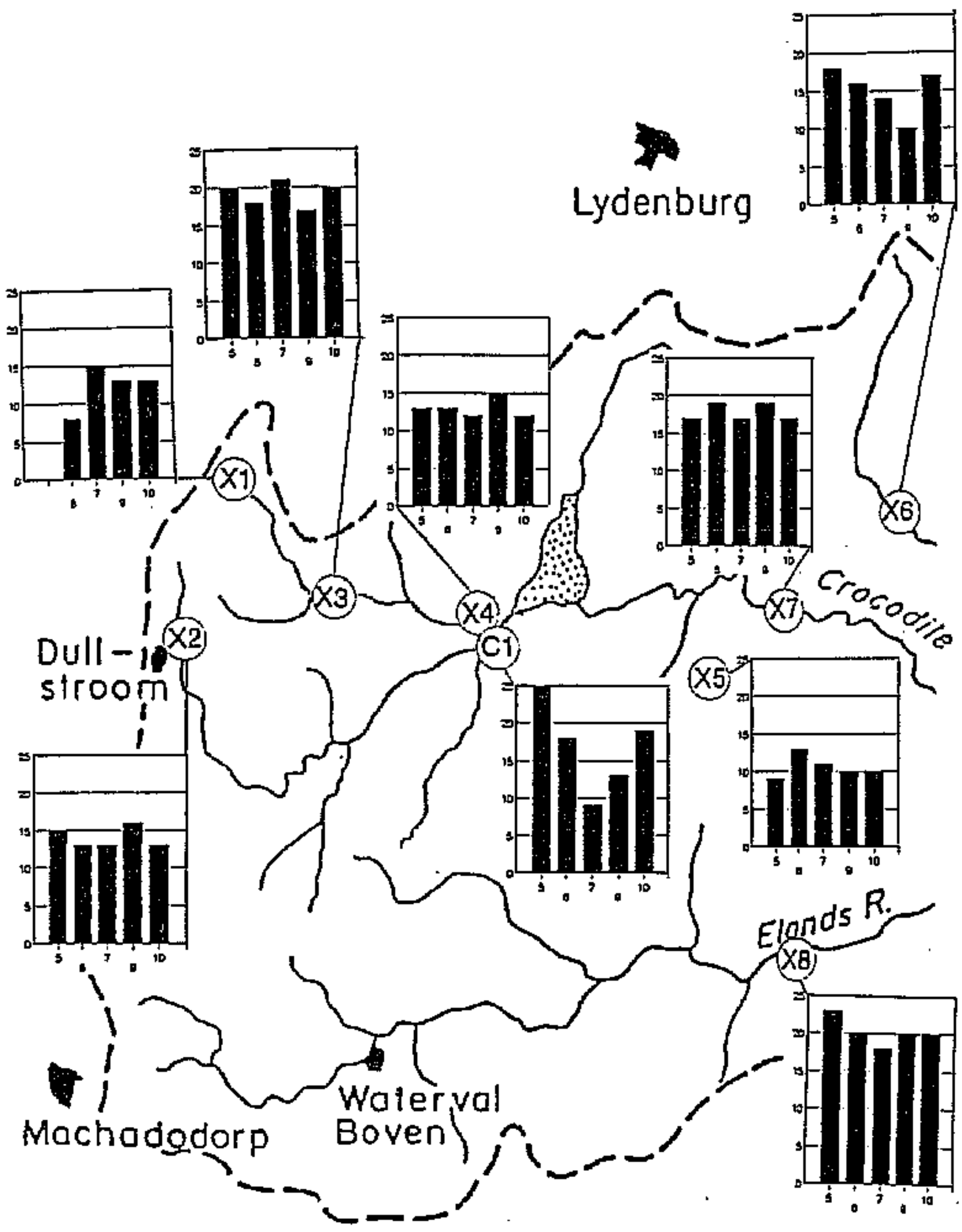


FIGURE 3: Numbers of taxa from sampling points in the Western part of the Crocodile catchment in 1992. Horizontal axis months when samples were collected, vertical axis number of taxa.

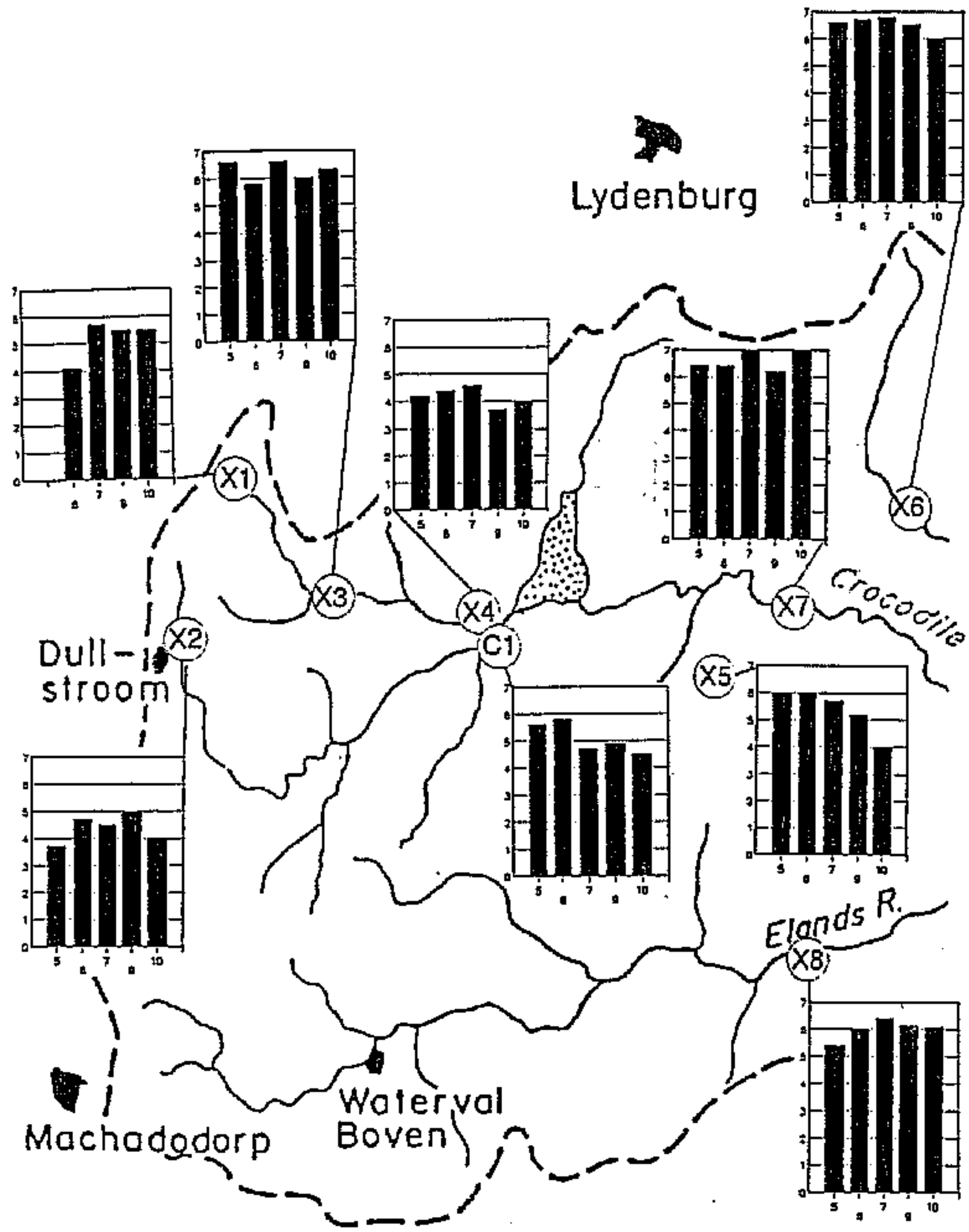


FIGURE 4: ASPT scores from sampling points in the Western part of the Crocodile catchment in 1992. Horizontal axis months when samples were collected, vertical axis ASPT score.

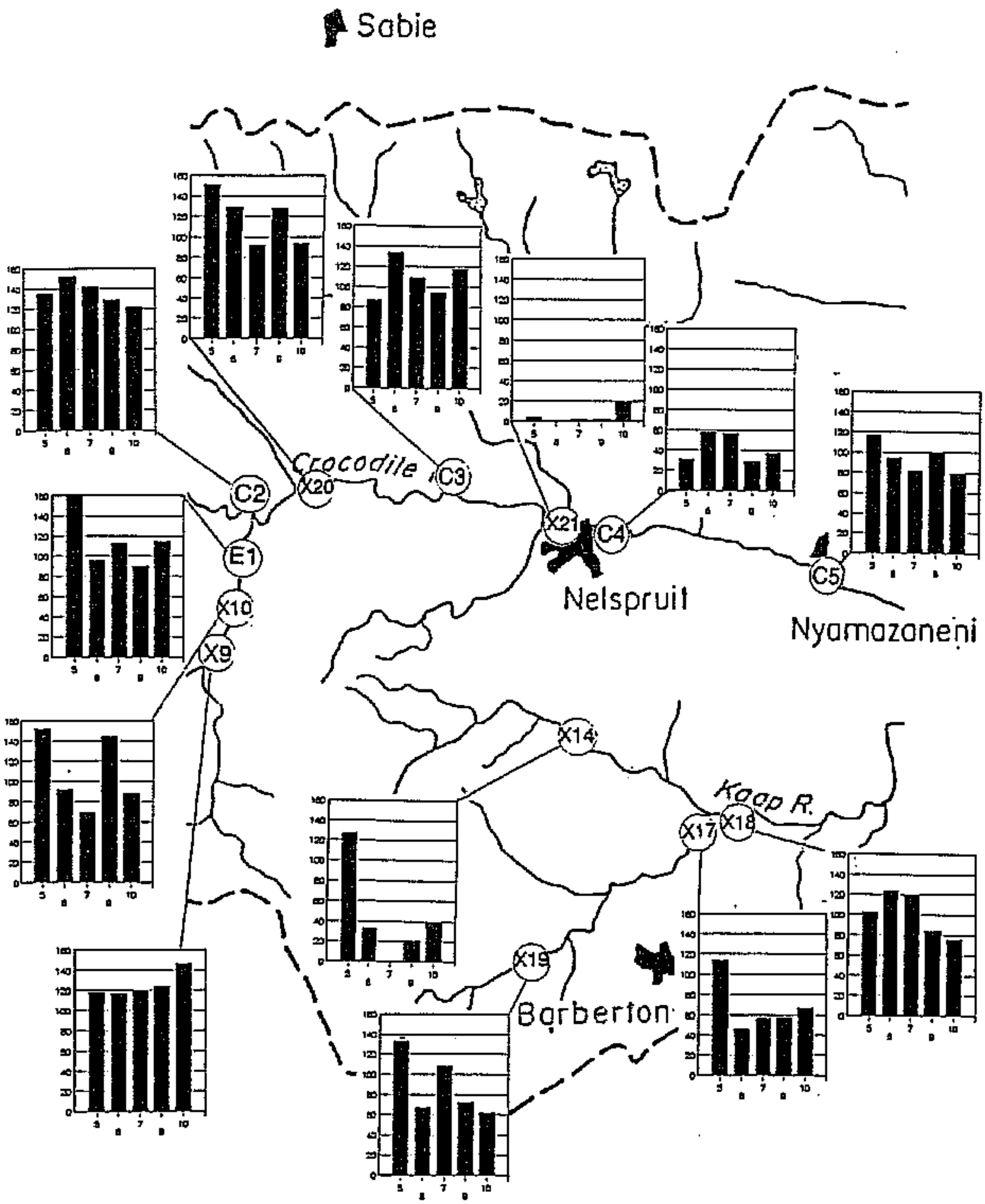


FIGURE 5: SASS2 scores from sampling points in the Central part of the Crocodile catchment in 1992. Horizontal axis months when samples were collected, vertical axis score.

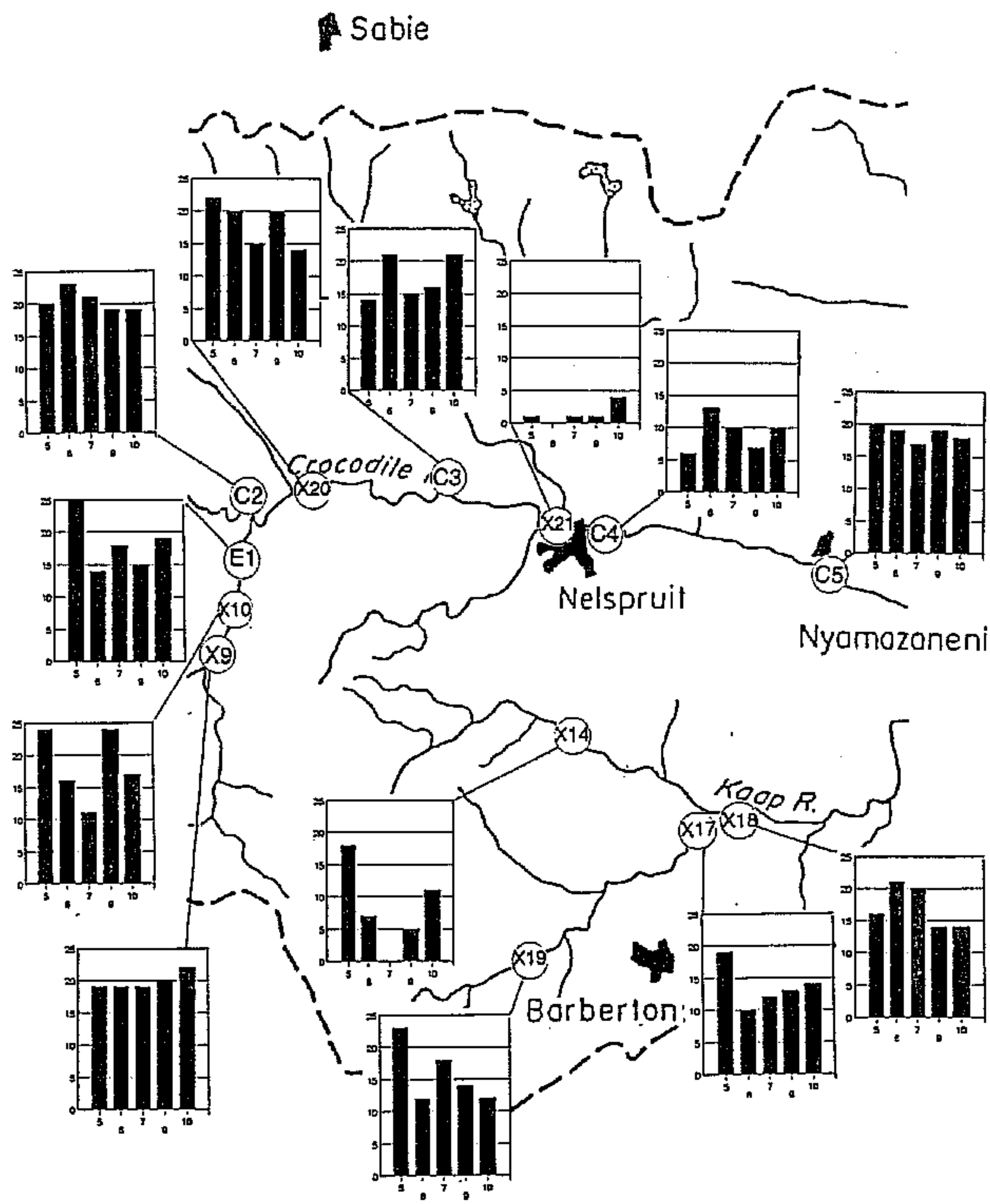


FIGURE 6: Numbers of taxa from sampling points in the Central part of the Crocodile catchment in 1992. Horizontal axis months when samples were collected, vertical axis number of taxa.

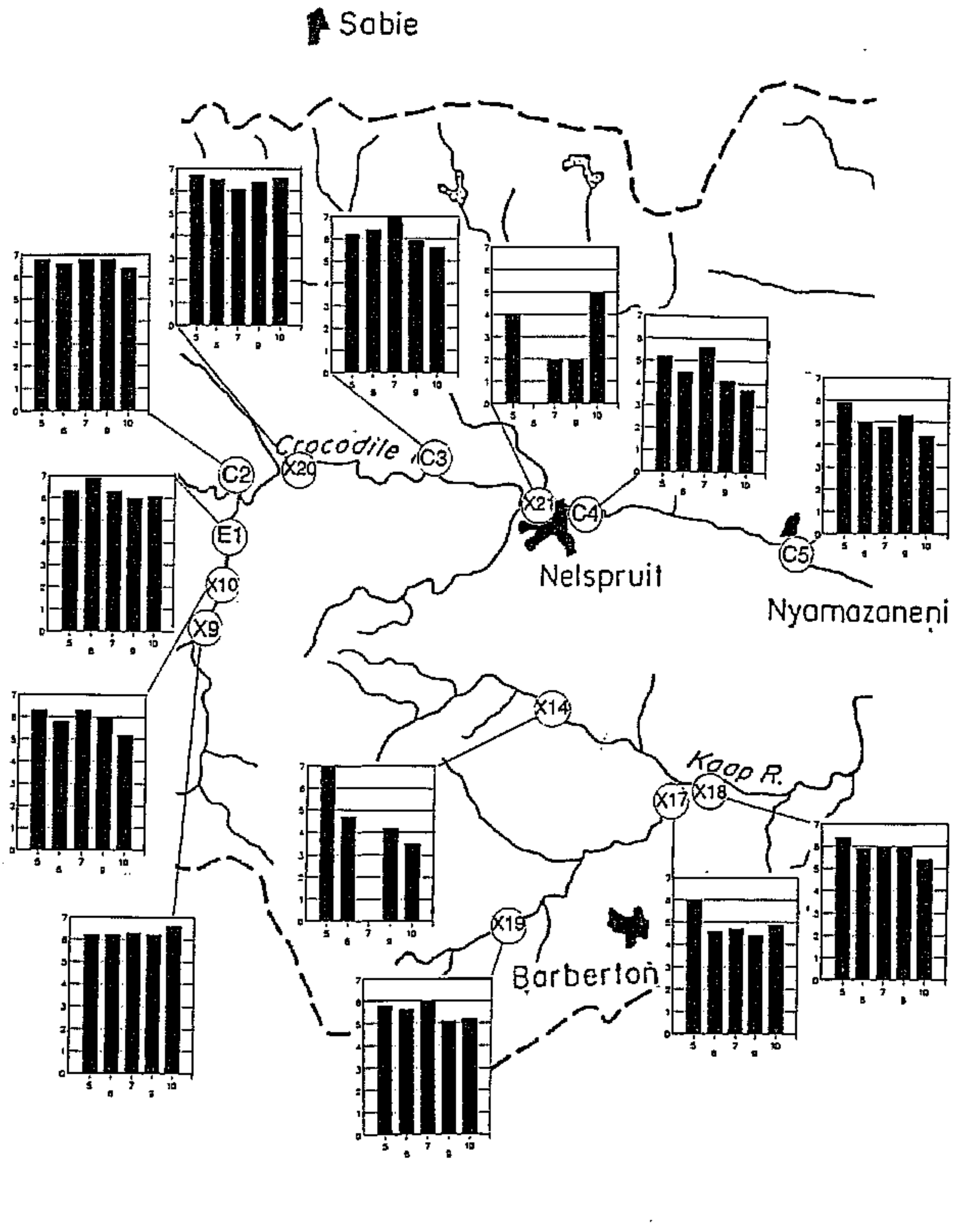


FIGURE 7: ASPT scores from sampling points in the Central part of the Crocodile catchment in 1992. Horizontal axis months when samples were collected, vertical axis ASPT score.

In reviewing the results from the central catchment of the Crocodile River attention must be drawn to the fact that in the Elands River there was no evidence of a continuing impact due to the effluent spill from the paper mill at Ngodwana in 1989. As evidenced by the SASS2 scores and ASPT, pollution sensitive families were as abundant at sampling points in the Elands River as they were anywhere in the Crocodile River basin.

The results from the central catchment show that both the SASS2 score and the ASPT must be taken into account in interpreting results. This is illustrated by Station X21 where the SASS2 scores revealed the paucity of the fauna, but the ASPT scores were sometimes fairly high. In such cases the interpretation rests heavily on the SASS2 score. The other point emphasized by the central area results is the power and efficiency of biological examination in revealing intermittent pollution (Station X14).

The Eastern Catchment

The sampling points in this area were on Louw's Creek, the Kaap River and the lower Crocodile (**Figures 8, 9** and **10**). At all three sampling points (X11, X12 and X13) on Louw's Creek SASS2 and ASPT scores were intermediate, indicating some deterioration in water quality. Unfortunately, water quality data for this stream is not available. At Kaapmuiden (K1) SASS2 scores were marginally lower than upstream at X18 and lower than at C6 in the Crocodile River downstream of the confluence. This is a sampling point where there was some suggestion from the chemical results (**Table 4**) that there were intermittent increases in heavy metal concentrations. Also the TDS concentrations (**Tables 4, 6**) were very high at this point. ASPT scores were lower than at the next upstream station (X18) (**Figure 7**).

SASS2 and ASPT scores in the Crocodile River at station C6 were slightly higher than at C5, suggesting a small improvement in water quality, which is not readily evident from the water quality data (**Table 1**). Moving further downstream to Komatipoort (C7), a large variety of animals was collected ((**Figure 9**) and SASS2 scores were sometimes high, but the ASPT was no more than 5 (**Figure 10**), suggesting that the variety of animals was due to an abundance of taxa with moderate to low scores. On average both SASS2 and ASPT were a little lower at Station C7 than at Station C6, which is in accordance with the general trend of water quality variation.

In review of the results from the eastern catchment of the Crocodile River, this was an area where SASS2 and ASPT scores were often intermediate, suggesting that there was some deterioration in water quality. This is reflected in the water quality data for the three

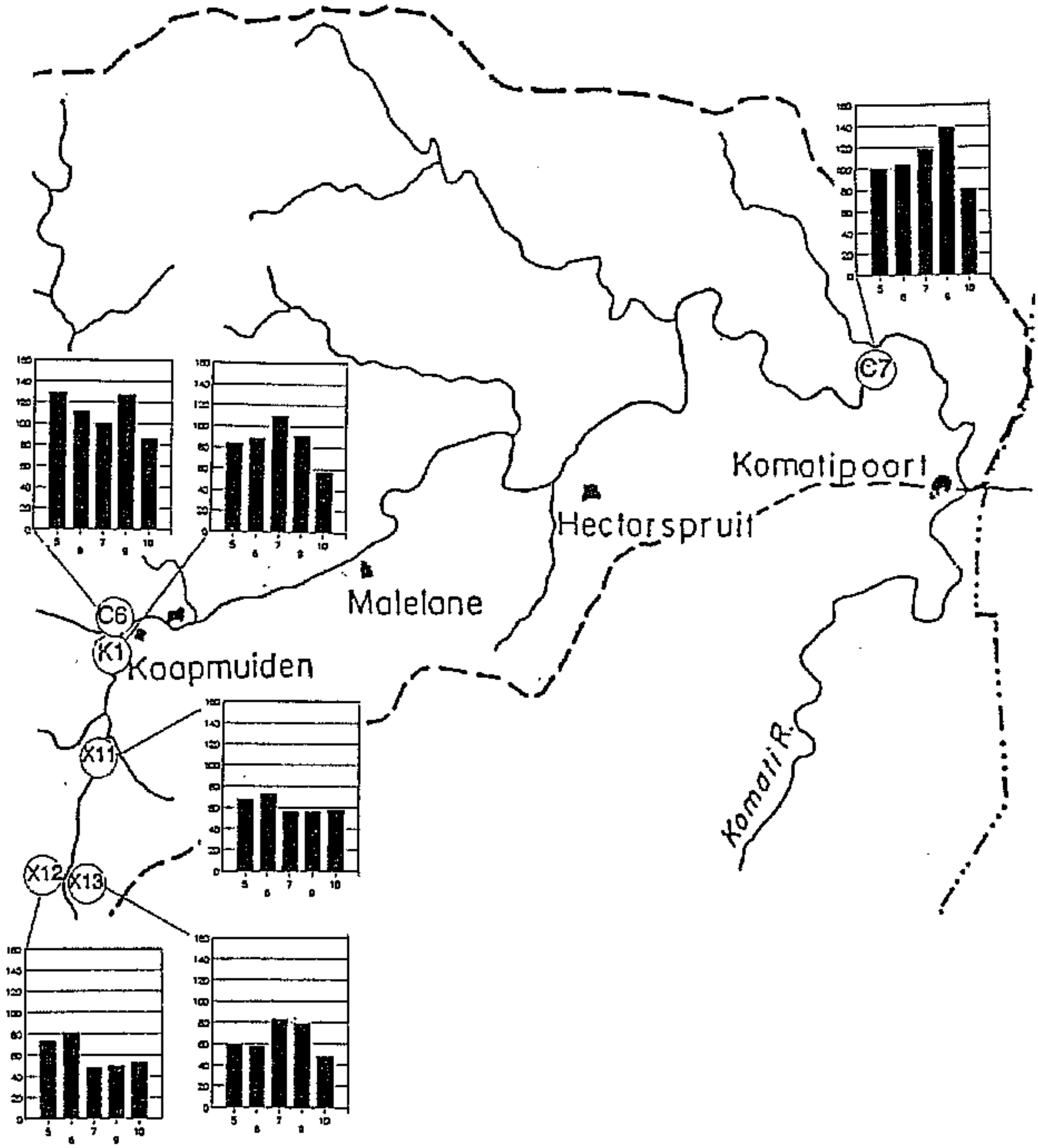


FIGURE 8: SASS2 scores from sampling points in the Eastern part of the Crocodile catchment in 1992. Horizontal axis months when samples were collected, vertical axis score.

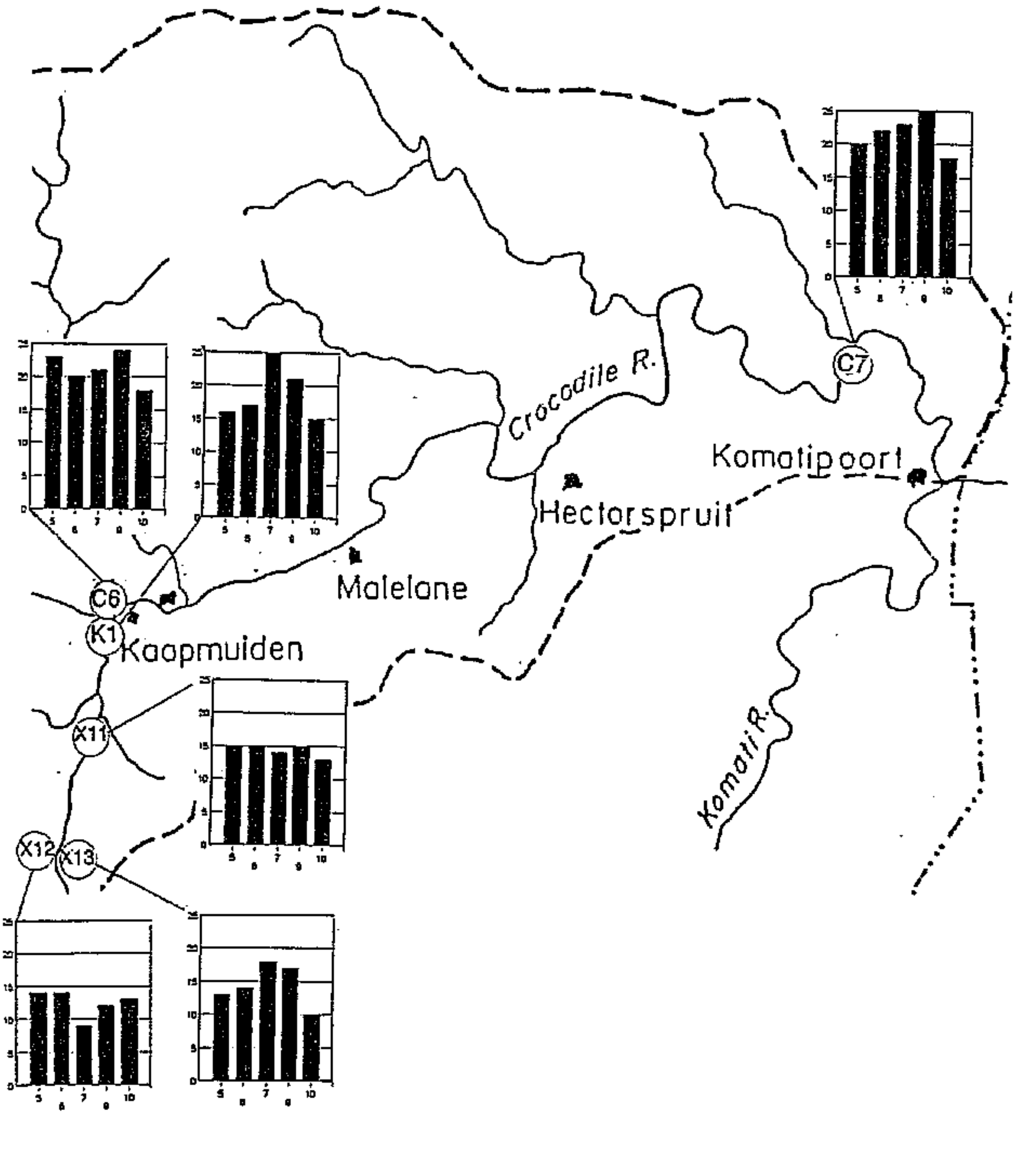


FIGURE 9: Numbers of taxa from sampling points in the Eastern part of the Crocodile catchment in 1992. Horizontal axis months when samples were collected, vertical axis number of taxa.

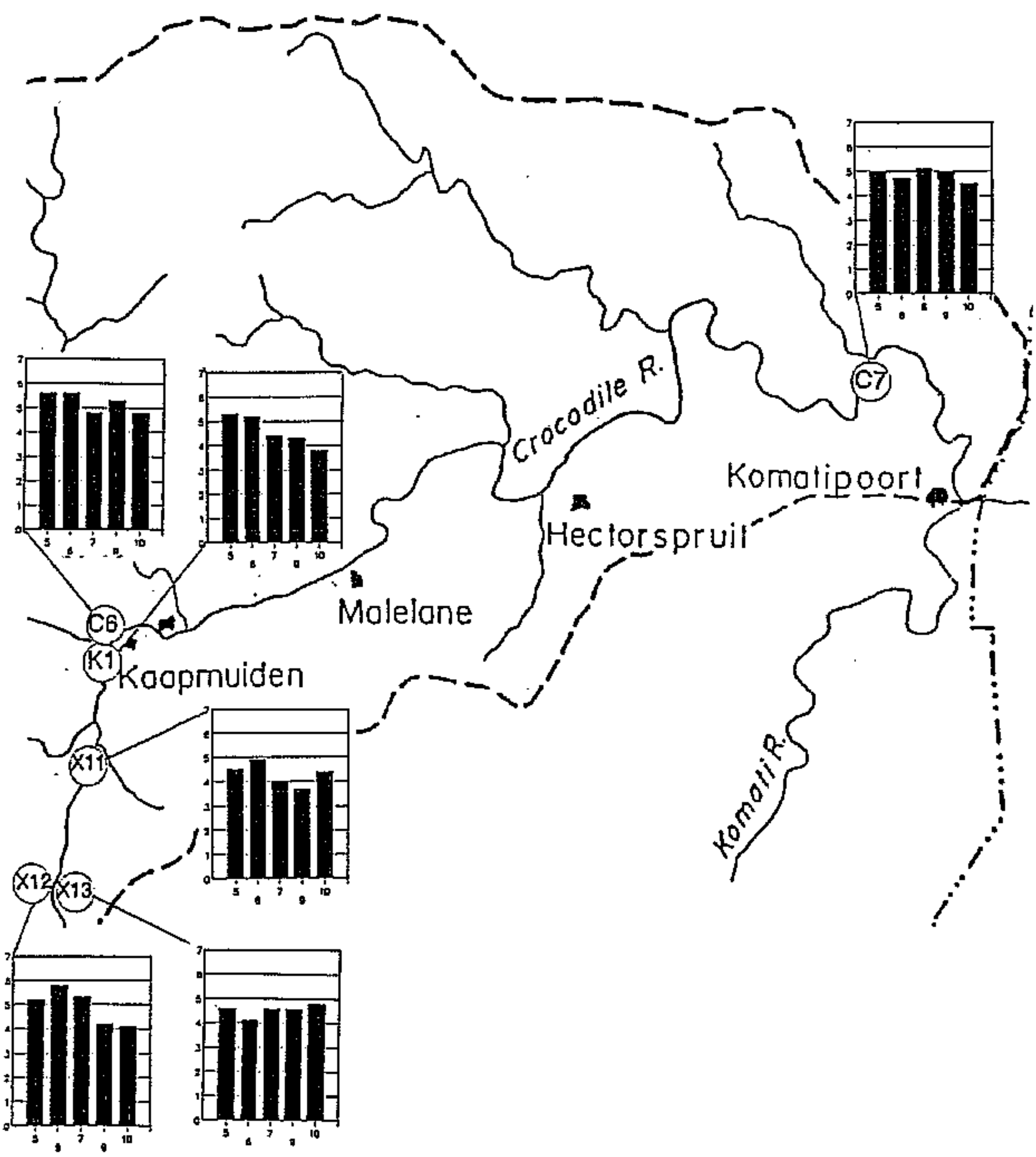


FIGURE 10: ASPT scores from sampling points in the Eastern part of the Crocodile catchment in 1992. Horizontal axis months when samples were collected, vertical axis ASPT score.

sampling points where water quality data were available (C6, C7, K1) but cannot be confirmed for the data from Louw's Creek. There is, however, every reason to suspect that water quality in Louw's Creek is not pristine, because of the active gold mining in its headwaters.

2.5 Comparison of SASS2 results with SASS4 results and of 1992 with 1993 data.

In this section data is shown in figures in which SASS2 scores and ASPT (previously presented) are shown above SASS4 scores and ASPT and in addition IWQS data from 1993 are shown under the 1992 data. Gaps in the figures arose out of the fact that in 1993 IWQS did not use all the sampling points used in 1992 by the project team.

The comparisons are made in **Figures 11 to 16**, where it may be seen that for the most part high SASS2 scores results in higher SASS4 scores, increases frequently being as great as 25 (**Figure 11**, site C2, **Figure 13** and 14, scattered individual samples). On the other hand when SASS2 scores were low SASS4 scores were identical or almost identical (**Figure 11**, Site C4, **Figure 14**, Site X21, **Figure 15** almost all sites). In general, the shapes of the bar charts for each pair of SASS scores at each site were similar, with peaks and troughs occurring in the same months, whether the invertebrates were scored using SASS2 or SASS4.

When SASS2 based ASPT scores were high (above 6), they tended to rise by about 1 when calculated from SASS4 results (**Figure 12**, sites X7, C2, **Figure 13**, all sites, **Figure 14**, sites X3, X5, X6). When SASS4 scores were low and hardly differed from SASS2 scores, as should be expected there was little difference in ASPT values based on the two versions of SASS (**Figure 11**, Site C4, **Figure 14**, Site X21, **Figure 15** almost all sites). However, unlike the SASS2/SASS4 comparison with respect to the shape of the bar charts, there were frequently small differences between the shapes of the charts when ASPT based on SASS2 is compared with ASPT based on SASS4 (**Figure 12**, sites X2, X7, X20, C5, **Figure 13**, sites X8, X10, **Figure 14**, sites X1, X5, X6, **Figure 16**, almost all sites). Sometimes SASS2 based ASPT values were more uniform than SASS4 based ASPT values and sometimes the reverse was true. Consequently there can be no preference for either SASS2 or SASS4 on grounds of the variability of the resulting ASPT values.

The data for 1993 in **Figures 11** to **16** show that there were no large changes in SASS4 and ASPT from 1992 to 1993. Where SASS4 was high (**Figure 11**, site C2) or low (**Figure 11**, site C4) in 1992, it was again high or low in 1993. As in SASS4 scores, so too there were no striking differences in ASPT scores recorded from one year to the next.

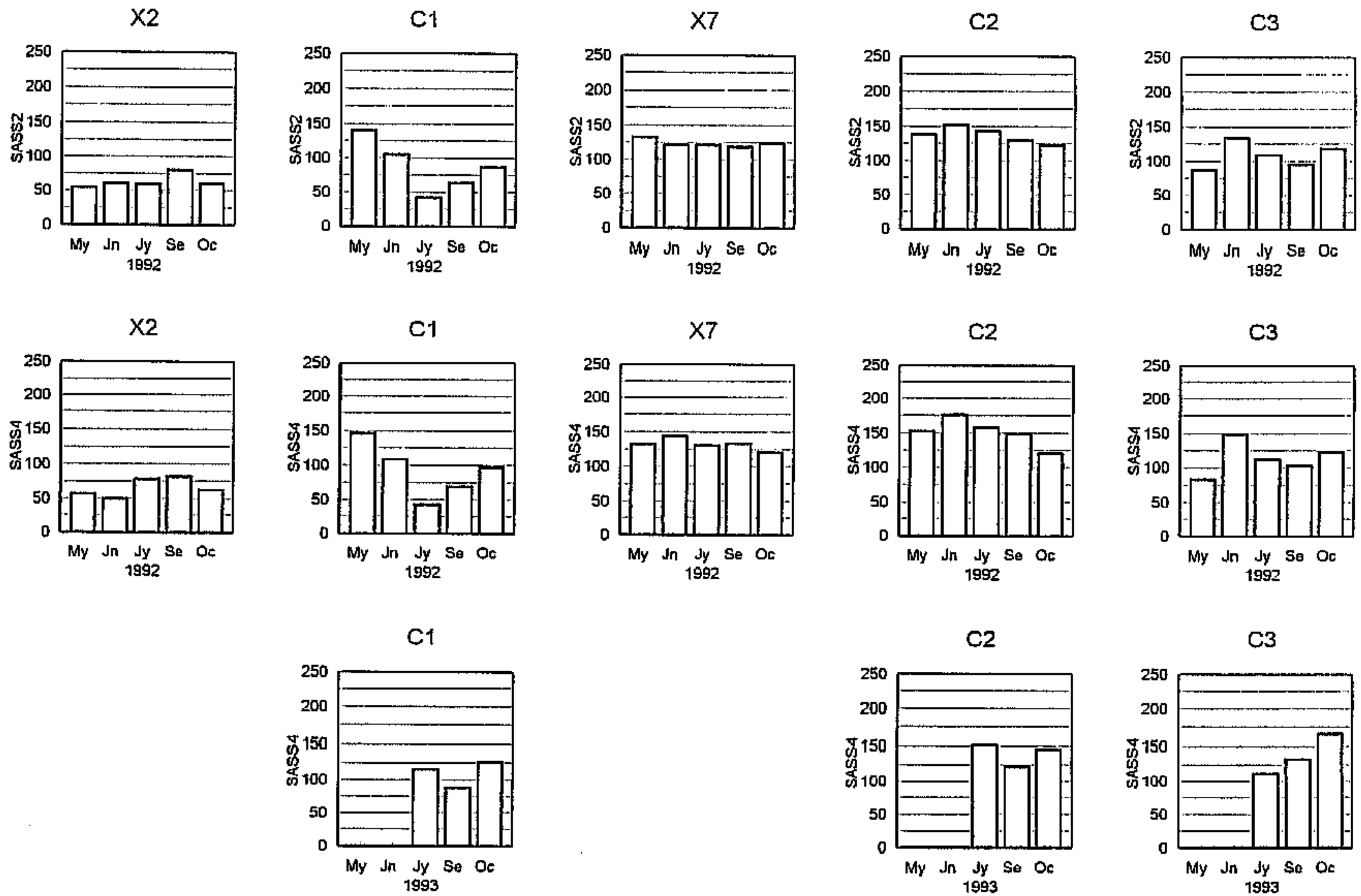
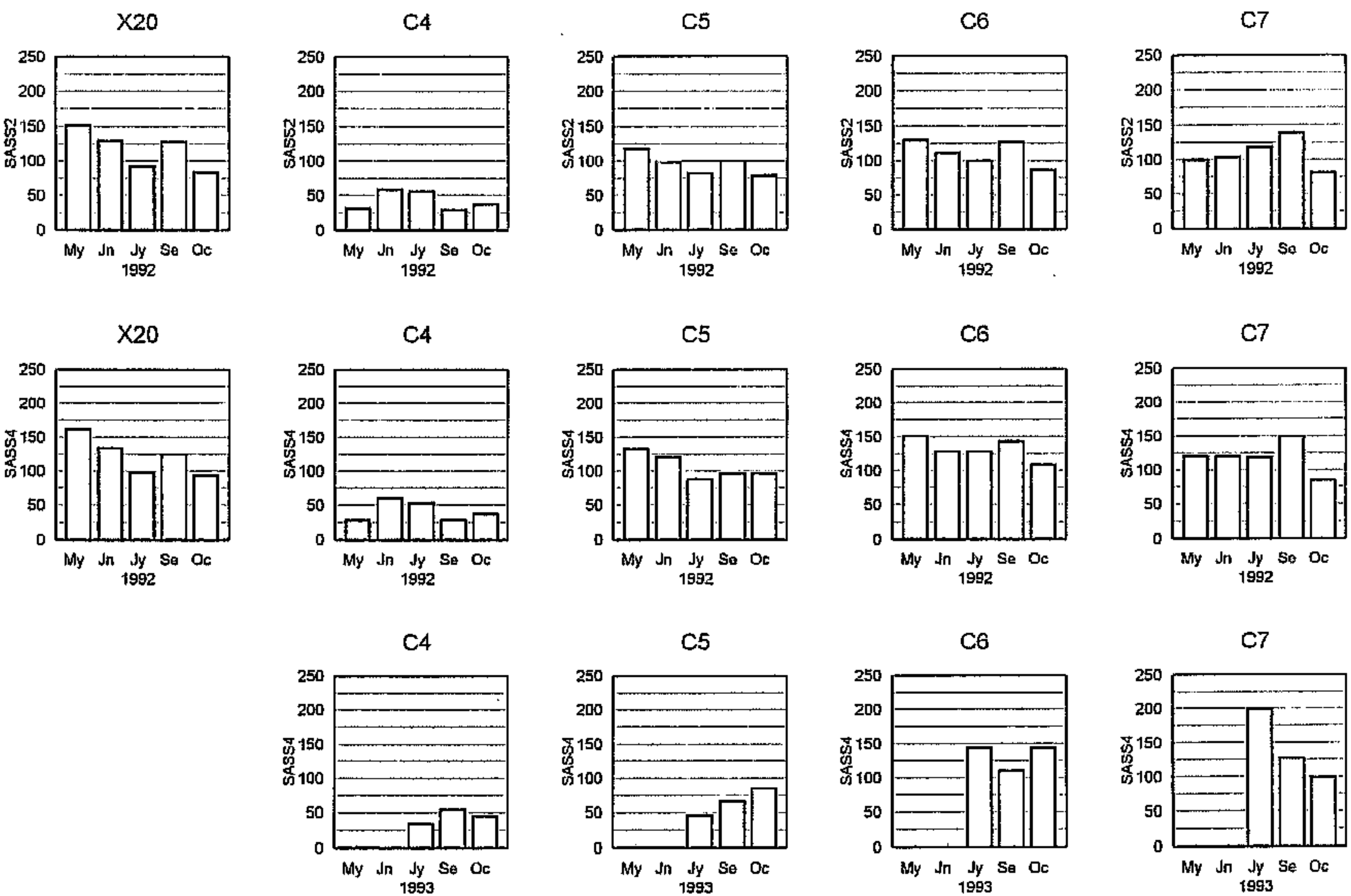


FIGURE 11: The Crocodile River. SASS2 and SASS4 scores by month and by sampling site from samples collected in 1992 and SASS4 scores from samples collected in 1993. **Figure 11** continues on the following page.

FIGURE 11: continued



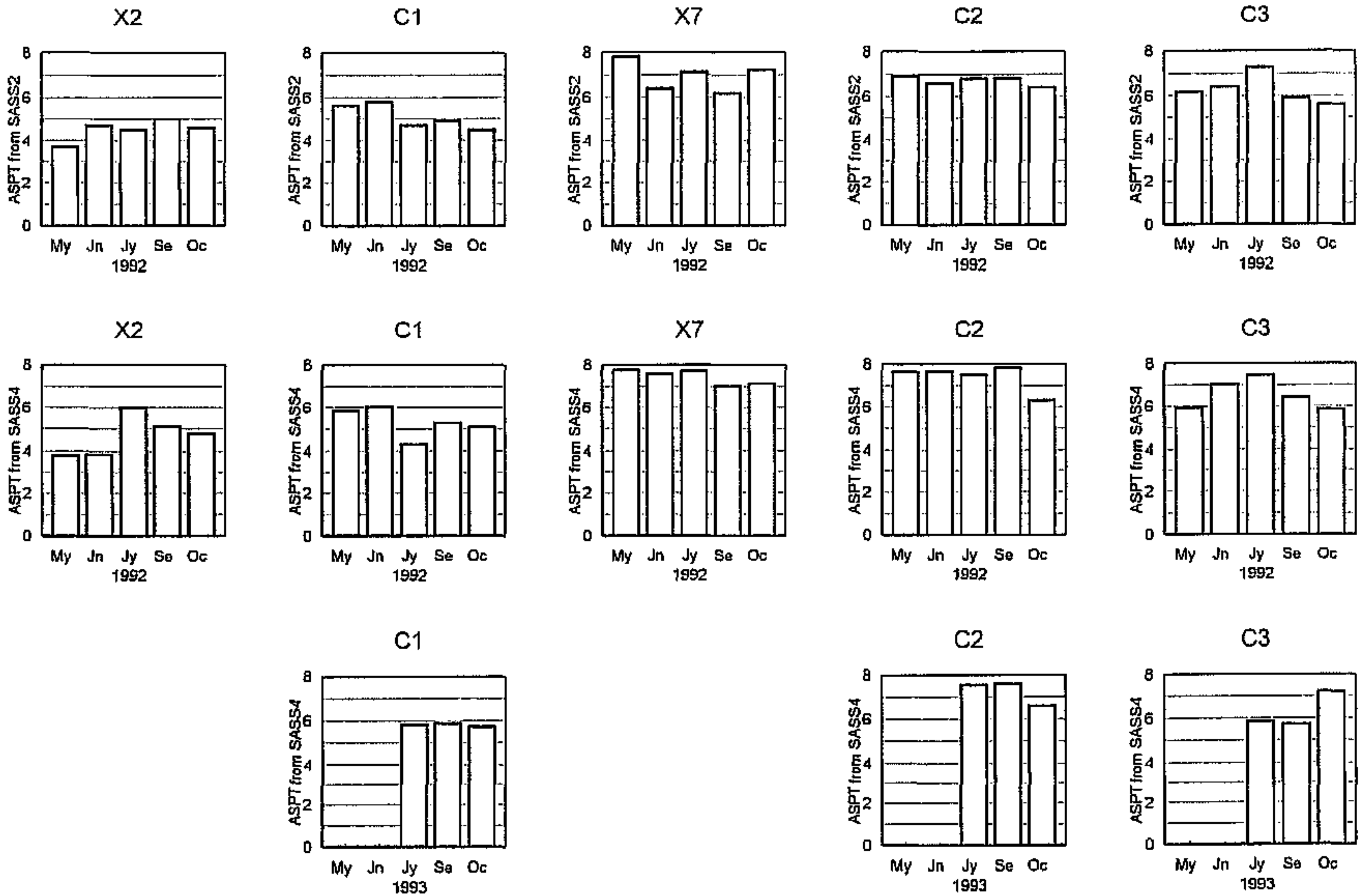
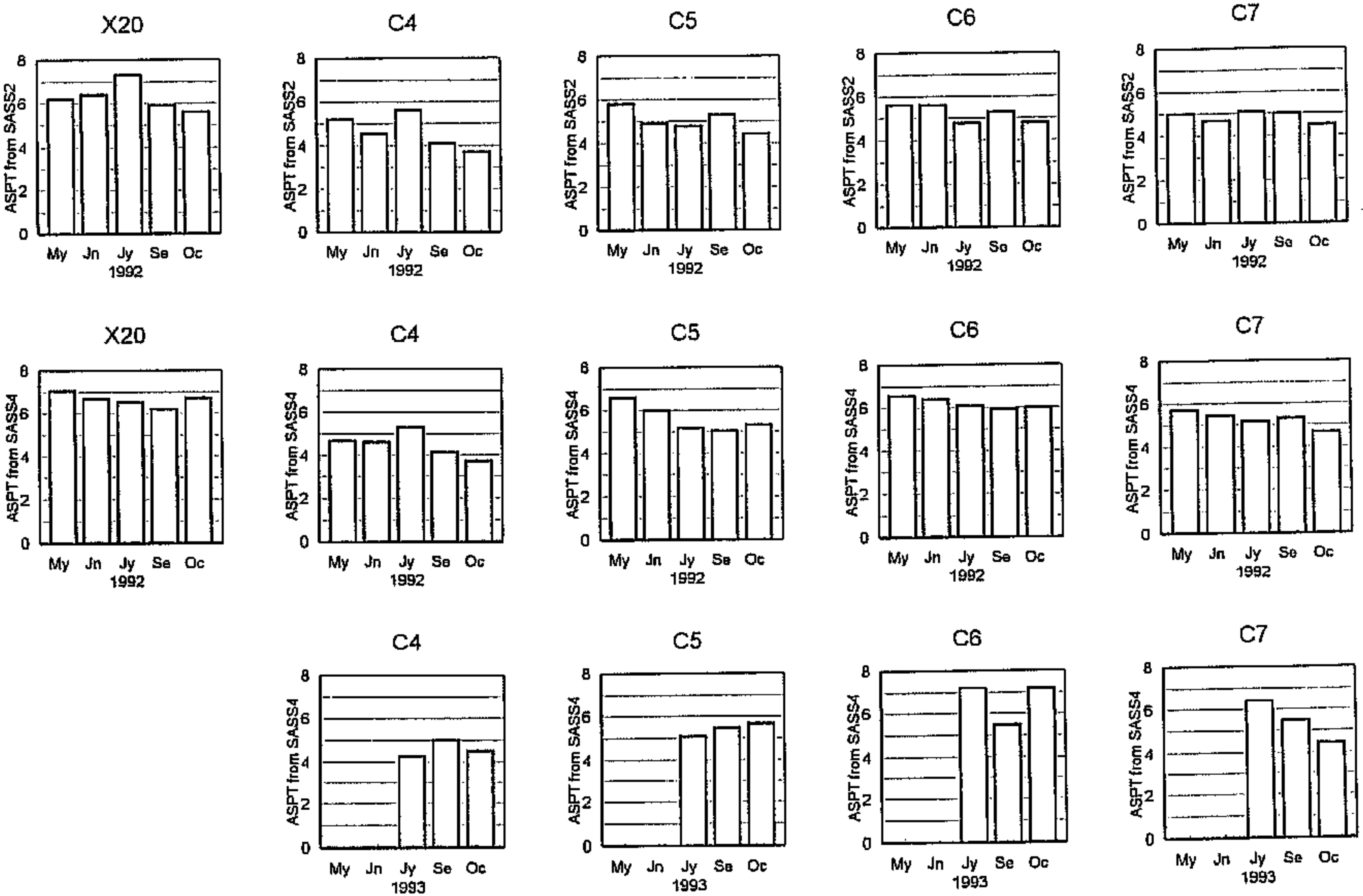


FIGURE 12: The Crocodile River. SASS2 based ASPT and SASS4 based ASPT by month and by sampling site from samples collected in 1992 and SASS4 based ASPT from samples collected in 1993. **Figure 12** continues on the next page.

FIGURE 12: continued



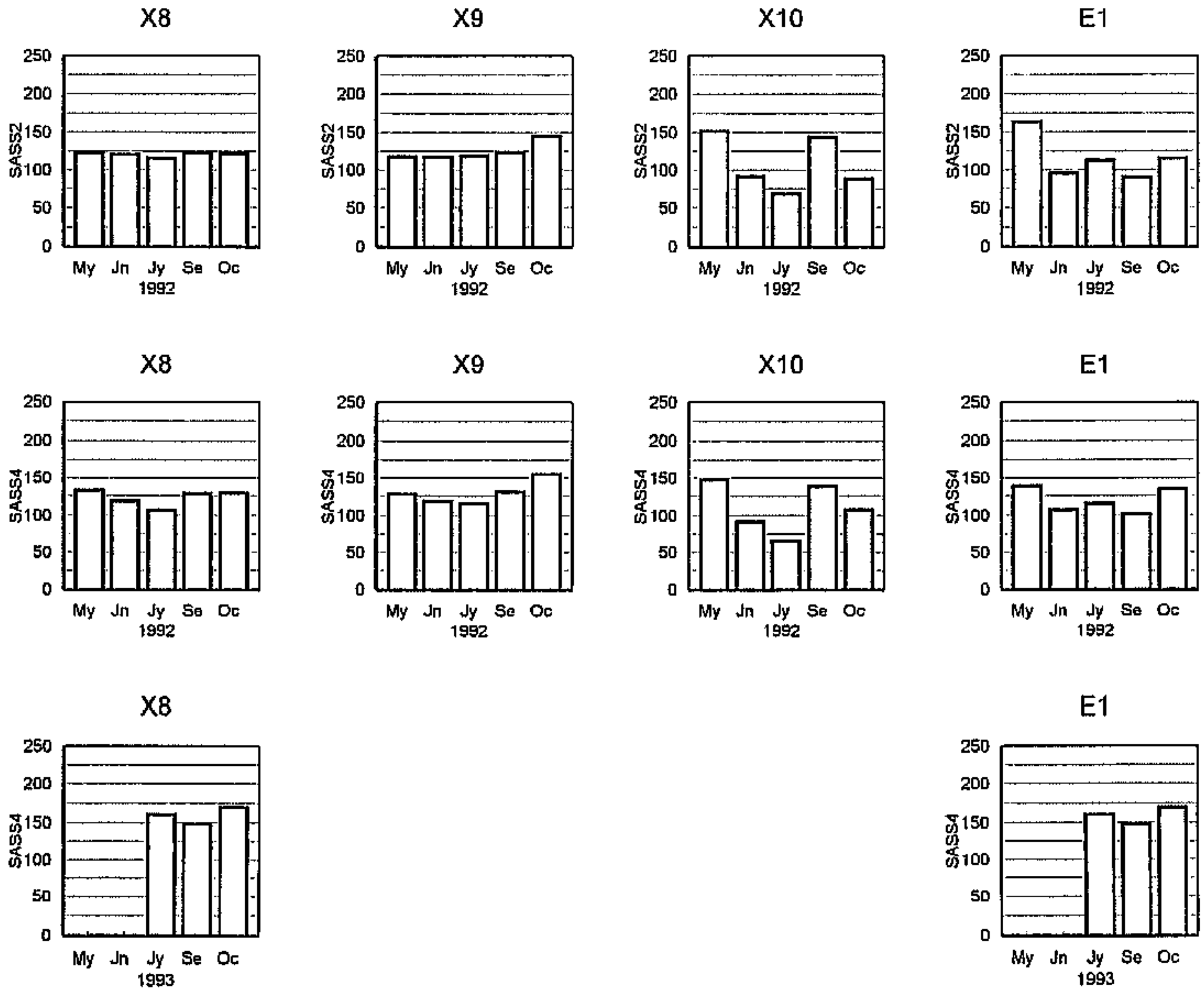
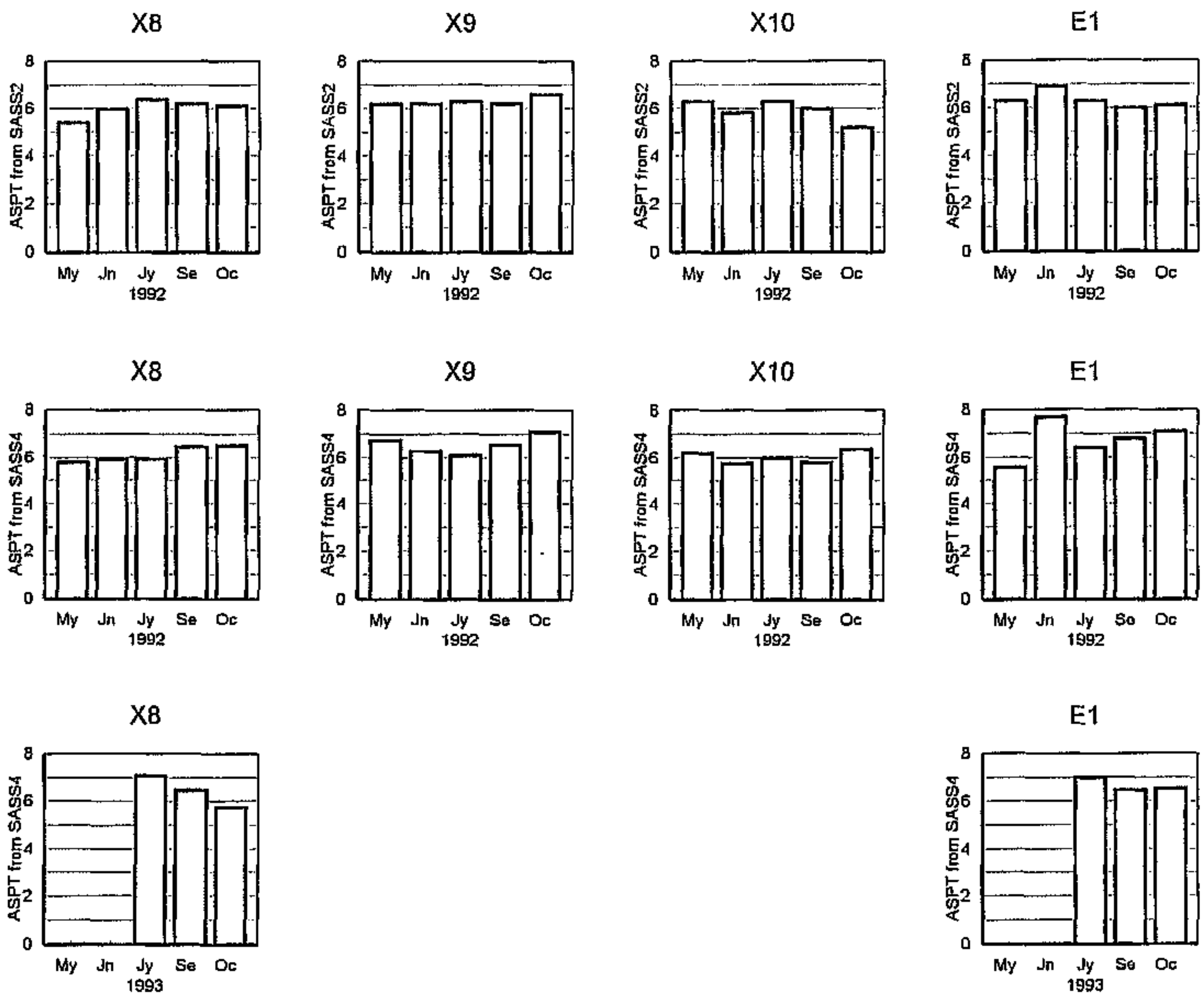


FIGURE 13: The Elands River. SASS2 scores and SASS2 based ASPT and SASS4 scores and SASS4 based ASPT by month and by sampling site from samples collected in 1992, and SASS4 scores and SASS4 based ASPT from samples collected in 1993. **Figure 13** continues on the following page.

FIGURE 13: continued



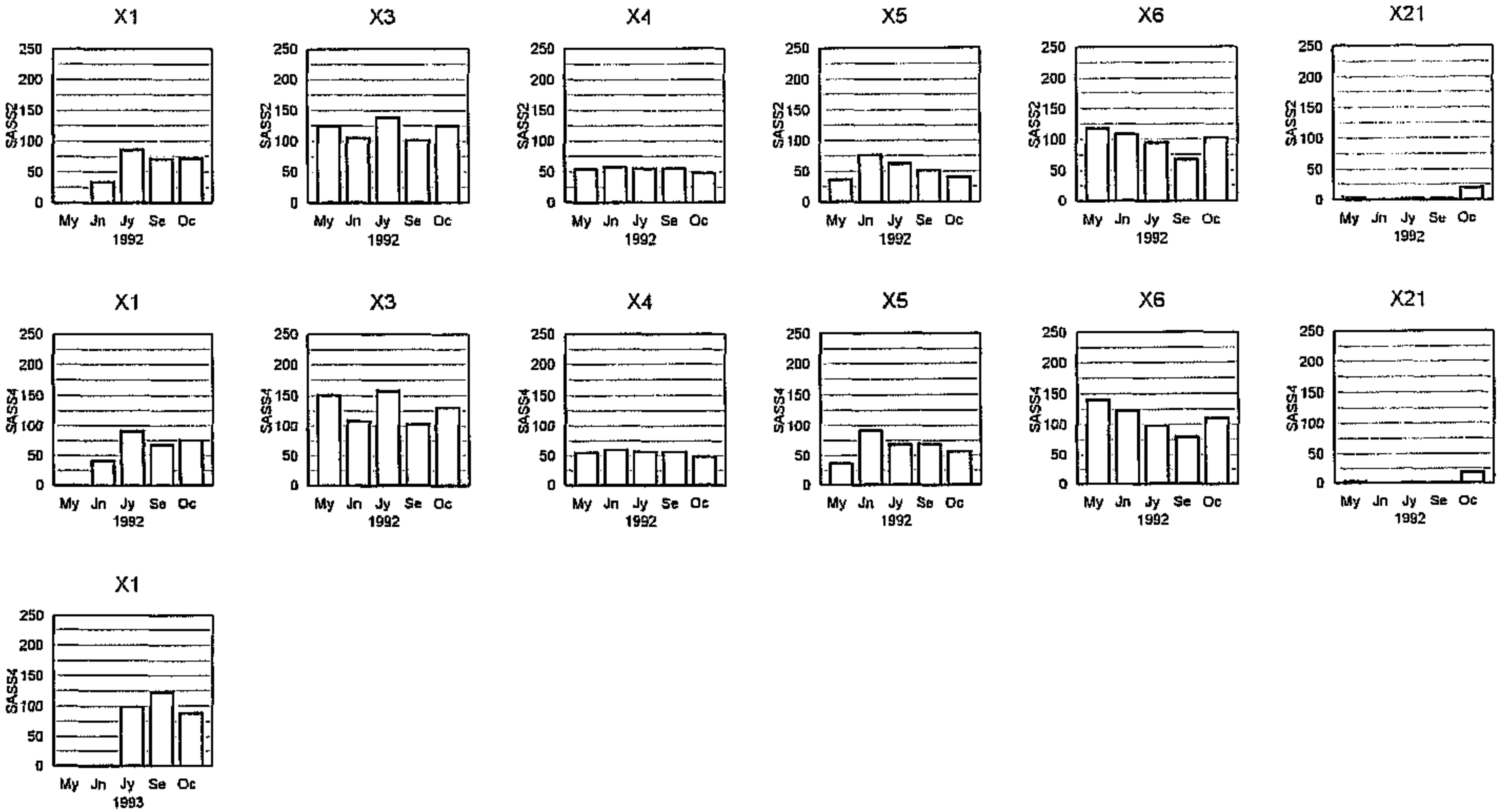
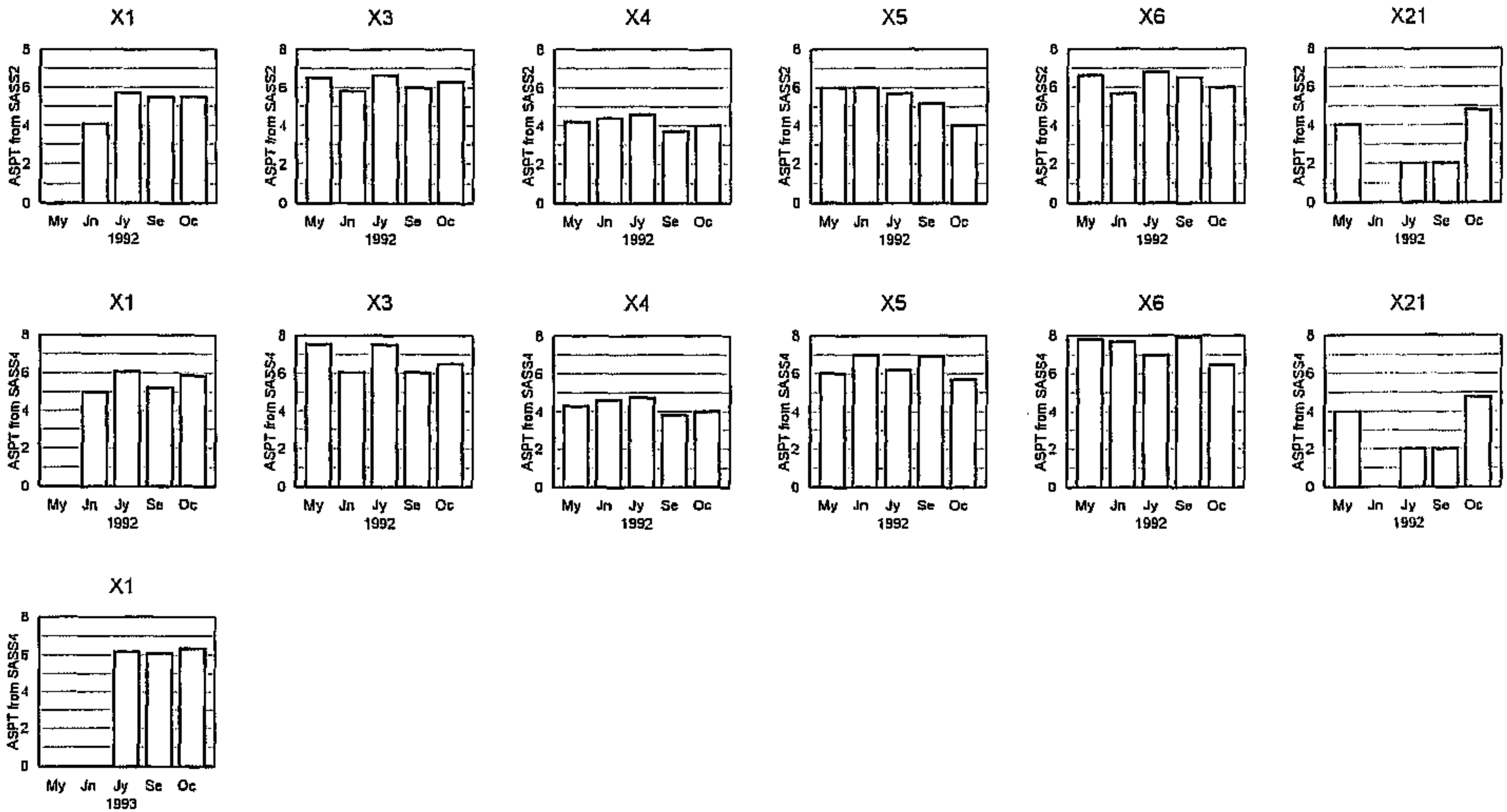


FIGURE 14: Tributaries of the Crocodile River, other than the Elands and Kaap Rivers. SASS2 scores and SASS2 based ASPT and SASS4 scores and SASS4 based ASPT by month and by sampling site from samples collected in 1992, and SASS4 scores and SASS4 based ASPT from samples collected in 1993. **Figure 14** continues of the following page.

FIGURE 14: continued



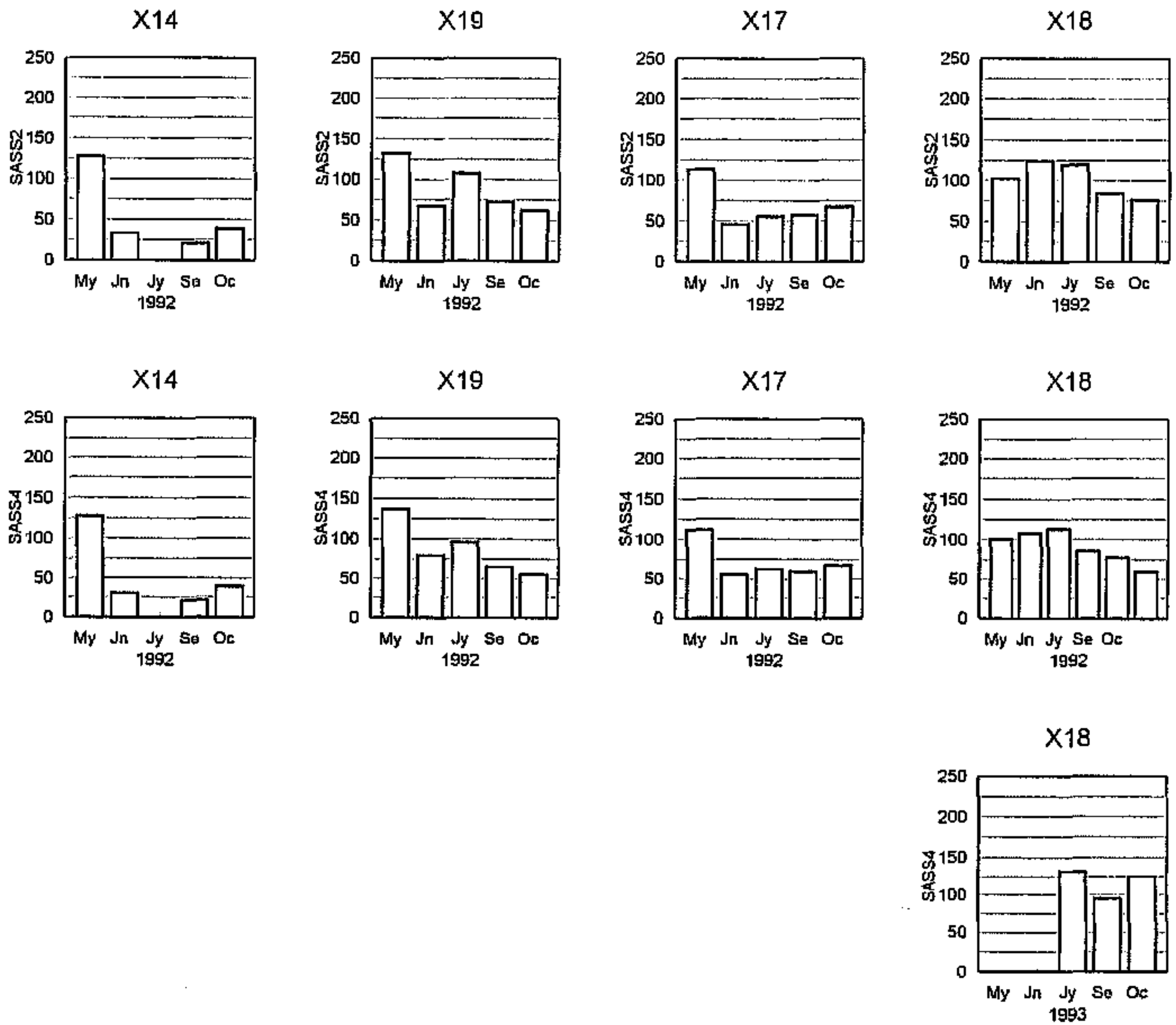
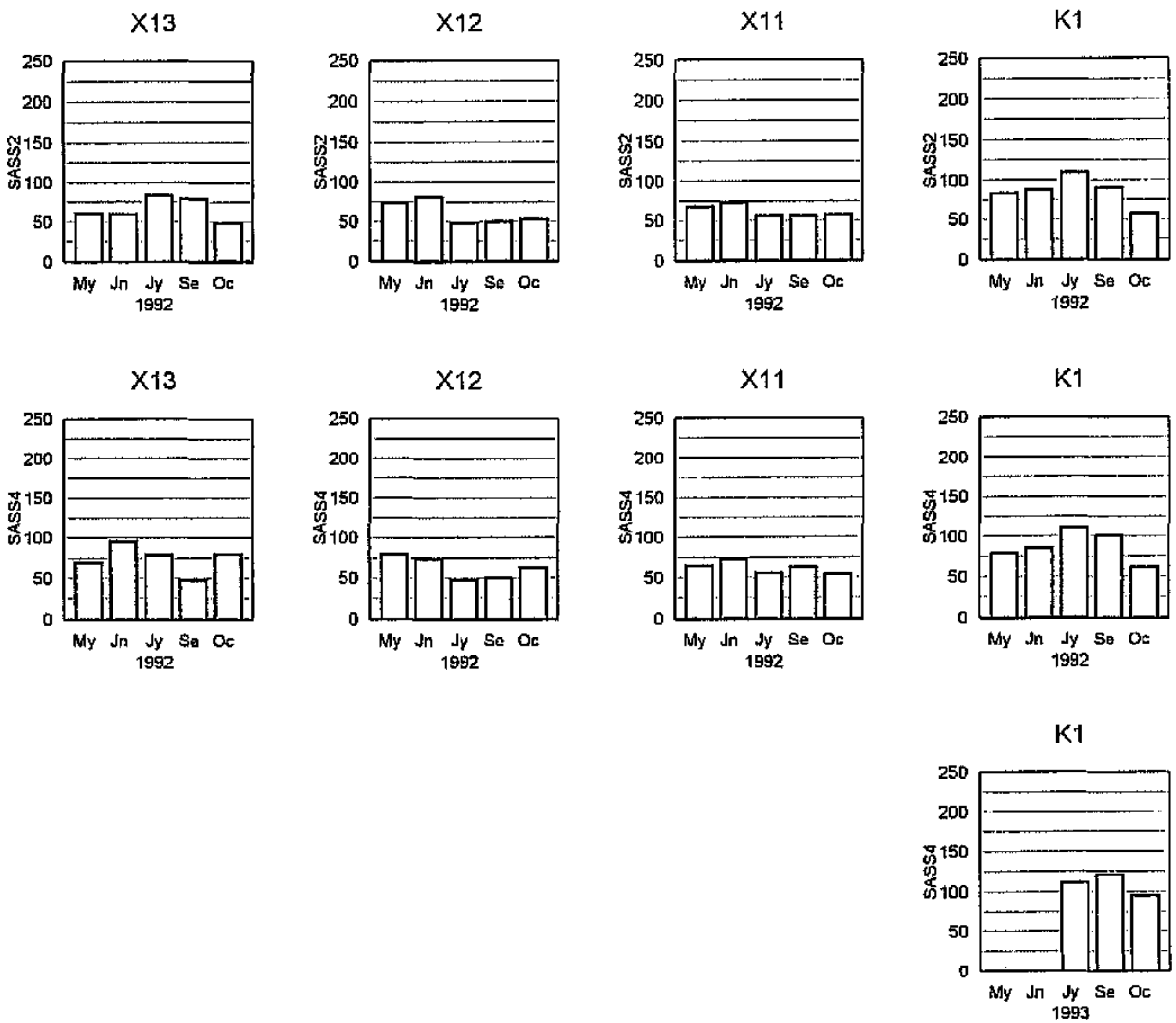


FIGURE 15: The Kaap River. SASS2 scores and SASS4 scores by month and by sampling site from samples collected in 1992 and SASS4 scores from samples collected in 1993. **Figure 15** continues on the following page.

FIGURE 15: continued



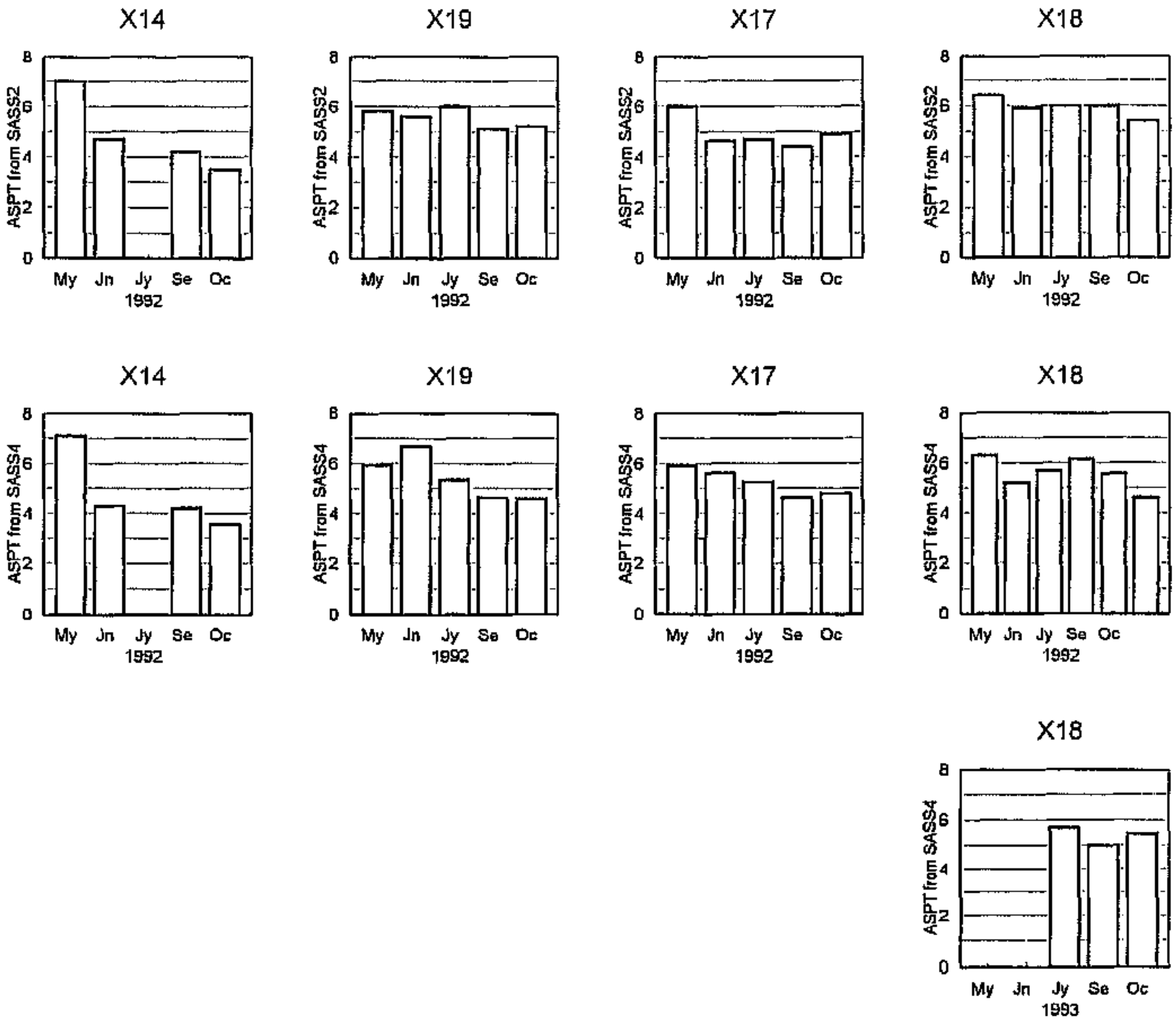
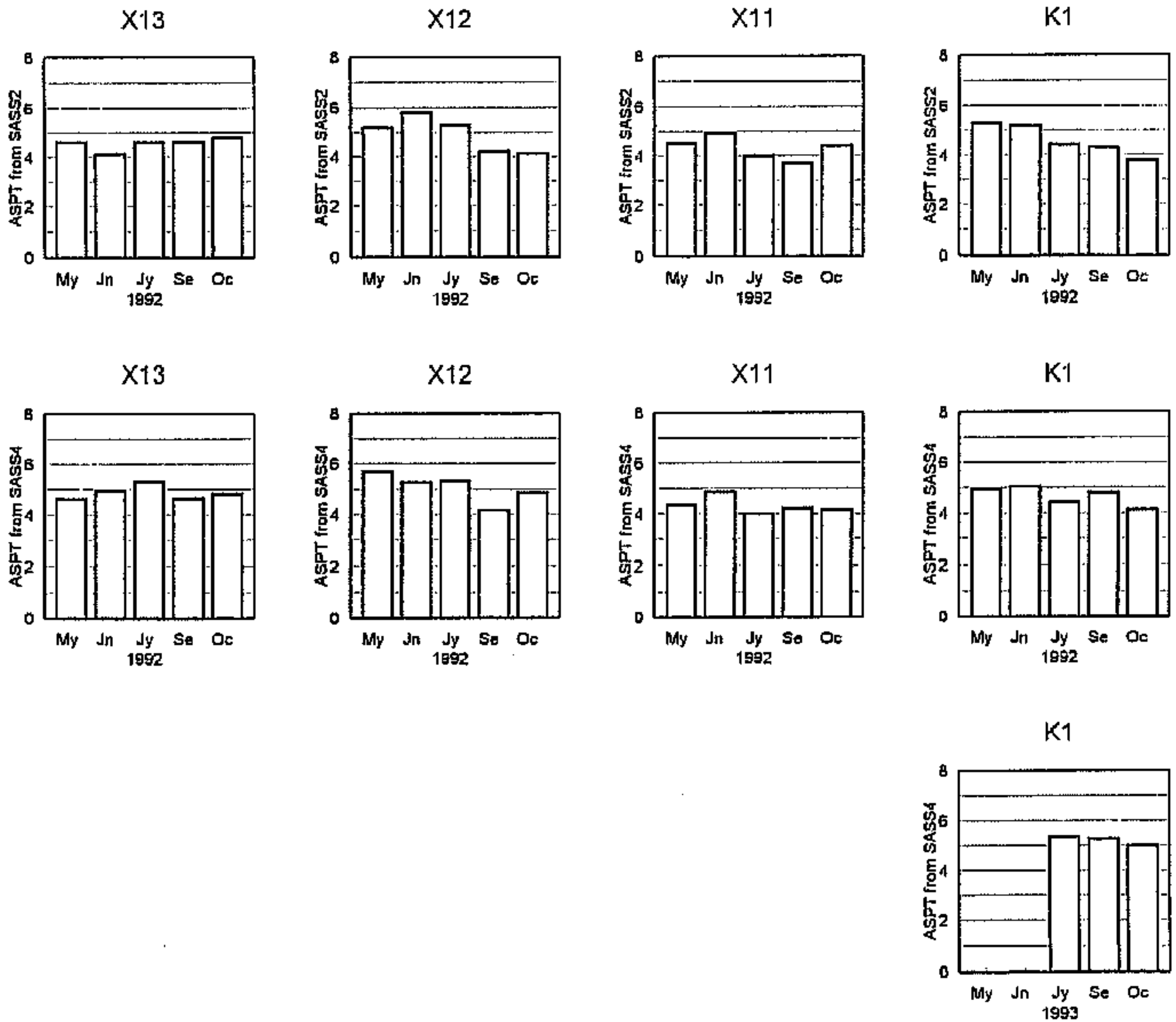


FIGURE 16: The Kaap River. SASS2 based ASPT and SASS4 based ASPT by month and by sampling site from samples collected in 1992 and SASS4 based ASPT from samples collected in 1993. **Figure 16** continues on the following page.

FIGURE 16: continued



The data contained in **Figures 11** to **16** do not reveal consistent seasonal differences in SASS4 scores or in ASPT values, given that all sampling was undertaken in the dry season.

2.6 Conclusions from the Crocodile System

The SASS scoring method is sensitive to changes in water quality, as evidenced by the high scores measured in many parts of the unpolluted upper catchment of the river and its tributaries, and the low scores obtained at places, such as downstream of Nelspruit, the whole Kaap catchment, the Besterspruit and the sampling point downstream of the trout farm, where water quality has been modified.

From the point of view of variation of scores in various geographical regions, site X1, near the source of the Lunsklip stream in Verloren Vallei nature conservation area, is of interest. There is no reason to believe that water quality in this stream is in any way impacted. However, the SASS4 score recorded there tended to be lower than at sampling points further downstream in the same stream and at many other natural sites at lower altitudes in the upper catchment (for example sites X7, C2, C3, X20, X3, X6, X8, X9, E1). This difference may be due to a lack of habitat diversity in this small stony-bottomed stream in which there was, for instance, no fringing vegetation habitat. It should be noted that despite the relatively low SASS4 score, the ASPT at Site X1 was high (above 6, **Figure 14**). The same type of situation (a moderate SASS4 score and a high ASPT) pertained at Site X5 (**Figure 14**), another small stream with limited habitat diversity. It may be concluded that the combination of a moderate SASS4 score and a high ASPT is indicative of unpolluted conditions in streams of limited habitat diversity.

Examination of the data for sites X7, C2, C3, C6, X8, X9, X10, E1, X20, X3 (**Figures 11** to **16**) where the fauna was diverse and SASS4 scores and ASPT were high, shows that the ranges of SASS4 scores lay between 70 and 175 and of ASPT between 5.5 and 7.8. In only one case (site X8, October 1993) at these sites was a SASS4 score of less than 100 coincident with ASPT of less than 6. In all other cases at these sites, SASS4 scores of less than 100 were associated with ASPT scores of 6 or more. It is concluded that SASS4 scores greater than 100 and ASPT scores of 6 or more indicate unmodified water quality. Unmodified water quality is also indicated by the combination of SASS4 less than 100 and ASPT greater than 6.

3. THE SABIE RIVER SYSTEM

The data presented in this section were collected in 1993 by the IWQS which has kindly made it available for inclusion in this report. The data cover the main stem of the Sabie River and several of its tributaries, which have been divided into Mountain tributaries and Lowveld tributaries for purposes of this report.

3.1 General description

The Sabie River rises on the Drakensberg escarpment. Its upper catchment is extensively forested with exotic species, though in between the plantations there are scattered patches of natural forest. The rainfall decreases considerably when the river reaches the Lowveld with the result that there are no perennial tributaries which rise in the Lowveld. The Sabie River is considered to be the least impacted of the five major rivers which cross the Lowveld in a west to east direction. In the lowveld section of the Sabie catchment there are large contrasts in land-use, the western part being very heavily populated and the eastern part being part of the Kruger National Park.

3.2 Sampling points

The sampling points from which the samples were collected in the Sabie System are described in **Table 8.** It should be noted that in the Sabie River the station numbers decline from the source area down the length of the river.

3.3 Water Quality

Mean concentrations of macro determinands in Sabie System water samples are shown in **Table 9** and heavy metal concentrations in samples in which one or other determinand exceeded a pre-defined concentration are shown in **Table 10.** There is no evidence in these two tables that the Sabie River System is polluted.

3.4 SASS4 scores, numbers of taxa and ASPT

SASS4 scores in the Sabie River ranged between 100 and over 200 (**Figure 17**). Scores peaked at Stations SB7 and SB6 (upstream of Sabie village) where they ranged between 175

TABLE 8: Sampling points in the Sabie River and its tributaries, used by IWQS in 1993.

Station number this report	DWAF Station number	Locality	River	Longitude			Latitude		
SABIE RIVER									
SB8	ZSABI-HFS	Horseshoe Falls	Sabie	25	07	47	30	41	37
SB7	ZSABI-CEY	Upstream Ceylon Forestry Station	Sabie	25	06	34	30	44	03
SB6	ZSABI-SAW	Sawmill, upstream of Sabie village	Sabie	25	06	05	30	45	05
SB5	ZSABI-RFT	Downstream of Rietfontein	Sabie	25	04	23	30	51	02
SB4	ZSABI-HLP	Hangklip, downstream of Goudstroom confluence	Sabie	25	03	44	30	54	26
SB2	X3HOO6.Q01	Perry's Farm, 10 km downstream Hazyview flow weir	Sabie	25	01	49	31	07	37
SB1	X3HO21.Q02	NKW, 10 km downstream of Skukuza flow weir	Sabie	24	48	03	31	31	01
MOUNTAIN TRIBUTARIES									
SY1	ZKSAB-TWF	Tweefontein, just upstream of confluence with Sabie	Klein Sabie	25	03	47	30	47	28
SY3	X3H003.Q02	Geelhoutboom (Forest Falls - 1 km upstream of flow weir)	Mac Mac	24	59	10	30	48	55
SY5	ZGOUD-BER	Bergvliet Forestry Station	Goudstroom	25	05	08	30	53	32
LOWVELD TRIBUTARIES									
SY4	ZMARI-MAR	Marite bridge	Marite	24	57	37	31	06	32
SY2	ZMAC-VEN	Venus Timber (Rietspruit)	Mac Mac	25	00	28	30	55	30
SD5	ZSAND-WAL	Wales	Sand	24	42	16	30	59	32
SDS1	ZKSAN-RBL	Rooiboklaagte	Klein Sand	24	39	30	31	05	18
SDS3	ZMOH-ZOEK	Zoeknog (Tswafeng)	Mohlombe	24	45	49	30	58	32
SDS4	ZMUTL-VIO	Violetbank	Mutlumuvi	24	45	28	31	00	53
SD3	ZSAND-DIN	Dingleydale	Sand	24	41	31	31	09	54

TABLE 9: The Sabie River System. Water quality; mean concentrations (mg ℓ^{-1}) of macro determinands measured in 1993 and 1994. Data provided by IWQS, DWAF.

SITE	n*	pH	EC	TDS	Na	K	Ca	Mg	Cl	SO4	TAL	F	PO4-P	NH4-N	NO3 + NO2 - N	Si
SABIE RIVER																
SB8	5	7.1	4.4	32	2	0.3	3	2	3	3	14	0.2	0.055	0.05	0.43	4.6
SB7	5	7.3	6.9	53	2	0.2	5	3	3	4	28	0.2	0.024	0.04	0.24	4.6
SB6	5	7.2	6.8	53	2	0.2	6	3	3	4	28	0.1	0.026	0.05	0.18	4.3
SB5	5	7.6	13.8	104	2	0.3	12	7	3	6	59	0.2	0.039	0.04	0.42	5.1
SB4	5	7.6	13.7	105	3	0.4	12	7	3	7	57	0.3	0.051	0.04	0.46	5.2
SB2	3	7.3	13.2	93	5	0.7	9	5	5	6	50	0.2	0.018	0.05	0.18	5.8
SB1	5	7.5	14.1	108	6	0.8	11	6	5	7	58	0.3	0.029	0.05	0.07	4.4
MOUNTAIN TRIBUTARIES OF THE SABIE RIVER																
SY1	5	7.5	14.5	112	2	0.3	13	8	3	3	68	0.1	0.023	0.04	0.28	4.8
SY3	5	7.4	12.1	91	2	0.3	10	6	3	4	51	0.1	0.037	0.04	0.34	4.2
SY5	5	7.4	8.3	60	7	1.1	4	2	5	4	28	0.2	0.027	0.03	0.13	11.3
LOWVELD TRIBUTARIES OF THE SABIE RIVER																
SY4	5	7.3	7.1	54	6	0.8	4	2	4	5	26	0.2	0.044	0.03	0.04	9.0
SY2	5	7.4	10.4	82	2	0.3	9	5	3	4	47	0.1	0.027	0.04	0.22	4.4
SD5	5	7.4	8.4	61	7	0.5	5	2	4	4	31	0.2	0.036	0.06	0.04	11.1
SDS1	5	7.5	13.1	105	15	0.8	6	3	6	5	55	0.3	0.034	0.03	0.03	10.0
SDS3	5	7.3	8.1	60	8	0.8	4	2	5	6	28	0.3	0.030	0.04	0.07	10.6
SDS4	4	7.2	8.2	62	8	0.8	5	2	4	4	31	0.2	0.056	0.03	0.04	11.1
SD3	5	7.5	15.7	114	19	0.9	6	3	10	7	54	0.3	0.031	0.02	0.03	8.2

n* = number of samples

TABLE 10: The Sabie River System. Water quality: concentrations ($mg\ell^{-1}$) of heavy metals in water samples in which specified concentration levels were exceeded. Data provided by IWQS, DWAF.

Metal		Ti	B	Sr	Cu	V	Al	Cr	Fe	Mn	Ni	Pb	Zn	Ba
Kempster max.*		12	5	200	0.200	0.500	1.5	0.100	1.000	1.000	0.050	0.100	0.100	5.000
High-lighted conc		0.250	0.250	1.000	0.100	0.250	0.750	0.050	0.500	0.500	0.025	0.050	0.050	2.000
SITE	DATE													
SABIE RIVER														
SB4	Oc93	0.000	.002	.012	0.000	0.000	.105	0.000	.351	.090	**.032**	0.000	.025	0.000
SABIE RIVER MOUNTAIN TRIBUTARIES														
SY5	Se93	.002	.014	.051	0.000	0.000	.041	.004	**.499**	0.000	.001	0.000	0.000	0.000
SY5	Oc93	.005	.013	.049	0.000	0.000	.255	0.000	**1.363**	0.000	.020	0.000	.015	0.000
SABIE RIVER LOWVELD TRIBUTARIES														
SY4	Jy93	0.000	0.000	.034	0.000	.001	.198	0.000	**1.069**	.013	.002	0.000	0.000	.013
SY4	Au93	.001	.010	.034	0.000	0.000	.063	.031	**.692**	0.000	.005	0.000	0.000	0.000
SY4	Oc93	.003	.009	.030	0.000	0.000	.246	0.000	**1.063**	0.000	0.000	0.000	0.000	0.000
SD5	Jy93	0.000	0.000	.053	0.000	.003	.088	0.000	**.889**	.034	.005	0.000	0.000	.035
SD5	Au93	0.000	.013	.049	0.000	0.000	0.000	0.000	**1.659**	0.000	.001	0.000	0.000	0.000
SD5	Oc93	.002	.051	.049	0.000	0.000	.079	0.000	**.845**	.001	0.000	0.000	0.000	0.000
SDS1	Jy93	0.000	0.000	.090	0.000	.001	.194	0.000	**1.717**	.071	.001	**.100**	.017	.056
SDS1	Oc93	.002	.018	.093	0.000	0.000	.158	0.000	**.756**	0.000	0.000	0.000	.013	0.000
SDS3	Jy93	0.000	0.000	.062	0.000	.002	.536	.010	**1.438**	.082	.006	0.000	.017	.135
SDS3	Au93	.005	.005	.048	0.000	.001	.477	0.000	**1.339**	.024	.004	0.000	0.000	0.000
SDS3	Oc93	.001	.014	.050	0.000	.003	.310	0.000	**1.308**	.010	**.065**	0.000	**.056**	0.000
SDS4	Jy93	0.000	0.000	.067	0.000	.001	.089	0.000	**1.099**	.061	.002	0.000	0.000	.001
SDS4	Au93	.002	.024	.041	0.000	0.000	.051	0.000	**.511**	0.000	.002	0.000	0.000	0.000
SDS4	Oc93	0.000	.015	.043	0.000	0.000	.098	0.000	**.507**	0.000	.002	0.000	0.000	0.000
SD3	Jy93	0.000	0.000	.097	0.000	.002	**.843**	.013	**1.434**	.035	.003	0.000	0.000	.020
SD3	Au93	.001	.009	.112	0.000	.001	0.000	0.000	**.565**	0.000	0.000	0.000	0.000	0.000
SD3	Oc93	.009	.013	.079	0.000	0.000	.228	0.000	**.615**	0.000	0.000	0.000	0.000	0.000

Measured, not detected in the samples included in this table: Hg, Be, Mo, Cd, Zr, Co, As

* see text

and about 210. With the exception of one score of about 170 at SB1, scores at the remaining sampling points ranged between 100 and about 150. Numbers of taxa were highest at the sampling points with the highest SASS4 scores. ASPT ranged between 5.8 and 7.8, with most values lying between 6 and 7.2. Apart from the fact that at the uppermost sampling point (SB8) ASPT was about 0.5 less than elsewhere, there was no trend of longitudinal change in ASPT values. Attention is drawn to the fact that the upper limit of the vertical scale of the ASPT charts in **Figures 17** to **19** is 10, whereas it is 8 in most other ASPT charts.

SASS4 scores in two of the three mountain tributaries of the Sabie (**Figure 18**) were similar to scores from the Sabie River, though scores were clearly higher at SY3 than at SY1. At both points ASPT values lay between 7 and 8, which is high. SASS4 and ASPT results from the third sampling point shown in **Figure 18** (SY5) were very much lower than in the other mountain tributaries and in the Sabie River itself. There is no obvious reason why this should be so (C. Thirion, IWQS - personal communication), though the fidelity with which the SASS scoring system reflects change, suggests that station SY5 is peculiar. The ASPT value was fairly high, which may be taken to indicate that although the SASS4 score and family diversity were moderately low, taxa sensitive to water quality change were well represented. This suggests that habitat diversity was low at this sampling point.

Among the Lowveld tributaries of the Sabie River (**Figure 19**), the Mac Mac (Station SY2) had SASS4 and ASPT scores similar to the Sabie River. ASPT at SY4 was also similar to the Sabie River, but here the SASS4 score was a little lower. The remaining sampling points shown in **Figure 19** all had SASS4 and ASPT scores generally lower than the Sabie River. A feature of the results from these remaining sampling points is that low SASS4 scores (SD5 July, SDS3 July, October) were associated with relatively high ASPT values. This suggests that components of the environment of the stream invertebrates other than water quality restricted the family diversity. It has been pointed out that sampling points SD5, SDS1, SDS3, SDS4 and SD3 all lie in an area where there is a high population density and general environmental degradation (C Thirion, IWQS - personal communication).

3.5 Conclusions from the Sabie System

SASS4 results confirm that the Sabie River has a high family diversity and unpolluted water. A point of considerable interest in the Sabie River is that SASS4 and ASPT scores remained high right down to the lowermost sampling point in the river. There was no real difference in ASPT between SB8 and SB1. In any attempt to regionalize expected SASS scores the matter of score variation along the length of a river is important. The Sabie results suggest

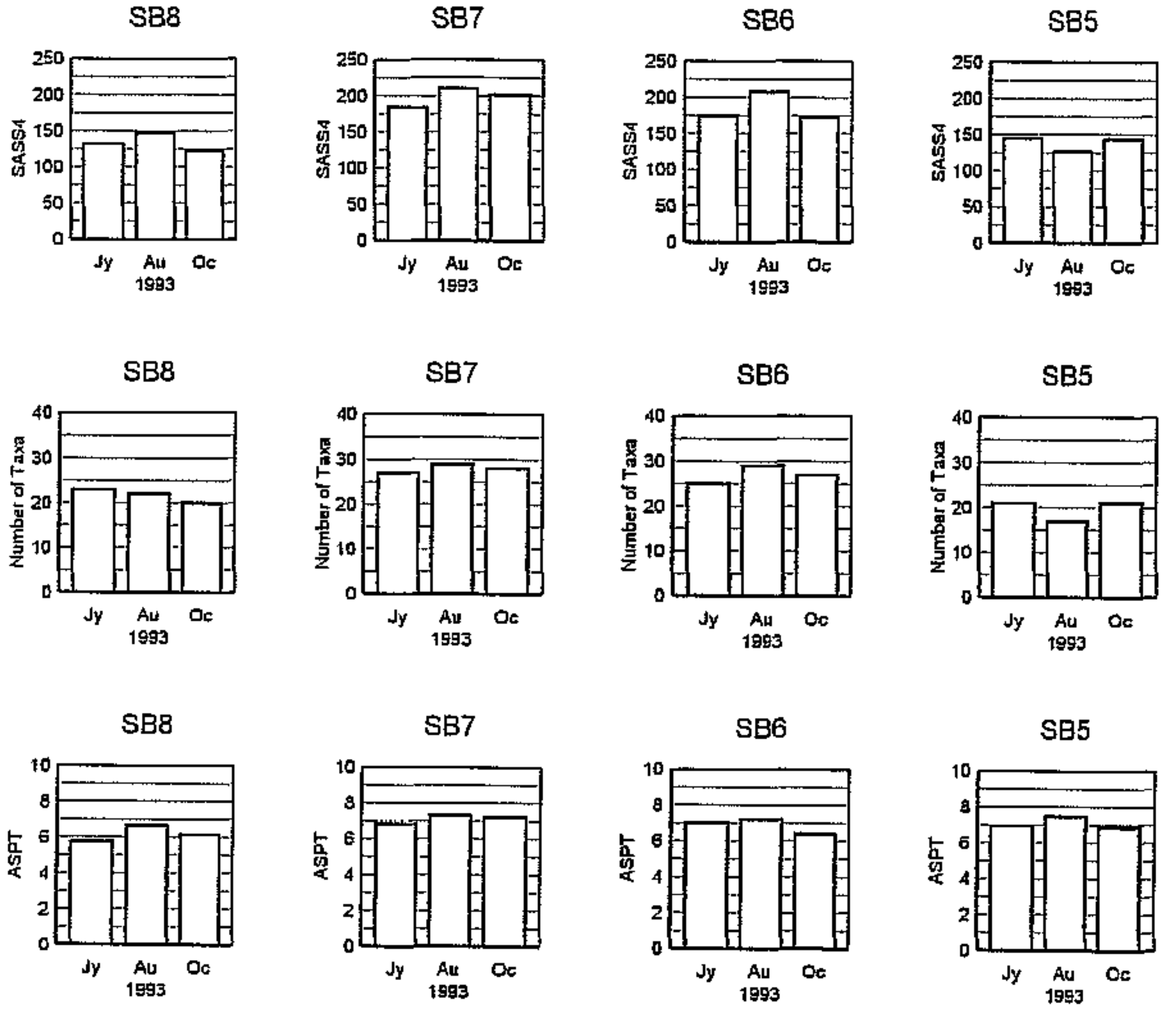


FIGURE 17: The Sabie River: SASS4 scores, numbers of taxa and ASPT by sampling point and month. SASS2 IWQS data converted to SASS4. **Figure 17** continues on the following page

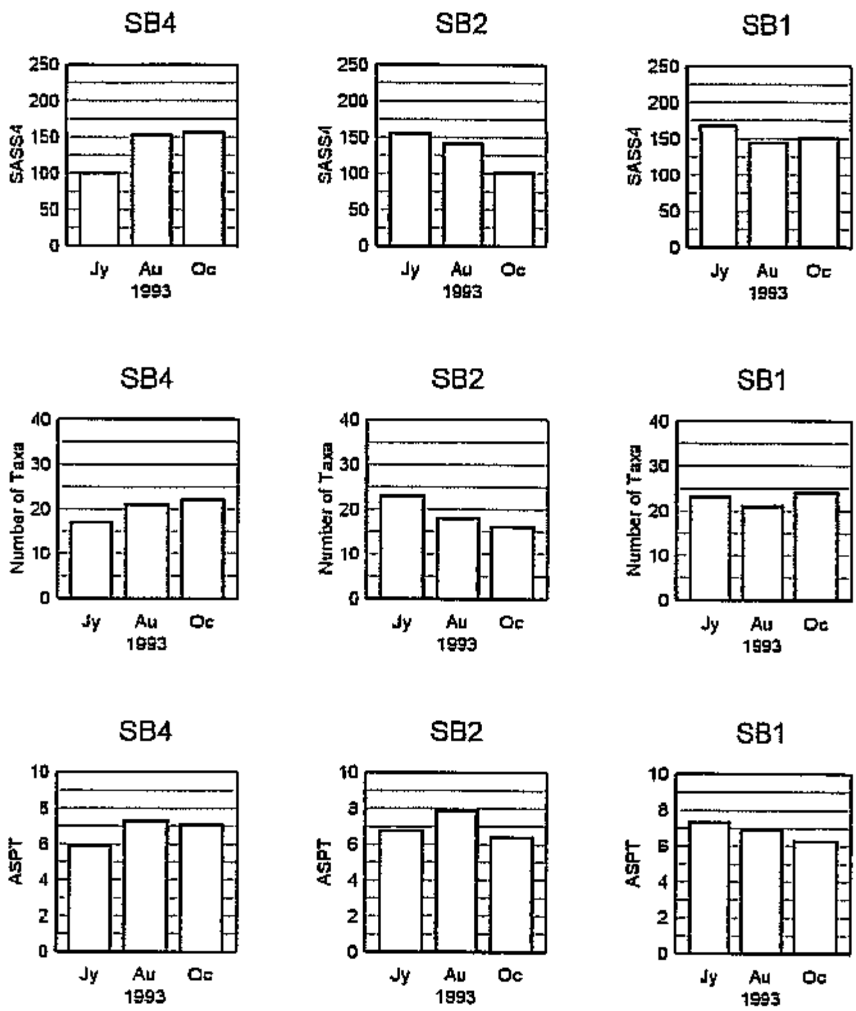


FIGURE 17: continued

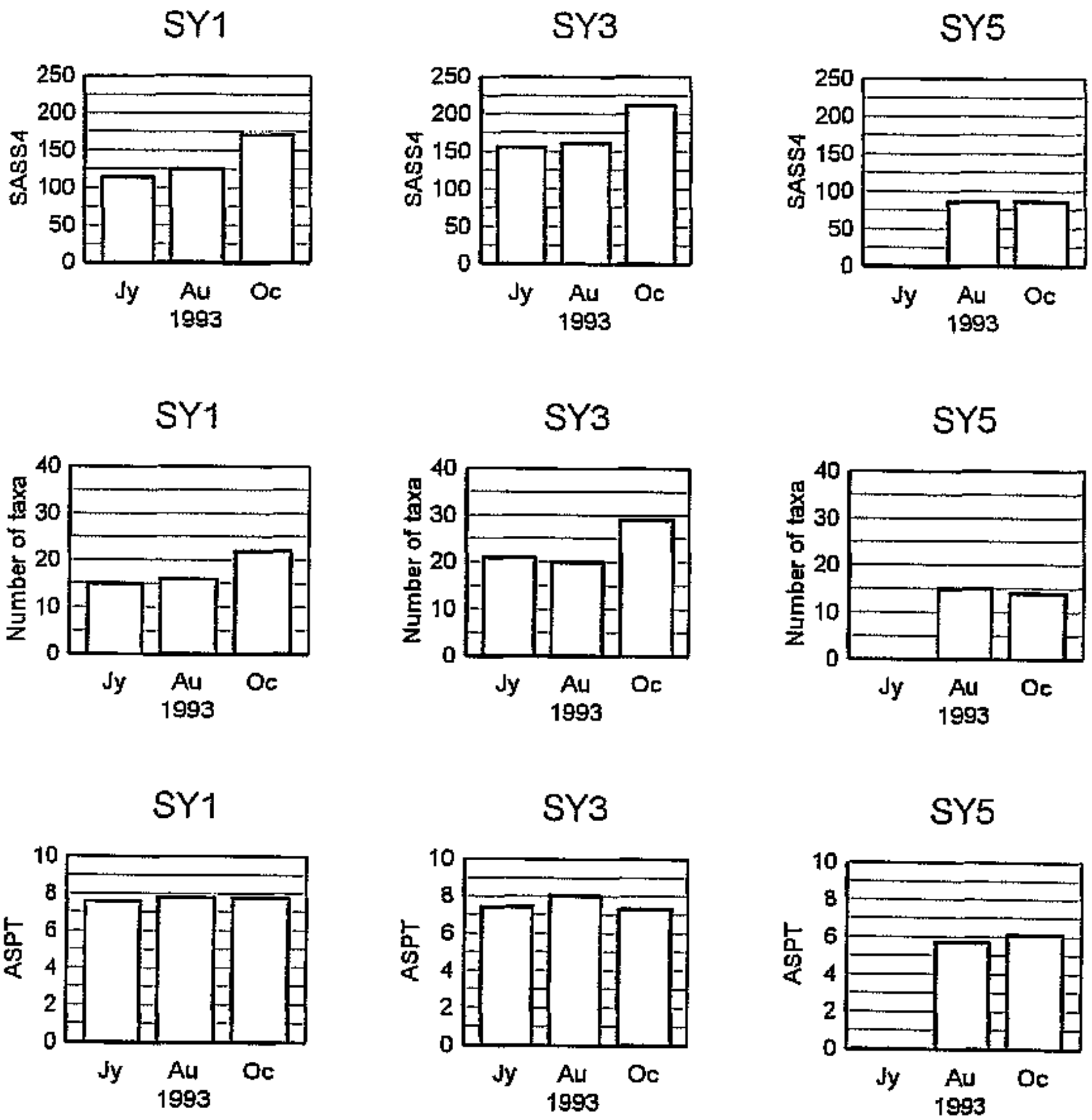


FIGURE 18: Mountain tributaries of the Sabie River: SASS4 scores, numbers of taxa and ASPT by sampling point and month. SASS2 IWQS data converted to SASS4.

that the only variation in SASS4 was an increase in the upper, but not headwater, reach of the river. This increase was due to a greater diversity of invertebrates which cancelled out the greater score when results were expressed as ASPT. In this unpolluted river, there was no longitudinal variation in ASPT.

Some of the results from parts of the Sabie River system suggest that habitat-related environmental degradation, other than that due to water quality, reduces the variety of invertebrates present, but this reduction bears little relation to the aquatic invertebrate community's response to water quality changes. The consequence is that SASS4 scores were low, but ASPT was almost as high as in the Sabie River, indicating that loss of habitat diversity played a role.

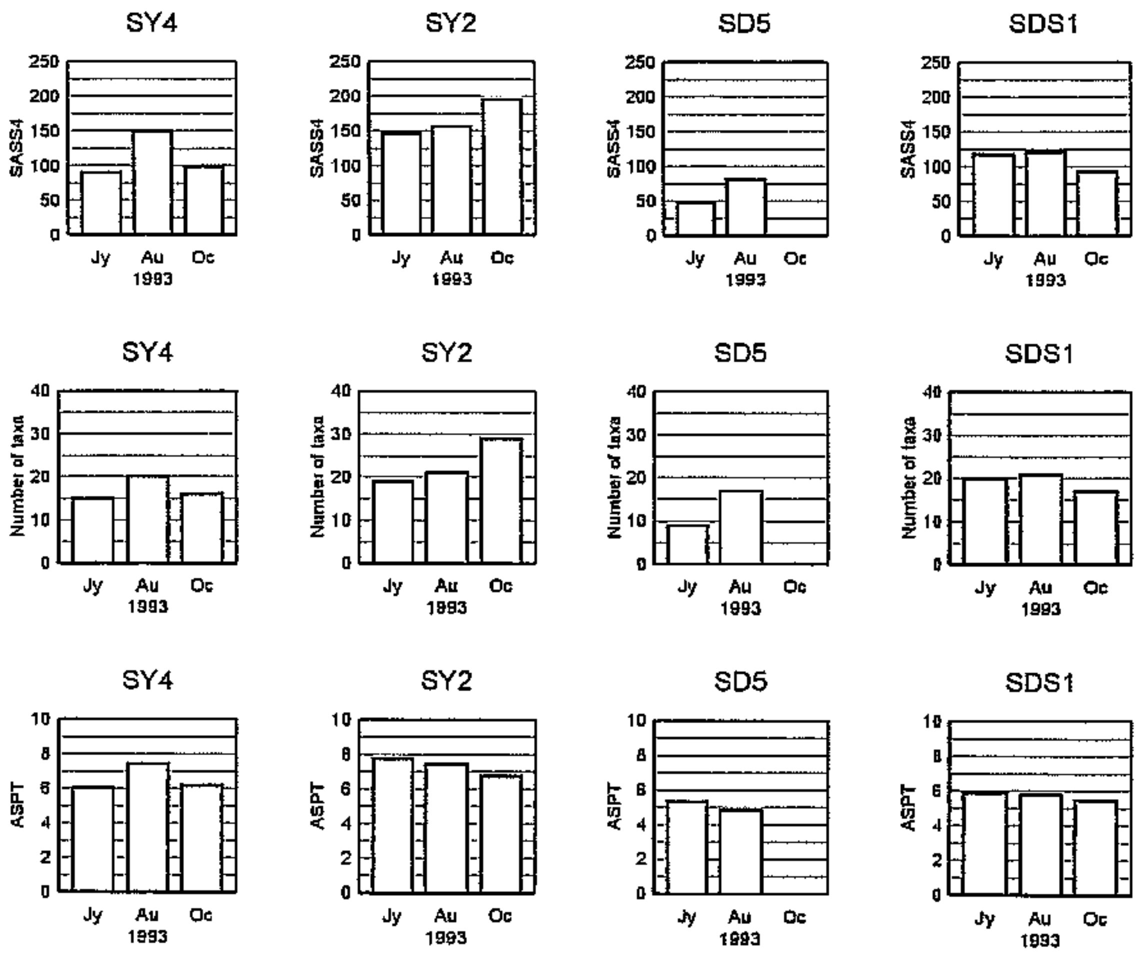


FIGURE 19: Lowveld tributaries of the Sabie River: SASS4 scores, numbers of taxa and ASPT by sampling point and month. SASS2 IWQS data converted to SASS4. **Figure 19** is continued on the following page

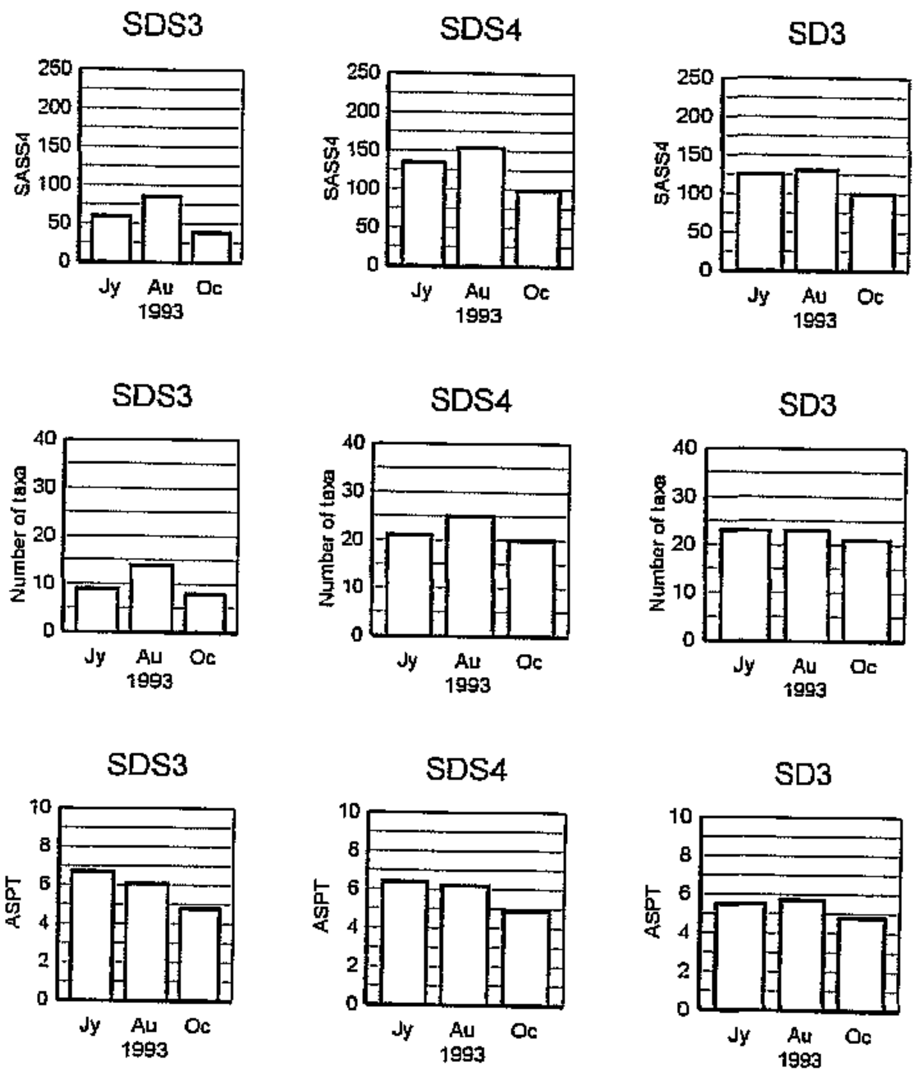


FIGURE 19 continued

4. THE OLIFANTS RIVER SYSTEM

This section is again based on results collected in 1993 and made available by the IWQS. The data cover the Olifants River from Groblersdal downstream and its tributaries in this area. It should be noted that Groblersdal is in the Middleveld and is a long way from the source of the river, which rises in the Highveld. Also the river has passed through several dams before it reaches Groblersdal. As in the case of the Sabie, the tributaries have been divided into Mountain plus Highveld and Middleveld plus Lowveld.

4.1 General description

From Groblersdal downstream to the gorge where the river cuts through the Drakensberg Escarpment, the Crocodile valley is in a low rainfall area in which there is a relatively high population density and extensive degradation of the terrestrial ecosystems. The major tributary of the river in this section is the Steelpoort River, in whose catchment there is extensive mining. After passing though the Drakensberg, where there is a restricted area of higher rainfall, the river again passes through relatively dry country. It is joined by the Blyde River and the Blyde's tributary, the Ohrigstad River, both of which rise in high lying country to the west of the Drakensberg Escarpment. The Selati River rises to the north of the Olifants River on the Escarpment. It joins the Olifants River near the boundary of the Kruger National Park, shortly after receiving the effluent from heavy industries at Phalaborwa. The river traverses the Kruger National Park before entering Mocambique.

4.2 Sampling points

Sampling points are shown in **Table 11**, numbered in descending order downstream in the Olifants River itself.

4.3 Water Quality

Mean concentrations (**Table 12**) of many macro determinands in the Olifants River System were high at most sampling points, as is reflected in the TDS results. There were only two sampling points (CH16, CH17 - mountain/highveld tributaries) where TDS was not very high (compare **Table 12** with **Table 9**). The higher individual concentrations are shown in **Table 13**. Even at the upper limit of the study area (point CH13) there were two occasions when the TDS exceeded 600 $mg\ell^{-1}$. In fact, all sampling points in the Olifants River other than

TABLE 11: Sampling points in the Olifants River catchment, used by IWQS in 1993

Station number this report	DWAF Station number	Locality	River	Longitude			Latitude		
OLIFANTS RIVER									
CH13	ZOLI-GROB	Groblersdal bridge	Olifants	25	09	42	29	24	51
CH11	B5H002.Q02	Zeekoegat, downstream of R37 bridge	Olifants	24	16	00	29	48	03
CH8	ZOLI-DIP	Diphuti, downstream of Abel Erasmus Pass	Olifants	24	22	44	30	39	58
CH7	B7H009.Q02	Liverpool, 100 m downstream of flow weir	Olifants	24	19	47	30	44	28
CH5	B7H007.Q02	Oxford (Gravelotte/Hoedspruit road)	Olifants	24	11	00	30	49	28
CH2	B7H015.Q02	Mamba (KNP), 2 km upstream of flow weir	Olifants	24	02	40	31	13	16
CH1	B7H017.Q02	Balule (KNP), downstream of bridge	Olifants	24	03	07	31	43	49
MOUNTAIN & HIGHVELD TRIBUTARIES									
CH19	ZSELA-LEG	Legalameetse (Schelem)	Selati	24	09	20	30	15	35
CH17	ZBLYD-GFS	Grootfontein Forestry Station, upstream of Pilgrim's Rest	Blyde	24	55	57	30	44	49
CH18	ZBLYD-PEL	Downstream of Pilgrim's Rest	Blyde	24	53	49	30	45	02
CH16	ZORIG-NAT	Ohrigstad Nature Reserve, upstream of dam	Ohrigstad	24	57	15	30	36	51
CH15	ZSTEE-WPK	Wapadskloof bridge	Steelpoort	25	34	59	29	52	46
MIDDLE & LOW VELD TRIBUTARIES									
CH14	ZSTEE.STO	Stoffberg (Laersdrift bridge)	Steelpoort	25	22	55	29	50	18
CH9	ZSTEE-BUR	Burgersfort bridge	Steelpoort	24	39	32	30	18	09
CH6	ZBLYD-PLP	Blydepark (Jongmansspruit), where crossed by Abel Erasmus Pass/Hoedspruit road	Blyde	24	24	16	30	47	55
CH4	ZSELA-FOS	Upstream of Foskor	Selati	23	58	36	31	04	25
CH3	B7H019.Q02	Foskor (500 m downstream of flow weir)	Selati	24	02	13	31	08	02

TABLE 12: The Olifants River System. Water quality; mean concentrations (mgℓ^{-1}) of macro determinands from water samples collected in 1993 and 1994

SITE	n*	pH	EC	TDS	Na	K	Ca	Mg	Cl	SO4	TAL	F	PO4-P	NH4-N	NO3 + NO2 - N	Si
OLIFANTS RIVER																
CH13	5	8.3	69.4	538	75	2.0	31	30	39	63	243	0.8	0.025	0.07	0.15	11.6
CH11	2	8.5	112.5	720	133	4.8	42	36	195	97	173	1.0	0.023	0.05	0.14	6.5
CH8	5	8.4	59.5	445	55	2.9	26	31	60	31	194	0.3	0.029	0.06	0.29	6.0
CH7	44	8.4	52.5	390	47	2.9	27	25	51	29	169	0.4	0.028	0.04	0.21	7.8
CH2	2	8.6	194.0	1525	133	49.5	83	141	153	669	240	3.0	0.107	0.09	0.57	9.9
CH1	2	8.4	196.5	1454	138	41.2	83	132	153	607	244	2.5	0.027	0.09	0.04	6.2
MOUNTAIN AND HIGHVELD TRIBUTARIES OF THE OLIFANTS RIVER																
CH19	4	8.1	27.9	218	4	1.4	26	16	6	5	131	0.3	0.023	0.04	0.11	5.4
CH17	4	7.9	9.8	73	2	0.4	8	5	2	5	41	0.2	0.012	0.03	0.12	4.5
CH18	4	7.8	14.8	104	4	0.3	13	8	4	17	47	0.2	0.016	0.08	0.26	4.5
CH16	4	7.7	6.5	52	3	0.3	6	3	3	5	27	0.3	0.022	0.03	0.04	4.9
CH15	4	8.3	39.5	305	22	2.4	33	17	9	28	157	0.4	0.019	0.06	0.63	9.1
MIDDLE AND LOWVELD TRIBUTARIES OF THE OLIFANTS RIVER																
CH14	5	8.1	36.5	280	29	1.9	25	14	12	41	127	0.4	0.097	0.04	0.26	7.9
CH9	5	8.6	84.4	659	67	1.6	33	56	69	44	312	0.2	0.026	0.06	1.73	13.9
CH6	5	8.0	23.9	176	13	1.0	17	10	9	17	88	0.3	0.022	0.06	0.13	6.7
CH4	5	8.4	105.3	837	139	11.2	45	39	127	67	331	0.6	1.624	0.05	0.04	7.9
CH3	4	8.3	221.8	1828	167	72.0	84	171	174	864	237	4.0	0.222	0.11	0.58	16.2

n* = number of samples

TABLE 13: The Olifants River System. Water quality; concentrations (mgℓ^{-1}) of macro determinands in samples in which specified concentration levels were exceeded

Determinand		pH	EC	TDS	Na	K	Ca	Mg	Cl	SO4	TAL	F	PO4-P	NH4-N	NO3-N	Si
High-lighted conc.		<7.6 to >8.9	>70	>500	>100	>10	>40	>50	>100	>60	>220	>1	>0.05	>0.1	>0.5	>10
SITE	DATE															
OLIFANTS RIVER																
CH13	Jn93	8.4	89.7	713	104	1.5	37	41	58	84	317	1.4	.035	.05	.22	14.8
CH13	Oc93	8.2	77.7	613	94	2.4	30	37	50	74	266	.8	.013	.06	.03	11.9
CH11	Jn93	8.5	83.0	545	95	5.1	36	25	126	77	147	1.0	.025	.03	.09	6.2
CH11	Jy93	8.5	142.0	894	170	4.5	47	47	264	117	198	1.0	.020	.06	.19	6.7
CH8	Oc93	8.2	35.6	259	20	3.5	19	20	15	12	133	.1	.072	.12	1.31	9.7
CH7	Jy93	8.5	77.6	538	70	1.7	32	39	87	38	221	.4	.019	.06	.06	5.9
CH7	Au93	8.1	73.5	506	62	2.4	30	36	77	34	217	.3	.012	.07	.10	7.6
CH7	Au93	8.7	84.5	591	83	3.0	32	43	109	43	227	.4	.021	.05	.07	4.7
CH7	Se93	8.7	77.3	530	72	2.8	29	39	89	37	214	.4	.030	.07	.07	4.7
CH7	Se93	8.1	83.2	609	85	3.3	27	45	122	51	224	.6	.034	.10	.05	10.5
CH7	Oc93	8.2	100.3	665	110	7.6	36	38	179	70	182	.5	.036	.15	.35	7.0
CH7	Oc93	8.9	68.8	561	81	4.5	26	42	78	39	237	.8	.020	.08	.02	6.7
CH7	Oc93	8.0	61.1	515	47	3.6	41	32	49	33	252	.7	.023	.02	.06	12.3
CH7	Oc93	8.0	37.5	279	19	3.5	20	23	15	13	147	.3	.046	.01	.97	10.4
CH2	Jy93	8.3	184.0	1383	127	46.6	73	125	134	592	230	2.7	.130	.10	.25	10.1
CH1	Jy93	8.3	213.0	1551	146	44.5	87	140	162	672	244	2.4	.025	.10	.02	6.9
MOUNTAIN AND HIGHVELD TRIBUTARIES OF THE OLIFANTS RIVER																
All concentrations less than high-lighted levels																
MIDDLE AND LOW VELD TRIBUTARIES OF THE OLIFANTS RIVER																
CH14	Jy93	8.1	68.9	503	74	2.5	31	26	32	95	197	.7	.031	.06	.15	7.6
CH9	Jn93	8.7	91.6	727	70	1.2	37	68	81	48	340	.1	.017	.04	1.74	14.3
CH9	Jy93	8.5	118.6	885	88	1.1	37	80	96	59	420	.2	.013	.07	2.32	17.3
CH3	Jn93	8.3	240.0	1774	166	76.1	75	171	183	809	236	4.1	.137	.06	.46	14.6
CH3	Jy93	8.3	246.0	1827	166	72.2	86	176	181	844	242	4.0	.272	.09	.45	15.4
CH3	Oc93	8.4	204.0	1852	167	72.6	79	175	163	928	214	3.7	.181	.13	.48	16.1

CH5 appear at least once in **Table 13**. The waters of high TDS recorded at Stations above CH5 must have passed that station, so it is fortuitous that no high TDS was recorded at Station CH5.

The source of the increases in the concentrations of many determinands at Stations CH2 and CH1 in the lower Olifants River would appear to be the Selati River, where concentrations of the same determinands was also high, whereas upstream of station CH2 at Station CH5 the concentrations were so low that Station CH5 does not appear in **Table 13**. In addition to high concentrations of other determinands, the Selati at Station CH3 had elevated orthophosphate concentrations, but this is hardly surprising as phosphates are mined at Phalaborwa.

The water quality data, although based on 5 or less water samples, shows that there is severe sporadic pollution of the Olifants River and of its Middleveld and Lowveld tributaries. It is reasonable to expect that there would be water quality impacts on the invertebrate communities of these rivers.

4.4 SASS4 scores, numbers of taxa and ASPT

Compared with the Sabie River, SASS4 scores, numbers of taxa and ASPT values were low in the Olifants River (**Figure 20**). It was only at Stations CH5 and CH6, which bracket the confluence of the poor water quality Selati River that SASS4 scores exceeding 100 (the absolute minimum score for any single sample from the Sabie River) were recorded. ASPT was always below 6, a score which was almost always exceeded in the Sabie River. SASS4 scores, numbers of taxa and ASPT values were low at all the other sampling points on the river. They were, however, not nearly as low as scores recorded at polluted sampling points such as the Besterspruit at Nelspruit (this appendix) or the streams of the Witwatersrand (Appendix A).

SASS4 scores, numbers of taxa and ASPT recorded in the mountain tributaries at sites CH19, Ch17 and CH16 (**Figure 21**) differed little from those in the Sabie River. At CH18, Blyde River below Pilgrim's Rest, SASS4 scores were low, but ASPT was high, indicating that water quality was unlikely to be the factor limiting the number of taxa found. The lowest scores in **Figure 21** were from the upper Steelpoort River at station CH15. It is of some interest that SASS scores (SASS version unspecified) reported for 1995 (Swart *et al.*, 1995) were higher than those shown in **Figure 21**.

Water quality at all Mountain and Highveld sampling points was such that no data qualified to be included in **Table 13**. This group of sampling points is represented in **Table 14** (heavy

TABLE 14: The Olifants River System. Water quality; concentrations ($mg\ell^{-1}$) of heavy metals in water samples in which specified concentration levels were exceeded

Metal		Ti	B	Sr	Cu	V	Al	Mo	Cr	Fe	Mn	Ni	Cd	Zn	Ba	Co
Kempster max*		12	5	200	0.200	0.500	1.5	0.100	0.100	1.000	1.000	0.050	0.030	0.100	5.000	1.000
High-lighted conc >		0.250	0.250	1.000	0.100	0.250	0.750	0.050	0.050	0.500	0.500	0.025	0/015	0.050	2.000	0.500
SITE	DATE															
OLIFANTS RIVER																
CH11	Jn93	0.000	.087	.224	0.000	.007	.727	.007	0.000	.936	.007	.004	0.000	0.000	.036	.020
CH8	Oc93	.435	.154	1.003	.463	.612	214.885	0.000	5.360	290.009	17.540	2.743	0.000	.556	2.226	.704
CH7	Jn93	0.000	.093	.124	0.000	.008	.090	.009	0.000	1.138	.014	.008	0.000	0.000	.039	.014
CH7	Oc93	.298	.162	1.280	.538	.631	224.465	0.000	5.530	256.009	23.170	3.228	0.000	.619	2.820	.912
CH2	Jy93	0.000	.116	2.714	0.000	.008	.020	0.000	0.000	0.000	0.000	.007	0.000	0.000	.008	0.000
CH1	Jy93	0.000	.111	2.240	0.000	.009	.135	0.000	0.000	.024	0.000	.012	0.000	.023	.063	0.000
MOUNTAIN AND HIGHVELD TRIBUTARIES OF THE OLIFANTS RIVER																
CH18	Jy93	0.000	0.000	.028	0.000	0.000	1.339	0.000	0.000	.409	.083	.011	0.000	0.000	0.000	0.000
CH18	Oc93	.006	.022	.010	0.000	0.000	.348	0.000	0.000	.757	.111	.001	0.000	.024	0.000	.014
CH16	Jy93	0.000	0.000	.010	0.000	.001	.050	0.000	.079	.186	0.000	.001	0.000	0.000	0.000	0.000
CH16	Oc93	0.000	.100	.020	0.000	0.000	.812	0.000	.002	.519	0.000	.002	0.000	.023	0.000	0.000
CH15	Oc93	0.000	.061	.136	0.000	0.000	.449	0.000	0.000	.608	.111	.007	0.000	.041	.040	0.000
MIDDLE AND LOWVELD TRIBUTARIES OF THE OLIFANTS RIVER																
CH14	Oc93	.004	.016	.063	0.000	0.000	.165	0.000	0.000	.511	.014	0.000	0.000	.041	.010	.002
CH9	Jy93	0.000	.115	.197	0.000	.019	.268	0.000	.257	.221	0.000	.011	0.000	0.000	0.000	0.000
CH9	Oc93	.085	.028	.151	0.000	.041	5.286	0.000	.028	6.530	.577	.028	0.000	.040	.050	.028
CH6	Ju93	0.000	.139	.032	0.000	0.000	.075	0.000	0.000	.292	.015	0.000	0.000	0.000	.007	.013
CH4	Ju93	0.000	.087	.233	0.000	.008	.108	.009	0.000	.266	0.000	.002	.029	0.000	0.000	.018
CH4	Oc93	.005	.246	.508	0.000	.006	.173	0.000	0.000	.204	.002	.001	0.000	.006	.035	.010

Measured - not detected in the samples included in this table Hg Be Pb Zr As

* see text

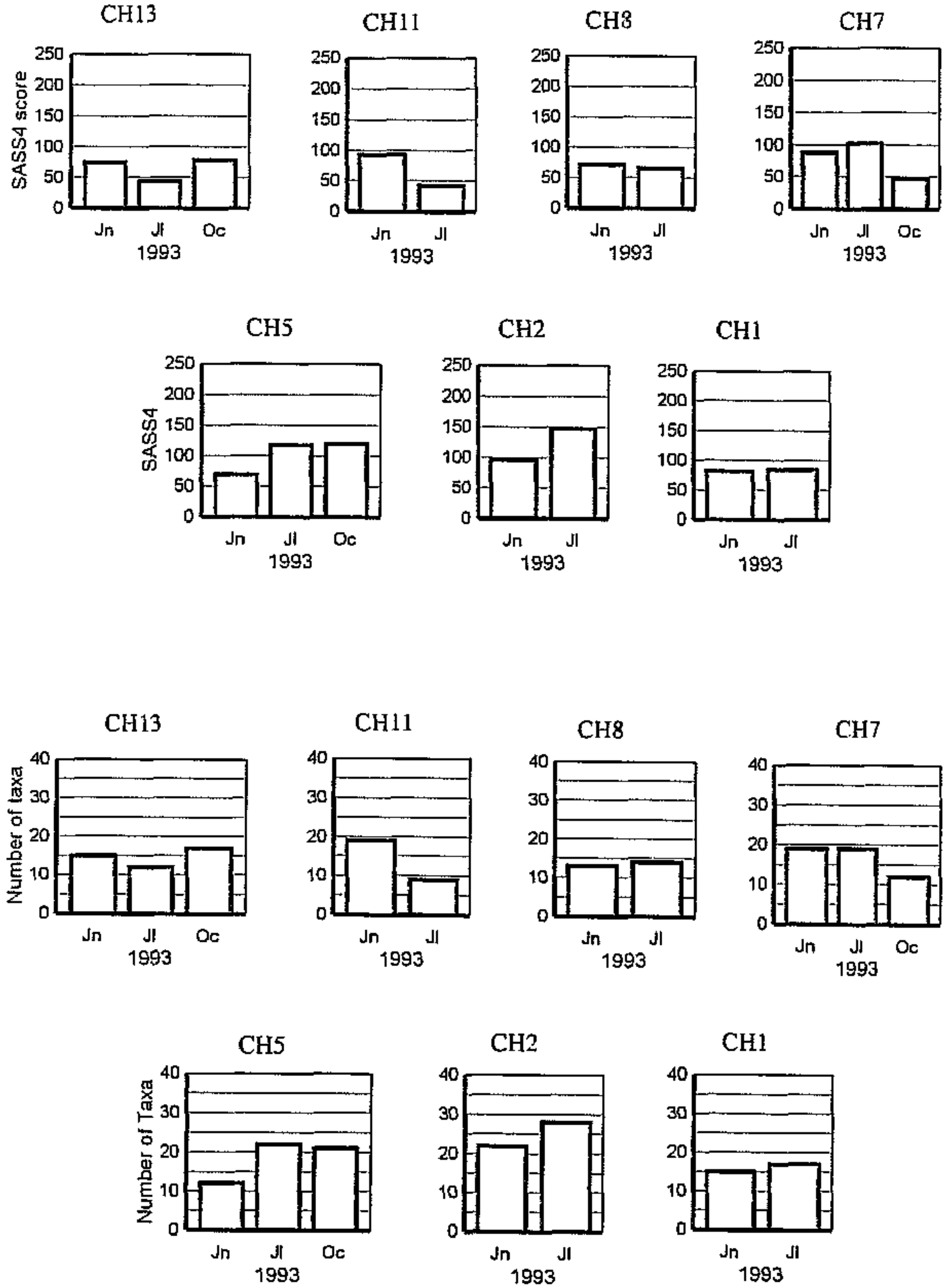


FIGURE 20: The Olifants River; SASS4 scores, numbers of taxa and ASPT by sampling point and month. SASS2 IWQS data converted to SASS. **Figure 20** is continued on the following page.

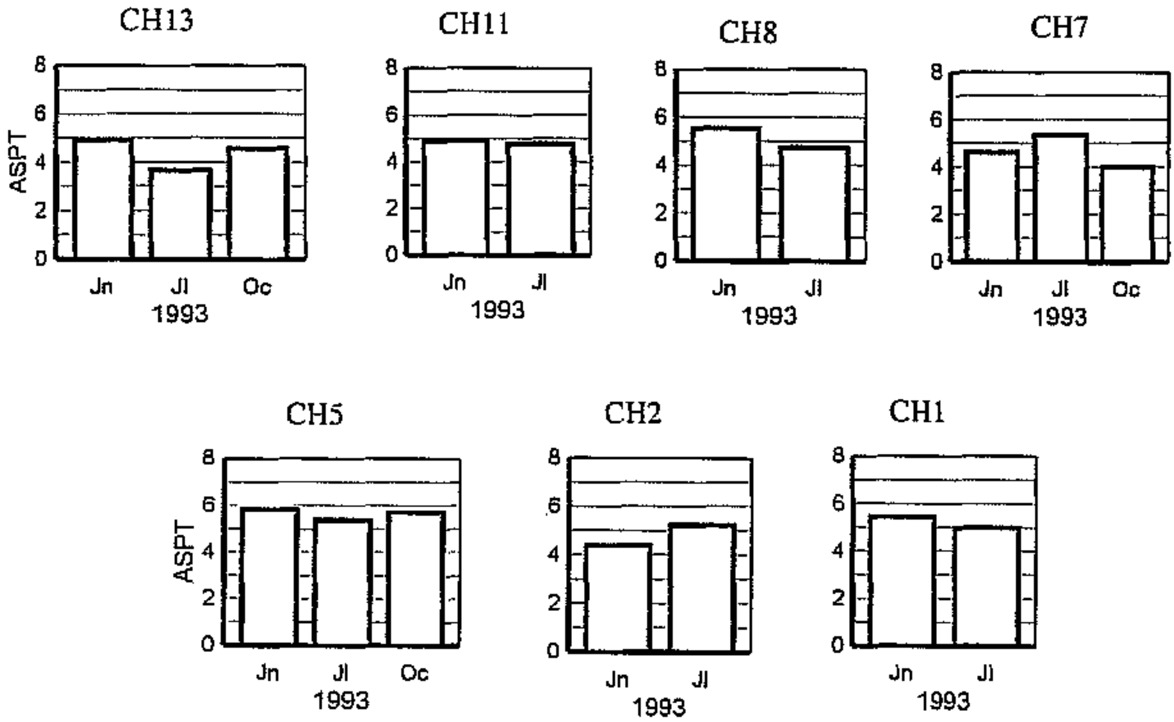


FIGURE 20: continued

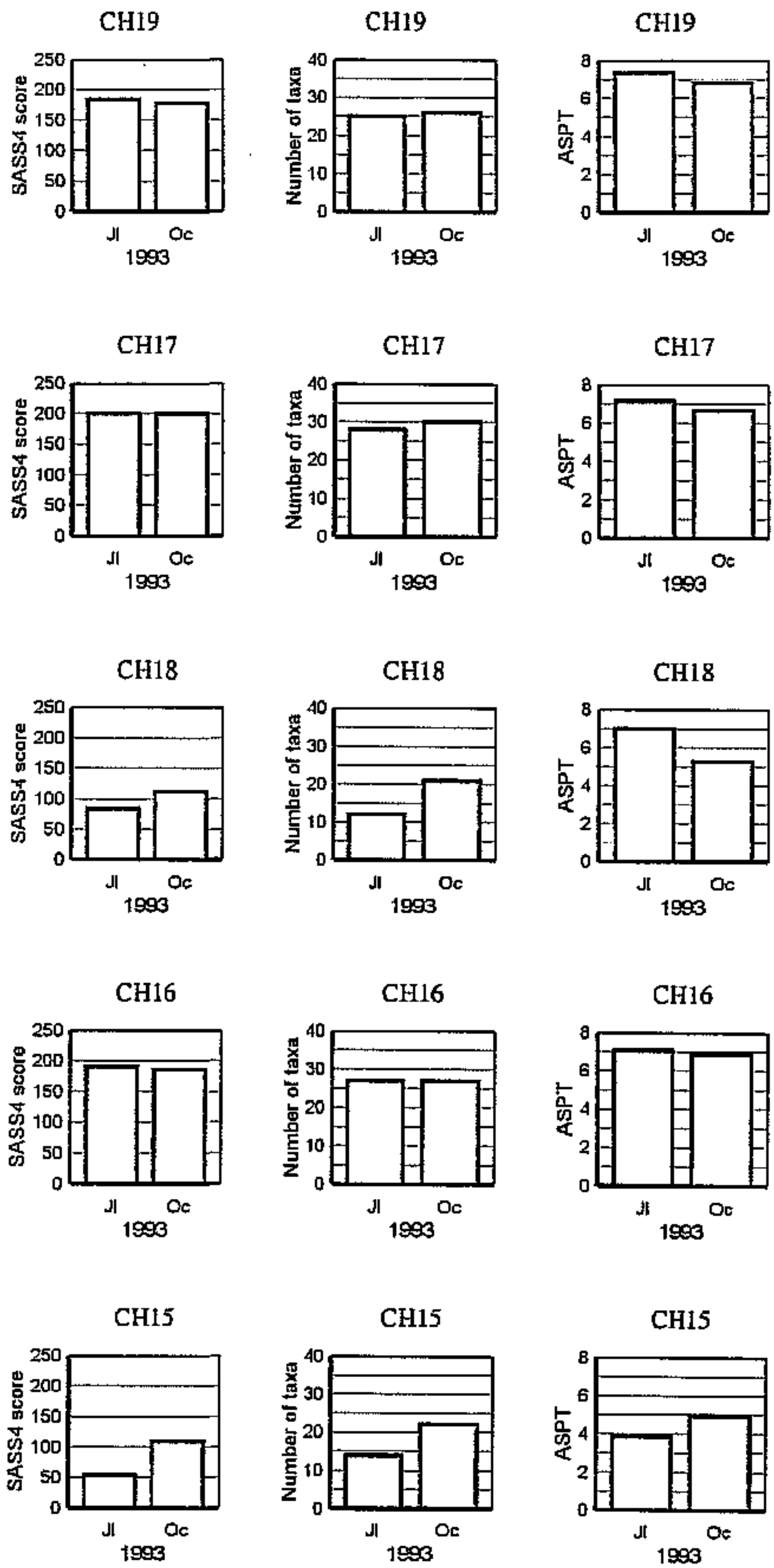


FIGURE 21: Mountain and Highveld tributaries of the Olifants River: SASS4 scores, numbers of taxa and ASPT by sampling point and month. SASS2 IWQS data converted to SASS4

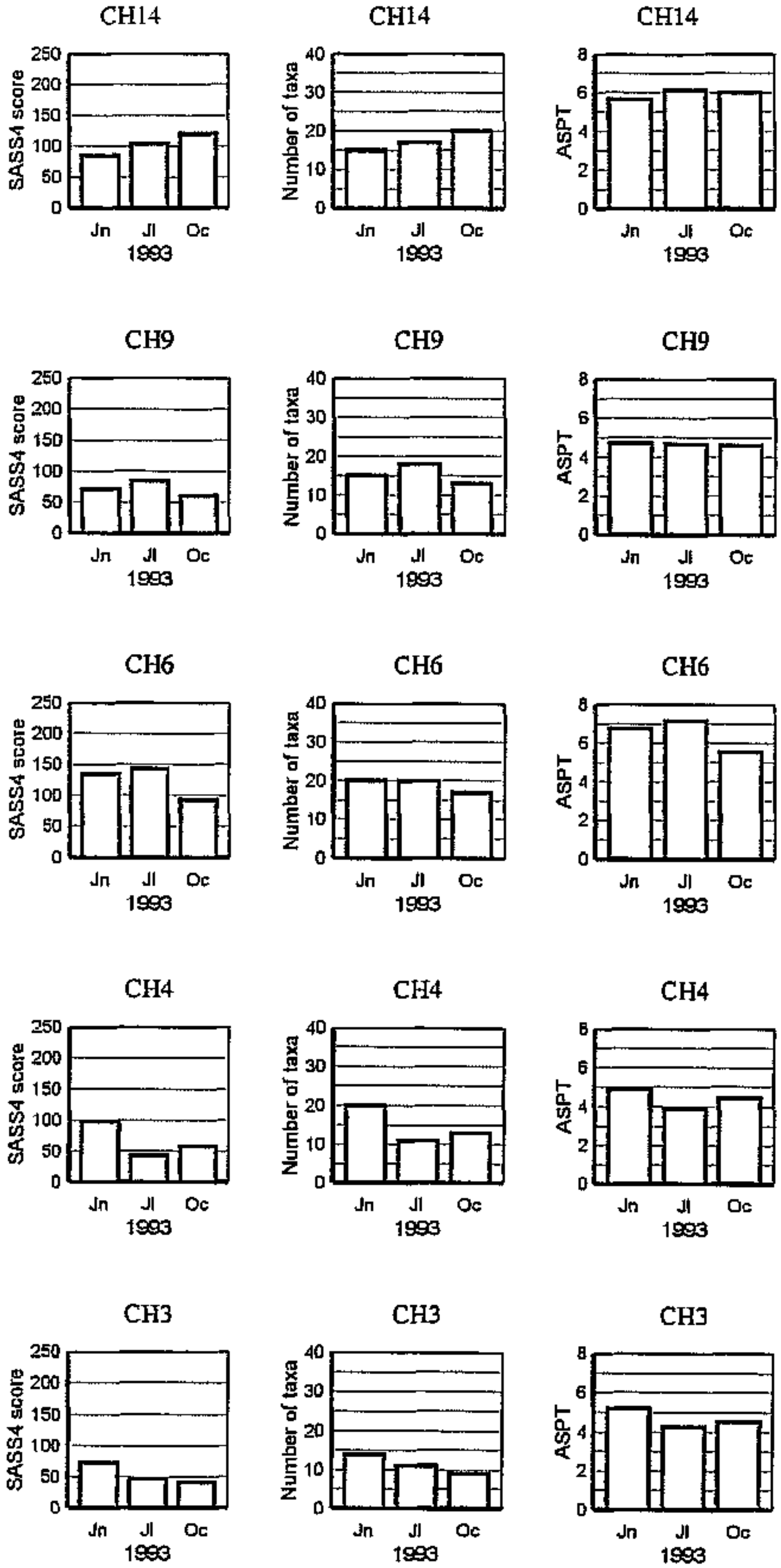


FIGURE 22: Middleveld and Lowveld tributaries of the Olifants River: SASS4 scores, numbers of taxa and ASPT by sampling point and month. SASS2 IWQS data converted to SASS4

metals), but not in such a manner that water quality should be regarded as likely to have a detrimental impact on the aquatic invertebrates. However, more recent studies (Swart *et al.*, 1995) have shown that there are impacts on water quality in the Steelpoort River at Site CH15 due to the proximity of this sampling point to a vanadium processing plant.

There were two water samples which had extraordinary high concentrations of heavy metals (**Table** 14, CH8 and CH7 October). The fact that these high concentrations occurred at adjacent sampling points in the same month would indicate that a slug of highly polluted water of unknown origin passed down the river and could be expected to have had an impact on all sampling points further downstream. In the Middleveld and Lowveld tributaries results from the Steelpoort River (**Table 14**, station CH9) indicate occasional deterioration in water quality as regards some metals, while Strontium concentrations were elevated in the lower Selati River at CH3. Strontium concentrations were also elevated in the Olifants River downstream of the Selati confluence.

Among the Middle and Lowveld tributaries of the Olifants River, results from the Blyde River at CH6 in the Lowveld were similar to results from the Sabie River, particularly as regards the ASPT. The lowest scores were recorded from the Selati River at CH4 and CH3 and scores at CH9 (Steelpoort River at Burgersfort) were little better. Further upstream on the Steelpoort River at CH14 scores and ASPT were higher than at CH9.

4.5 Conclusions from the Olifants System

In certain respects the Olifants River data confirm conclusions drawn from the Sabie and Crocodile Rivers. In unpolluted mountain tributaries along the Drakensberg Escarpment overlooking the Lowveld, SASS4 scores may be expected to usually exceed 125 and reach to over 200. ASPT scores typically range between 6 and 8. Lowveld Rivers of good water quality and generally in good environmental condition, as is the case with the Blyde River at CH6, are similar to mountain tributaries with respect to SASS4 and ASPT.

While the SASS4 scores, numbers of taxa and ASPT from the sampling points of poor water quality in the Olifants River were lower than at unimpacted sampling sites, they were higher than would be expected from the water quality data. It is particularly surprising that the highest scores from the Olifants River were recorded at CH5 and CH2, on either side of the confluence of the poor water quality Selati River. It must, however, be realized that the actual toxicity of metals under field conditions is not particularly well known. Metal toxicity is influenced by many synergistic and antagonistic factors, as well as being modified by the pH of the water, whose mean values in the Olifants River System ranged between 7.7 (unpolluted mountain tributary) and 8.6 (**Table 12**).

5. DISCUSSION AND CONCLUSIONS

In the description of results the evaluation of habitat conditions has received scant attention. There would appear to be a need for habitat diversity assessment - the more diverse the habitat, the greater the taxon diversity that will be present and the greater the SASS4 score. This has been found to be the most likely explanation for the lower than expected SASS4 scores at sites X1 and X5 in the Crocodile catchment. In both these cases the author was familiar with the sites, but there is no record of the habitats from which the data provided by IWQS was collected. This makes it impossible to take habitat diversity into account in interpreting the IWQS SASS4 scores, such as those from the uppermost sampling point on the Sabie River (SB8). It is therefore essential to the correct interpretation of results to record the habitats from which samples were collected.

However, from the results thus far obtained, it would seem that ASPT is largely independent of habitat diversity. Indeed this finding would appear to be rational, in that each habitat would be expected to support some taxa which would be classified as pollution sensitive (high scoring taxa) and some that would be classified as pollution tolerant (low scoring taxa). Thus there is a logical argument that habitat diversity should have little impact on ASPT, since the absence of a habitat(s) should result in the loss of both tolerant and sensitive taxa. Nevertheless. the confidence level of interpretations of results would be considerably higher were there to be a record of the habitats sampled.

Calculation of factors to normalise recorded SASS4 scores and numbers of taxa for sampling points where habitats were missing would require the generation of an entirely new data base. In this data base, at each sampling point separate SASS4 scores and numbers of taxa would have to be recorded for each of the available habitats. From this data it should be possible to calculate scores and numbers of taxa to be added to each sampling point score to account for missing habitats. Large as this operation might be, it is complicated by the fact that account would have to be taken of water quality as a modifier of scores recorded from habitats. This would defeat the object of the exercise, for correct modification of the sample score would pre-suppose knowledge of the water quality. Another consideration is that when there is severe pollution, differences in the occurrence of families in the communities of different habitats tend to disappear. Thus in the biological detection of severe pollution habitat differences between sampling points become irrelevant.

It can only be concluded that interpretation of moderate level SASS4 scores (50 to 100) requires close attention to ASPT. It is concluded that if SASS4 is greater than 100 and ASPT is greater than 6, the possibility of water quality deterioration is remote. When SASS4 is less than 50, there has been water quality deterioration, but ASPT is no longer a reliable aid in interpretation of results. When SASS4 lies between 50 and 100, ASPT values greater than 6 indicate unpolluted conditions, but restricted habitat diversity. In this (50 - 100) SASS4 range, ASPT values less than 6 indicate water quality deterioration, the lower both the SASS4 score and the ASPT value the greater the deterioration.

The SASS4 data from the Sabie River is important as it reveals that there is no reduction in ASPT along the river. The Sabie enters the Kruger National Park having been exposed to much less impact than any comparable river in the eastern part of South Africa. Within the park impacts are negligible. The lower reaches of the Sabie are therefore probably closer to their natural state than those of any other river in the country. It may be concluded from this that the lower reaches of the many rivers in which ASPT scores decline from the upper reaches have been subject to unnatural impacts, for which the greatest probability is changes in water quality.

6. REFERENCES

Kempster, P L, W H J Hattingh & H R van Vliet (1980) *Summarized Water Quality Criteria.* Technical Report No TR 108, Hydrological Research Institute, Department of Water Affairs, Forestry and Environmental Conservation, Pretoria.

Swart, S J, S H J Jooste, D J Roux & L Hill (1995) *The impact of contamination emanating from Transvaal Alloys at Wapadskloof on the water quality and biotic integrity of the upper Steelpoort River.* Report No N B240/00/0000/REQ/1395, Institute for Water Quality Studies, Department of Water Affairs and Forestry, Pretoria.

Appendix C

SASS assessment of the condition of selected streams and rivers in the Kwazulu-Natal Midlands, based on information provided by Umgeni Water.

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LIST OF FIGURES

EXECUTIVE SUMMARY

In this Appendix SASS4 data gathered by Umgeni Water from streams in the Mgeni River catchment and from the Sterkspruit at Hammarsdale are presented together with water quality data.

At many sampling points data was collected in both the rainy and the dry season. The data evidence no difference in mean SASS4 scores and ASPT values between the two seasons, though there is reason to believe that some recorded summer SASS4 scores were low, due to difficulties in accessing permanently inundated parts of the river channel in this season.

While there was great variation in SASS4 scores at unpolluted sites (5 to 95 percentile range 55 to 185), low scores at these sites were higher than scores at polluted sites on the Msunduze River and Sterkspruit. There was less variability in ASPT scores at the unpolluted sites (5 to 95 percentile range 5.2 to 7.5), than there was in SASS4 scores.

At sites where water quality data revealed severe pollution, SASS4 scores were less than 50 and sometimes as low as 10. At these sites ASPT was unusually variable. It was conclued that when SASS4 is less than 50, ASPT is of little use in interpreting the results in relation to water quality. On the other hand as SASS4 increases above 50, more and more reliance can be placed on ASPT in the interpretation of results. At unpolluted sites in the Mgeni River, ASPT was seldom less than 5.5 (**Figure 10**).

SASS4 data from the unpolluted parts of the Mgeni River varied widely, as did ASPT data. In neither case is it possible to identify a single site which might be taken to be consistently representative of "pristine" conditions. It is concluded that it will probably be necessary to arbitrarily identify cut-off scores for both SASS4 and ASPT, above which conditions should be considered to be unequivocally unpolluted.

ACKNOWLEDGEMENTS

All the chemical and biological data used in this report has been provided by Umgeni Water. I thank the organisation, and especially Dr Chris Dickens for his role in making the data available to me. Dr Dickens played a particularly active and constructive role in the RBA Forum out of whose activity came SASS4. In reviewing a draft of this appendix, he provided useful insights on site specific conditions. These have been particularly useful in accounting for anomolous results.

While Umgeni Water provided the data, the interpretations and views expressed in this Appendix are solely those of the author.

1. INTRODUCTION

The information contained in this appendix was gathered by Umgeni Water from its area of responsibility for water quality. This area includes the Mgeni River and its catchment and the Mlaas River and its catchment. In the Mgeni catchment the Msunduze is a large tributary, which flows through Pietermaritzburg where there are many impacts on water quality. The Sterkspruit, into which the effluent from a sewage treatment works at Hammarsdale operated by Umgeni Water flows, is a tributary of the Mlaas River. The treatment works receives effluents from textile mills and from a chicken processing plant.

The biological data from Umgeni Water is particularly useful in that it is backed up by extensive chemical analyses of the stream water and in that it extends into the wet season. It includes both polluted and unpolluted streams.

2. METHODS

SASS sampling was undertaken by Umgeni Water biologists at sampling points used in a routine water quality monitoring programme. Over the period covered in this appendix, the scoring version changed from SASS2 to SASS3 to SASS4. Only SASS scores, numbers of taxa and ASPT were provided by Umgeni Water for purposes of this report. All versions of SASS were changed to SASS4 using the regression formulae given in the main report. ASPT was calculated from the SASS-score-converted-to-SASS4 divided by the number of taxa recorded.

Chemical and bacterial data were collected by Umgeni Water using their standard methods. Since the occurrence of invertebrates is not governed by average conditions, but by extremes, the highest concentrations of determinands recorded have been presented. It is recognised that there are dangers in this approach, for false outliers are not unknown. Where there was a large difference between the highest and second highest concentration, attention is drawn to the second highest concentration in footnotes to the tables.

3. RESULTS

3.1 The Mgeni River and its tributaries upstream of Nagle Dam

Sampling sites dealt with in this section are listed in **Table 1** and shown on **Figure 1.** As can be seen from **Table 2**, samples for *E. coli*, nitrate and ammonia determination were collected at approximately weekly intervals while BOD and COD were measured very much less frequently.

Table 1: Umgeni Water sampling sites in the Mgeni River and in some of its tributaries.

Site number	Location
1	Lions River at Weltevreden
2.1	Mgeni River at Petrus Stroom
2	Mgeni River at Midmar Dam inflow
6	Mgeni River at Mortons Drift (above Albert Falls Dam)
7	Karkloof stream above Mgeni confluence
12	Mgeni River below Mpolweni confluence
14	Mgeni River above Nagle Dam
20	Mgeni River at New Inanda Weir
21	Mngeweni Stream above Mgeni confluence
26.2	Mgeni River below Inanda Dam

Table 2: Water quality in the Mgeni River. Sites and numbers of analyses made for various determinands between September 1992 and January 1995.

Site number	*E. coli*/100 ml	NO_3-N mgℓ^{-1}	NH_4-N mgℓ^{-1}	BOD mg$O_2\ell^{-1}$	COD mg$O_2\ell^{-1}$	DO mg$O_2\ell^{-1}$
1	121	123	121	10	4	-
2.1	124	123	122	10	6	-
2	124	123	123	10	6	-
6	108	107	106	9	5	-
7	107	107	106	9	6	-
12	106	106	106	9	5	-
14	121	122	120	8	-	-
20	120	121	120	29	28	-
21	119	117	119	8	6	-
26.2	122	122	121	10	3	118

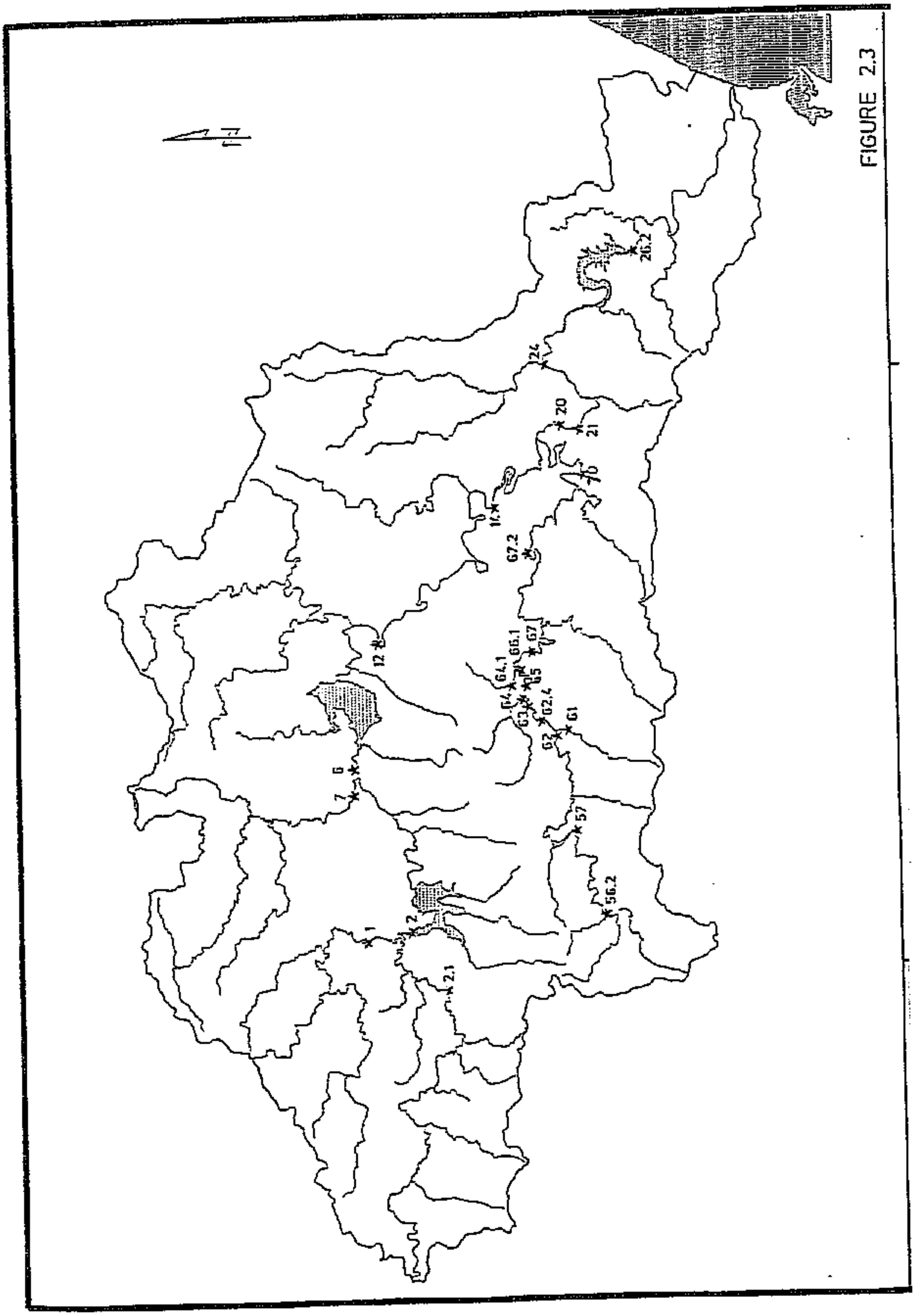

Figure 1: A map of the Mgeni catchment showing the location of biological sampling sites. Taken from "Umgeni Water Quality Management Plan" (Dept. Water Affairs & Forestry, Umgeni Water & Ninham Shand), Figure 2.3.

The concentration of none of the determinands, save COD, shown in **Table 3** was unusually high when the two outlying maximum values are substituted by the next highest concentrations. The COD at site 20 was high, but this is plausible since the next highest concentration was only 2 $mgO_2\ell^{-1}$ lower than the maximum. Also the site was located just downstream of the confluence of the Msunduze River, which gathers all the run-off of Pietermaritzburg and its peri-urban areas, with the Mgeni.

The available data show that water quality is good in the Mgeni River and is unlikely to have an impact on the invertebrate communities. Although there is nutrient enrichment of Inanda Dam, the water leaving the dam is of reasonably good quality (**Table 3**). Cold, anaerobic, hypolimnetic water is at times discharged from the dam, though re-oxygenation takes place by Site 26.2, There is fairly abundant filamentous algal growth at this site. SASS4 scores were lower below Inanda Dam than in the rest of the river. Nevertheless the Mgeni River data is particularly useful, for it means that, for the most part, comparison of variation in results along the river may be taken to represent the manner in which natural variation in SASS scores takes place along a river.

Sites 1, 7 and 21 were located on tributaries of the Mgeni. The Mngcweni (Site 21) drains Cato Ridge where it receives an abattoir effluent. At Site 21 nitrate, ammonia and BOD values were a little higher than would be expected in a natural stream.

Table 3: Water quality in the Mgeni River. Maximum concentrations of *E. coli*, Nitrates, Ammonia, Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) and maximum and minimum concentrations of Dissolved Oxygen (DO); September 1992 to January 1995.

Site number	*E. coli*/ 100 ml	Nitrates $mg\ell^{-1}$	Ammonia $mg\ell^{-1}$	BOD $mgO_2\ell^{-1}$	COD $mgO_2\ell^{-1}$	maximum DO $mgO_2\ell^{-1}$	minimum DO $mgO_2\ell^{-1}$
1	7400	0.66	0.15	2.9	37.7	-	-
2.1	2900	1.71	0.37	2.5	40.7	-	-
2	13900	0.68	0.22	2.8	21.5	-	-
6	6600	1.19	0.32	1.8	23.6	-	-
7	3020	1.5	0.1	1.9	23.7	-	-
12	8000	2.37	0.1	1.4	164[2]	-	-
14	7000	0.69	4.78[1]	2.5	-	-	-
20	22200	3.37	0.1	3.2	81	-	-
21	4560	7.14	0.99	3.8	42.2	-	-
26.2	1700	1.16	0.47	2.2	27.7	11.6	5.0

1. next highest concentration 0.08; 2. next highest concentration 44.1.

Seasonal variation in SASS4 scores, numbers of taxa and ASPT values in the Mgeni River and its tributaries are shown by sampling site in **Figure 2**. Analysis of the frequency with which the highest and lowest SASS4 and ASPT scores at single sampling points occurred in the various months (**Table 4**) shows that the present data do not reveal trends for scores to be higher or lower in particular months. Given the limited number of samples at each sampling site, it would appear that there is no seasonality in the occurrence of high and low scores. This is confirmed in **Figure 3** where monthly mean values of SASS4, numbers of taxa and ASPT for all **Table 1** sampling points are shown. Seasonality in SASS scores is considered further in Section 4 (Discussion and Conclusions).

Table 4: The frequencies with which the highest and lowest SASS4 and ASPT scores occurred in various months in the Mgeni River data set.

	Ja93+Fe94	May 93+94	Se93+Au94	Nov 93+94
SASS4 highest score	3	2	3	2
SASS4 lowest score	3	2.5	3	1.5
ASPT highest score	2	4.5	1.5	2
ASPT lowest score	3	3	1	2

Variation in SASS4 scores, numbers of taxa and ASPT values in the Mgeni River by sampling site is shown in **Figure 2**. **Figure 2** reveals a tendency for the SASS4 to be lower at Sites 1, 2, 21 and 26.2 than elsewhere. This is clearly illustrated by the mean values for these characteristics (**Table 5**). Site 1 receives the water transferred from the Mooi River and has an unnatural variation in flow, since transfer from the Mooi River is intermittent and was taking place during the study period. However this is not the only possible cause of the relatively low scores at Site 1. There are many more dairies and piggeries in the Lions river catchment than in the upper Mgeni River. Although these have not been shown to change water quality, results using the Biotic Index (Chutter, 1972) consistently indicated that conditions at Site 1 were worse than at Site 2.1 (C. Dickens, Umgeni Water - personnal communication).

River channel conditions at Site 2 were unsuited to SASS4 sampling (C Dickens, Umgeni Water - personnal communication) due to the large size of the stones in the rapids. There is evidence of water quality deterioration at Station 21 (see above). It is possible that the proximity of Site 26.2 to Inanda Dam resulted in a reduction in invertebrate diversity.

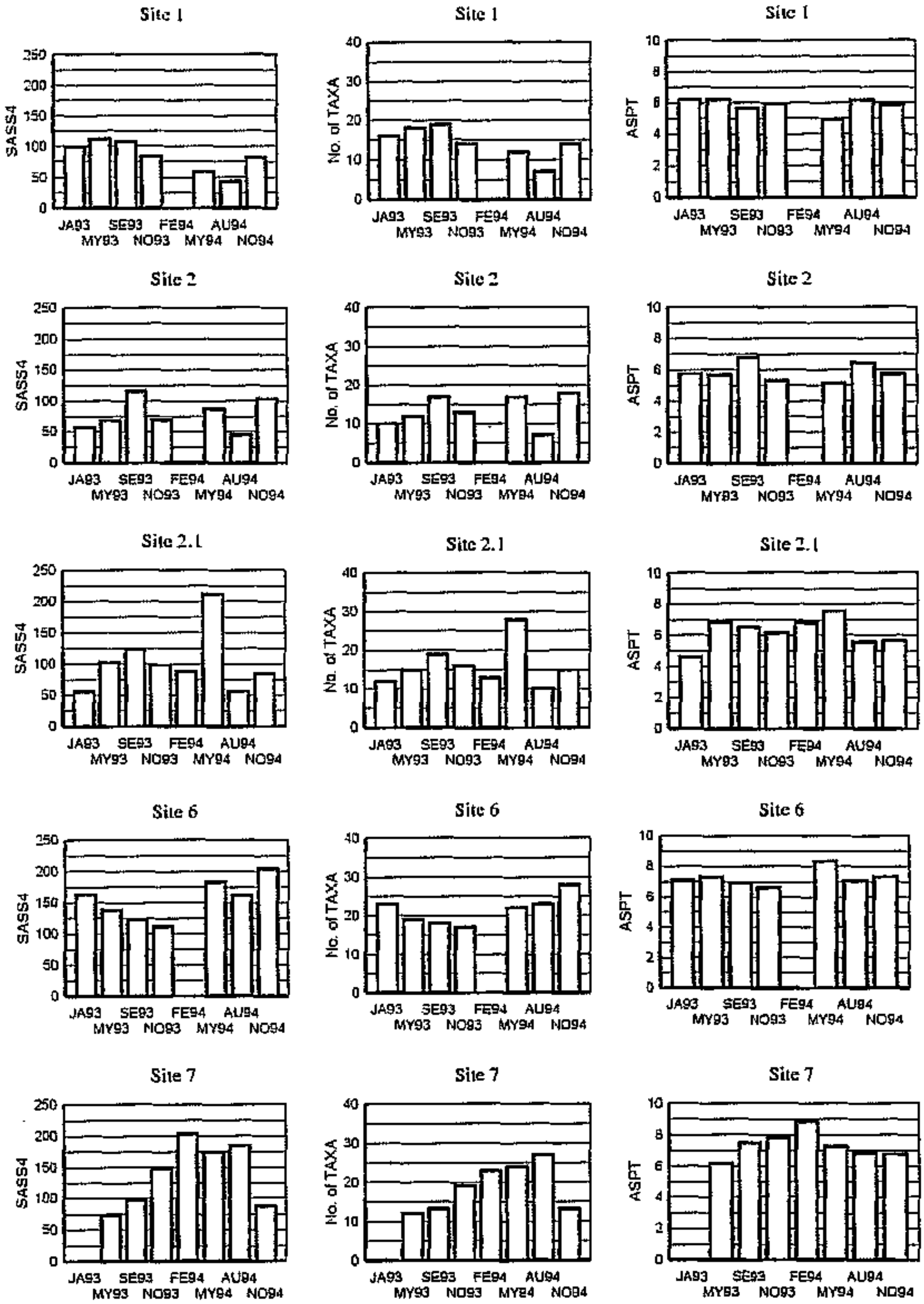

Figure 2: SASS4 scores, numbers of taxa and ASPT values by sampling site recorded from the Mgeni River, Sites 1 to 7, in 1993 and 1994. Continued over/..

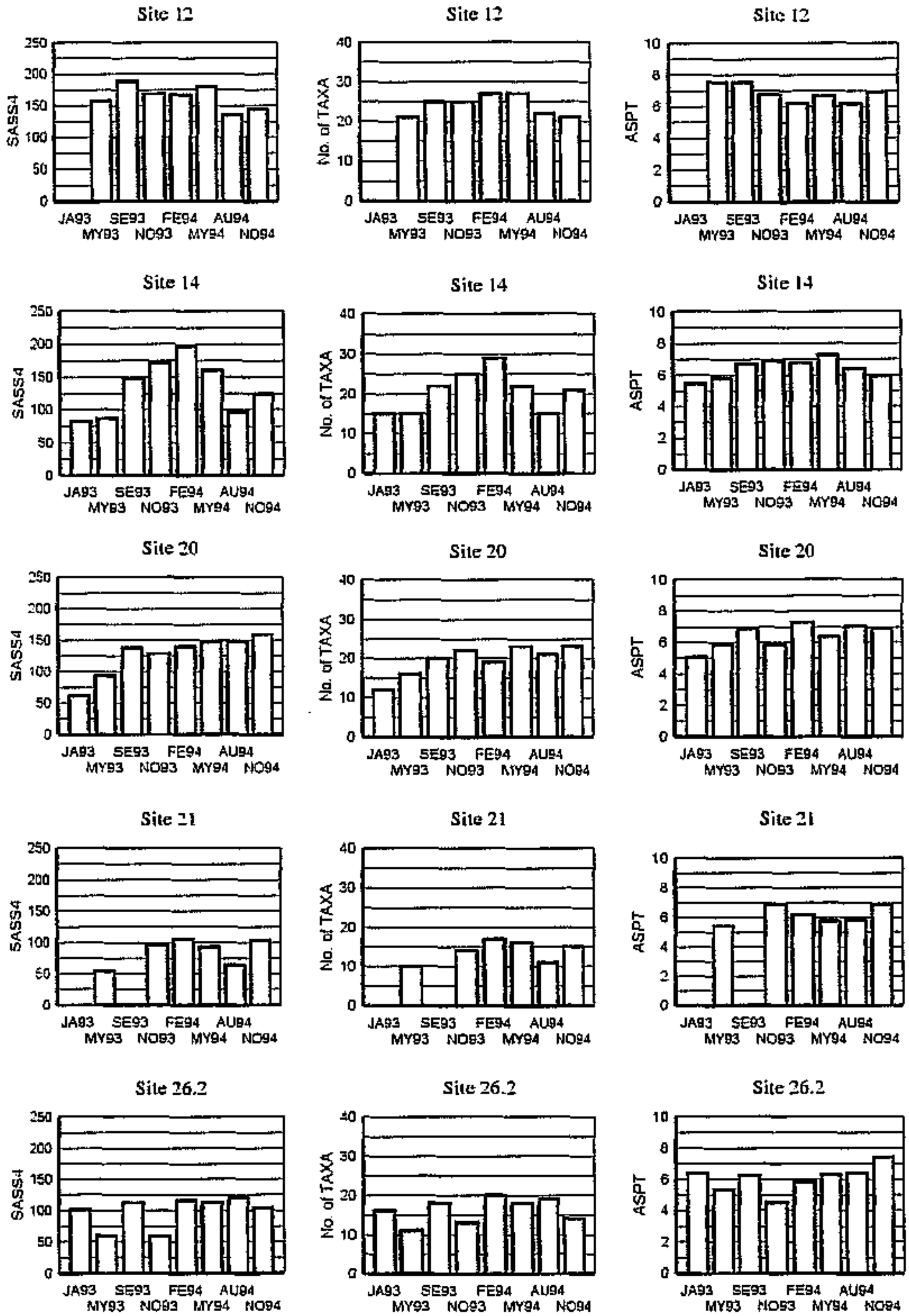

Figure 2: Continued, Sites 12 to 26.2

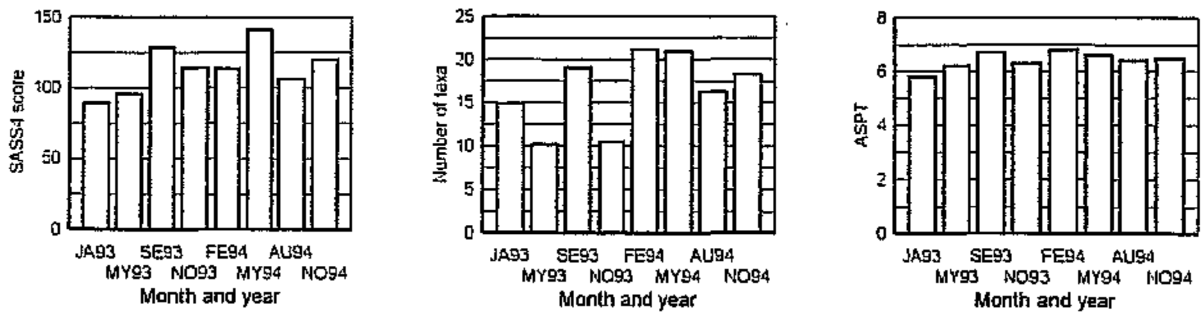

Figure 3: Mean SASS4 scores, numbers of taxa and ASPT values by month from 10 sites on the Mgeni River and its tributaries.

Table 5: Mean SASS4 scores and mean ASPT values for sampling points on the Mgeni River and some of its tributaries.

Site	mean SASS4	mean ASPT
1	84	5.8
2	78	5.8
2.1	126	7.1
6	156	7.2
7	138	7.3
12	164	6.5
14	134	6.4
20	127	6.4
21	86	6.2
26.2	98	5.9

The monthly data for Site 2.1 (**Figure 2**) show that the mean SASS4 value for this sampling point was greatly influenced by the out-lying high value measured in May 1994. It is reported that in May 1994 sampling conditions were ideal - all habitats were available to sample and the flow was such that it was possible to collect from permanently inundated parts of the river channel (C.Dickens, Umgeni Water - personnal communication). When the outlying score is omitted, the remaining SASS4 scores are little different from those recorded from Sites 1 and 2 (**Figure 2**). The Karkloof tributary (Site 7) had a high mean SASS4 score.

Mean ASPT values did not vary in quite the same manner as mean SASS4 scores. ASPT was lowest at sites 1, 2 and 26.2, highest at sites 2.1, 6 and 7 and intermediate at sites 12, 14, 20 and 21. Due to the possible unnatural impacts on scores at Sites 1, 2 and 26.2 at the up- and down-stream extremes of the sampling area, the Mgeni data do not allow for assessment of the longitudinal variation of SASS-based scores in the river.

3.2 The Msunduze River

Sampling points on the Msunduze River are shown on **Figure 1** and described in **Table 6.** At the uppermost sampling point the catchment of the river has a dense rural population and the population density remains high along the river valley all the way down to the Mgeni confluence. Rates of soil erosion in the heavily populated rural areas are high and the Msunduze is known as a turbid, silty river in the rainy season. The Msunduze is subject to impacts from a light industrial area which includes two tanneries on the upstream side of Pietermaritzburg town and to urban storm water which appears to be a significant pollution source (C Dickens - personnal communication). As it leaves the town it receives the polluted Dorpspruit and Baynespruit and then the effluent from the Darvill Sewage Treatment Works.

Table 6: Umgeni Water sampling sites in the Msunduze River.

Site number	Location
56.2	Msunduze dirt road crossing
57	Above Henley Dam
62	Msunduze Edendale road, downstream of 2 tanneries and industry, just upstream of Camps Drift pool
62.4	Camps Drift below weir
63	Msunduze above Dorpspruit confluence
65	Above Dump, just below confluence of Dorpspruit
66.1	Msunduze immediately below chlorinated Darvill sewage works effluent and above Baynespruit confluence
67	Msunduze about 2 km below Darvill sewage Works below Baynespruit confluence
67.2	Msunduze at Nkanyezini
70	Msunduze Eddy Hagen Drive (road to Nagle Dam)

The numbers of water samples on which the chemical data shown in **Table 8** is based is shown in **Table 7.** Sampling frequency was very much lower at Site 67.2 than elsewhere, and BOD and COD were analysed less frequently than *E. coli*, nitrates and ammonia. Dissolved oxygen was measured only at Site 66.1.

Table 7: Water quality in the Msunduze River. Sites and numbers of analyses made for various determinands between September 1992 and January 1995.

Site number	Number of determinations of:					
	E. coli/100 ml	NO_3-N $mg\ell^{-1}$	NH_4-N $mg\ell^{-1}$	BOD $mgO_2\ell^{-1}$	COD $mgO_2\ell^{-1}$	DO $mgO_2\ell^{-1}$
56.2	118	115	117	27	23	-
57	118	115	117	27	22	-
62	122	120	121	29	26	-
62.4	231	181	181	19	19	-
63	123	123	122	22	20	-
65	122	120	121	30	27	-
66.1	199	198	198	18	111	100
67	124	122	121	29	26	-
67.2	32	32	32	-	-	-
70	121	120	119	29	28	-

Table 8 shows that water quality, as regards nitrates, ammonia, BOD and COD, declined from the uppermost Site down to Site 67, with major stepwise increases in concentration taking place between Sites 57 and 62, and between Sites 65 and 66.1. There was marked improvement in the quality of the water between Sites 67 and 67.2. Water quality was poorest at Sites 66.1 (where the Dissolved Oxygen concentration was as low as 1.3 $mgO_2\ell^{-1}$) and 67.

Table 8: Water quality in the Msunduze River. Maximum concentrations of *E. coli*, Nitrates, Ammonia, Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) and maximum and minimum concentrations of Dissolved Oxygen (DO); September 1992 to January 1995.

Site number	*E. coli* cells/ 100 ml	Nitrates $mg\ell^{-1}$	Ammonia $mg\ell^{-1}$	BOD $mgO_2\ell^{-1}$	COD $mgO_2\ell^{-1}$	maximum DO $mgO_2\ell^{-1}$	minimum DO $mgO_2\ell^{-1}$
56.2	103000[1]	1.78	0.13	4.2	38.7	-	-
57	139000[2]	1.56	0.23	4.8	34.3	-	-
62	72000	2.91	1.54[7]	9.7	241[13]	-	-
62.4	54000	2.63	0.71	3.4	38.3	-	-
63	130000	2.83	0.79	9.6[10]	46.5	-	-
65	345000	2.39	0.68	23.2[11]	271[14]	-	-
66.1	400000[3]	7.48	5.74	5.3	56.9	11.2	1.3
67	4100000[4]	7.09	5.47	20.8[12]	51.1	-	-
67.2	58000[5]	8.02[6]	1.48[8]	-	-	-	-
70	151000	4.71	1.6[9]	4.0	106[15]	-	-

Next highest values:

1. 30000	5. 3200	9. 0.35	13. 61.3
2. 58000	6. 4.4	10. 4.1	14. 37.8
3. 90000	7. 0.64	11. 8.5	15. 75.2
4. 67000	8. 0.16	12. 10.4	

Biological sampling frequency was higher in the Msunduze River than in the Mgeni. There were however only three months in which all sites were investigated (**Figure 4**). In broad terms the SASS scores varied following the changes in water quality given in **Table 8**, with lowest SASS4 scores, numbers of taxa and ASPT being recorded at Sites 66.1 and 67. The chlorination of the sewage works effluent in part accounted for the low scores at Site 66.1, while the Baynespruit which joins the Msunduze upstream of Site 67 (see **Table 11**, **Figure 7** below) would have further contributed to a decline in water quality. The results reflected the conclusion that the water quality was best at Sites 56.2 and 57, was worst in the middle reaches and recovered at Sites 67.2 and 70.

There is one difference between the chemical and biological assessment of the water quality. It is that the biological assessment indicates that in February and August Site 62 was more similar to Sites 56.2 and 57 than it was to the sites further downstream. Chemically, Site 62 was more similar to the sites immediately downstream than it was to the sites upstream.

At the sites with better water quality, that is 56.2, 57, 62, 67.2 and 70 there was little difference between the site scores recorded in the three months. However, between Sites 62.4 and 67 Scores were higher in April 1993 than they were in either February 1993 or August 1993 (**Figure 4**).

The full set of results for the Msunduze River are given by sampling point in **Figure 5**. The data confirm that SASS4 scores were particularly low at Sites 65, 66.1 and 67 and were relatively high from the uppermost and lowermost sites in the study area. The great variation in ASPT scores when SASS4 scores are low, which has been commented on in Appendix A, is confirmed in **Figure 5** at Sites 66.1 and 67. The data from these two sites suggests that when SASS4 is less than 50, it is a more reliable predictor of water quality than is ASPT. However, when SASS4 scores exceed about 75, ASPT becomes the better predictor of water quality (**Figure 5**, Sites 57, 62, 67.2, 70).

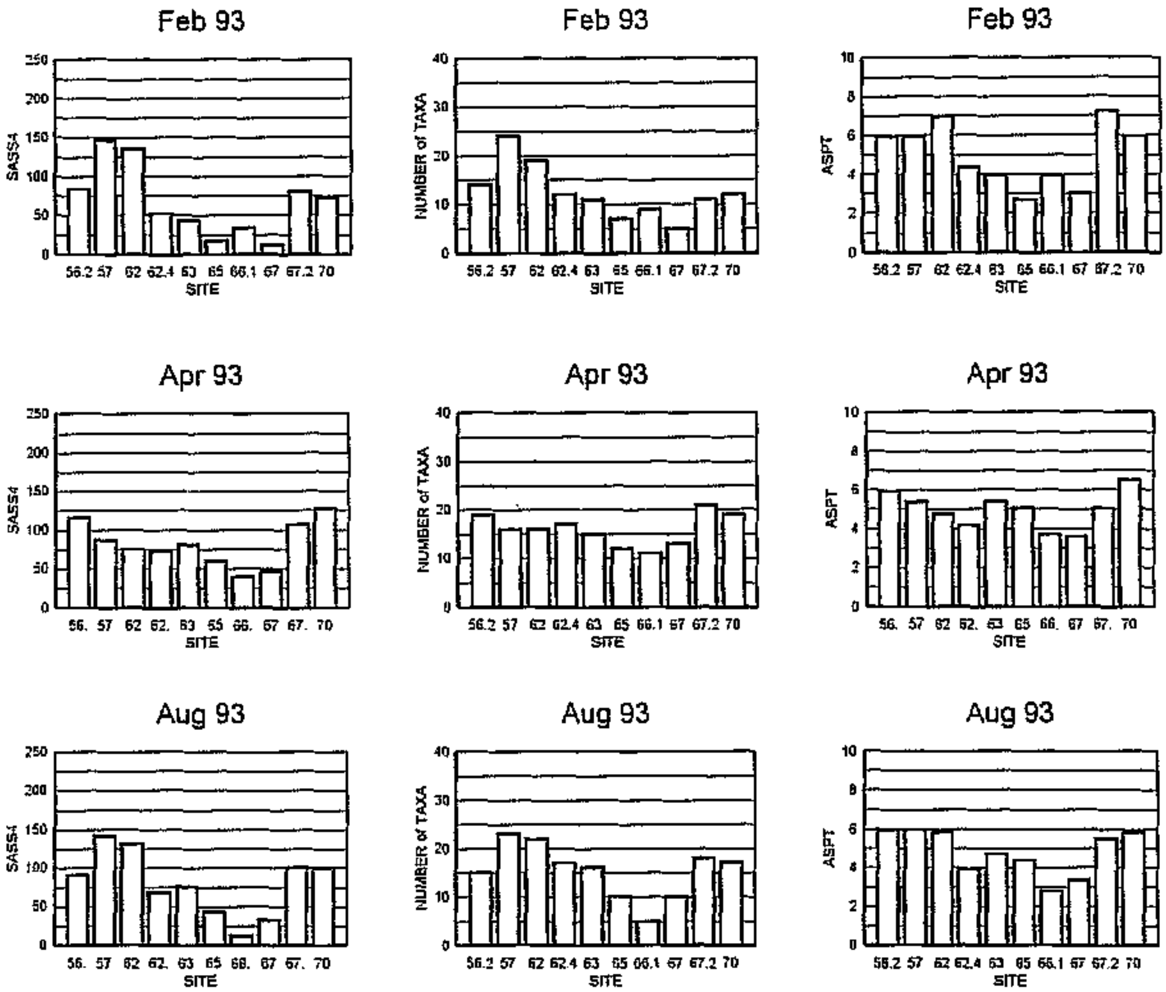

Figure 4: SASS4 scores, numbers of taxa and ASPT values recorded from the Msunduze River in February, April and August 1993.

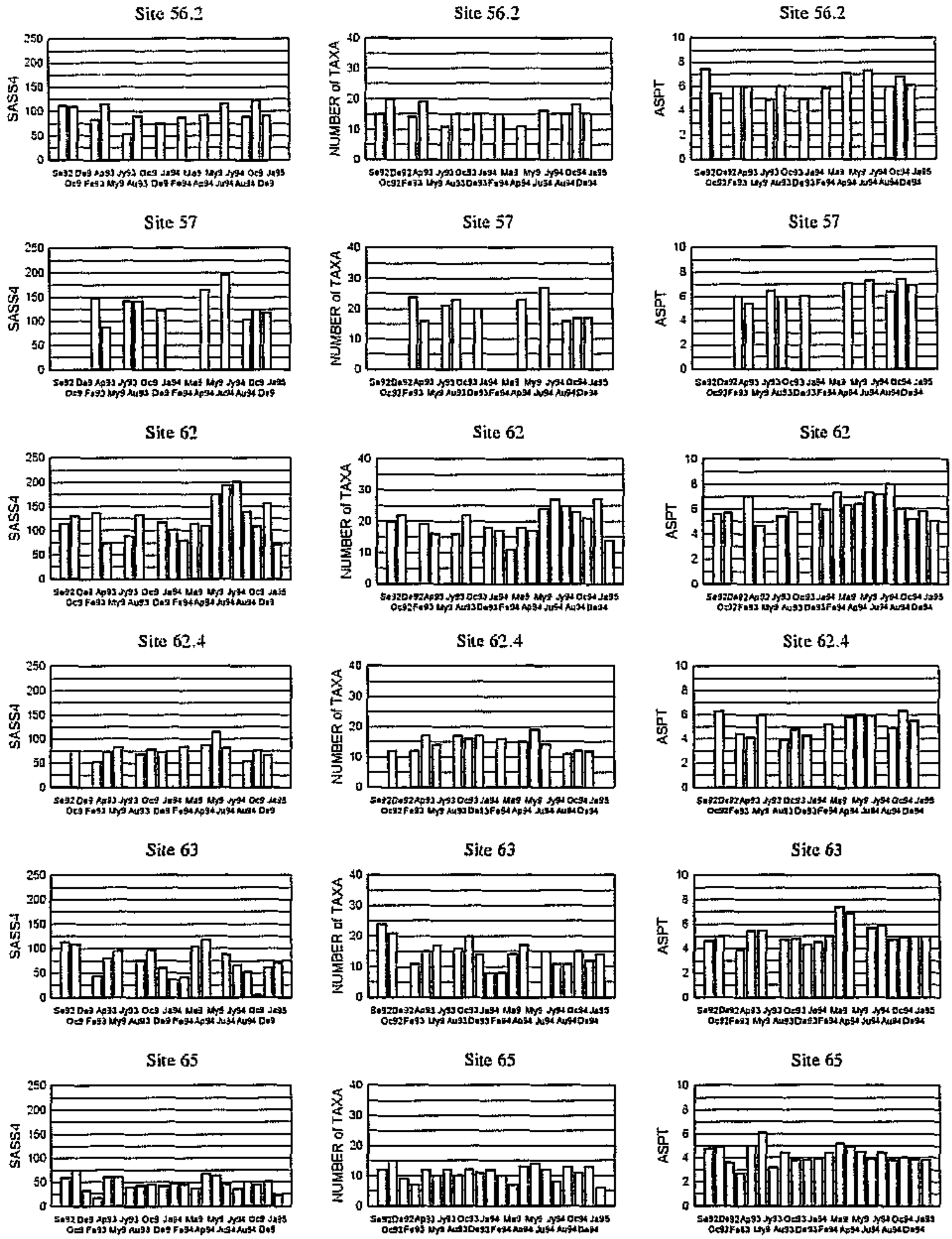

Figure 5: SASS4 scores, numbers of taxa and ASPT values by sampling site recorded from the Msunduze River, Site 56.2 to 65, in 1993 and 1994.

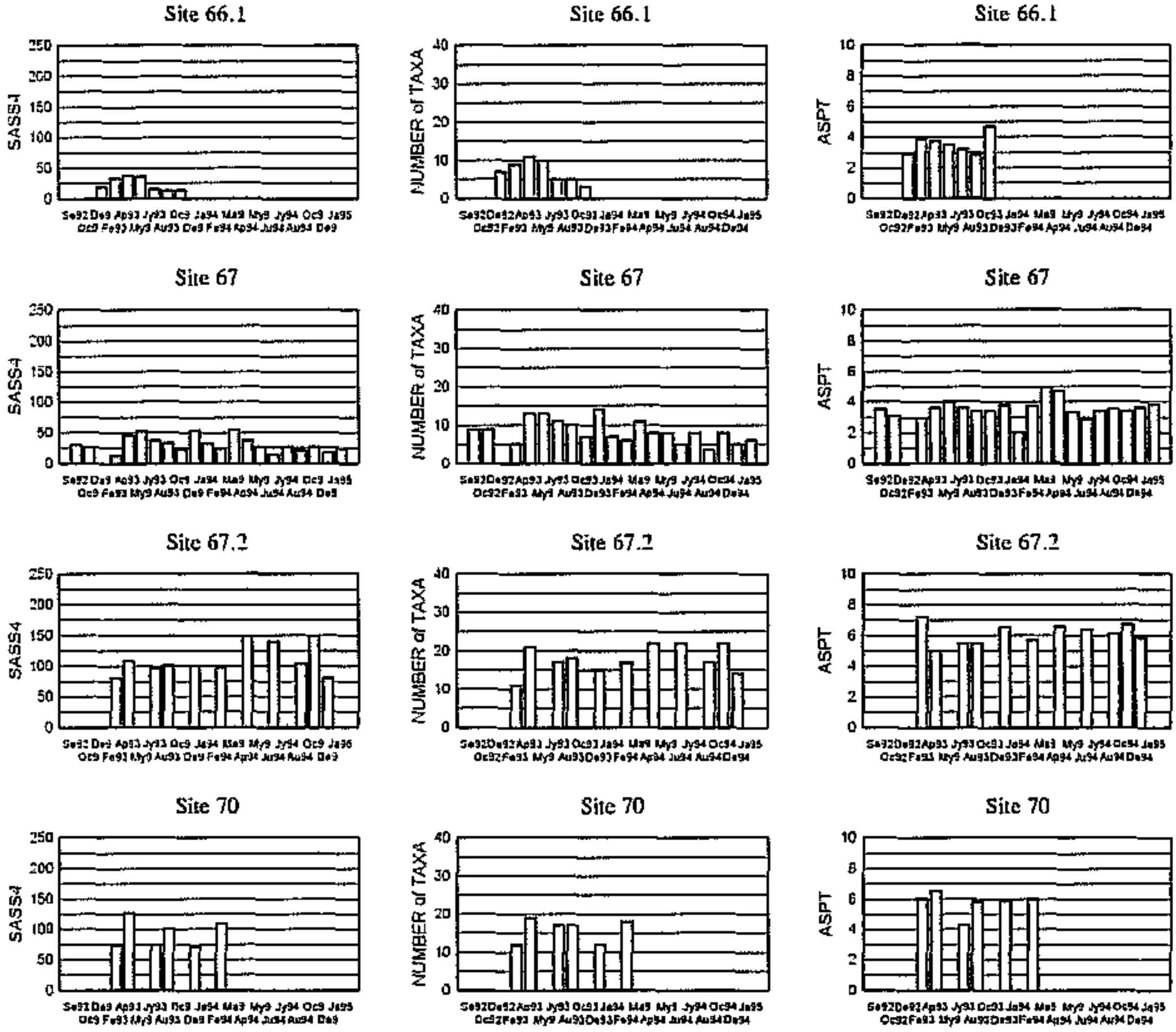

Figure 5: Continued, Sites 66.1 to 70

3.3 Tributaries of the Msunduze River

The Msunduze River has three tributaries, the Slangspruit, the Dorpspruit and the Baynespruit, which flow through Pietermaritzburg and which are polluted. The condition of the Slangspruit reflects the impact of dense informal settlements without formal sanitation facilities.

The localities of sampling points are shown in **Table 9** and the numbers of water samples for chemical analysis collected from these points are shown in **Table 10**. Unfortunately, water analysis was carried out at only one sampling point on each of the Dorpspruit and the Baynespruit.

Table 9: Umgeni Water sampling sites in the tributaries of the Msunduze River.

Site number	Location
61	Slangspruit, which drains informal settlements
64.3	Dorpspruit below Nestlé
64	Dorpspruit above Msunduze confluence
64.2	Baynespruit Greytown road
64.1	Baynespruit Drift, downstream of 64.2

Table 10: Water quality in the tributaries of the Msunduze River. Numbers of analyses of various determinands between September 1992 and January 1995, by site.

Stream and Site number	Number of determinations of:				
	E. coli cells/100 ml	Nitrates $mg\ell^{-1}$	Ammonia $mg\ell^{-1}$	BOD $mgO_2\ell^{-1}$	COD $mgO_2\ell^{-1}$
Slangspruit 61	122	122	122	22	19
Dorpspruit 64	124	122	122	9	-
Baynespruit 64.1	124	123	121	9	-

BOD was high in the Slangspruit and the Baynespruit (**Table 11**) and in the Dorpspruit was also well above the natural background level of less than 2 $mgO_2\ell^{-1}$ recorded in the Mgeni River. The Slangspruit water had high concentrations of nitrates and ammonia but concentrations were lower in the Dorpspruit and the Baynespruit, which were similar to one another in respect of these two determinands. Bacterial counts were high in all three streams.

Table 11: Water quality in the tributaries of the Msunduze River. Maximum concentrations of determinands; September 1992 to January 1995.

Site number	*E. coli* cells/100 ml	Nitrates $mg\ell^{-1}$	Ammonia $mg\ell^{-1}$	BOD $mgO_2\ell^{-1}$	COD $mgO_2\ell^{-1}$
61	380000	8.94	6.57[2]	10.7	94.6[4]
64	220000[1]	3.76	0.88	6.3	-
64.1	9200000	2.78	0.95	26.5[3]	-

Next highest values: 1. 34000; 2. 3.41; 3. 9.76; 4. 54.1

In the Slangspruit SASS4 scores were intermediate (**Figure 6**) ranging between 30 and 75 with an outlier at 90. ASPT varied between 3.8 and 5 with an outlier (not coincident with the SASS4 outlier) of 5.8. These biomonitoring results suggest an intermediate water quality, for scores were not nearly as high as they would have been in unpolluted sections of the Mgeni River and not as low as have been found in other parts of the Msunduze River.

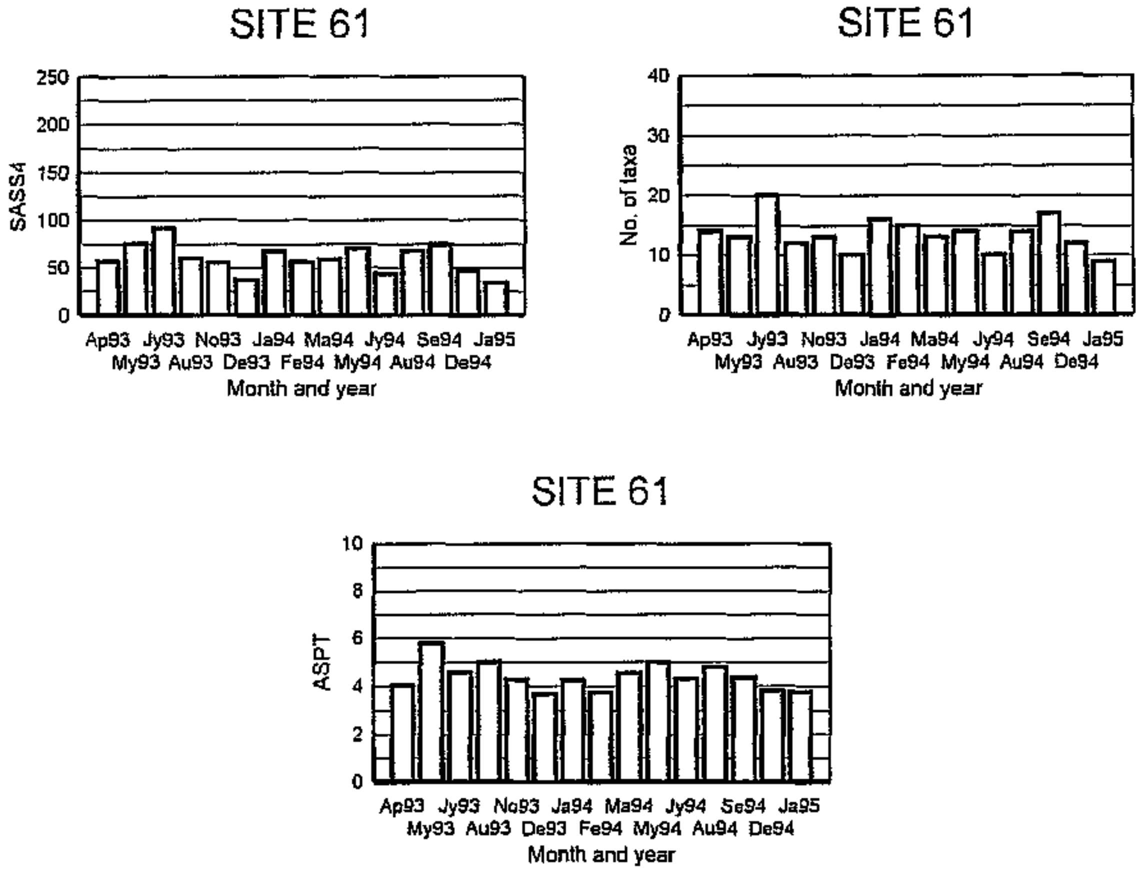

Figure 6: SASS4 scores, numbers of taxa and ASPT values recorded from the Slangspruit in 1993 and 1994.

The SASS4 scores from the Dorpspruit at Site 64.3 (**Figure 7**) for which there is unfortunately no chemical data, were low and the only other sampling point with such low scores was the Baynespruit (see below). SASS4 scores were mostly lower than 25, numbers of taxa frequently less than 5 and ASPT often less than 3.5. At Site 64 the SASS4 scores, numbers of taxa and ASPT suggested an improvement in the quality of the water. Scores were however still considerably less than they were at unpolluted sites in the Mgeni River and its tributaries.

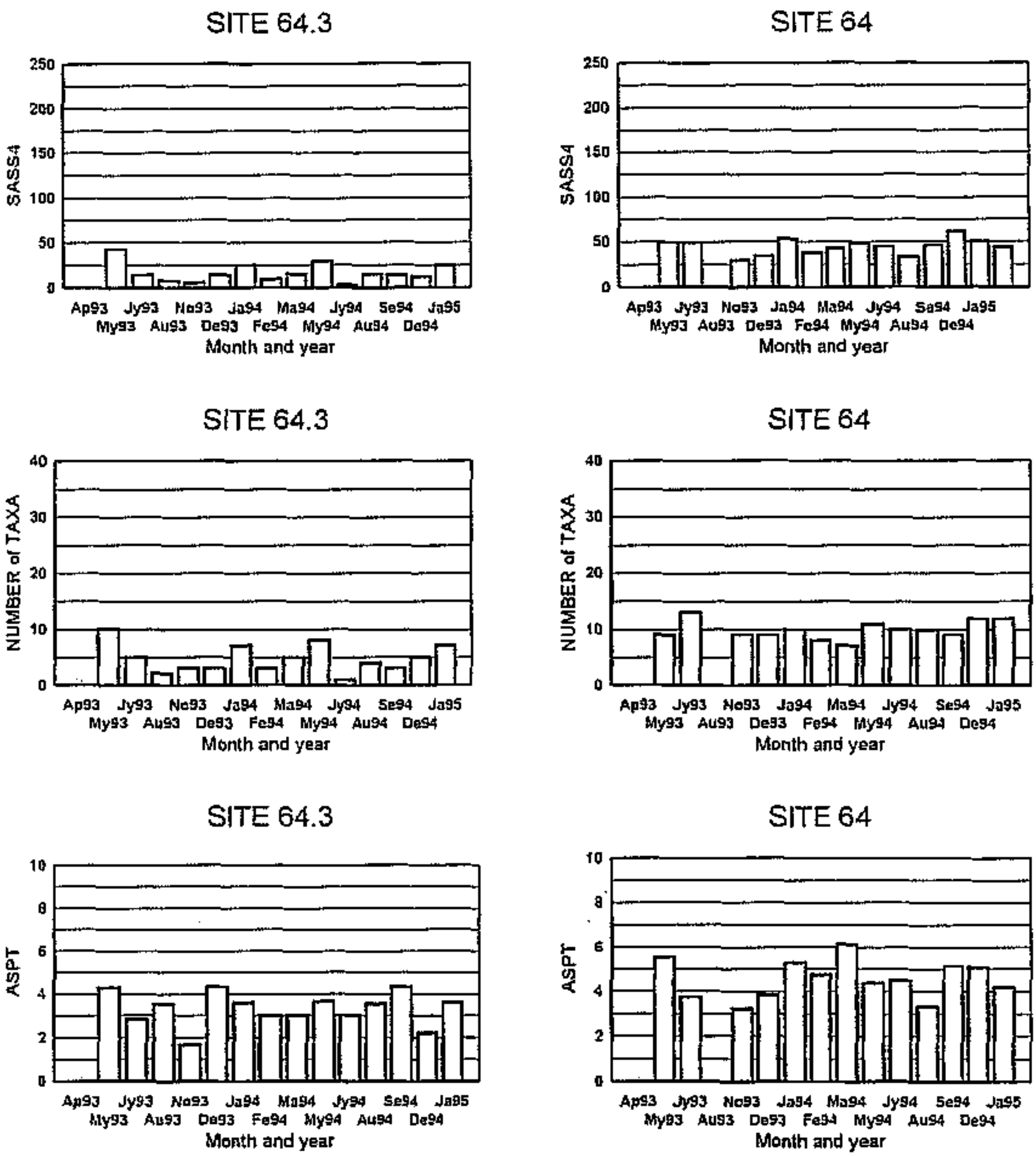

Figure 7: SASS4 scores, numbers of taxa and ASPT values by sampling site recorded from the Dorpspruit in 1993 and 1994.

In the Baynespruit SASS scores were also very low (**Figure 8**). At Site 64.1 they were comparable to Dorpspruit Site 64.3. The biological deterioration between Sites 64.2 and 64.1 on the Baynespruit was similar in extent to the deterioration between Sites 64.3 and 64 on the Dorpspruit.

In as far as the record of chemical conditions in these stream goes (**Table 11**) the chemical quality of the water does not follow the quality determined from the biological data closely, though both sets of results support each other in that both show that water quality was impaired. From **Table 11** the worst water quality appeared to be that at Site 61, but biological results from this site indicated a considerably better water quality that this site than at Site 64.1 on the Baynespruit, which is intermittently polluted by vegetable oil (note BOD, **Table 11**).

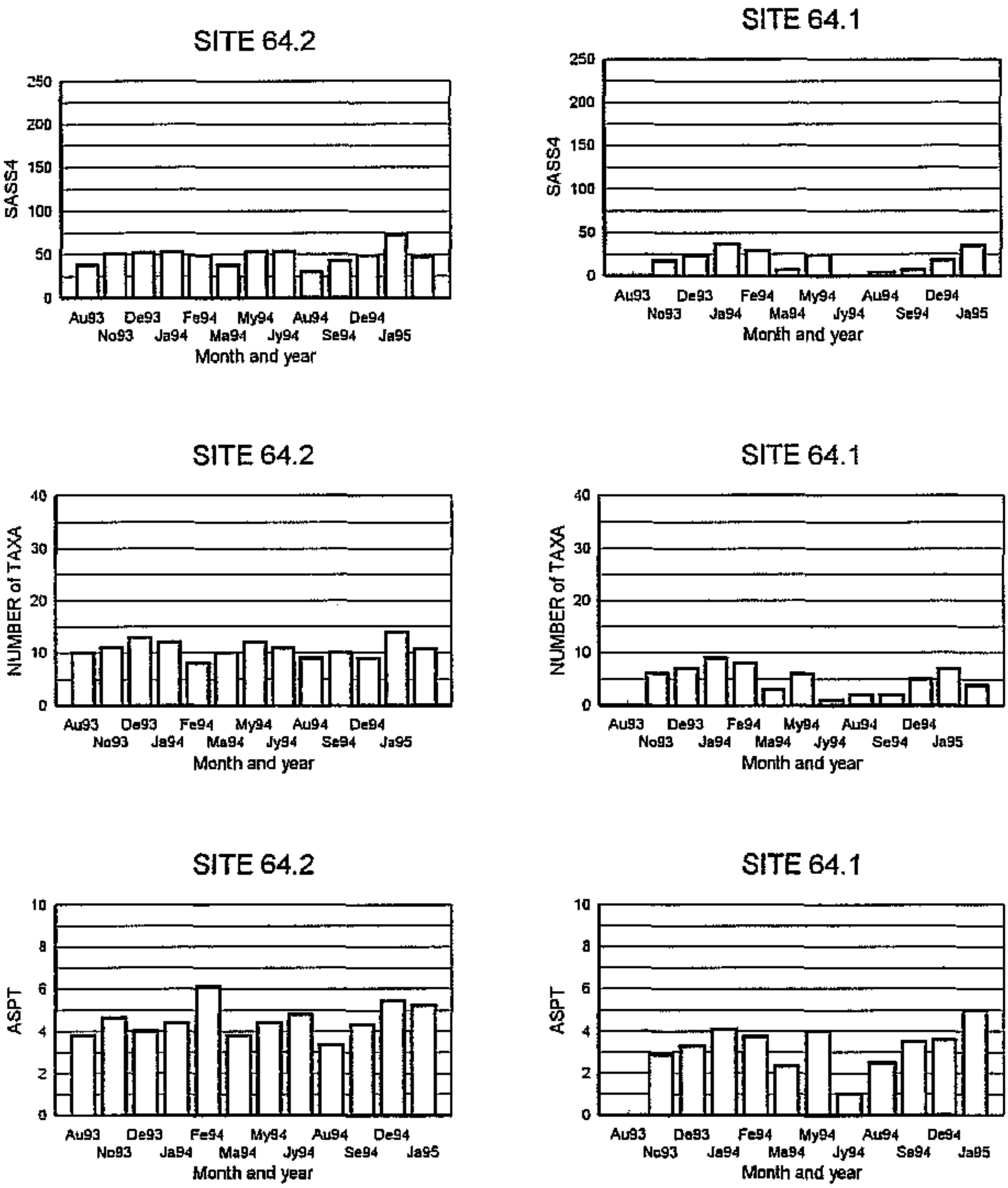

Figure 8: SASS4 scores, numbers of taxa and ASPT values by sampling site recorded from the Baynespruit in 1993 and 1994.

In the Baynespruit it is probable that there is intermittent contamination of the stream by waste from a number of vegetable oil processing plants. This is seldom picked up in the water samples for chemical analysis (C. Dickens, Umgeni Water - personal communication). It is probable that the highest BOD recorded at this sampling point (26.5 $mgO_2\ell^{-1}$) is not a spurious outlier but does represent conditions which do occur in the Baynespruit.

3.4 The Sterkspruit, Hammarsdale - a tributary of the Mlaas River

The Sterkspruit flows past Hammarsdale into Shongweni Dam, which has drowned its confluence with the Mlaas River. It receives run-off and sewage treatment plant effluent from the Hammarsdale industrial area. Sampling sites extended from above Hammarsdale down to the inflow to Shongweni Dam (**Table 12**). Dissolved oxygen was regularly measured at sampling sites in this stream and, except at Site 94.3 where monthly sampling was undertaken, sampling was mostly at weekly intervals (**Table 13**).

Table 12: Umgeni Water sampling sites in the Sterkspruit, Hammarsdale. **N.B. Contrary to practise in the other rivers, in the Sterkspruit sites are numbered in ascending order UPSTREAM, so that site numbers read in descending order in the tables and figures.**

Site number	Location
94.3	Spencers Farm
94.1	Above Hammarsdale Sewage Treatment Works
93	Below Hammarsdale
92	Quarry sand
91	Inflow to Shongweni Dam

Table 13: Water quality in the Sterkspruit, Hammarsdale. Sites and numbers of analyses made for various determinands between September 1992 and January 1995.

Site number	Number of determinations of:					
	E. coli/100 ml	NO_3-N $mg\ell^{-1}$	NH_4-N $mg\ell^{-1}$	BOD $mgO_2\ell^{-1}$	COD $mgO_2\ell^{-1}$	DO $mgO_2\ell^{-1}$
94.3	25	25	25	25	25	24
94.1	118	117	119	117	114	113
93	120	118	119	29	27	103
92	120	120	119	29	27	110
91	92	92	91	27	11	85

Although Site 94.3 is upstream of the Hammarsdale area it would appear to be subject to some water quality deterioration (**Table 14** - BOD, minimum DO). Even at Site 94.1, above the Hammarsdale sewage treatment works, there was severe dissolved oxygen depletion, and elevated concentrations of the other determinands shown in **Table** 14. The *E. coli* counts are of interest for both the high counts shown in **Table 14** are considerably greater than the next highest counts. In fact the abundance of *E. coli* in the Sterkspruit was generally so low as to suggest that bacterial growth in this stream was inhibited.

The chemical data at Site 93 below the sewage works included some high ammonia concentrations, a low minimum DO and a high COD. The quality of the Sterkspruit improved a little to the site next downstream (92). At Site 91 the maximum *E. coli* count and COD shown in **Table 14** were considerably higher than the next highest records and water quality was usually much improved over that at Site 92.

Table 14: Water quality in the Sterkspruit, Hammarsdale. Maximum concentrations of determinands and maximum and minimum concentrations of Dissolved Oxygen (DO); September 1992 to January 1995.

Site number	*E. coli*/ 100 ml	Nitrates $mg\ell^{-1}$	Ammonia $mg\ell^{-1}$	BOD $mgO_2\ell^{-1}$	COD $mgO_2\ell^{-1}$	maximum DO $mgO_2\ell^{-1}$	minimum DO $mgO_2\ell^{-1}$
94.3	1260	3.04	0.35	8.8	-	8.9	3.0
94.1	740000[1]	4.38	7.45	30.4	66.9	10.8	0.4
93	7000	6.05	23.7[4]	6.5	90.9	12.1	1.7
92	5200	11.4[3]	12.7	5.7	104	13.1	2.2
91	990000[2]	1.42	2.3	4.6	150[5]	10.5	5.4

Next highest values: 1. 1340; 2. 75000; 3. 7.28; 4. 12.1 5. 53

SASS4 scores at Site 94.3 varied between 50 and 120 (**Figure 9**), but ASPT was less variable and averaged 5 (**Table 15**). Both these ranges of scores were centred about levels which were somewhat lower than would be expected from natural conditions in the Mgeni and its tributaries (**Figure 2**). This is in accord with the water quality data which indicated that BOD tended to be high and the minimum DO low.

Table 15. Mean SASS4 scores, numbers of taxa and ASPT from the sampling sites on the Sterkspruit.

Sampling site	SASS4	Number of taxa	ASPT
94.3	80	16	5.0
94.1	18	5	3.3
93	15	5	3.3
92	72	12	6.1
91	82	15	5.6

As would be expected from the chemical data (**Table 14**) there was a considerable decline in SASS4 scores from Site 94.3 to Sites 94.1 and 93 (**Figure 9**). ASPT values for these two sites were much more variable than they had been at Site 94.1, confirming the previously made observation that the ASPT results from sites where SASS4 scores were low are variable. The biological assessment confirmed the chemical record in showing considerable improvement in water quality between Sites 93 and 92.

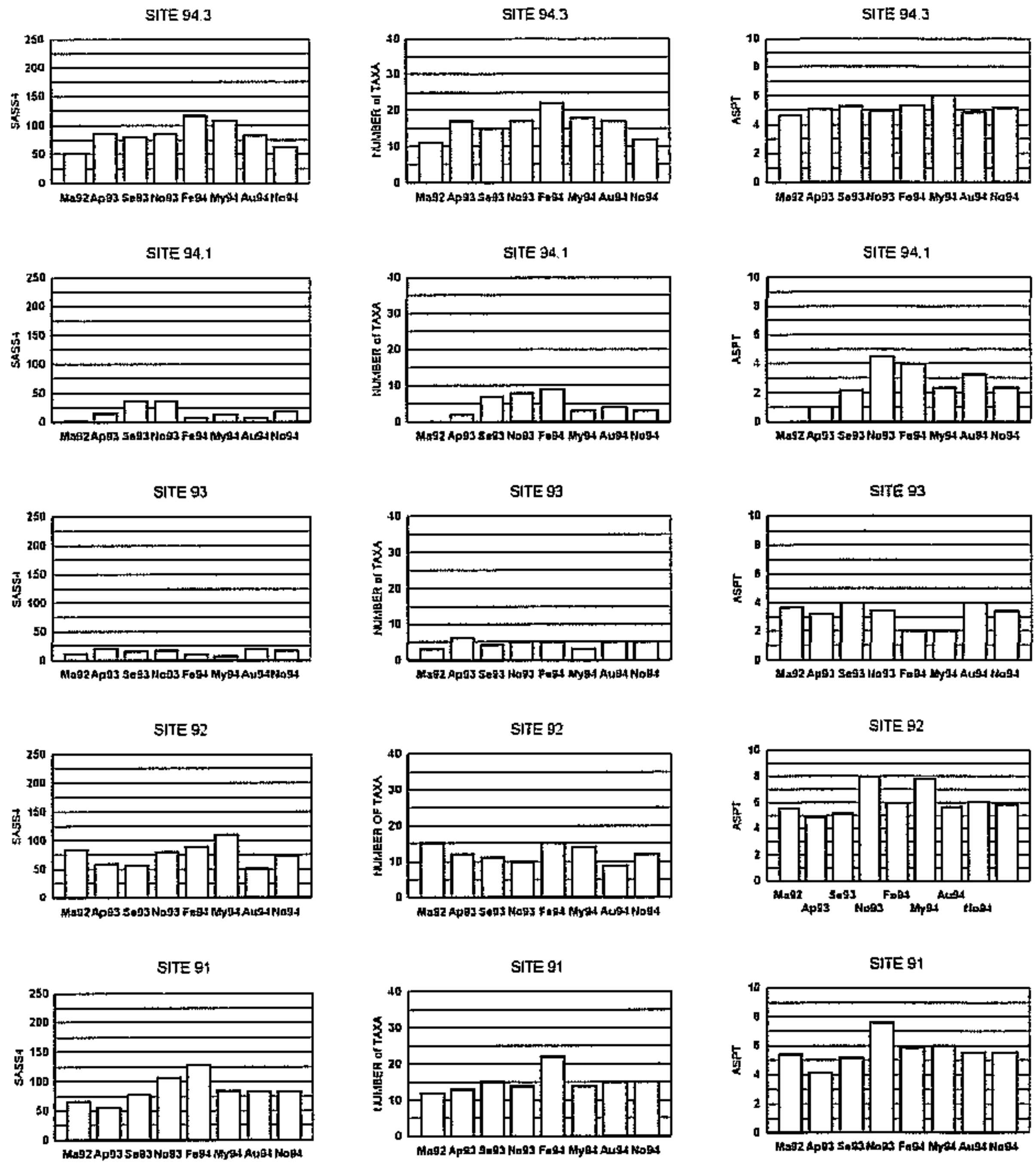

Figure 9: SASS4 scores, numbers of taxa and ASPT values, recorded from the Sterkspruit in 1993 and 1994, by sampling site.

The improvement in chemical water quality between Sites 92 and 91 (**Table 14**) was not reflected in the SASS scores. As shown in **Table 15**, while mean SASS4 and number of taxa were greater at Site 91 than at Site 92, ASPT was greater at Site 92 than at Site 91. None of the differences was sufficiently large to allow conclusions to be drawn that there were real differences in the SASS scores at these two sites. It would appear that the availability of habitats for sampling at these two points had a considerable impact on the scores recorded. Site 92 had a reasonable stones in current habitat. At Site 91 the river was wide, shallow and sandy and the stones in current were part of a man-made drift (C. Dickens - personnal communication).

Table 15 also shows that there was little difference between the mean SASS4 scores, numbers of taxa and ASPT between the uppermost sampling point (Site 94.3) and Sites 92 and 91.

4. DISCUSSION AND CONCLUSIONS

Presentation of the above results has been impeded by the author's lack of familiarity with the sampling points and river conditions on each sampling visit. It was only through enquiring about apparently out-lying SASS values that certain important insights were achieved. For instance, the explanation that the apparently out-lying SASS4 score at Site 2.1 on the Mgeni (**Figure 2**) represented the result to be expected when sampling conditions were ideal is important. It lead to the conclusion that although sampling took place during summer months, the results were very probably often much lower than they would have been had it been possible to access the permanently inundated parts of the river channel.

It is certain that, due to flow regulation, summer accessibility to the permanently inundated sections of the river channel was better downstream of Midmar Dam (the uppermost large impoundment on the Mgeni River) than it was upstream of the dam. Broadly speaking SASS4 scores were higher downstream of Midmar Dam (**Figure 2**), which confirms the hypothesis.

In the unpolluted Mgeni River, variation of ASPT values was considerably less than that of SASS4 scores. This is interpreted as indicating that although sampling conditions may have an impact on the number of taxa collected and hence on the SASS4 score, in unpolluted rivers ASPT value is less dependent of sampling conditions than is SASS4.

Results from the polluted tributaries of the Mgeni River showed that when the SASS4 score is low, ASPT is very variable at single sampling points. This is due to the fact that when there are few taxa present, the occurrence of a single moderately high-scoring (8 or higher) taxon readily distorts the ASPT. In this case, however, the SASS4 score is the important criterion in assessing water quality at the sampling point.

The Umgeni Water SASS results confirm that SASS4 results can be related to water quality. Scores were low where there is known pollution and high where pollution has not been recorded. Some of the variability in scores at single sampling points is considerable (see **Figures 2** (Sites 2.1, 7, 14 and 20), **5** (most Sites), **6**, **8** and **9**. Unfortunately records of chemical and physical variation at the sampling points and of sampling conditions at the time of sampling either do not exist or are, by their very nature (chemical conditions), incomplete. In particular it is important to bear in mind that variation in water quality in urban streams can be intermittent, extreme and of short duration. Also invertebrate communities do recover fairly rapidly. Evidence of this may be seen in the results from polluted rivers in this Appendix, where SASS4 scores sometimes increased in successive months (eg **Figure 5** (Site 62), **Figure 6** and **Figure 9** (Sites 92, 91).

In discussion in the SASS Forum, it has been suggested that SASS scores should be regionally rated against the sampling points in each region where scores were highest. Reference to **Figure 2** reveals that even at sites where scores were very high (2.1, 6, 7) the range of scores was wide. Nevertheless, at all three sites the maximum SASS4 score lay between 200 and 225. The lowest scores at these points were, respectively, just over 50, about 110 and 75. ASPT results were far less variable, fluctuating within relatively narrow ranges.

The frequency of occurrence of particular SASS4 scores, numbers of taxa and ASPT values in the data set for the unpolluted Umgeni River (**Figure 2**) is shown in **Figure 10**. The shapes of the curves in this figure show that there are no clearly defined inflections in the upper parts of the curves for SASS4 scores and numbers of taxa. While there is such a point at approximately ASPT 7.5, percentile 95, it would appear from the Mgeni River data that it contributes little to the identification of a regional SASS4 score or ASPT representative of pure waters.

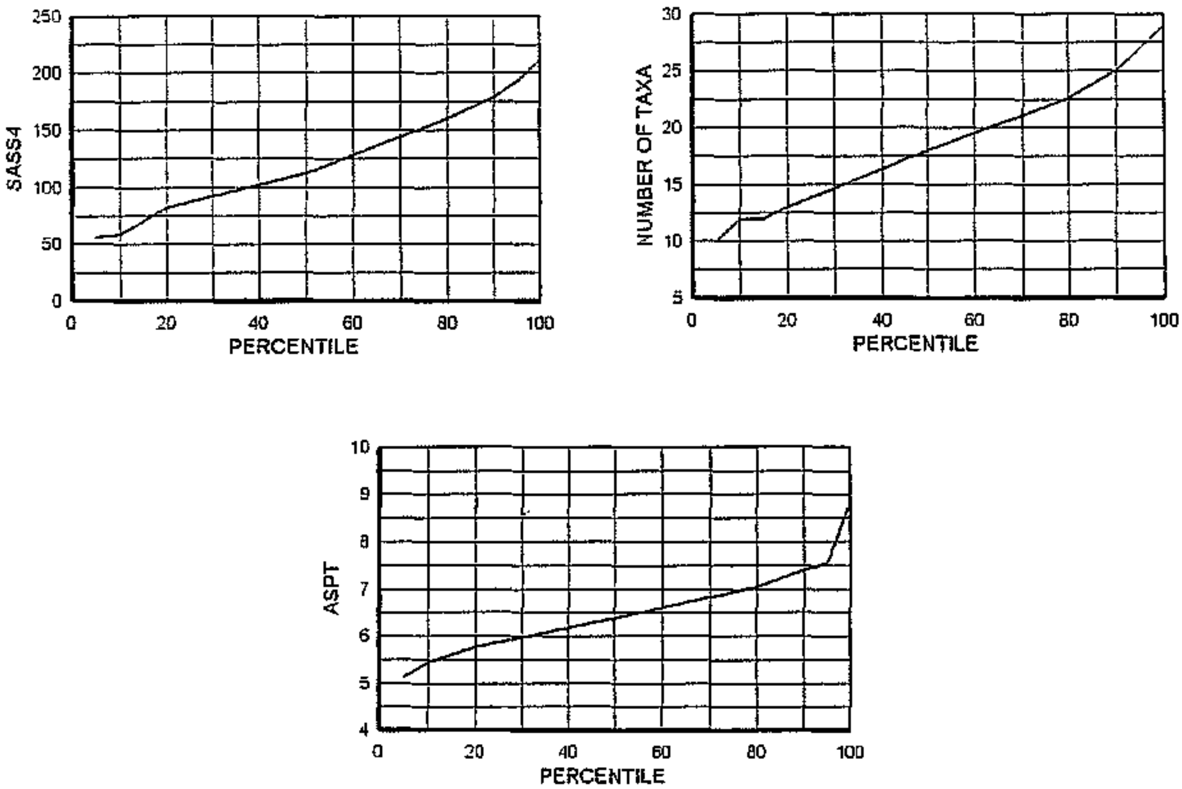

Figure 10: The relationship between the frequency of occurrence (as percentiles) and SASS4 scores, numbers of taxa and ASPT values in the Mgeni River, from the data included in **Figure 2.**

Finally the Mgeni River results are interesting in that they reflect a far greater degree of variation at single unpolluted sites than did the data collected in 1992 from the Crocodile River system in Mpumalanga. It is suspected that this important difference is due mainly to the fact that the Crocodile River samples were all collected in the dry season.

5. REFERENCE

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

Appendix D

SASS assessment of the condition of streams and rivers in Kwazulu-Natal

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SECTION HEADINGS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

In this appendix data gathered from northern Kwazulu/Natal and from the area in and around Durban and Pinetown is presented. The sampling sites include many for which there is a historical record of water and biological quality. It has been useful to compare SASS4 results with this record. This has been done on a sampling point by sampling point basis, which gives closer attention to detail than has been given in the appendices which precede this appendix (D).

SASS4 results are mostly supported by the assessment of water quality made using the Biotic Index (Chutter 1972). Both assessment methods do relate in a meaningful way to water quality in most instances, though the boundary between no deterioration in water quality and small deterioration in water quality is blurred. In particular the meaning in terms of water quality of samples in which SASS4 is well over 100 (say greater than 120), but ASPT is less than 5.5 is somewhat ambiguous.

Two events which had an impact on the SASS4 scores observed occurred during the study. The first was the movement of a sand-winning plant upstream of a sampling point closer to the sampling point. This resulted in a decline in both SASS4 scores and ASPT. A spate at another sampling point had a similar effect. These occurrences raise the necessity for people undertaking SASS4 assessments of water quality always to be on the look-out for happenings which might have an impact on the measured score.

The difficulties in adopting a statistical approach to the intensity of the association between SASS4 scores and water quality are discussed. Important obstacles include that the biological assessment is based on a community which represents conditions over a prolonged period to be measured in weeks and months rather than in minutes or hours, which is the case with the chemistry of polluted urban streams. The second obstacle is that it is often unclear which determinand(s) should be used to represent water quality. It is concluded that the difficulties cannot be overcome and that authoritative statistical analysis is unlikely to contribute to the further development of rapid biological assessment of the SASS type.

ACKNOWLEDGEMENTS

The field studies in Kwazulu/Natal were carried out by Brian Fowles and Trudi Dor of WATERTEK in Durban to whom grateful thanks are due. Brian has been meticulous in advising on the choice of sampling points in relation to his recent hydrobiological investigations in the province. He ensured that the data from his studies was presented in a very lucid fashion, as is evident from the figures in this appendix.

1. INTRODUCTION

The studies in Natal were undertaken in 1992, when SASS2 was the current version of SASS. The sampling point by sampling point results presented in this appendix are all scored following SASS4. The maps on which the SASS results are shown alongside the Biotic Index (Chutter 1972) values were prepared in, and remain, SASS2. SASS2 values differ slightly from SASS4 values, but these small differences are insufficient to invalidate the comparisons between the results of SASS assessment and assessment following the Biotic Index.

The content of the appendix concerns a wide area of Natal from the interior through to the coast. The study area is unusual in that many of the sampling points used have previously been studied with regard to both water chemistry and invertebrate communities. In 1984 B K Fowles undertook a repeat survey of the Tugela Basin, using the sampling points established by W D Oliff about 30 years previously (Oliff 1960a, 1960b, 1963, 1964). Fowles' data has not been published. He biologically assessed water quality using the Biotic Index (Chutter 1972).

In 1989 Fowles made a survey of streams and rivers in the Durban area. The results of this survey are also not published, but Fowles again used the Biotic Index to assess water quality. The unusual aspect of the SASS results reported here is that Fowles' 1984 and 1989 sampling points were used in the SASS study, allowing for the broad comparison of SASS results with Biotic Index results. The comparison is limited by the fact that there is no recent information on the chemical quality of the water at the sampling points. At a few sampling points it would appear that there have been recent and substantial changes in water quality. This conclusion has been drawn due to the fact that the number of sampling points where the two biological assessments gave rise to similar conclusions greatly out-weighed the number of points where they differed.

Assessment of water quality from the SASS4 results in this appendix has been based on the conclusions arrived at in Appendix B, namely:

SASS4 >100,	ASPT >6	water quality natural, habitat diversity high
SASS4 <100,	ASPT >6	water quality natural, habitat diversity reduced
SASS4 50 - 100,	ASPT <6	some deterioration in water quality
SASS4 <50	ASPT variable	major deterioration in water quality

One combination no included in the above list is SASS4 >100 and ASPT <6. Logic would require that this might indicate a slight deterioration in water quality.

2. RESULTS

2.1 Northern Kwazulu/Natal Coalfields, Buffalo, Bushmans and Mooi Rivers

The attraction of including this area is that it has been much studied starting with Oliff's work in the late 1950's and continuing to Fowles' re-survey in 1984. Both these studies contained biological data from which biological index (Chutter 1972) scores were calculated. The confusing aspect is that sampling points resort under a variety of sampling point numbers, so that for this region sampling point numbering has been abandoned for fear of adding further confusion. The area is remote from Durban, where the researcher was based. All rivers were very low in May and when the second visit was made in July, flow had ceased at so many places that there was time to sample near Estcourt and Mooi River on the return journey to Durban. As it was not considered worthwhile to travel all the way to northern Kwazulu/Natal for a handful of sampling points, it was decided to concentrate on stream and rivers nearer to Durban.

The water quality data from the 1984 report is re-produced here as **Table 1**.

Slang River

Slang River the bridge at Vlakdrif on the road between Volksrust and Utrecht, some 13 km below the Zaaihoek Dam. This was Oliff's station 15 during the Buffalo River study of 1960 and was also used in the re-survey of the Tugela river study of 1984 as **Station 1**. The water quality is good (**Table 1**) with land use in the catchment not impacting it detrimentally. Between 1960 and 1984 Biotic Index scores remained almost constant at about 2.5, indicating very slightly enriched water.

The following scores were recorded in May 1992:

SASS4 123 # taxa 21 ASPT 5.9

Interpretation - as expected, scores appropriate to good water quality.

Buffalo River at Ngogo

Where crossed by the road from Ngogo railway station to Wakkerstroom. This sampling point is suspected to be in the close vicinity of Ngogo Weir (Oliff 1963) and was **Station 2** in the 1984 survey. At this point the river had passed from Vlakdrif through very steep and rugged countryside with farming being the major activity in the catchment. River channel deeply incised (stable banks) and sandy bottomed with

Table 1: Water quality during the 1984 re-survey of the Tugela catchment, Northern Kwazulu/Natal. Copied from a Steering Committee Report written by B K Fowles.

STATION NUMBER	1	2	3	5	8	9	10	11	13	15
ALTITUDE*	1706	1247	1219	1420	1173	1257	1178	1172	1213	1167
TEMPERATURE	9.5	10.0	11.2	10.2	12.5	11.9	15.0	13.1	10.2	10.8
pH	7.4	7.7	7.8	7.5	7.28	7.7	7.2	7.2	7.7	7.7
SUSP. SOLIDS	41	24	10	2	17	9	30	15	7	44
CONDUCTIVITY	10.5	11.6	13.5	6.1	12.7	11.9	72.4	36	9.1	27.8
TOT.DISS.SOLIDS	70	77	90	41	85	79	483	242	61	185
ALKALINITY	24	39	61	23	43	45	109	62	36	76
FREE CO_2	2.0	1.7	2.0	1.6	4.8	1.9	13.0	7.4	1.5	3.1
DISS.OXYGEN	9.21	9.21	8.77	9.13	8.91	9.75	8.95	9.5	8.77	7.98
% SATURAT^n O_2	100	95	93	97	97	105	102	104	91	83
S.R.PHOSPHORUS	2	2	3	3	5	2	8	151	2	93
T.P.FILTERED	11	7	9	7	9	10	78	161	6	105
T.P.UNFILTERED	41	23	13	9	29	14	141	297	9	193
AMMONIA	33	15	11	13	4	15	775	62	9	270
KJEL.N.FILTERED	359	287	166	92	219	172	1407	437	87	589
DISS.ORGANIC N.	326	272	155	79	215	157	632	375	78	319
KJEL.N.UNFILT.	389	293	208	122	236	180	1431	538	136	701
NITRATE	270	142	173	30	32	18	514	1385	203	1301
NITRITE	6	2	2	1	2	5	12	36	1	46
SILICA	6.2	5.8	7.1	5.6	4.7	5.6	3.6	3.9	7.3	5.1
IRON	5	4	20	11	1	9	7	1	4	10
CALCIUM	8	9	11	6	10	9	57	26	8	21
MAGNESIUM	4	5	7	2	5	4	34	12	4	10
SODIUM	6	6	6	4	8	8	51	25	4	18
POTASSIUM	2	1	1	0.5	4	1	5	5	0.3	3
CHLORIDE	11	9	4	2	6	4	21	14	4	12
SULPHATE	14	11	10	8	40	17	302	111	8	54

* See units of measure at the foot of next page.

Continued/......

Table 1 continued/......

STATION NUMBER	16	17	19	21	22	23
ALTITUDE	1135	1212	1174	1273	1081	1055
TEMPERATURE	12.5	15.5	11.0	13.0	12.5	10.4
pH	7.3	4.5	8.4	7.4	8.0	8.5
SUSP. SOLIDS	48	29	5	5	11	6
CONDUCTIVITY	20.0	440	95.8	6.8	19.6	31.1
TOT.DISS.SOLIDS	133	2934	639	45	131	207.
ALKALINITY	67	0	152	33	88	146
FREE CO_2	6.7	0.0	1.2	2.8	2.1	0.9
DISS.OXYGEN	8.91	1.01	9.74	9.09	8.82	9.57
% SATURATION O_2	96	12	102	101	94	97
S.R.PHOSPHORUS	54	1	849	1	2	5
T.P.FILTERED	72	7	985	9	6	16
T.P.UNFILTERED	162	16	1251	11	15	47
AMMONIA	22	1497	69	22	7	57
KJEL.N.FILTERED	350	1632	682	138	256	345
DISS.ORGANIC N.	328	435	613	116	249	288
KJEL.N.UNFILT.	482	2046	813	201	262	414
NITRATE	1018	57	3895	8	21	758
NITRITE	9	2	52	0	1	20
SILICA	5.7	8.2	1.3	6.7	4.2	3.5
IRON	3	24019	1	11	3	7
CALCIUM	14	132	69	6.5	14	25
MAGNESIUM	9	461	48	4.2	9	11
SODIUM	13	223	78	5.6	14	23
POTASSIUM	2	11	6	1	2	3
CHLORIDE	9	11	33	4	15	14
SULPHATE	31	4024	431	4	6	65

Altitude - m.a.m.s.l.; Temperature °C; Conductivity mSm^{-1}; all combined phosphorus and nitrogen in $\mu g\ell^{-1}$; Suspended solids, TDS, Free CO_2, DO, Si, Fe, Ca, Mg, Na, K, Cl, and SO_4 all in $mg\ell^{-1}$; Alkalinity $mg\ell^{-1}$ $CaCO_3$.

snags and sparse gravel. Water quality little different from Station 1 (**Table 1**). This is the type of sampling point where the Biotic Index (Chutter 1972) is useless, as there is no stones in current biotope to be sampled.

Sampled in May and July, scores recorded:

May	SASS4 83	# taxa 17	ASPT 4.9
July	96	18	5.3

Interpretation - SASS4 score would be expected to be on the low side due to the lack of a stones in current habitat. However the ASPT of less than 6 suggests that there was a small decline in the water quality. **Table 1** shows no evidence of such a decline.

Buffalo River at Clontarf

Upstream of the bridge on the road from Clontarf railway siding to Weltevreden farm. This is the same station as that used (as station 1) for a year round study on the rapidly developing area of Newcastle in 1973. It is situated between Ngogo and Newcastle. The major land use is farming but there are two disused coal mines, Jubama and Ingogo, which pose potential pollution hazards through coal stockpiles and coal discard dumps.

Sampled in May:

SASS4 113 # taxa 21 ASPT 5.4

Interpretation: water quality probably similar to Ingogo, but again the is no evidence of untoward water quality (**Table 1**, Station 3).

Buffalo River at Steildrif

Upstream of the road to Steildrif in the vicinity of Spookmill, a sampling point used by Oliff in his study of the Buffalo river in 1960. **Station 15** in 1984 survey (**Table 1**). It is also just downstream of a Station 5 used in the 1973 study of the Newcastle area. It is situated downstream of the Osizweni sewage treatment works, the town of Newcastle with the Iscor works and the two densely populated towns of Madadeni and Osizweni. Biotic Index values were about 3 in 1960 and about 2 in 1984. From the look of the river in 1992, a rather higher (worse water quality) score would have been expected. 1984 water quality showing high bound nitrogen concentrations (**Table 1**).

Sampled in May and July, scores recorded:

May	SASS4 55	# taxa 14	ASPT 3.9
July	58	15	3.9

Interpretation: indicative of moderate deterioration of water quality - intermediate SASS4, intermediate number of taxa, low ASPT in circumstances where there was a good habitat diversity. Results of the type expected from the algal laden waters and the proximity of Newcastle and Osizweni.

Buffalo River at De Jagers Drift

Above the bridge at De Jagers Drift on the road between Dundee and Vryheid. This was one of the sampling stations used by Oliff in 1960 (Station 7) and was used again in the Tugela re-survey study of 1984 when it was referred to as **Station 16.** This station is situated in open country with little other than farming locally influencing the water quality. Bound nitrogen concentrations were lower than at Station 15, but were still fairly high (**Table** 1). There was abundant benthic algae, which are usually associated with nutrient enrichment. Biotic index scores on 1960 and 1984 were indicative of "clean unpolluted waters".

Sampled only in May, scores recorded:

SASS4 121 # taxa 25 ASPT 4.8

Interpretation: Biota recovered somewhat compared to Steildrif, but ASPT still indicative of some water quality deterioration.

A general comment on the Buffalo downstream of Newcastle - the SASS4 scoring system indicates that water quality has deteriorated in this stretch of the river since 1984. In view of the population growth of Madadeni and Osizweni, this is not unexpected.

Ngagane River

Between an old disused bridge and the road bridge on the road from Newcastle to Madadeni. This was station 6 in the Newcastle study of 1973. This sampling point was referred to as **Station 10** in the re-survey of the Tugela river study of 1984. Concentrations of all the major ions and of bound nitrogen were high (**Table 1**). This river has been impacted in the past by coal mine drainage in the catchment and industries situated between this point and Chelmsford dam such as Karbochem some 5 km upstream. Biotic Index values improved from "slightly enriched" to "Clean unpolluted" from 1960 to 1984.

Sampled in May and July, scores recorded:

May	SASS4 79	# taxa 16	ASPT 4.9
July	104	20	5.2

Interpretation - results indicative of a moderately impaired water quality, which is reflected in **Table 1**.

Mzinyatshana River

Upstream of the bridge over the Mzinyatshana river on the road from Dundee to Osizweni (old Newcastle road) at a place, near the old St. Georges colliery, called Poona. This was Oliff's station 39 in the Buffalo River study and **Station 17** in the re-survey of the Tugela river of 1984. This stream was acid in 1984 (**Table 1**) as a result of the abandoned Hattingspruit and St. Georges collieries in the catchment. Recently open cast coal mining was practised in the immediate catchment. On the sampling visit in 1992 all objects protruding out of the water had a white crystalline band, the conductivity meter went off scale and the pH was above 8. Obviously water quality in the stream had undergone a big change since 1984. Stones in the stream bed were cemented together by a greyish-brown precipitate on and within which invertebrates were found. In 1960 the Biotic Index value indicated severe pollution due to low pH.

Sampled only in May, scores recorded:

SASS4 119 # taxa 23 ASPT 5.2

Interpretation - ASPT is too low to indicate unimpaired water quality, but a great variety of families present so there was a high SASS4 score. High sulphate concentrations are apparently tolerated by a surprisingly wide variety of invertebrates and also by *Tilapia sparmanni*, the vlei kurper. It was unnecessary to use a biotic index to detect the salinity!

Blood River

Just downstream of the road bridge on the road from Viljoenspost to Bloedrivier above the confluence of the Springspruit with the Blood river. The sampling station could actually be on the Grootspruit river, and coincides with Oliff's station 42 (Buffalo river study) and **Station 21** of the re-survey study of 1984. This part of the river is also exposed to impacts from coal mines and natural outcrops of coal on two upper tributaries in the catchment near Utrecht, but water quality was excellent in 1984 (**Table 1**).

Sampled only in May, scores recorded:

SASS4 152 # taxa 27 ASPT 5.6

Interpretation - the biological assessment is that where SASS4 is as high as 152, it is highly unlikely that water quality is impaired, even though the ASPT is low in relation to the SASS4. The chemical data show that the water quality at this point is good.

An overview of the biological results from northern Kwazulu/Natal is given in **Figures 1** and 2, where it can be seen that at most sites the SASS4 method reflected Biotic Index changes.

Little Bushmans River near Estcourt

Downstream of a small bridge below the Masonite factory in Estcourt on the Little Bushman's river. This was the same sampling point as Oliff's station 5 in his late 1950's study of the Bushman's river and was referred to as **Station 37** in the 1984 re-survey of the Tugela river. This part of the river is severely impacted by the masonite board factory on the south bank, though the main indication of the chemical nature of the impact in the 1984 water analysis is a depressed percentage saturation oxygen and an elevated free carbon dioxide concentration (**Table 2**).

Sampled only in July, scores recorded:

SASS4 28 # taxa 7 ASPT 4.0

Interpretation - SASS4 assessment shows a very poor water quality, which is more in agreement with expectations than with the 1984 water analysis.

Bushman's River downstream of Estcourt

Approximately 8 km below the town of Estcourt's sewage purification works on the Bushman's river. This was the same sampling point as Oliff's station 16 in his Bushman's river study and **Station 40** in the re-survey of the Tugela study in 1984. Impacts due to the sewage purification works and the town of Estcourt with its industry are minor at this point (cf Stations 39 (above Estcourt) and 40 in **Table 2**).

Sampled only in July, scores recorded:

SASS4 107 # taxa 19 ASPT 5.6

Interpretation - ASPT was too low for water quality to be considered unimpaired, but the indicated degree of water quality deterioration is minor. **Table 2** shows a good water quality.

Table 2: Water quality during the 1984 re-survey of the Tugela catchment, upper Tugela & Bushmans Rivers. Copied from a Steering Committee Report written by B K Fowles. Units of measure at the foot of **Table 1**.

RIVER* STATION NUMBER	TUG 32	TUG 33	TUG 34	TUG 35	LB 36	LB 37	LB 38	BUS 39	BUS 40	TUG 41
ALTITUDE	1226	1105	948	939	1204	1141	1140	1135	1097	640
TEMPERATURE	12.5	11.0	12.0	12.5	12.0	9.5	18.0	10.5	11.0	16.0
pH	7.7	7.5	8.1	7.7	7.7	7.6	7.0	7.7	7.5	8.4
SUSP. SOLIDS	1	25	85	129	5	3	23	35	26	25
CONDUCTIVITY	6.1	7.3	11.8	9.6	14.4	19.0	32.4	5.7	8.2	27.8
TOT.DISS.SOLIDS	41	49	79	64	96	127	216	38	55	185
ALKALINITY	33	35	60	46	69	87	40	29	32	123
FREE CO_2	1.4	2.3	1.1	2.2	3.0	4.6	8.6	1.2	2.2	0.9
DISS.OXYGEN	8.97	8.74	9.87	9.10	9.02	7.69	5.31	9.25	9.53	9.89
% SATURATION O_2	98	91	103	96	97	78	65	95	99	108
S.R.PHOSPHORUS	1	3	3	1	121	7	44	2	85	3
T.P.FILTERED	3	10	7	4	132	17	59	7	92	10
T.P.UNFILTERED	7	23	63	65	181	35	315	19	130	57
AMMONIA	7	17	13	13	35	35	227	8	21	21
KJEL.N.FILTERED	36	108	156	132	361	264	493	78	132	252
DISS.ORGANIC N.	29	91	143	119	326	229	266	70	111	231
KJEL.N.UNFILT.	108	235	398	422	506	373	1349	151	265	500
NITRATE	3	270	120	219	184	3	436	151	247	135
NITRITE	0	2	3	2	6	0	32	0	10	6
SILICA	6.4	4.2	3.9	4.1	2.4	1.4	5.2	5.8	5.7	3.3
IRON	2	11	0	0	16	10	12	3	12	5
CALCIUM	7	7	12	9	9	18	24	7	7	23
MAGNESIUM	2	3	5	4	6	7	4	2	3	11
SODIUM	2	3	6	5	11	13	34	3	10	25
POTASSIUM	0.3	1	1	1	2	2	2	0.5	1	2
CHLORIDE	0.3	1	2	2	7	8	65	1.4	13	14
SULPHATE	3	4	5	4	6	8	10	2.5	4	14

* river names abbreviated - TUG = Tugela, LB = little Bushmans, BUSH = Bushmans

Mooi River

Below an old steel bridge opposite the Weston Agricultural College about 10 km downstream of Mooi River. The sampling point used by Oliff in 1960. **Station 43** in the re-survey of 1984. The farming town of Mooi River with its textile industry and creamery may impact on the water quality. The 1984 water quality results in **Table 3** show small increases in phosphates, ammonium and organic nitrogen.

Sampled only in July, scores recorded:

SASS4 95 # taxa 16 ASPT 5.9

Interpretation - SASS4 scores indicate a situation marginal between unimpaired and very slightly impaired water quality.

2.2 Pinetown, Durban and Coastal Area

Most sampling points in this area were visited in May, July, September and November. There is extensive historical data on water quality in the streams studied, but such is the nature of industrial development in the catchments of streams in the area that it tends to rapidly become outdated. The water quality and Chutter's Biotic Index values reported refer to an unpublished study made by B K Fowles in 1989.

Umbilo River, **Station 2**

Situated in a park just downstream from Caversham Road in the centre of Pinetown. It is downstream of the large Westmead Industrial Park and is subjected to regular pollution particularly from the textile and pharmaceutical factories upstream. In 1989 Chutter's Biotic Index score for this sampling point was 10, indicating a water which was unfit for most forms of invertebrate life. Ammonium, Kjeldahl nitrogen and soluble phosphate concentrations were very high and the Oxygen concentration was 0.5 $mg\ell^{-1}$ **(Table 4).**

Scores recorded:

May	SASS4	30	# taxa	10	ASPT	3.0
July		45		13		3.5
Sept		39		11		3.6
Nov		14		6		2.3

Interpretation - SASS4 scores and ASPT were both very low and reflected a very poor water quality, confirmed by the available chemical quality data.

Table 3: Water quality during the 1984 re-survey of the Tugela catchment, Mooi and lower Tugela Rivers. Copied from a Steering Committee Report written by B K Fowles. Units of measure and river abbreviations, see **Tables 1** and **2.**

RIVER STATION NUMBER	MOOI 42	MOOI 43	MOOI 44	TUG 45	TUG 46	TUG 47	TUG 48	TUG 49
ALTITUDE	1654	1364	648	533	476	448	179	29
TEMPERATURE	11.2	14.5	19.0	17.0	23.5	22.5	21.5	21.0
pH	7.6	8.8	8.8	8.5	8.6	8.5	8.5	8.3
SUSP. SOLIDS	2	3	7	16	12	18	9	3
CONDUCTIVITY	5.0	10.1	42	37.0	38.1	39.5	32.7	32.7
TOT.DISS.SOLIDS	33	67	281	247	254	263	218	218
ALKALINITY	27	47	196	144	172	177	136	134
FREE CO_2	1.5	0.1	0.6	0.9	0.9	1.1	0.9	1.4
DISS.OXYGEN	9.25	11.54	11.63	8.34	8.34	8.85	8.29	8.38
% SATURATION O_2	103	134	135	103	103	107	97	94
S.R.PHOSPHORUS	3	23	5	2	2	1	1	1
T.P.FILTERED	7	42	10	10	10	8	9	9
T.P.UNFILTERED	15	64	28	32	32	28	24	21
AMMONIA	8	32	24	4	4	4	4	4
KJEL.N.FILTERED	72	337	276	237	237	259	178	148
DISS.ORGANIC N.	64	305	252	233	233	255	174	144
KJEL.N.UNFILT.	163	440	404	406	406	382	296	248
NITRATE	23	5	5	16	16	1	9	1
NITRITE	0	1	1	0	0	0	0	0
SILICA	5.1	2.0	4.7	5.0	5.0	5.2	5.3	4.4
IRON	11	21	3	2	2	2	4	1
CALCIUM	6	7	33	28	28	29	24	25
MAGNESIUM	2	4	24	18	18	20	16	16
SODIUM	2	11	37	39	39	38	30	33
POTASSIUM	0.3	1	2	2	2	2	2	2
CHLORIDE	1	5	24	28	31	28	24	28
SULPHATE	2	6	15	21	17	21	19	20

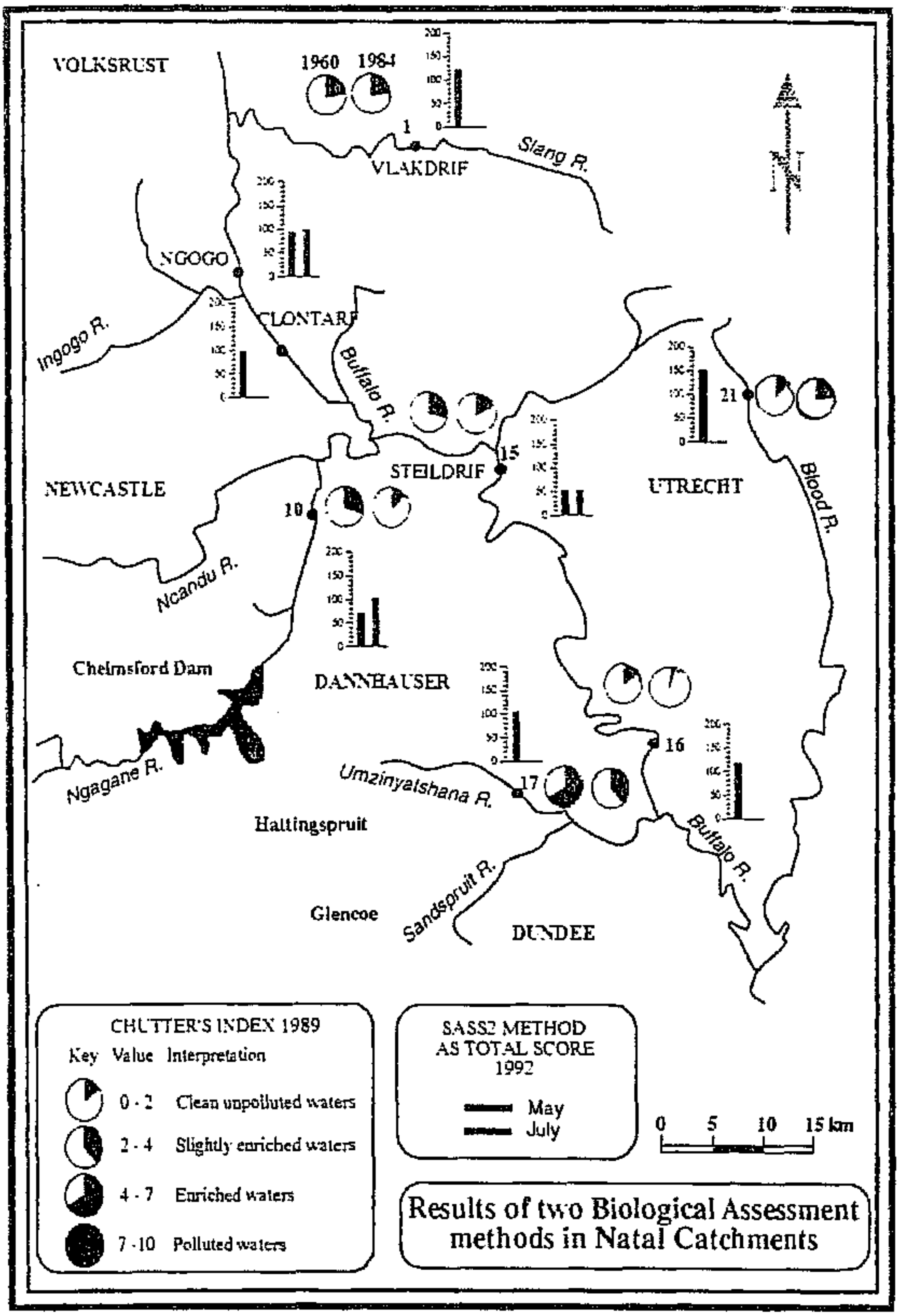

FIGURE 1: A summary of biological data from Northern Kwazulu/Natal showing Chutter's Biotic Index values in 1960 and 1984 and SASS2 total scores in 1992

Table 4: Chemical nature of the Umbilo River in 1989. From an internal report written by B K Fowles.

STATION		2	3	4	5	6	7
Temperature	°C	22.0	19.5	22.0	20.0	21.5	21.5
pH		6.9	7.7	7.6	8.0	8.1	8.1
Conductivity	mSm^{-1}	130	38	113	112	85	45
TDS	$mg\ell^{-1}$	1185	139	833	818	614	333
Dissolved oxygen	$mg\ell^{-1}$	0.5	9.6	8.7	8.4	8.2	9.2
Ammonium	$\mu g\ell^{-1}$	5878	46	422	82	97	45
Kjeldahl - N	$\mu g\ell^{-1}$	23954	1240	3486	2576	1570	713
Nitrite - N	$\mu g\ell^{-1}$	18	104	56	36	29	174
Nitrate - N	$\mu g\ell^{-1}$	84	2364	2942	4836	2776	1885
Sol. phosphorus	$\mu g\ell^{-1}$	2516	53	5872	5988	3677	94
Alkalinity	$mg\ell^{-1}$	164	57	107	116	106	87
Susp. Solids	$mg\ell^{-1}$	157	15	7	8	4	16
Turbidity	NTU	130	12	6	5	4	10

Umbilo River, **Station 3**

Situated in the Paradise Valley Nature Reserve approximately 4 km downstream of the previous station. Between the two stations the river flows through up-market residential areas and there is an apparent rapid recovery in water quality over this short distance. Fish life within the reserve area is monitored regularly by the Kwazulu/Natal Parks Board and is indicative of an improved water quality compared to upstream. At this point there had been considerable changes in the bound nitrogen, which was now mainly nitrate. Oxygen levels were normal (**Table 4**). Chutter's Biotic Index value was high (7.1) indicating a poor water quality.

Scores recorded:

May	SASS4	34	# taxa	9	ASPT	3.8
July		67		16		4.2
Sept		74		18		4.1
Nov		65		16		4.1

Interpretation - The SASS4 scores show that there was recovery of the fauna from the sampling point upstream, but they indicate that there was still considerable deterioration in water quality.

Umbilo River, **Station 4**

Downstream of the Pinetown Sewage Treatment Plant drying ponds and approximately 600 m below the treated effluent discharge pipe. The water at this point is regularly discoloured with dyes and comprises probably 60% effluent during the winter months. The sewage plant treats all of Pinetown's domestic sewage and most of its industrial waste and some from New Germany. The chemical results from 1989 show an increase in ammonium and Kjeldahl nitrogen, and a large increase in soluble phosphate (**Table 4**). Unfortunately components of the textile dyes such as heavy metals were not investigated. Chutter's Biotic Index score was 8.7, indicating a severely polluted water.

Scores recorded:

May	SASS4	7	# taxa	3	ASPT	2.3
July		1		1		1.0
Sept		11		4		2.8
Nov		2		1		2.0

Interpretation - The SASS4 scores reflect the extremely poor water quality.

Umbilo River, **Station 5**

Approximately 5 km below the Pinetown Sewage Works adjacent a small purification works near the Queensburgh caravan park. It is situated on the boundary between the Durban municipal area and that of Queensburgh. The river is in a steep valley at this point flowing relatively fast over rocky rapids. It does however still indicate the effect of the sewage works upstream, the water often being foamy and discoloured with textile dyes. From Station 4 there was an improvement in water quality in the ammonium and Kjeldahl nitrogen concentrations decreased and nitrate increased. Soluble phosphorus concentration remained high (**Table 4**). Chutter's Biotic Index was 6.9 confirming the enriched nature of the water.

Scores recorded:

July	SASS4	51	# taxa	12	ASPT	4.3
Sept		30		7		4.3
Nov		41		11		3.7

Interpretation - The impaired quality of the water is reflected in the low SASS4 scores, but there was considerable improvement over the scores at Station 4.

Umbilo River, **Station 6**

Downstream of the road bridge on the M7 below the confluence of the Umbilo River with the Mkumbane River. A municipal garden refuse dump is situated 300 m upstream of this point on the south bank. Since the previous station the river has passed through mostly undeveloped scrub land adjacent the M7 freeway. There was some improvement in water quality, due to a reduction in the concentrations of bound nitrogen and soluble phosphorus (**Table 4**). This improvement is reflected in the Biotic Index value which fell to 4.6.

Scores recorded:

July	SASS4	57	# taxa	15	ASPT	3.8
Sept		48		11		4.4
Nov		68		16		4.3

Interpretation - the improvement in water quality reflected in the Biotic Index and water analysis is not mirrored in the SASS4 scores, which were indicative of a slight deterioration of water quality from Station 5 to Station 6. It may be that water quality has deteriorated since the previous studies.

Mkumbane River, **Station 7**

Situated in a canalized part of the river adjoining the municipal sports fields. This river originates in the suburb Chesterville bordering Westville and is joined by a small tributary 500 m upstream which drains the light industrial area of Westridge. The river has been canalized with cement interlocking blocks to prevent flooding of the low-lying surrounding sports fields. The quality of the water was better than that of the Umbilo at Station 6 (**Table 4**). The Biotic Index value was 4.0, indicative of some deterioration in water quality.

Scores recorded:

July	SASS4	57	# taxa	12	ASPT	4.5
Sept		37		10		3.7
Nov		56		14		4.0

Interpretation - SASS4 scores suggest that water quality was moderately impaired at this sampling point. They are about the same as at Station 6, which means that if the water quality has remained similar to what it was in 1989, the SASS4 scores did not follow water quality changes.

Palmiet River, **Station 8**

Just upstream of the bridge over the Palmiet River in Padfield Road. At this point the source of the river is some 2 km upstream and this station was used as a control point in previous studies. Kloof municipality's garden refuse dump is situated in the catchment. There was a large grassy field on one bank of the streamlet (< 1 m wide) and an up-market residential area on the other bank. However, the housing is served by septic tanks. The limited amount of chemical data available (**Table 5**) indicates, from the nitrate levels, that there may have been contamination from septic tank effluent. Chutter's Biotic Index score was 2.9 confirming mild organic pollution.

Scores recorded:

May	SASS4	107	# taxa	19	ASPT	5.6
July		116		21		5.2
Sept		141		24		5.9
Nov		120		23		5.2

Interpretation - SASS4 scores are not contrary to expectations from the water quality and Biotic Index, but some of the ASPT values are low for a good water quality.

Palmiet River, **Station 11**

Upstream of Birdhurst Road bridge in Cowies Hill. Since the previous station the river has passed through approximately 5 km of heavily industrialized and commercialized area. The river at this point has often been severely polluted which has angered residents living on the banks of the river. Historic water quality (**Table 5**) indicates severe nitrogen pollution (ammonium, nitrite extremely high, nitrate) and an increase in conductivity/TDS. The Biotic Index value was 8.7, a value which would be associated with a highly polluted water.

Scores recorded:

May	SASS4	30	# taxa	8	ASPT	3.8
July		25		9		2.8
Sept		18		6		3.0
Nov		11		4		2.8

Interpretation - Low SASS4 scores and ASPT confirm that the water was severely polluted as is evident from the water analysis.

Table 5: Chemical nature of the Palmiet River in 1989. From an internal report written by B K Fowles.

STATION		8	11	12	13	14
Temperature	°C	16.0	19.5	18.0	18.0	18.5
pH		7.4	8.1	8.1	7.6	9.2
Conductivity	mSm^{-1}	22.9	61.4	35.8	37.9	34.5
TDS	$mg\ell^{-1}$	126	319	341	251	261
Dissolved oxygen	$mg\ell^{-1}$	8.9	11.3	10.5	11.0	11.5
Ammonium - N	$\mu g\ell^{-1}$	15	260	29	38	2
Kjeldahl - N	$\mu g\ell^{-1}$	345	1537	656	644	689
Nitrite - N	$\mu g\ell^{-1}$	17	2516	27	32	5
Nitrate - N	$\mu g\ell^{-1}$	1739	4665	1174	1964	551
Soluble Phosphorus	$\mu g\ell^{-1}$	16	51	57	51	7
Alkalinity	$mg\ell^{-1}$	24	113	61	62	101
Suspended solids	$mg\ell^{-1}$	8	10	5	4	3
Turbidity	NTU	8	10	5	2	3

Palmiet River, **Station 12**

Situated approximately 300 m below the bridge off Stafford Road in Westville. At this point the river has flowed through an up-market residential area and has shown signs of recovery in water quality, although the water is often still discoloured with dyes and is foamy. Both the available water quality (**Table 5**) and the Biotic Index value (5.1) showed that the river had improved between this sampling point and the previous point, though it was by no means in a good state.

Scores recorded:

May	SASS4	77	# taxa	20	ASPT	3.9
July		76		18		4.2
Sept		36		12		3.0
Nov		50		10		5.0

Interpretation - SASS4 confirmed previous findings, intermediate SASS4 and intermediate ASPT, but both better than at previous sampling point. Variables which would measure the extent of dye and foam pollution were not determined, but are probably important in the biological response at this point.

Palmiet River, **Station 13**

Situated 100 m upstream of the Blair Atholl Road bridge over the Palmiet River in the centre of Westville. Regular flooding of the river occurs at this point during heavy rainfall events. Gradients are steep and the river bottom is very rocky over this section, as the river makes its way down to its confluence with the Mgeni River. Past studies and complaints by residents living on the river banks suggest that the water quality at this point is impacted by organic pollution probably arising from a combination of the many septic tanks, shallow topsoil and steep gradients in the Westville catchment. The topography and rocky nature of the land has resulted in very few Westville properties being connected to water-born sewage systems. The recorded bound nitrogen concentrations (**Table 5**) and the Biotic Index value indicate mild organic pollution.

Scores recorded:

May	SASS4	85	# taxa	18	ASPT	4.7
July		88		22		4.0
Sept		56		13		4.3
Nov		56		15		3.7

Interpretation - SASS4 scores can only be interpreted as showing that there was virtually no improvement from Station 12 to Station 13. This is contrary to previous studies, but conditions in the river may have deteriorated in the three years that have elapsed since the previous studies.

Palmiet River, **Station 14**

In the grounds of the University of Durban-Westville, adjacent the university horticultural nursery. Again the banks are steep and the river bed is very rocky. There have been indications of a continuation of the organic pollution detected in past studies at station 13 some 4 km upstream. In the 1989 water sample the pH of the water was unusually high and the concentrations of ammonium and nitrate were very much lower than at the previous sampling point (**Table 5**). The Biotic Index value of 7.8 was high and indicated a far more severely polluted water than the analyzed water sample.

Scores recorded:

May	SASS4	103	# taxa	20	ASPT	5.2
July		111		22		5.0
Sept		103		21		4.9
Nov		88		21		4.2

Interpretation - SASS4 results suggest a water of reasonable quality (SASS2 high, ASPT intermediate), slightly improved over the previous station, but by no means as good as would be expected from the 1989 water quality and at the same time by no means as bad as the 1989 Biotic Index value.

Figure 2 shows that the Umbilo is nowhere unpolluted and this is confirmed by the 1989 biological results (and by the chemical data in **Table 4**). Biologically, the best water quality found in 1992 in the Palmiet River was at the very headwaters (Station 8). In both 1989 and 1992 the quality of the river was poor at stations 11 and 12, but downstream there would appear to have been radical changes in water quality between 1989 and 1992. At Station 13 the 1989 data showed a mildly polluted water but a worse water quality was apparent in 1992. At Station 14 the 1989 Biotic Index value suggested a highly polluted water, but the water analysis (**Table 5**) did not. The SASS4 score for 1992 suggested a slightly polluted water, which is an improvement over the biological assessment of 1989 but a deterioration from the chemical data of 1989.

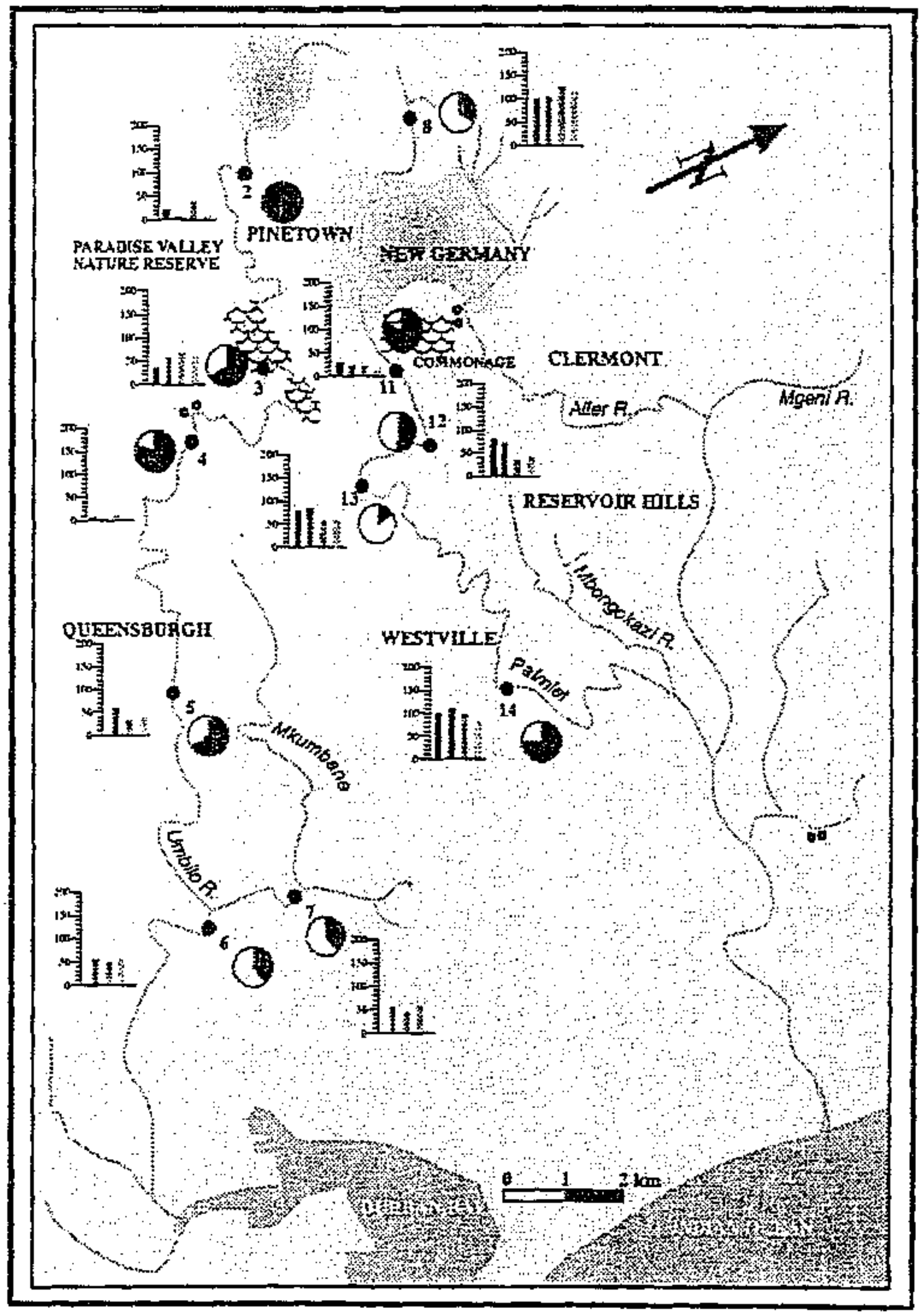

Figure 2: A map of the Pinetown area showing the position of sampling points on the Umbilo and Palmiet Rivers, 1989 Biotic Index values and the SASS2 scores recorded in 1992.

The following sampling points were included in the study in an attempt to include a range of water quality conditions in streams at lower altitudes than those of northern Natal. There are unfortunately not available water quality data for these sampling points.

Molweni River Station

Above the bridge over the Molweni River on the Kloof Falls road in Forest Hills. At this point the river flows over rugged terrain in the Krantzkloof Nature Reserve, having drained the residential areas of Hillcrest and Everton upstream. The river water has been of good unpolluted quality in the past. Thirty years ago is was renowned as a stream where several species associated with inland mountain streams could be found, but this seems no longer to be the case.

Scores recorded:

May	SASS4	78	# taxa	15	ASPT	5.2
July		112		22		5.1
Sept		111		21		5.2
Nov		85		18		4.5

Interpretation - The ASPT scores are in the range where, combined with the high SASS4 scores, there is evidence of minor water quality change. The scores appear to support the disappearance of taxa known to have been present in years gone by.

Mgeni River Station (below Nagle Dam)

Approximately 5-6 km below Nagle Dam on a right hand bend in the road from Cato Ridge to the dam. It is approximately 8 km above the confluence of the Mgeni and Msunduze rivers. The Mgeni River at this point contains clean water having flowed through farming land on its passage from Albert Falls Dam (it by-passes Nagle Dam). There are battery chicken farms and feedlot stock farms in the upper catchment just below Albert Falls Dam which are unlikely to show impact on the water quality at this point.

Scores recorded:

May	SASS4	141	# taxa	27	ASPT	5.2
July		144		27		5.3
Sept		143		26		5.5
Nov		168		29		5.8

Interpretation - SASS4 scores are high, but ASPT ranged from intermediate towards high as the months went by, for reasons which are not understood. Water quality probably slightly impaired.

Mzinyati River Station

Upstream of the un-tarred road bridge on the road from Inanda Seminary to Armstrong Hill in the Inanda Location of Kwazulu. The river drains a densely populated rural area where a small amount of subsistence and sugar farming is undertaken. Soil erosion is obvious in the catchment and the people use the river water for drinking and clothes washing. The stream is mainly sandy bedded, though there were stones to sample. Stream margins lined by aquatic grasses.

Scores recorded:

May	SASS4	87	# taxa	16	ASPT	5.4
July		80		17		4.7
Sept		70		16		4.4

Interpretation - The SASS4 scores and ASPT scores are intermediate and suggest some deterioration in water quality.

Mdloti River, Above Hazelmere Dam

Upstream of the bridge on the road from Verulam to Ndwedwe. The sampling point is approximately 500 m upstream from St Mary's Convent School and approximately 1.5 km from the headwaters of Hazelmere Dam. The catchment comprises mainly the rural area of Ndwedwe in Kwazulu with extensive sugar farming in the immediate catchment. A few hundred metres upstream and downstream of the sampling point mining of the river sand is a major activity. Neither previous water quality nor biological data available. This is a sandy bedded river with a small rapid at the road bridge and small patches of fringing vegetation. In September and November the mining of river bed sand had moved very much closer to the sampling point.

Scores recorded:

May	SASS4	136	# taxa	22	ASPT	6.2
July		136		24		5.7
Sept		93		17		5.7
Nov		77		16		4.8

Interpretation - The first two month's scores showed that water quality was good - high SASS4 and high ASPT. When the sand mining moved closer to the sampling point, there was a loss of species richness, with a disproportionate loss of pollution sensitive families which is shown by the decline in the ASPT. The most obvious impact of sand mining is an increase in the turbidity of the river, but there may well be less obvious effects such as lowering the dissolved oxygen content of the water by disturbing anaerobic zones in the sand.

Mdloti River, Mount Moreland

Approximately 3 km off the main road from Mhloti Beach to Verulam, at a place called Mount Moreland. The sampling station is upstream of a small concrete road bridge used mainly by vehicles associated with the sugar industry. The surrounding lands are all under sugar cane. Verulam town, with its sewage works on the banks of the river, undoubtedly impacts the river water quality at this point some 3 km downstream. Unfortunately no previous water quality or biological data is available for this point, which was chosen for the sandy nature of its bed. The river bed is sandy with a wide fringe of floating grass extending from the banks.

Scores recorded:

May	SASS4	66	# taxa	13	ASPT	5.1
July		68		13		5.2
Sept		65		14		4.6
Nov		26		7		3.7

Interpretation - SASS4 scores are not in conflict with the suggestion that there was organic pollution of the river from Verulam. In November the river had obviously recently been in spate and there was a loss in species richness and much lower SASS4 scores and ASPT.

Figures 4 and **5** show the position of the sampling points on the Mgeni and Mdloti Rivers. Biologically none of the rivers had a fauna indicative of polluted waters.

3. DISCUSSION AND CONCLUSIONS

In this appendix it has been shown that SASS4, which is a rapid and relatively inexpensive method for the detection of water pollution, performs as well as the more expensive Biotic Index. For the most part both indices indicated the presence and degree of pollution in a similar manner, although between 8 and 3 years separated the SASS4 and Biotic Index assessments. The exception was part of the Palmiet River in which the biological assessment of water quality showed a deterioration in the stream between 1989 and 1992. The fact that the deterioration was measured at successive sampling points lends credence to the conclusion that the change was real and not an artifact of assessment methods.

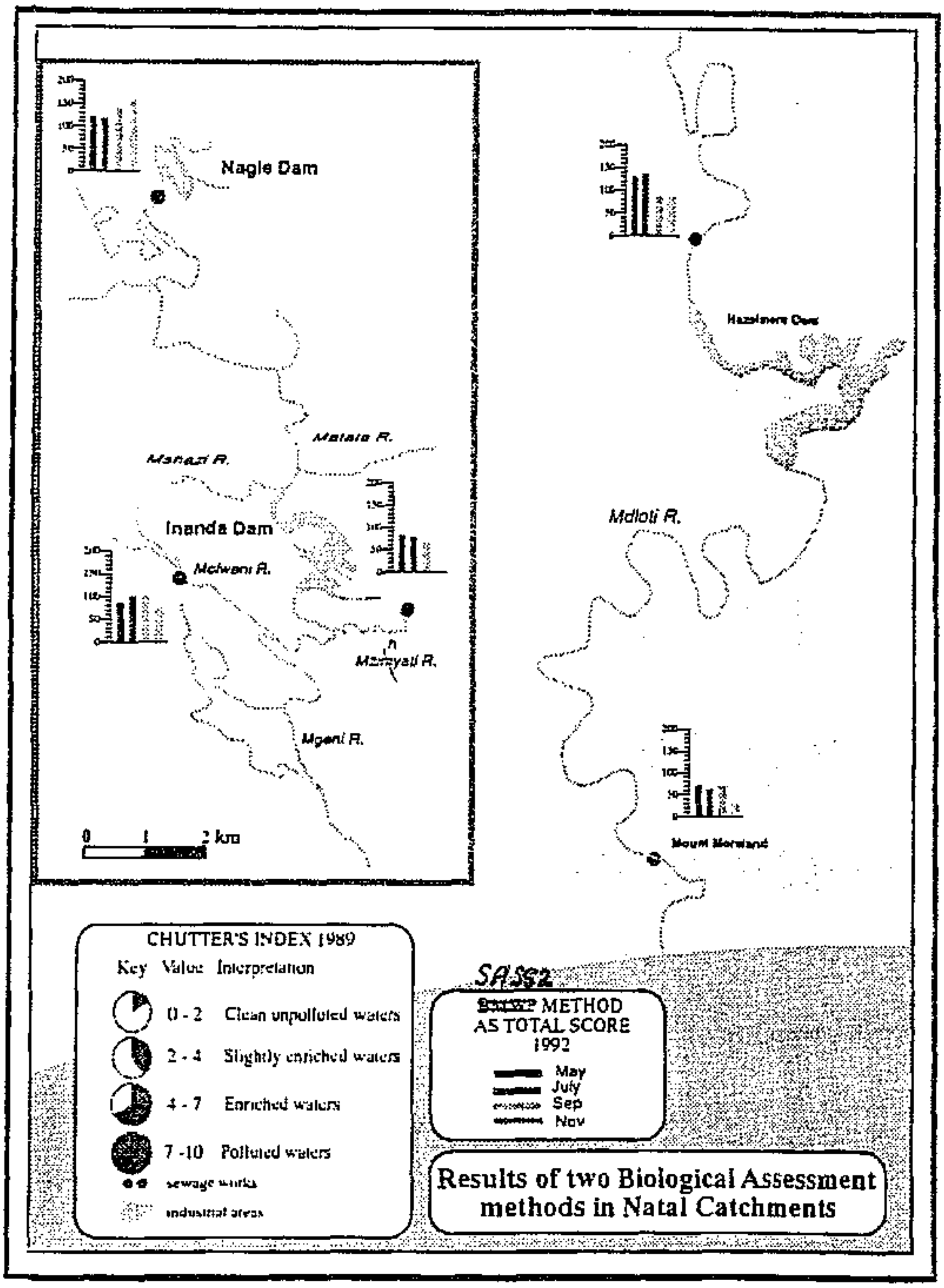

Figure 3: Maps of the lower Mgeni and Mdloti Rivers showing the position of sampling points and the SASS2 scores recorded

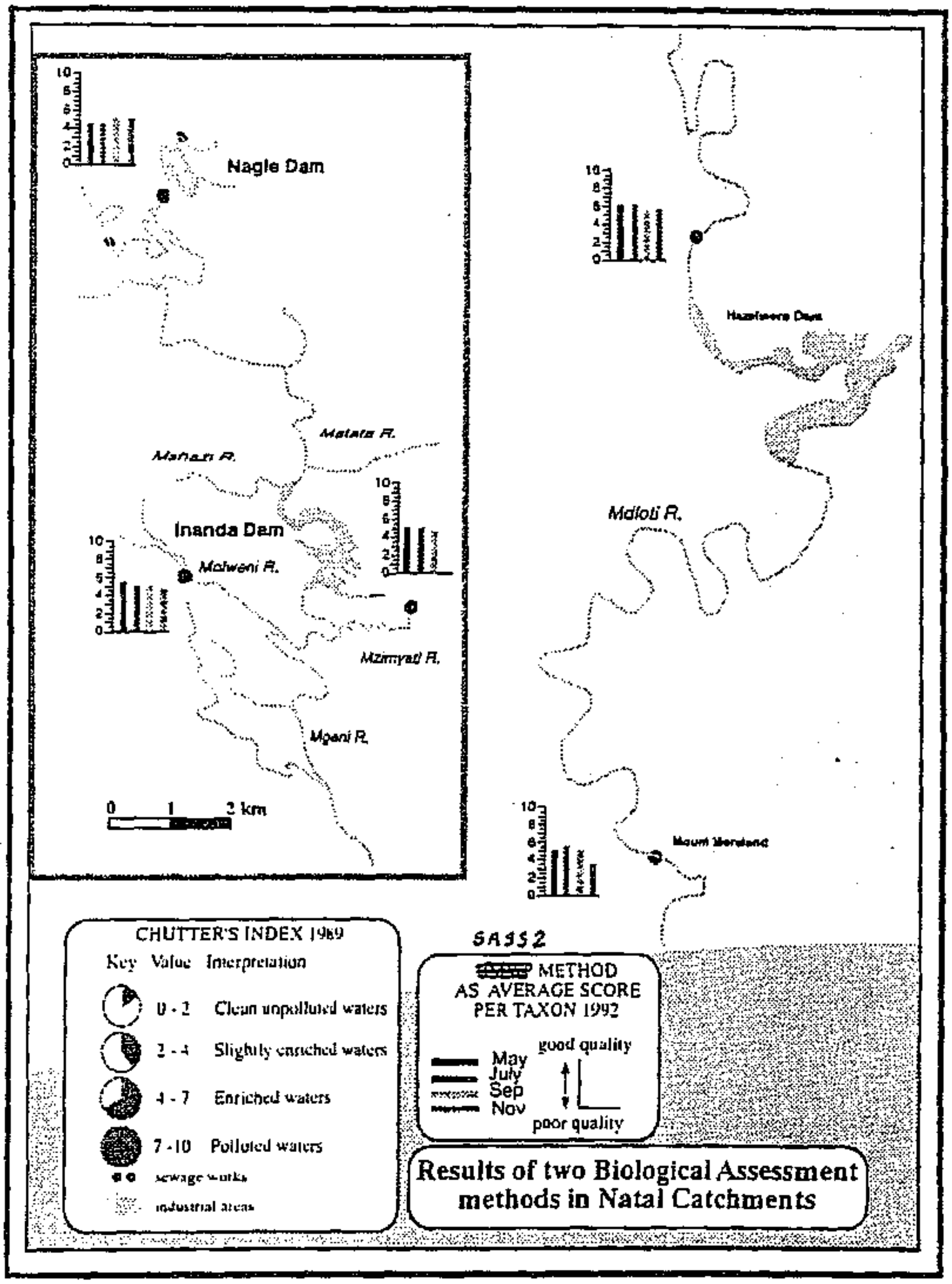

Figure 4: Maps of the lower Mgeni and Mdloti Rivers showing the position of sampling points and the ASPT scores recorded

The ranges of SASS4 scores in combination with ASPT scores associated with severity of water quality deterioration from the data given in Appendix B were useful. Conclusions based on this interpretation of SASS4 results were mainly valid when compared with the associated water quality. There did however appear to be a group of sampling points in which the combination SASS4 >100, ASPT <6 (on the borderline between water quality deterioration and no deterioration) occurred. The interpretation of such results has rested on how much greater than 100 the SASS4 score has been and how much less than 6 the ASPT.

Interpretation of results is easier when more than one sample is available from a sampling point. For the most part scores at single sampling points varied asystematically from sample to sample, often within a fairly limited range. There was usually no obvious reason for such variation. It is to be doubted that the variation was brought about by short term changes in water quality at sites where water quality is known to be good.

The data base includes two examples of events which appeared to bring about changes in SASS4 scores. The first was the movement of a sand-winning operation, initially about 500 m upstream of a sampling point, nearer to the sampling point (Mdloti River upstream of Hazelmere Dam). This resulted in a reduction of SASS4 and of ASPT, which could have been due to greater turbidity, greater river transport of sand or to changes in water quality due to washing of anaerobic sand. Similar biological conditions were found in the Streams and rivers of Lesotho (**Appendix** E) and were ascribed to impacts due to sediment.

The second event was the impact of a spate on the same river at Mount Moreland, again resulting in a loss of taxa and a drop in the ASPT. Both the movement of the sand-winning operation and the spate point to the need for an awareness amongst technicians undertaking SASS sampling for the necessity to observe and report any events which could have an impact on the scores measured. Rapid Biological Assessment may be relatively simple in its demands on taxonomic skills and in the interpretation of results. This simplicity should not, however, excuse field workers from the responsibility to look for extraneous factors which could impact the results achieved. The necessity for the careful recording of the habitats sampled at each sampling point has been addressed in Appendix B.

In this and in the other appendices, no attempt has been made to relate SASS4 results to water quality by means of statistical analyses. Reasons for this frequently include water quality data limited in number of analyzed samples and in variety of determinands. It should also be remembered that the invertebrate community is more likely to respond to maximum concentrations than to mean concentrations and that the duration of exposure to the high concentration will be likely to be as important as the actual concentration. However, in attempting to relate a surrogate measure (biological property) of water quality with actual water quality, there are two facts which prevent the use of mathematical analyses such as correlation and regression. The first is the time period represented by the biological (weeks, possibly months) and chemical (possibly hours) samples. Theoretically, this could be overcome by the very frequent measurement of chemical variables over long periods of time, but this utterly impractical. The second fact is that there are many chemical variables which deleteriously impact river biology. No one has yet been able to derive a scale of water quality embracing all the chemical variables so that comparisons between water and biological quality have been based on picking out single or very few variables at a time. However this approach can offer only special case solutions to a general problem.

4. REFERENCES

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Appendix E

SASS assessment of the condition of some streams and rivers in Lesotho

EXECUTIVE SUMMARY

SASS scores were recorded at eight sampling points on the Malibamatso River in the Lesotho Highlands and six sampling points in the Lesotho Lowlands (Caledon River catchment) in September and October 1992. The intention of this study was to establish whether the scoring scheme was applicable in this mountainous region of Southern Africa. Water quality in these streams is good, other than the high sediment load.

A feature of Lesotho streams and rivers is the lack of fringing vegetation and the abundance of sediment in the stream beds. SASS samples could be drawn only from stony habitats, a sampling limitation which contributed to the low scores encountered. A further factor contributing to the low scores was a lack of high scoring taxa. It was concluded that, due to the abundant sediments, the observed scores were lower than they would otherwise have been.

There were faunistic differences between the Highland and Lowland streams, in that Heptageniidae and Perlidae were found only in the Highland streams and not in the Lowland streams. Leptophlebiid mayflies were more frequently found in the Highlands than in the Lowlands and the opposite was true of the Tricorythidae. It was concluded that these differences could be due to differences in the nature of the sediment (sand of dolomitic origin) in the Highlands and in the Lowlands (predominately silt originating from Karoo Sequence Formations).

The Lesotho SASS data showed that scores are responsive to changes (sediment load) in streams and rivers other than changes in chemical water quality. This important point must be taken into account in the evaluation of SASS results.

1. INTRODUCTION

In September and October 1992 opportunity arose to undertake SASS sampling in the streams and rivers likely to be impacted by Phase 1A of the Lesotho Highlands Water Project. The sampling points lay in two ecologically distinct areas. The first area was the mountainous interior through which the Malibamatso River and its tributaries flow. This area is underlain by dolerite, which is friable and results in large amounts of coarse sediment being carried into the streams. The second area was the Caledon River valley in the Lesotho "lowlands". Here the major geological formations are sandstones, shales and mudstones. Erosion of the soils overlying these formations leads to the deposit of large amounts of fine silt in river beds.

In neither of these two areas was there fringing aquatic vegetation and the sample results were based on stones in and out of the current. Surface waters were neutral to alkaline and chemically of high quality with low concentrations of dissolved salts. In summer freshets and floods, the sediment load was high and sufficient to embed stones, filling the interstices between stones with small particulate matter.

There is some evidence that during mid-summer when small livestock is dipped in tanks for parasite control, biocides find their way into streams causing very localised impacts on the stream fauna. Since the sampling reported here took place eight or nine months after the dipping season and dipping tanks were remote from the sampling points, it is unlikely that any marked impact due to biocides would remain. This impact is not thought to occur in the Caledon valley as the livestock is mostly in the mountains in the dipping season.

2. RESULTS

The sampling points, their locality and their SASS4 results are shown in **Table 1**. The aquatic invertebrate fauna of stones habitats in Lesotho rivers was low in diversity, the highest numbers of taxa found in individual samples being eleven in the Highlands (Stations 1 to 8) and ten in the Lowlands (Stations 9 to 14). The highest SASS4 scores and ASPT were recorded at Station 1, the Malibamatso River upstream of the Pelaneng confluence. Given that only stone habitats were sampled, the SASS4 results at Station 1 confirmed that water quality was not impaired due to the high ASPT score.

SASS4 score was low at Station 6 in October and ASPT was very high due to the low number of taxa and the presence of a high scoring taxon. The Station 6 September score was more balanced than the October score.

Table 1: Sampling points and SASS4 results from streams in Lesotho. Sampling points 1, 2, 6 and 7 have subsequently been drowned by Katse Dam.

Station number	Description	Latitude[1]	Longitude[1]	SASS4 results[2]	
				September 1992	October 1992
MALIBAMATSO RIVER CATCHMENT - "HIGHLANDS"					
1	Malibamatso R. upstream of Pelaneng R. confluence	290453	283020	63 : 9 : 7.0	62 : 9 : 6.9
2	Malibamatso R. downstream of Pelaneng R. confluence	290530	283020	36 : 8 : 4.5	49 : 9 : 5.4
3	Malibamatso R. at Bridge below Katse Dam	291942	283018	48 : 9 : 5.3	42 : 7 : 6.0
4	Malibamatso R. at Ha Leoka	283924	283754	32 : 7 : 4.6	41 : 9 : 4.6
5	Malibamatso R. at Paray	292943	283901	46 : 10 : 4.6	38 : 8 : 4.8
6	Pelaneng R. upstream of Malibamatso R. confluence	290456	282927	52 : 9 : 5.8	27 : 4 : 6.8
7	Bokong R. upstream of Katse sewage works	291946	282820	49 : 9 : 5.4	45 : 8 : 5.6
8	Matsuko R. at Ha Nang crossing	291853	283440	54 : 11 : 5.0	56 : 11 : 5.1
CALEDON RIVER CATCHMENT - "LOWLANDS"					
9	Nqoe Stream upstream of 'Muela Dam	284630	282813	42 : 8 : 5.2	18 : 6 : 3.0
10	Nqoe Stream at bridge on Oxbow road	282854	282640	50 : 10 : 5.0	46 : 9 : 5.1
11	Hololo R. at Khukhune	284403	282529	48 : 9 : 5.3	31 : 7 : 4.4
12	Caledon R. at Joel's Drift	284145	282046	33 : 7 : 4.7	47 : 10 : 4.7
13	Hlotse R. at Khabo's	285052	285051	flow too low to sample	53 : 10 : 5.3
14	Mphosong R. near Morotong R. confluence	281349	285854	47 : 9 : 5.2	43 : 9 : 4.8

Footnotes:
1. Latitude and longitude are recorded in degrees, minutes and seconds
2. SASS scores are shown as SASS4 sample score, colon, number of taxa, colon, Average Score Per Taxon (ASPT).

There was a large drop in both SASS4 score and ASPT at all the Malibamatso River sampling points downstream of Station 1. This finding suggests that the deterioration in conditions was due to the Pelaneng River. In this river the stones were particularly embedded by sand. A characteristic of the SASS4 results in the Malibamatso River after Station 1 and of its tributaries (Stations 6, 7 and 8) was that SASS4 scores were very low in relation to the chemical quality of the water, while the ASPT values were for the most part high in relation to the SASS4 score.

The scores in the Highlands and the Lowlands are summarised and compared in **Table 2**, omitting Station 1 and Station 6 in October (where ASPT and probably the whole sample were not representative). Median scores and ASPT were similar in both areas, though ranges of scores and ASPT differed. Minimum SASS4 and ASPT were higher in the Highlands than in the Lowlands.

It is evident that some of the taxa found belonged to the high scoring, sensitive-to-water-quality-change taxa (see high ASPT at Station 1 - September and October, Station 3 - October and Station 6 - October).

Table 2: SASS4 results from Lesotho. Summary information, Highlands and Lowlands results.

Locality	Number of samples	SASS4		ASPT	
		Median	Range	Median	Range
Highlands exc. Stn. 1 & Stn. 6, October	13	46	56 - 32	5.1	6.0 - 4.5
Lowlands	11	46	53 - 18	5.0	5.3 - 3.0

3. DISCUSSION

The intention of undertaking SASS4 sampling in Lesotho was that the results would provide a useful data base on the efficacy of the SASS4 method in mountain streams in the interior of South Africa. The reported low scores were unexpected, but have been confirmed by subsequent work in the area (F C de Moor, personal communication).

Two factors are associated with the low scores found - the lack of habitat diversity, which is certain, and the apparent large sediment loads of the rivers, which is hypothesized from the amounts of silt found in rapids and other stony bottomed areas. Water quality, excluding sediment concentration, in the study area is known and is unlikely to be a factor restricting the diversity of the aquatic invertebrate communities.

Examination of the score sheets for the Lesotho Highlands (Stations 1 to 8) shows that only four relatively high scoring families were found. These were the Perlid stoneflies (score 12), the Heptageniid mayflies (score 10), the Leptophlebiid mayflies (score 13) and the Tricorythid mayflies (score 9). Scores at Station 1 were high because all four of these families were recorded there in both sampling months. No more than two of these four families were found at any other single sampling point.

Perlidae and Heptageniidae were not recorded in the Lowlands and Leptophlebidae were less common than they were in the Highlands. In September Tricorythidae were present in five of the six Lowland samples, but they were found at only one station in October. In the Highlands Tricorythidae were present in four of the eight samples on each sampling visit.

These differences in the occurrence of the Perlidae, Heptageniidae, Leptophlebiidae and Tricorythidae in the Highlands and Lowlands might be due to the nature of the sediment deposited in the habitats sampled. In the Highlands sediment tended to be sand-sized particles of dolomite, whereas in the Lowlands it was mixed sand and fine mud derived from the sandstones, shales and mudstones of the upper formations of the Karoo Sequence. It may be that Perlidae and Heptageniidae do not tolerate high loads of fine silt, though they may tolerate sand among the stones where they are found.

A conclusion drawn from studies in other areas was that SASS4 scores between 50 and 100 should be interpreted by reference to the ASPT (Section 7.2 in main report). If a variety of habitats has been sampled and if the SASS4 score is in the 50 - 100 range and ASPT is above 6. water quality is unlikely to be impaired; whereas if ASPT is below 6 and the SASS4 score is in this range, there is likely to be some deterioration in water quality. Obviously scores from Lesotho should be expected to be low due to the poor habitat diversity, but ASPT values above 6 were seldom encountered.

It is suggested that had conditions in the Lesotho Highlands rivers been such that there was no elevated sediment load, ASPT scores above 6 should have been the rule rather than the exception. The consequence of this conclusion is that the SASS4 scores are responsive to general environmental conditions and not only to changes in chemical water quality - unless sediment load is regarded as a component of water quality.

Results from sampling points in the Caledon valley Lowlands (Stations 9 to 14) indicated greater impacts on the aquatic invertebrates than was the case in the Highlands. The highest ASPT values recorded were only 5.3 and SASS4 scores well below 50 were common.

4. CONCLUSIONS

Streams in Lesotho are greatly impacted by high sediment loads. Vegetation based habitats are generally lacking. In these circumstances taxon diversity and SASS4 scores are lower than would otherwise be expected. There are nevertheless some relatively high scoring taxa which can survive the changed conditions. The result is that the unusual combination of SASS4 score less than about 50 and ASPT greater than 5.5 occurred (see **Table 1**, Station 3 October, Station 6 September and October and Station 8 October).

The SASS results from the streams in Lesotho show that environmental changes other than the chemical quality of the water effect SASS scores. In particular it would appear that high sediment loads in rivers result in changes in the invertebrate communities so that SASS4 scores were low, but ASPT was sometimes high.

Four relatively high scoring taxa were found in Lesotho rivers. Of these the Perlidae, Leptophlebiidae and Heptageniidae appeared to be less tolerant of fine silt than and the Tricorythidae.

Appendix F

SASS assessment of the condition of the rivers in the East Cape

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EXECUTIVE SUMMARY

SASS4 sampling was done in the Buffalo river, East London and two of its tributaries, in the Great Fish River, in the Bloukrans River at Grahamstown and in the Palmiet River, Howiesonspoort near Grahamstown. Water quality at these sampling points ranged from natural to highly modified. SASS4 scores changed with changing water quality in a manner consistent with change in the parts of South Africa where the pH of natural waters is neutral to alkaline.

An exception was the Great Fish River in which there was no reason to expect change in water quality as the river flow is due to the transfer of water from Gariep Dam on the Orange River. It was found that, over the three month sampling period, the SASS4 scores and the number of taxa recorded declined by over half. Two factors may have been responsible for this. Firstly the water was always turbid and it was difficult to achieve consistent sampling from month to month. Secondly, transferred water created a permanent flow in a previously intermittent river. Although this change occurred some years ago, the diversity of invertebrate fauna is still increasing. In this circumstance aberrant results may occur.

ACKNOWLEDGEMENTS

Mr A B Lucas of the East London Regional Office of the Department of Water Affairs provided useful advice on water quality in the Buffalo River. Ms A C Uys, Institute for Water Research, Rhodes University, assisted in the field work in this area. I greatly appreciate the help of the Mr Lucas and of Ms Uys.

1. INTRODUCTION

The applicability of the SASS method to rivers in the East Cape was investigated through sampling the macroinvertebrate communities of the Buffalo River, the Bloukrans River, the Palmiet Stream in Howiesonspoort near Grahamstown and the Great Fish River.

This part of the East Cape is an area of erratic rainfall, both in terms of its seasonality and quantity. It lies between the winter rainfall area and the summer rainfall area. It is said that in some years the area has both rainy seasons, while in others it has neither! The East Cape between Port Elizabeth and East London supports few perennial rivers. Three of the rivers included in the SASS survey have regulated flows.

Most of the Buffalo River flow is abstracted for domestic and industrial use in King Williams Town, Zwelitsha, Bisho, Mdantsane and East London. Much of the used water is returned to the river in and below King Williams Town and below Bridle Drift Dam.

The Great Fish River now flows perennially, due to the transfer of water from the Gariep Dam on the Orange River. Prior to the transfer, the Great Fish ceased flowing for prolonged periods and the invertebrate community of the river was highly modified. One sampling point was surveyed. It was at Double Drift, which now lies within a nature conservation area.

The Bloukrans River flows through Grahamstown where it received run-off from poorly serviced areas before the town's sewage works effluent was discharged into the river. The fact that there was flow in the stream was due mainly to the effluent.

The Palmiet is a small perennial stream at the bottom of Howiesonspoort in which the flow is natural. It has not been subjected to a major study.

SASS samples were collected at monthly intervals between June and August 1993 at all sampling points. There were no contemporary studies of water chemistry with which the SASS results may be compared. The three rivers are known to be alkaline and have from time to time been studied in some detail.

SASS2 scoring sheets were used in the field and the SASS4 results reported here have been calculated from the SASS2 results following the method given in the report to which this is an appendix.

2. RESULTS

2.1 The Buffalo River

The Buffalo River has recently been the object of a comprehensive report (van Ginkel *et al* 1993) which attempted to summarise the many studies of the river that have taken place over the years. It was concluded that water quality problems have existed in the river for many years, but have not shown any clear cut trends of change with time. The river could be divided into three reaches; a problem-free upper reach (upstream of King Williams Town), a middle reach where water quality problems were apparent (from King Williams Town to Bridle Drift Dam) and a lower reach without apparent water quality problems (below Bridle Drift Dam). The sampling points are shown in **Table 1**.

Table 1: Sampling points on the Buffalo River and its tributaries.

Site	River	Reach*	Description
1	Buffalo	Upper	Bridge where the river enters King Williams Town. Up stream of all point sources of effluent release.
2	Buffalo	Middle	Bridge in Cathcart Road, below the King Tannery
3	Buffalo	Middle	Below King Williams Town sewage treatment works
4	Buffalo	Middle	Buffalo River downstream of the confluence of the Isana stream
5	Mlakalaka	Tributary	Mlakalaka tributary below road bridge
6	Second Creek	Tributary	Second Creek below inflow of solid waste dump drainage.
7	Buffalo	Lower	Buffalo Pass near East London

* reaches defined by van Ginkel *et al* (1993).

SASS4 results from the Buffalo River are shown in **Table 2**. Scores and ASPT were higher in the upper and lower reaches than in the middle reaches, confirming the conclusion of van

Ginkel *et al* (1993) that conditions in the river were worse in the middle reach of the river than in the upper or lower reaches. In the river (as opposed to its tributaries) the lowest scores were recorded at Station 3, below the King Williams Town sewage works. It should be pointed out that the proximity to the sewage works does not in this case imply that the poor conditions were due solely to the sewage works.

Of all the sampling points, the lowest scores were recorded from Second Creek (Station 6), which drains straight into East London harbour. The steaming drainage of a large solid waste dump drained into this stream just upstream of where it was sampled. The Mlakalaka stream (Station 5) SASS4 results suggest that the stream is similar in water quality to the middle reaches of the Buffalo into which it discharges.

Table 2: SASS4 results from the Buffalo River, East Cape. Results are SASS4 score : number of taxa : Average Score Per Taxon (ASPT)

Sampling point	Reach*	June 1993 results	July 1993 results	August 1993 results
1	Upper	118 : 19 : 6.2	116 : 21 : 5.5	105 : 21 : 5.0
2	Middle	68 : 16 : 4.2	64 : 16 : 4.0	73 : 19 : 3.8
3	Middle	53 : 13 : 4.1	33 : 10 : 3.3	40 : 11 : 3.6
4	Middle	66 : 14 : 4.7	60 : 15 : 4.0	58 : 13 : 4.5
5	Tributary	54 : 13 : 4.2	60 : 13 : 4.6	62 : 15 : 4.1
6	Tributary	35 : 9 : 3.9	32 : 8 : 4.0	53 : 11 : 4.8
7	Lower	102 : 18 : 6.7	105 : 19 : 5.5	114 : 20 : 5.7

* reaches defined by van Ginkel *et al* (1996).

2.2 The Bloukrans River

Samples were collected from three points on the Bloukrans River. The Station 1 was about 400 m upstream of the Grahamstown sewage treatment works outfall, Station 2 was below the sewage treatment works outfall and Station 3 was about three kilometres further downstream. No water quality data were available for these three points, but it was reasonable to assume that water quality was poor from the very appearance of the stream.

Results from the Bloukrans River are shown in **Table 3**. At all sampling points scores indicated very poor water quality. It would appear that if the sewage works effluent could be considered to have any impact, it was to very slightly improve conditions in the stream. This effect might be associated with an increase, due to the sewage works effluent, in the flow of the stream, which was a trickle at sampling point 1.

Table 3: SASS4 sampling results from the Bloukrans River. See **Table 2** for explanation of table contents.

Sampling point	June 1993 results	July 1993 results	August 1993 results
1	7 : 4 : 1.8	20 : 5 : 4.0	8 : 3 : 2.7
2	35 : 10 : 3.5	30 : 8 : 3.8	12 : 4 : 3.0
3	-	5 : 2 : 2.5	6 : 2 : 3.0

2.3 The Great Fish River

No marked changes in river conditions were found from sampling visit to sampling visit. Flow was more or less constant, as was conductivity. The water was always too turbid to see the bottom where sampling was taking place. SASS4 score, number of taxa and ASPT were high in June, whereafter SASS4 score and number of taxa declined in July and August. The decline was very much less evident in ASPT. It was assumed that the flow of the river being water transferred from the Gariep Dam, there would be unlikely to be water quality changes sufficient to change SASS4 scores in the manner reflected in **Table 4**. The lesser change in the ASPT suggests that water quality was probably not responsible for the change in SASS4 score and number of taxa. The most probable explanation is that scores declined due to differences in sampling success, themselves at least in part due to the fact that the water was turbid.

Table 4: SASS4 scores from the Fish River at Double Drift. See **Table 2** for explanation of table contents.

	SASS4 results
June 1993	137 : 22 : 6.2
July 1993	89 : 16 : 5.6
August 1993	52 : 9 : 5.8

2.4 The Palmiet Stream

The Palmiet stream has an undisturbed catchment facing south west on the hills to the west of Grahamstown. The water was of neutral pH, with a low conductivity (17 to 20 mSm^{-1}). SASS4 scores, numbers of taxa and ASPT were all high (**Table 5**), confirming that water quality was unimpaired.

Table 5: SASS4 scores from the Palmiet River at Howiesonspoort. See **Table 2** for explanation of table contents.

	SASS4 results
June 1993	197 : 28 : 7.0
July 1993	143 : 24 : 6.0
August 1993	155 : 24 : 7.0

3. DISCUSSION

The results presented in this Appendix show that the invertebrate fauna of the Eastern Cape rivers responds to water quality change in the same way as that of other parts of South Africa where the pH is neutral to alkaline. Results from the Great Fish River were variable for no apparent reason, though the fact that this river flows only due to the transfer of water from the Orange River system may contribute to the unusual situation. The river is considered not to support as great a diversity of invertebrates as a natural river, though the invertebrate diversity has gradually increased since the transfer started (F C de Moor, personal communication). Nevertheless difficulties in sampling due to the turbidity of the water may also have played a part in the unusual degree of variation in the scores recorded from month to month.

4. CONCLUSIONS

SASS4 results from the Eastern Cape show that the method produces scores that respond to water quality change in a manner similar to that found in other parts of South Africa where the pH of the water is naturally neutral to alkaline. In natural rivers SASS4 score exceeds 100 and ASPT exceeds 6.0.

5. REFERENCES

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Appendix G

SASS assessment of the condition of streams and rivers in the Southern Cape

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EXECUTIVE SUMMARY

The streams and rivers of the southern Cape fall into two groups following the natural pH of the water. Streams draining Table Mountain Sandstone have brown acid water with a pH less than 6. Other streams are mildly acid (pH 6.0 to 6.9) or alkaline. It has long been known that the acid, brown water streams have a distinctive invertebrate fauna, including many taxa with Gondwanaland affinities. For the most part these taxa do not occur in mildly acid to alkaline conditions.

The purpose of the investigations in the southern Cape was to examine the SASS4 scores in acid brown water streams and to compare them with those from mildly acid and alkaline streams. In natural, acid, brown water streams SASS4 scores tend to be high and ASPT to be very high, when compared to scores from alkaline rivers in other parts of South Africa. It is concluded that a guideline for unpolluted acid, brown water is that SASS4 should exceed 125 and ASPT should exceed 7.

Polluted acid, brown water streams were not found, so it was impossible to derive guideline SASS4 scores and ASPT for degrees of severity of water quality change in the acid streams. However, it is probable that pollution of acid brown waters results in increases in pH to the alkaline range, in which case SASS4 scores and ASPT should be expected to behave as they would in polluted alkaline streams.

ACKNOWLEDGEMENTS

Staff of the Port Elizabeth Regional Office of the Department of Water Affairs accompanied the Project Leader to the Kleinbos and Keurbooms sites during a preliminary visit to the area made in August 1993. Ms A C Uys, Institute for Water Research, Rhodes University, assisted in the field work in this area. I greatly appreciate the help of the Department and of Ms Uys. Ms H Dallas provided information on mountains streams in the Karoo and Dr F C de Moor sampled in the Baviaanskloof.

1. INTRODUCTION

The streams of the southern Cape lie in an area in which there is year-round rainfall. They fall into two biological groups (Harrison & Agnew 1962) associated with the pH of the stream water. The invertebrate fauna of the strongly acid (pH < 6), brown water streams draining Table Mountain Sandstone includes many endemic species with Gondwanaland associations. In clear water, slightly acid (pH 6 to 6.9) streams, which were sometimes physically close to acid, brown water streams, only one or two species associated with Table Mountain Sandstone were found. In these streams and in alkaline streams which were usually inland from the coastal range, the invertebrate fauna was similar to that found in alkaline streams in the remainder of South Africa, given that there are longitudinal changes in the species composition of most streams.

Harrison and Agnew pointed out that the endemic fauna of the south Cape acid, brown water streams is also found in the Western Cape in association with streams draining Table Mountain Sandstone. The SASS scores in the Western Cape are the subject of Appendix H.

Against this zoogeographical backdrop it was expected that modifications to the SASS scoring system might be required. Indeed, this proved to be the case and several of the taxa included in SASS4 are found only or mainly in the southern and western Cape. In addition it was necessary to test suitability for these areas of guideline values for the interpretation of SASS4 developed in other parts of the country.

The studies conducted under the auspices of the Water research Commission contract have been augmented by additional data kindly made available by Helen Dallas of the University of Cape Town on four Karoo streams. Mandy Uys (Institute for Freshwater Studies, Rhodes University) helped with the sampling of streams in the southern Cape, while Ferdi de Moor (Albany Museum, Grahamstown) measured SASS in streams of the Baviaanskloof area.

2. RESULTS

The study area reported here stretched from approximately Humansdorp in the east to the Gouritz River west of Mossel Bay (**Table 1**). Acid brown water streams, slightly acid clear water streams and alkaline streams were sampled. It is reported with pleasure that the major weakness in the data base for this area is that there were too few acid streams, in which there was reason to believe that water quality was impaired, to allow for the recording of the response of the acid stream fauna to water quality change. The only water quality data available from this area is the field pH and conductivity measurements made of project visits, though there is circumstantial evidence of water quality change in some alkaline streams.

Table 1: Sampling points in the Southern Cape

Site	Longitude	Latitude	Description	Data in Table:
Bloukrans	23 38 17 E	33 57 15 S	Upstream of flow weir in Pass	2
Elands	24 03 04 E	33 58 52 S	Where crossed by national road	2
Silver	22 33 52 E	33 57 50 S	Inland Knysna/George road	2
Duiwe	22 53 33 E	33 51 29 S	Upstream of sawmill	2
Kaaimans	22 32 16 E	33 57 36 S	Inland Knysna/George road	2
Homtini	22 55 11 E	33 55 52 S	Inland Knysna/George road	2
Karatara	22 51 14 E	33 55 18 S	Inland Knysna/George road	2
Hoogekraal	22 46 45 E	33 55 32 S	Inland Knysna/George road	2
Touws	22 37 06 E	33 56 45 S	Inland Knysna/George road	2
Sout	22 45 48 E	34 01 13 S	"behind Knysna"	3
Diep	22 41 54 E	33 56 21 S	Inland Knysna/George road	3
Swart	22 32 06 E	33 57 26 S	Coastal Knysna/George road	3
Kleinbrak 1	22 01 27 E	34 03 47 S	Robinson Pass	3
Kleinbrak 2	22 03 33 E	33 56 13 S	below weir	3
Langtou	21 46 58 E	33 58 37 S	Upstream of Herbertsdale	3
Gouritz	21 45 54 E	34 04 57 S	Downstream of Herbertsdale	3
Keurbooms 1	23 10 00 E	33 48 15 S	Inland, upstream of trout farm	4
Keurbooms 2	23 10 48 E	33 48 55 S	Inland, opposite trout farm	4
Keurbooms 3	23 11 37 E	33 49 11 S	Downstream of trout farm 3 km	4
Keurbooms 4	23 22 44 E	33 56 29 S	At Plettenberg Bay water intake	4
Kleinbos 1	24 48 56 E	33 58 04 S	Upstream of sawmill	5
Kleinbos 2	24 49 04 E	33 58 28 S	Just downstream of sawmill	5
Kleinbos 3	24 49 05 E	33 58 33 S	150 m downstream of Kleinbos 2	5
Scholtzkloof			Karoo, Prince Albert area	6
Waterval			Karoo, Prince Albert area	6
Huis			Karoo, Prince Albert area	6
Dorps			Karoo, Prince Albert area	6
Baviaans 1	24 15 30 E	33 37 10 S	Near Geelhoutbos resort	7
Baviaans 2	24 16 12 E	33 37 16 S	Low water bridge	7
Geelhoutbos	24 14 42 E	33 38 09 S		7
Groot	24 36 50 E	33 41 50 S		7
Wit	24 32 03 E	33 39 26 S		7
Gamtoos	24 38 05 E	33 44 39 S		7

2.1 Acid brown water streams (Table 2).

During the present study pH levels recorded from the acid brown water streams of the southern Cape were lower than those reported by Harrison and Agnew. Results from acid brown water streams, in which there was no reason to suppose that there may have been water quality deterioration, are shown in **Table 2**. A feature of the SASS4 scores from these streams is that they were always high compared to scores from alkaline streams in the more northern parts of the country and ASPT was also high (consistently above 7).

2.2 Mildly acid to alkaline clear water streams (Table 3)

Sampling points shown in **Table 3** are not all from streams with a natural water quality. The Sout River rises in an informal settlement to the north of Knysna. The sampling point on the Swart River was where it is crossed by the national road from George to the Wilderness, that is a little distance downstream of the Garden Route Dam. In both these cases SASS4 scores and ASPT values were low.

The Diep River lies on the boundary between acid brown water and mildly acid clear water conditions. The SASS4 score was high and ASPT was 6.9. Kleinbrak 1 was a small foothill stream with SASS4 and ASPT within the range recorded in natural alkaline streams. From the SASS4 scores and ASPT, Kleinbrak 2 would be classified as water quality definitely impacted (a full suite of habitats was sampled). Unfortunately, there is no known reason for the poor scores and the Project Leader is not sufficiently familiar with the site to know whether it is on a perennial river.

The Langtou River had a very low flow when it was sampled, but scores were higher than they were at Kleinbrak 2. In addition red-fin minnows were present which implies that if the river does stop flowing it does not dry up completely. Scores were also low in the Gouritz River, but at the point sampled the habitats were poor - no stones in current, scrappy fringing vegetation. Nevertheless the recorded SASS4/ASPT combination indicated some deterioration in water quality. The conductivity in this river was 133 mSm^{-1}, which implies that the TDS was probably of the order 900 to 1000 $m g\ell^{-1}$.

2.3 The Keurbooms River (Table 4)

The Keurbooms River rises relatively far inland and is initially a mildly acid, clear water stream. It was sampled upstream and downstream of a trout hatchery and then near the coast

Table 2: SASS4 data from sampling points on acid, brown water streams in the southern Cape. See **Table 1** for sampling localities.

Site	Bloukrans	Elands	Silver	Duiwe	Kaaimans	Homtini	Karatara	Hoogekraal	Touws
Date	Aug 93	Nov 93	Nov 93	Nov 93	Nov 93	Nov 93	Nov 93	Nov 93	Nov 93
pH	4.1	4.5	4.3	4.9	4.5	4.7	4.5	4.4	4.8
SASS4	187	173	168	194	182	163	160	121	167
# taxa	22	19	19	23	20	18	19	15	23
ASPT	8.5	9.1	8.8	8.4	9.1	9.1	8.4	8.1	7.3

Table 3: SASS4 data from sampling points on weakly acid and alkaline streams in the southern Cape. See **Table 1** for sampling localities.

Site	Sout	Diep 1	Swart	Kleinbrak 1	Kleinbrak 2	Langtou	Gouritz
Date	Nov 93	Nov 93	Nov 93	Nov 93	Nov 93	Nov 93	Nov 93
pH	7.1	5.7	6.6	6.8	6.7	6.8	7.5
SASS4	88	196	51	169	83	129	86
# taxa	19	28	10	24	17	24	17
ASPT	4.6	7.0	5.1	7.0	4.9	5.4	5.1

(Keurbooms 4), where it has received a large amount of acid brown water from the coastal streams. As may be seen in **Table 4** the pH dropped between Keurbooms 3 and 4.

The trout hatchery was inactive at the time of the sampling visit, for it is a hatchery and not a farm where trout are grown out. The maximum water demand in such an activity occurs in the early winter when the fry hatch and are raised to a suitable stage to be delivered to the trout farms. As may be seen in **Table 4**, SASS4 scores and particularly ASPT at the mildly acid sampling points above and below the hatchery were lower than those recorded at the acid brown water sampling points (**Table 2**). They were in the ranges to be expected in alkaline streams of natural water quality in other parts of the country. At Keurbooms 5 there was a marked increase in ASPT to a level similar to that found in other brown water streams.

Table 4: SASS4 data from sampling points in the Keurbooms River. See **Table 1** for sampling localities.

Site	Keurbooms 1	Keurbooms 2	Keurbooms 3	Keurbooms 4
Date	Aug 93	Aug 93	Aug 93	Aug 93
pH	6.1	6.1	6.3	5.5
SASS4	108	183	173	149
# taxa	16	28	28	18
ASPT	6.8	6.5	6.2	8.3

The variation in SASS4 and particularly in ASPT in the Keurbooms River confirms that higher scores occur in the acid brown water streams than in mildly acid to alkaline streams.

2.4 The Kleinbos River (Table 5)

The Kleinbos River was sampled upstream and downstream of a sawmill and timber processing factory where poles are treated with preservatives. The stream is an acid brown water stream with an extremely low pH upstream of the factory. As the water passed the factory the pH rose, but remained acid. SASS4 scores fell downstream of the factory, as did ASPT. Nevertheless, both SASS4 scores and ASPT remained in ranges where it would be difficult to argue that the factory had an impact on water quality. Water samples collected by the regional office of the Department of Water Affairs and Forestry on the first visit to the Kleinbos River, showed a very slight increase in the ammonia content of the water downstream of the factory, but no changes in the concentrations of other determinands.

Table 5: SASS4 data from sampling points in the Kleinbos River. See **Table 1** for sampling localities.

Site	Site 1	Site 1	Site 2	Site 2	Site 3
Date	Aug 93	Nov 93	Aug 93	Nov 93	Nov 93
pH	3.7	3.9	5.4	4.7	4.7
SASS4	180	190	149	141	112
# taxa	21	21	19	18	14
ASPT	8.6	9.0	7.8	7.8	8.0

2.5 Mountain streams in the Karoo (Table 6)

Ms Helen Dallas provided results of sampling four mountain streams in the Karoo. Her data are shown in **Table 6**. The pH of three of the streams lay between 6.5 and 6.7, that is within the range of what have been considered biologically neutral to alkaline streams. The fourth stream (Dorps) had a pH of 5.7 and therefore fell into the acid stream category. SASS4 scores and ASPT in the Dorps stream were similar to those of other acid streams.

The range of variation of pH in the Scholtzkloof, Waterval and Huis streams was narrow (6.5 to 6.7, **Table 6**). Although SASS4 scores were near or just below 100 in the Scholtzkloof and Waterval streams, ASPT was so high that both these streams must be regarded as unimpacted. SASS4 score in the Huis stream was very high, although the ASPT was similar to that of the Scholtzkloof and Waterval streams.

Table 6: SASS4 data from sampling points in the Karoo. See **Table 1** for sampling localities.

Site	Scholtzkloof	Waterval	Huis	Dorps
Date	30/11/93	3/12/93	2/12/93	3/12/93
Description	unimpacted mountain stream	below waterfall on Meiringspoort road	unimpacted mountain stream	relatively unimpacted stream at foot of Swartberg Pass
pH	6.5	6.5	6.7	5.7
SASS4	102	94	176	163
# taxa	13	12	23	15
ASPT	7.8	7.8	7.7	10.9

The SASS4 results from these Karoo streams suggest that they would respond to changes in water quality in a manner similar to the changes which take place in other parts of the country where waters have a pH greater than 6.

2.6 Streams in the Baviaanskloof (Table 7)

The pH at all the sites sampled in the Baviaanskloof, which is an inland area to the west of Port Elizabeth, were mildly acid to alkaline. As can be seen in **Table 7**, taking account of the footnotes on missing habitats, SASS4 scores and ASPT values were similar to the range of scores and values found in unpolluted streams in other parts of the country.

Table 7: SASS4 data from sampling points in the Baviaanskloof. See **Table 1** for sampling localities.

Site	Baviaans 1	Baviaans 2	Geelhoutbos	Groot	Wit	Gamtoos
Date	28/2/94	28/2/94	1/3/94	26/2/94	27/2/94	27/2/94
pH	8.2	6.7	6.4	8.4	6.4	7.8
SASS4	93*	141	147	134	142	87**
# taxa	15	23	21	20	21	17
ASPT	6.2	6.1	7.0	6.7	6.8	5.1

* Only stones in current sampled.
** No stones in current or marginal vegetation.

3. DISCUSSION

The data from the southern Cape show that the SASS4 scores and ASPT values measured in unpolluted acid brown water streams are higher than those in unpolluted mildly acid to alkaline clear water streams. The Keurbooms River in which the mildly acid conditions became acid nearer the coast, vividly illustrated the difference in the scores, particularly in the ASPT, likely to be recorded in acid and other streams.

Considering the scores reported from acid brown water streams, it would appear that in unpolluted conditions the ASPT score exceeds 7, and the SASS4 score usually above 125. There is a problem in assessing the impact of water quality changes on acid brown water streams, for no streams of this nature in which definite pollution occurred could be found. It is not unlikely that pollution of an acid stream would result in increase of the pH into the mildly acid to alkaline range, in which case the fauna would be expected to change into a typical alkaline water assemblage, showing the changes in SASS4 and ASPT reported earlier in Appendices A to F. This might indeed be what has happened in the Swart River below the Garden Route Dam, for from the colour of the surface water in the dam, the Swart River upstream of the dam is probably an acid, brown water stream.

4. CONCLUSIONS

SASS4 scores and ASPT values in natural acid, brown water streams do differ from those in mildly acid to alkaline streams. The scores in waters in the mildly acid range (pH 6.0 to 6.9) are similar to those in the alkaline range (pH >7).

No streams were found in which pH remained acid with water pollution, so that it is not possible to set complete guidelines for the assessment of water quality from SASS4 scores in acid brown water streams. However from the scores recorded in the southern Cape it would appear that SASS4 scores in excess of 125 and ASPT in excess of 7 are to be associated with undisturbed acid brown water streams.

5. REFERENCES

Harrison, A D & J D Agnew 1962 The distribution of invertebrates endemic to acid streams in the Western and Southern Cape Province. Annals of the Cape Provincial Museums **2**: 273-291

Appendix H

SASS assessment of the condition of streams and rivers in the Western Cape

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SASS4 scores and ASPT values were measured in a wide range of streams and rivers in the western Cape. Polluted and unpolluted mountain and foothill rivers were sampled. In this winter rainfall area all sampling was undertaken in the summer, low flow period.

SASS4 scores and ASPT values in naturally acid (pH <6) unpolluted streams and rivers were found to be similar to those recorded in the southern Cape acid, brown water streams. These scores were slightly higher than scores from mildly acid to alkaline (pH >6) streams, so that guideline values of SASS4 and ASPT had to be adjusted upwards from the values arrived at from mildly acid to alkaline streams. The acid stream guideline values are as follows (with the equivalent alkaline stream values in parenthesis):

Unpolluted	SASS4 125 (100)	ASPT >7 (>6)
Slight to moderate pollution	SASS4 125-60 (100-50)	ASPT <7 (<6)
Moderate to severe pollution	SASS4 60-0 (50-)	ASPT unreliable

SASS4 results from the western Cape confirm that this method of assessing water quality is sensitive to water quality changes due to trout farms (Kraalstroom), to urban and industrial effluent (Eerste River and Plankenberg stream) and to dams (Palmiet River) and that the method responds to water quality changes in both acid and alkaline waters. Results from streams which are no longer perennial suggested that the above guidelines for the interpretation of SASS4 apply only to streams with permanent flow.

ACKNOWLEDGEMENTS

It is a pleasure to acknowledge the help and interest of Helen Dallas in this work. After accompanying the Project Leader on the first preliminary sampling visit, she faithfully collected samples over the ensuing summer and provided data on a number of sampling points which were not included in the original sampling programme.

1. INTRODUCTION

The Western Cape is a winter rainfall area. This means that the data gathering for testing SASS was undertaken in the summer. However, winter rainfall also means that the rainfall does not coincide with the agricultural growing season. This has major consequences for the manner in which the rivers are used and the flows managed and for river water quality. The single field trip which the project leader undertook in November 1993 left him with the impression that there were no lowland (as opposed to mountain) streams and rivers in which there would be end of summer flows, unless they were sustained by releases from dams or from effluent treatment plants. It is questionable whether there are perennial streams and rivers in the Western Cape which are unpolluted after they leave the mountains.

Streams and rivers in the Western Cape are similar to those in the southern Cape (Appendix G) in that some are acid, brown water and others are mildly acid to alkaline. The acid, brown water streams have invertebrate faunas which are similar to those found in the southern Cape. Harrison & Elsworth (1958) showed that the so-called Cape endemic fauna was limited to acid streams and that as soon as the water became neutral or alkaline, a fauna similar to that in other parts of South Africa appeared. This change was vividly illustrated in the faunal differences between the upper and lower Great Berg river.

The studies conducted under the auspices of the Water Research Commission contract have been augmented by additional data kindly made available by Helen Dallas of the University of Cape Town. Much of this data has appeared in Dallas 1995, and in Dallas, Day and Reynolds (1994). After the first visit to the study area, all the sampling and sample analysis was carried out by Miss Dallas.

Study sites were chosen with a view to collecting data from a range of sites in which there had been varying degrees of water quality change.

2. RESULTS

As may be seen from the length of the lists of sampling points (**Tables 1 & 2**), the number of sites sampled in the Western Cape was large. In contrast to the southern Cape, there were many streams and rivers in which there were large water quality changes.

Table 1: Sampling points in the Western Cape.

Site code	River	Location	pH	Longitude	Latitude	1:50 000 sheet
A1	Kraalstroom	Mountain stream: above trout farm	6.0-6.9	19 08	36 46	3319CC
B1	Kraalstroom	Immediately below trout farm effluent	5.4-6.0	19 08	36 46	3319CC
B2	Kraalstroom	50 m below trout farm effluent	5.6-5.9	19 08	36 46	3319CC
B3	Kraalstroom	250 m below trout farm effluent	5.9-6.1	19 08	36 46	3319CC
B4	Kraalstroom	500 m below trout farm effluent	6.1-6.4	19 08	36 46	3319CC
B5	Kraalstroom	1000 m below trout farm effluent	6.0-6.1	19 08	36 46	3319CC
MOL1	Molenaars	Du Toits Pass, above bridge construction	5.0-6.1	19 11	33 43	3319CA
MOL2	Molenaars	Du Toits Pass, below bridge construction	5.5-6.4	19 11	33 43	3319CA
JFB	Great Berg	Above Jim Fouche Bridge, stony foothill zone	6.2-6.5	19 02	33 52	3319CC
DJT	Great Berg	Daljasophat, below Paarl sewage works	6.3-6.7	18 53	33 42	3318DB
PKB	Great Berg	Piketberg Road Bridge (Malmesbury shales)	7.3-8.5	18 45	32 58	3318DB
T24	Twenty-four	Halfmanshof road bridge	7.7-8.9	18 56	33 10	3318BB
EERS1	Eerste	Jonkershoek valley, mountain stream	5.5-5.6	18 56	33 58	3318DD
EERS2	Eerste	Below Stellenbosch, above sewage works	6.6-8.0	18 50	33 56	3318DD
EERS3	Eerste	Below Stellenbosch sewage works	7.0-7.9	18 48	33 58	3318DD
PLANK	Plankenberg	Below Stellenbosch industrial area	6.4-6.8	18 49	33 57	3318DD
OLIF1	Olifants	Algeria Causeway	6.3	18 57	32 22	3218BD
ROND	Rondegat	Above Algeria Campsite, Cederberg	5.3	19 03	32 22	3219AC
MATJ	Matjies	Sand drift, Cederberg	4.7	19 16	32 29	3219AD
BRAND	Brandkraals	Cederberg	4.9	19 22	32 34	3219CB
GROOT	Groot	Cederberg	4.9	19 25	32 39	3219CB
PALM1	Palmiet	Headwaters upstream of impacts	4.2-4.6	19 03	34 02	3419AA
PALM2	Palmiet	Below Nuweberg Dam	4.5-4.8	19 03	34 05	3419AA
PALM3	Palmiet	Below Kogelberg Dam	6.3-7.0	18 59	34 13	3418BB
PALM4	Palmiet	Lower reaches in Kogelberg State Forest	5.8-6.6	18 58	34 19	3418BB
EPD	Elandspad	Unimpacted mountain stream - joined by Kraalstroom	5.8	19 07	33.46	3319BA
LNG	Lang	Unimpacted mountain stream - Trib. of Eerste R.	5.5	18 58	33 59	3318DD
PKF	Perdekloof	Unimpacted mountain stream - Trib. of Du Toits R.	4.3	19 09	33 53	3319BA

2.1 The Kraalstroom, a mountain stream impacted by a trout farm

There is a trout farm in the mountain catchment of the Kraalstroom, in which trout are held over the summer. As the flow of the river drops during the summer dry season a greater and greater proportion of the river flow is diverted through the farm. The entire stream flow may be diverted. The consequence is a large organic load on the stream below the farm.

The recorded pH values in the Kraalstroom (**Table 1**) varied about pH 6, which in the southern Cape rivers was regarded as the critical level for separation of acid, brown water streams and mildly acid to alkaline streams. In view of the apparently irrational manner in which the recorded pH values fluctuated along the stream, it is appropriate to examine the recorded fauna in deciding whether or not the stream should be regarded as acid or mildly acid to alkaline. The consistent presence of Notonemouridae, Ephemerellidae, Corydaliidae and Helodidae (all acid water families) at Site A1 indicates that the stream upstream of the trout farm was biologically an acid stream.

Figure 1 shows that the ASPT at Site A1 was consistently greater than 7 and on all occasions after the first visit the SASS4 score was greater than 125. Following the criteria established for unimpaired water quality in acid streams of the southern Cape, the SASS4 assessment of the Kraalstroom above the trout farm is that water quality is natural there. As may be seen in **Figure 1** the trout farm had a major impact on the stream fauna which rapidly recovered, but not to its original condition, over a distance of one kilometre. Careful examination of **Figure 1** reveals that at sites B1, B2 and B3 there were many occasions when the SASS4 score was less than 50. As found in earlier appendices, low SASS4 scores were associated with erratic ASPT values. This is illustrated in the February 1994 ASPT values in the Kraalstroom.

The rapid recovery of the stream is to be expected as the pollution of the river was due to a readily decomposed organic load of fish faeces and unconsumed trout food. The stream is particularly steep at the trout farm and the rate of aeration of the water is therefore high.

2.2 The Molenaars River upstream and downstream of bridge construction

The pH of the Molenaars River ranged between 5 and 6.4 (**Table 1**) and the invertebrates included taxa typical of acid waters. Both upstream and downstream of the bridge site most SASS4 results were SASS4 > 125 and ASPT > 7 (**Figure 2**). There were no large consistent changes in SASS4 scores or in ASPT between the two sites. It can only be concluded that the bridge construction activity had minimal impact on SASS scores.

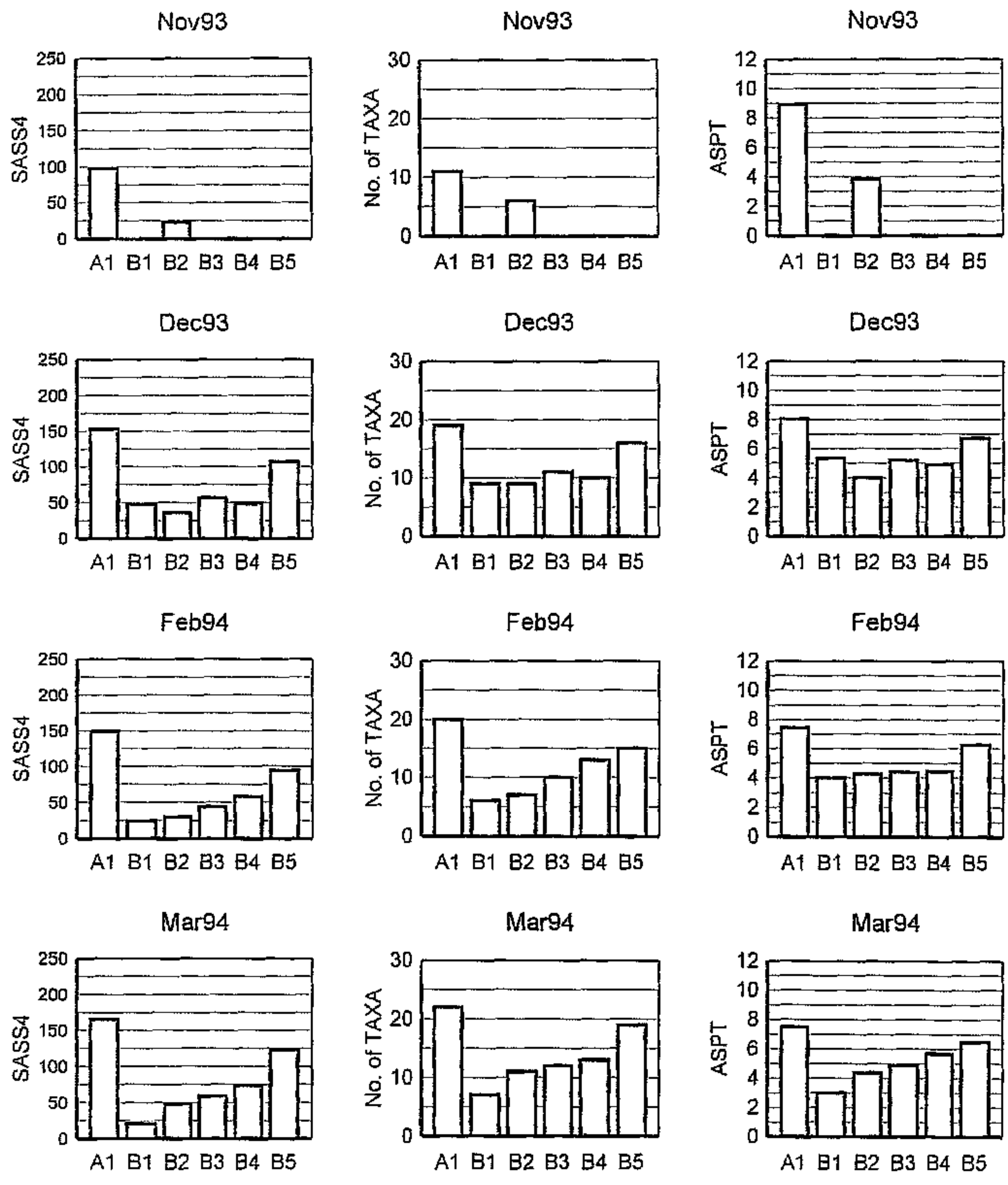

Figure 1: SASS4 scores, numbers of taxa and ASPT in the Kraalstroom

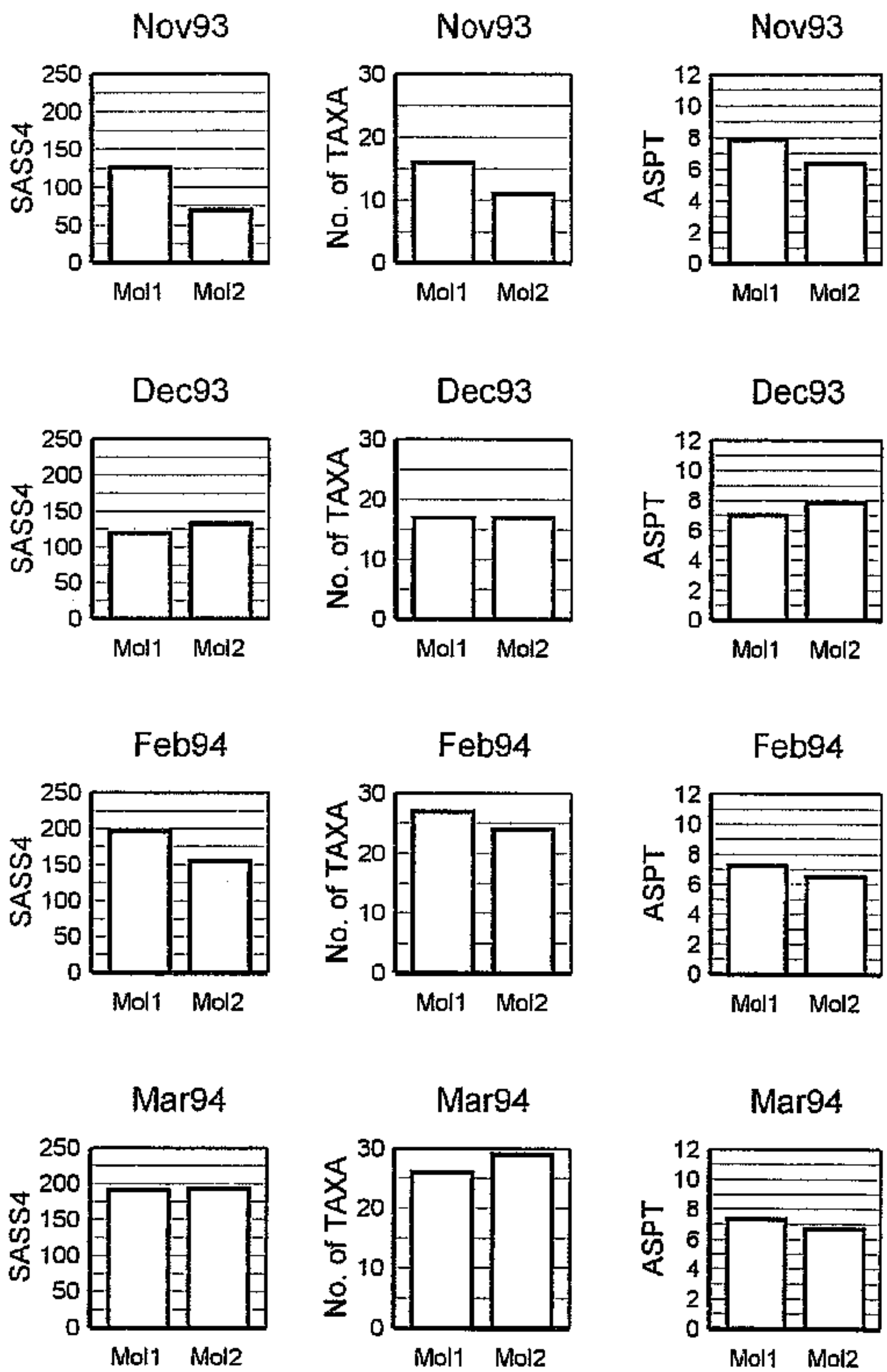

Figure 2: SASS4 scores, numbers of taxa and ASPT in the Molenaars River

2.3 The Twenty-four Rivers

The Twenty-four Rivers sampling point was sampled three times during the study period. The stream is alkaline (**Table 1**) and ceases flowing towards the end of the summer. The pH of this river rose over the study period from 7.7 (November) to 8.1 (December) to 8.9 (February). The SASS4 data (**Figure 3**) reveal that in November scores indicated a clean water alkaline stream (SASS4 >100, ASPT >6). As the summer progressed through December and January the SASS4 score and the ASPT also both declined. It is possible that the decline in SASS4 scores and ASPT over the study period was due to the change in pH. Certainly families which were not found after November included the Notonemouridae and 2 caddis families which are far more frequently found in acid waters than in alkaline. The fact that the flow was minimal by February cannot be ignored in attempting to find a reason for the decline in the SASS4 and ASPT scores.

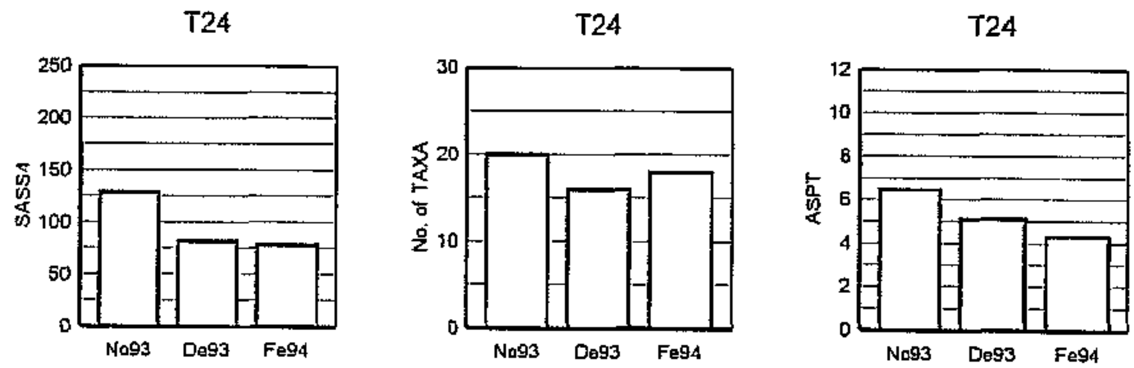

Figure 3: SASS4 scores, numbers of taxa and ASPT in the Twenty-four River

2.4 The Eerste River, urban and industrial pollution

The Eerste River rises in a protected area upstream of Jonkershoek. It soon passes through Stellenbosch, where it receives urban run-off, treated effluent and the highly polluted Plankenberg stream. At site Eers1 the stream was acid (**Table 1**) and supported an invertebrate community which had a very high SASS4 score (up to about 213) and an ASPT which was always high and rose to 10 in one sample (**Figure 4**). The water quality was unimpaired at site Eers1. From Eers2 downstream, the Eerste River was alkaline (**Table 1**). SASS4 scores and ASPT declined by about 50% below Stellenbosch and declined even further downstream of the inflow of the town's sewage works effluent. The Plankenberg stream was one of the most severely polluted streams (as assessed from its invertebrate fauna) encountered in the entire country. As has been found in many other polluted streams the behaviour of ASPT tended to become erratic, when SASS4 was less than 50.

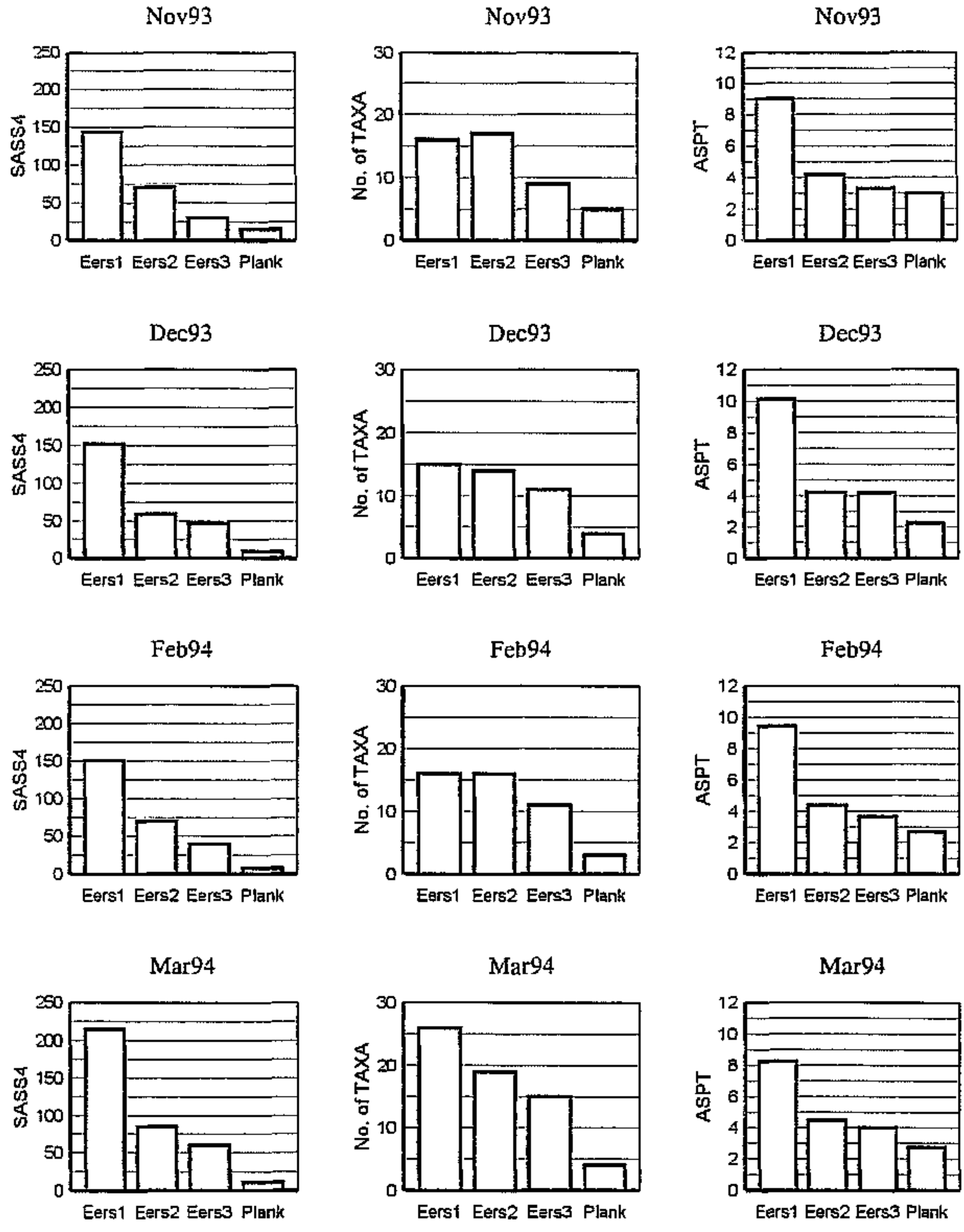

Figure 4: SASS4 scores, numbers of taxa and ASPT in the Eerste River and its tributary the Plankenberg stream

2.5 The Palmiet River, impacted by intensive agriculture and dams

The Palmiet River headwaters and downstream to below Nuweberg Dam were acid (**Table 1**). Both the Nuweberg Dam and the Kogelberg Dam have deep water release points, which means that hypolimnetic water is released at all times other than when the dams are spilling. The water below Kogelberg Dam was mildly acid, but the pH declined a little at the lowermost sampling point. Between Palm3 and Palm4 the river flows though an extensive area of natural vegetation, known as the Kogelberg State Forest.

Both Sites Palm2 and Palm3 were close (< 1 km) to the dams upstream and were probably at times exposed to poor quality hypolimnetic water. The SASS4 scores and ASPT reveal that the dams had a major impact on the stream invertebrates (**Figure 5**), with SASS4 scores below 50 frequently being recorded at sites Palm2 and Palm3. Habitat diversity was lower at Palm3 than elsewhere in that there was no fringing vegetation habitat. However, the fauna was so poor at this point that the absence of this habitat was unlikely to have raised the SASS4 score to levels where a different interpretation of the result would have been made.

Results from Palm1, where SASS4 was >125 and ASPT >7 at all times, were typical of unpolluted acid water sites. The river recovered considerably between Palm3 and Palm4. Although Palm4 scores were not as high as they had been at Palm1, at most times they were above or very near the guideline values (SASS4 >125, ASPT >7) for natural waters.

In **Figure 5** there are instances of relatively high ASPT associated with very low SASS4 scores, for example Palm2 in November and Palm3 in March.

2.6 Streams in the Cederberg

Of the five streams sampled in the Cederberg, only the Olifants River at the Algeria Causeway was mildly acid (**Table 1**). All habitats were sampled at all sites. Algal growth was recorded at sites Matj and Groot, possibly indicative of some nutrient enrichment.

SASS4 scores and ASPT in the Rondegat and Brandkraal Rivers were above 125 and 7 respectively (**Figure 6**), confirming the assumption made when they were chosen for sampling that water quality was unimpaired. Scores in the other rivers were lower than would be associated with unimpaired water quality. The water quality data required to test this conclusion does not exist though, as mentioned above, algal growth at Sites Matj and Groot was indicative of nutrient enrichment.

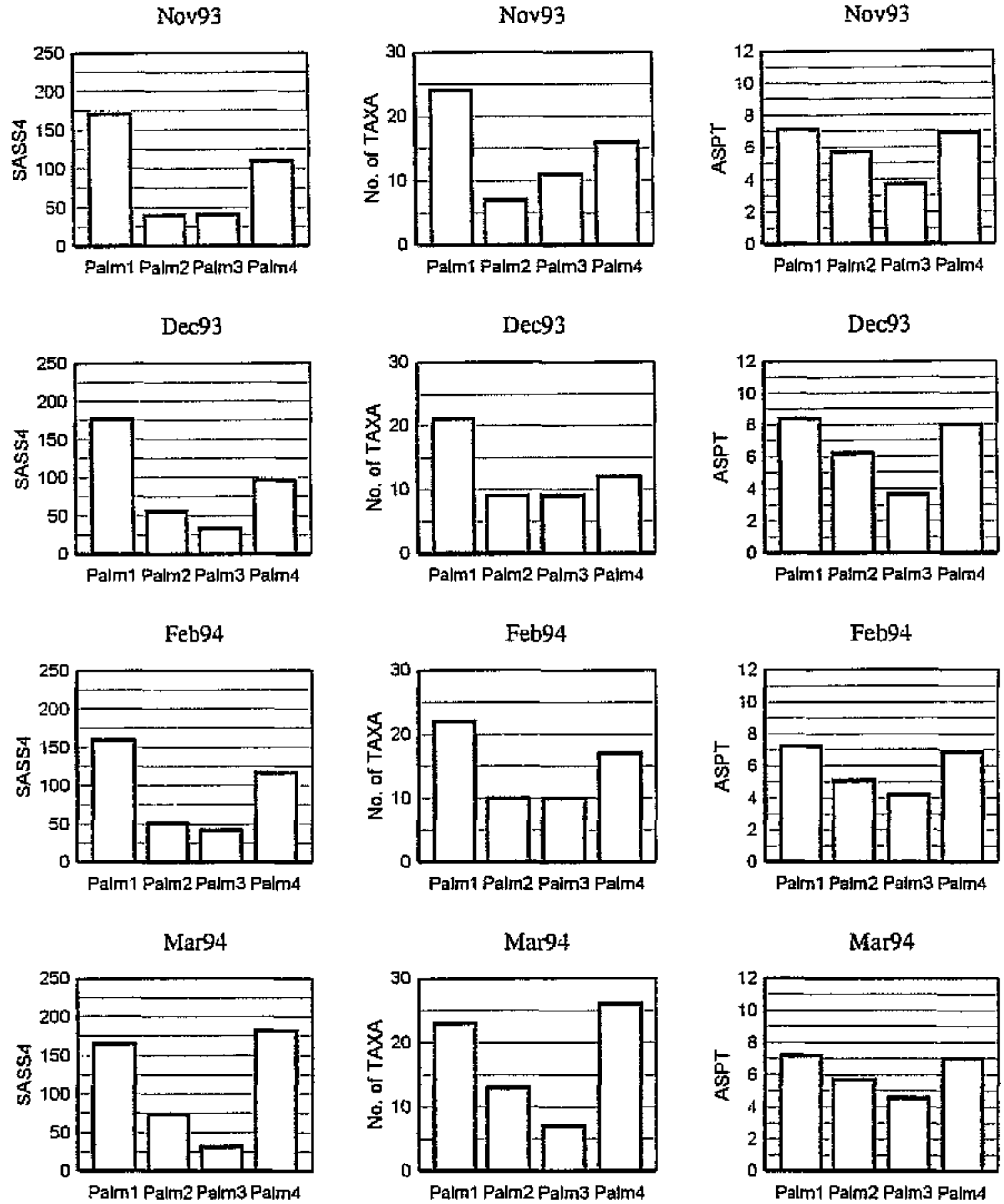

Figure 5: SASS4 scores, numbers of taxa and ASPT in the Palmiet River

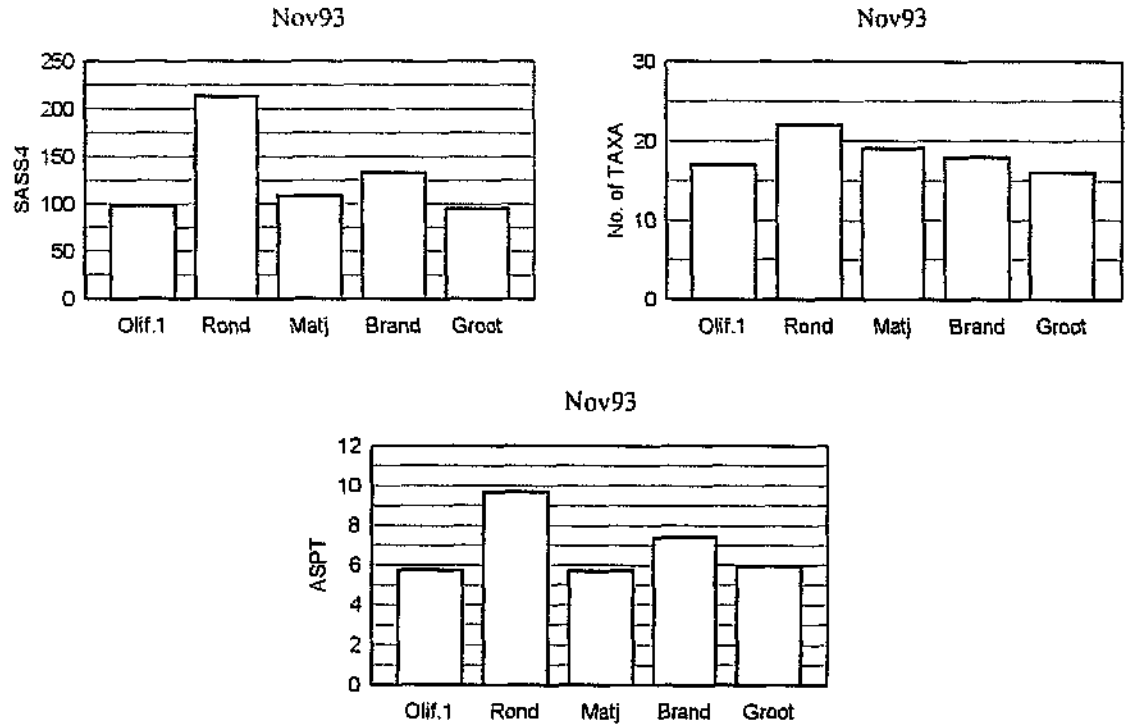

Figure 6: SASS4 scores, numbers of taxa and ASPT in streams and rivers in the Cederberg

2.7 Unimpacted Mountain streams

The pH of the three mountain streams was acid, and was lower in the Perdekloof than in the other two streams (**Table 1**).

The Lang River differed from the others in that the tree canopy closed over the channel, so that there was no fringing vegetation to sample. This meant that habitat diversity was less in the Lang River than at the other two sites.

At all three sites ASPT was approximately 8 (**Figure 7**). SASS4 was lower at site LNG than at the other two sites, doubtlessly due to the lesser habitat diversity there. Site EPD had one of the highest SASS4 scores recorded anywhere. The SASS data from these three sites confirms that where a full complement of habitats is available to sample in naturally acid, unpolluted, streams in the western Cape mountains, SASS4 will exceed 125 and ASPT 7. The results also confirm a finding made in many other parts of the country - a missing habitat such as stones in the current or marginal vegetation in a stream with unimpaired water quality results in a low sample score, but ASPT is unaffected.

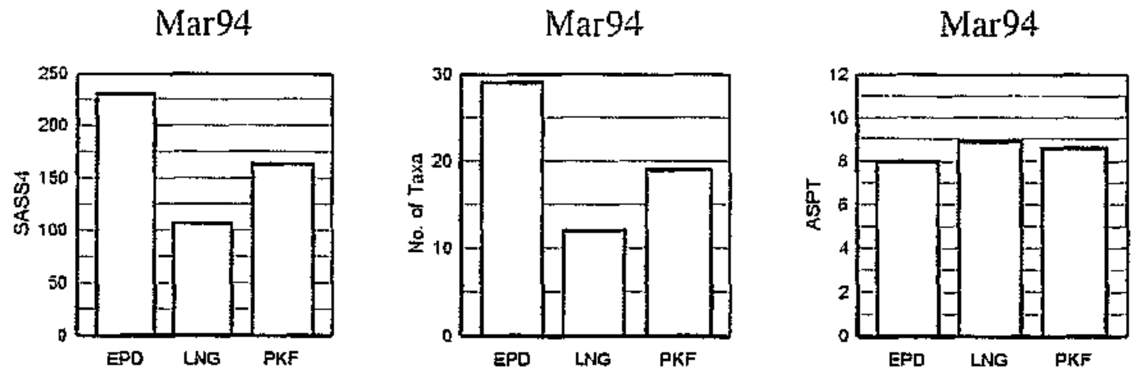

Figure 7: SASS4 scores, numbers of taxa and ASPT in unimpacted mountain streams in the western Cape.

2.8 Three sites on the Great Berg River

At all three sampling points the Great Berg River was mildly acid to alkaline (**Table 1**). In November, December and February there was no marginal vegetation to sample at site JFB, but this habitat was available and sampled in March.

SASS scores for the sampling points are shown in **Figure 8**. At site JFB ASPT was always close to 6, but it was only in March when all habitats were available for sampling that SASS4 exceeded 100. The conclusion to be drawn from the SASS data at Site JFB is that water quality was not impaired for the invertebrates, though during the study reported by Dallas, Day and Reynolds (1994), it was suggested that JFB was a site where there was organic and nutrient enrichment.

The following site downstream from JFB, DJT was not sampled in November. It is below Paarl sewage works. SASS4 scores were between 50 and 100 and ASPT less than 6, indicating slight deterioration in water quality (see Appendices A and C).

At site PKB SASS4 scores were in the lower half of the intermediate water quality range (50 to 100). At the same time ASPT was mostly just in the unimpacted range (>6). This represents a small improvement in the quality of the water over that at DJT. There was nevertheless a low taxon diversity at PKB, for reasons which are obscure.

Other data from these three Great Berg River sampling points is included in Section 2.9 below.

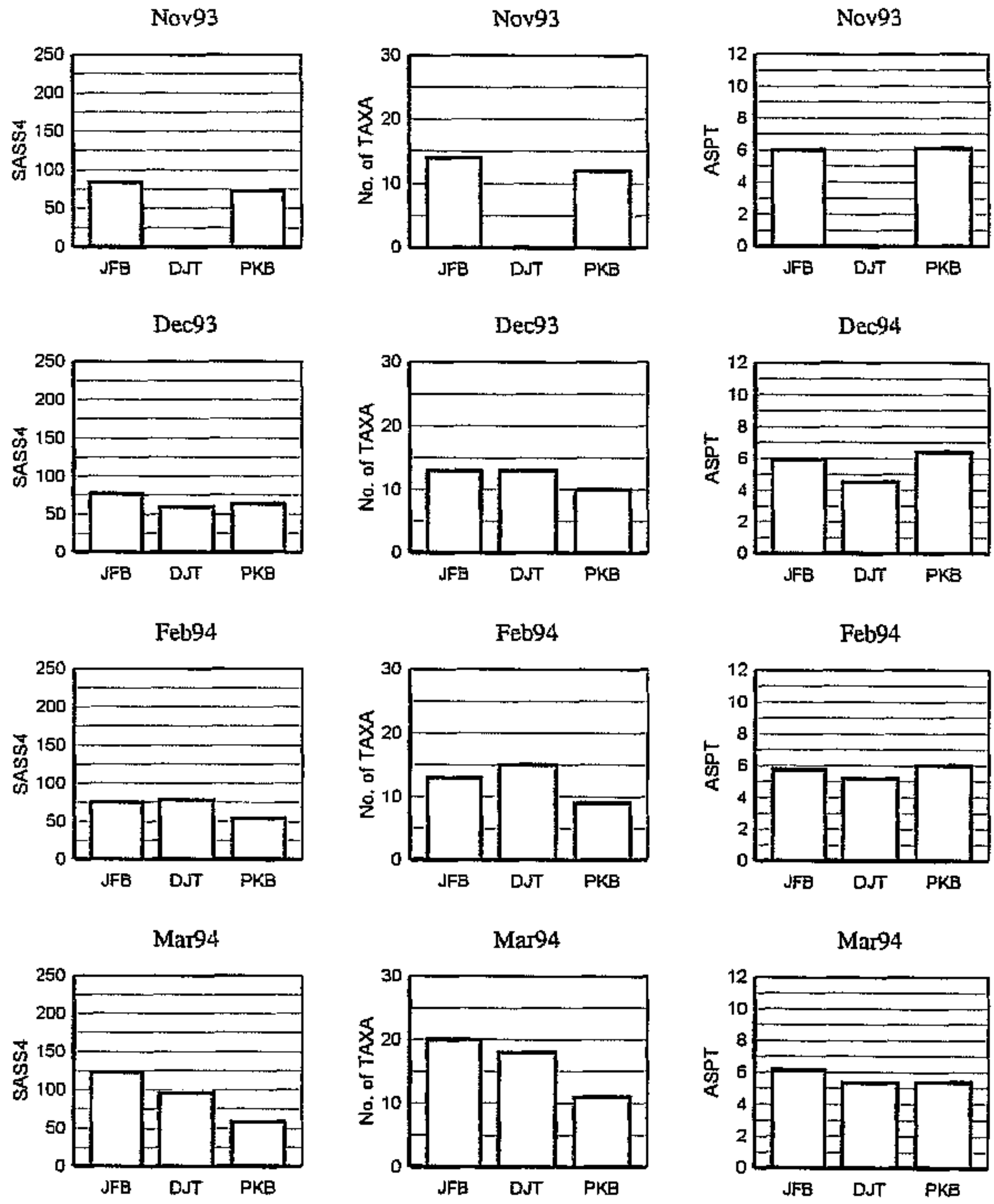

Figure 8: SASS4 scores, numbers of taxa and ASPT at three sites in the Great Berg River

2.9 An intensive study of the Great Berg River in September 1993

SASS scores were measured at sixteen sites along the Great Berg River in September 1993 (**Table 2**). The river water was acid at the uppermost three sites, followed by a single site where the pH was 6.5 and then by a site where it was 5.9 (BTF). From the next site, JFB (the same site as described in 2.8 above) downstream the river was mildly acid to alkaline.

SASS4 results are shown in **Figure 9**. As noted in the figure it was not possible to sample marginal vegetation and stones in current habitats at certain sampling points. Marginal vegetation habitats were missing from some sampling points in the upper reaches and stones in current from some sampling points in the lower reaches. SASS4 scores from sampling points where habitats were missing were undoubtedly lower than those where all habitats were found.

From the uppermost sampling point down as far as point JFB, SASS4 scores were higher than downstream and ASPT was unusually high (8 and upwards). Despite the fact that some SASS4 scores were lower than 125 (acid waters, pH $<$ 6) and 100 (weakly acid to alkaline waters, pH $>$ 6) upstream of JFB, the very high ASPT scores show that water quality was unimpaired at this time at these sampling points.

At the next two sampling points (CDR and DJT) SASS4 scores and ASPT suggest a poor water quality, scores being below 30. In these circumstances little weight should be given to ASPT, as concluded from results from sites with very poor water quality (**Appendices A and C**). Regarding point DJT, the results of this September survey suggest a far greater deterioration in water quality than those reported in Section 2.8 above. There is no obvious reason why this should be so. It is therefore not possible to decide whether or not this is due to a weakness in the SASS4 method resulting in a spurious result, or alternatively to a change in water quality, perhaps due to seasonal events.

From site LLB downstream SASS4 scores at all the sampling points where there was no stones in current habitat were lower than scores where there were stones in current habitats. The absence of stones in current habitats had less impact on the site to variation in ASPT.

SASS4 scores and ASPT from station LLB to BRD were all in the range associated with some deterioration in water quality. It would appear from SASS4 results (taking account of the missing stones in current habitat at SNT) that water quality improved at sites PKB and SNT to the borderline between water quality natural and water quality slightly impaired. The results from PKB reported in Section 2.8, lead to a similar conclusion. Scores at KFN, the upper limit of salt water intrusion from the estuary, were so low that it is almost certain that the water quality was unsuited to a freshwater fauna.

Table 2: Sampling points used in the comprehensive study of the Great Berg River and its tributaries, September 1993 and the pH measured. Data provided by Ms H Dallas and subsequently used in Dallas, Day & Reynolds (1994, Appendix 6.2a) and in Dallas (1995, Appendix B).

Site name	Site description	River	Longitude	Latitude	pH
UBG	Upper Berg River, unimpacted	Berg	33 59	19 04	4.5
FOR	Below forestry operations	Berg	33 59	19 04	4.0
ABT	Above Theewaterskloof water transfer tunnel	Berg	33 57	19 04	4.4
BET	Below Theewaterskloof water transfer tunnel	Berg	33 54	19 03	6.5
BTF	Below Dewdale trout farm	Berg	33 54	19 03	5.9
JFB	Jim Fouche Bridge, below confluence of Franschhoek tributary	Berg	33 52	19 02	6.7
CDR	Cecilia's drift above Paarl	Berg	33 46	18 58	8.1
DJT	Daljasophat in Paarl, below sewage treatment works	Berg	33 42	18 53	6.6
LLB	Lady Loch Bridge below Wellington	Berg	33 38	18 58	6.6
HRM	Hermon road bridge	Berg	33 26	18 57	6.9
GOU	Road bridge at Goedverwag below Gouda	Berg	33 15	18 57	7.2
MAT	Below Drieheuwels Weir	Berg	33 08	18 52	7.2
BRD	Bridgetown farm	Berg	33 05	18 51	7.3
PKB	Below road bridge on N7 near Piketberg	Berg	32 58	18 45	8.1
SNT	Sanddrift farm	Berg	32 54	18 35	7.7
KFN	Kersefontein farm	Berg	32 54	18 20	7.7
ASS	Assegaaibos tributary	Assegaaibos	33 58	19 05	5.6
FTR	Franschhoek tributary	Franschhoek	33 54	19 06	7.2
WTR	Wemmers tributary at road bridge, below spillage dam	Wemmers	33 51	19 02	5.1
DWS	Dwars tributary at road bridge	Dwars	33 52	18 59	6.5
KUI	Kuils tributary at Maatjies river gauging weir	Kuils	33 03	18 50	7.9
SOU	Sout tributary	Sout	33 01	18 22	8.3
T24	Twenty-four River tributary below road bridge at Halfmanshof	Twenty-four	33 10	18 56	6.0
KRM	Krom tributary of Maatjes(kuils)	Krom	33 01	18 50	7.9

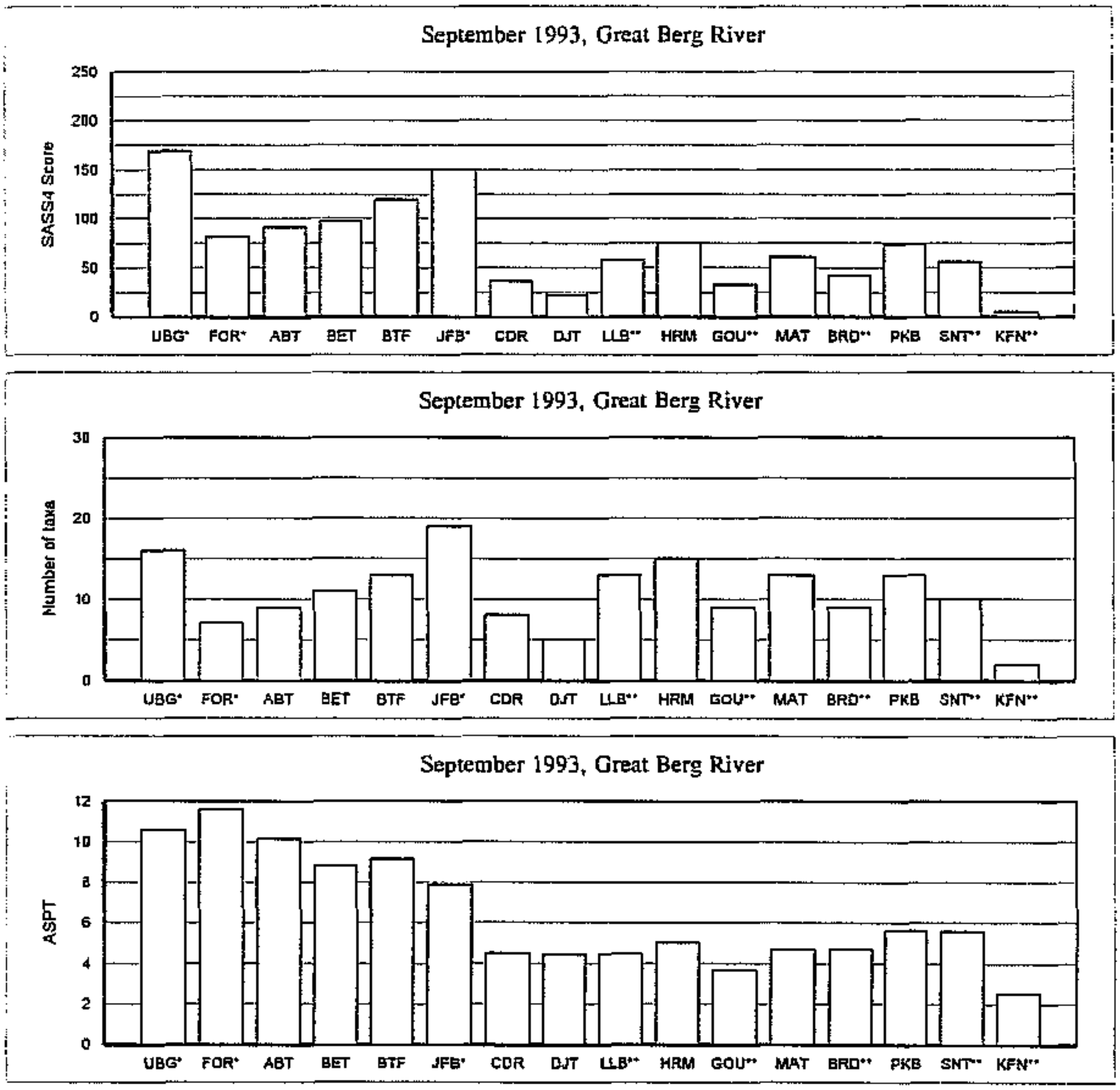

Figure 9: SASS4 scores, numbers of taxa and ASPT at sixteen sites on the Great Berg River in September 1993. Data courtesy of Ms H Dallas. * - no marginal vegetation, ** - no stones in current.

Dallas *et al* (1994) included water quality data for these sampling points in their Appendix 6.2e. There is little evidence of a large change in water quality between sampling point JFB and the next point downstream CDR. Nitrates increased from 0.56 $mg\ell^{-1}$ to 1.40 $mg\ell^{-1}$, suggesting that there was minor deterioration in water quality. Nitrate concentration continued to increase downstream to site LLB, was low at the following site and then increased again. TDS increased along down the course of the river. The available water quality data do not help to explain the changes in SASS4 scores, indicating perhaps the limitations of attempting to categorise water quality differences on the basis of single water samples.

2.10 Studies on Great Berg River tributaries in September 1993

Sampling points are shown in **Table 2**. A wide range of conditions, shown in **Table 3**, was recorded in the tributaries of the Berg River. The pH at sites ASS and WTR was less than 6, and greater than 6 at the remaining sites. The TDS, due to the catchment geology, was high at sites KUI, SOU and KRM. The nitrate concentration at site FRT was twice as high as in any other tributary, reflecting mild pollution of the stream. The unusual changes in pH at the Twenty-four Rivers site, T24, have previously been discussed (Section 2.3 above). The only perennial streams under present-day conditions of abstraction were at sites ASS and DWS. There was no marginal vegetation habitat in the Sout River (SOU), but at the other sites all major habitats were sampled.

Against this background it is hardly surprising that generalisations on the SASS4 scores measured cannot be made, except that scores were low and the numbers of taxa were also low. The highest SASS4 score measured was at Site ASS, and was low for an acid stream (**Figure 10**). However the ASPT was very high, indicating a natural water quality.

At FTR SASS4 score and number of taxa were very low, though in relation to this score, ASPT was high. Examination of the sample record (Dallas *et al*, 1994, Appendix 6.2d) shows that the high ASPT was due to one taxon which scored 15, while the next highest taxon score was 4. This sample provided yet another example of the necessity of placing low emphasis on ASPT when the SASS4 score is low. The SASS4 score reflected the impacted condition of the river.

Site WTR was below the Wemmers spillage dam and the low SASS4 scores may have been due to the proximity of the dam, because it is well-known that dams do result in changes in

the downstream invertebrate fauna near the dam. Also the stream probably ceases flowing from time to time.

Table 3: Conditions in Great Berg River Tributaries. Information provided by H Dallas and from Appendix 6.2e Dallas *et al* (1994).

Site	pH	TDS	NO_3	Permanent flow	Other
ASS	<6	12	0.04	Yes	
FTR	>6	70	1.69	No	Impacted water quality
WTR	<6	18	0.70	No	
DWS	>6	43	0.81	Yes	
KUI	>6	1027	0.38	No	
SOU	>6	8553	0.01	No	No marginal vegetation
T24	>6	29	0.01	No	
KRM	>6	4574	0.01	No	

pH was in the acid range at Site DWS, where an extremely small variety of invertebrates was collected. The reason for this is not apparent. It is difficult to accept that the sample, containing just four taxa, was representative.

Scores were low at the remaining sampling points (KUI, SOU, T24 and KRM), though the number of taxa collected, while still relatively low, was greater than at DWS. It is assumed that these low scores can be associated with the fact that none of the streams was perennial and the high TDS at three of them. In addition there was no marginal vegetation at Site SOU. Unfortunately the high TDS streams were also not perennial, so that it is not possible to use the results to indicate the response of SASS4 scores to high TDS waters.

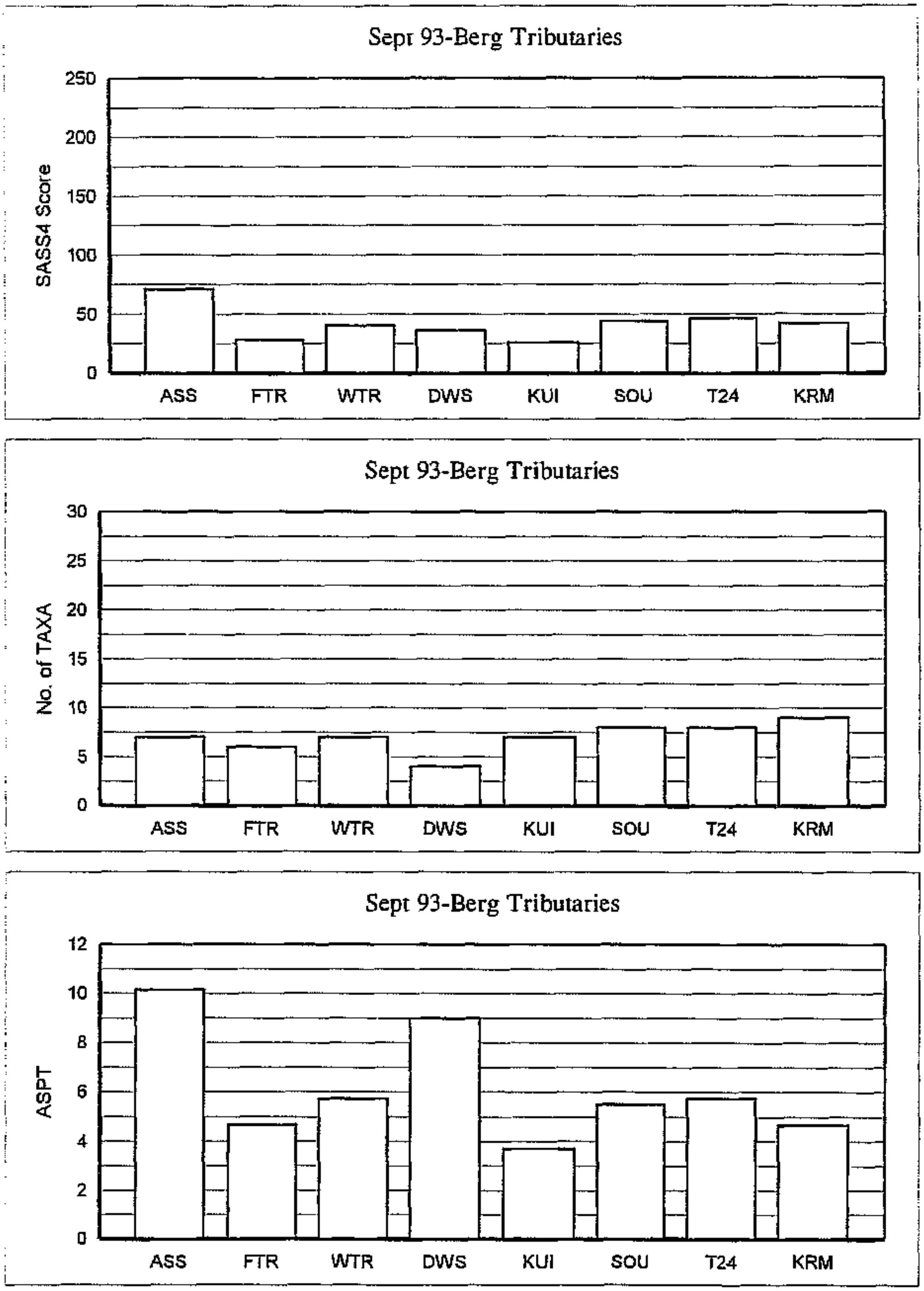

Figure 10: SASS4 scores, numbers of taxa and ASPT in eight tributaries of the Great Berg River, September 1993. Data courtesy of Ms H Dallas.

3. DISCUSSION

SASS data from the western Cape confirms the conclusion drawn from the acid streams of the southern Cape. The distinctive fauna of these streams results in higher SASS4 scores and ASPT values than are found in streams where the pH is > 6. The data show that polluted acid streams are not exceptional with respect to SASS4 scores and ASPT, which respond to water quality changes in a manner similar to their response in alkaline water. However the raising of the guideline boundaries of SASS4 for unimpaired water quality from 100 in alkaline waters to 125 in acid waters and of the ASPT from 6 to 7 means that there is probably no direct equivalence of water quality in acid and alkaline streams for identical SASS4 and ASPT scores. In other words SASS4 of 50 in an alkaline stream would not indicate the same degree of water quality deterioration as SASS4 of 50 in an acid stream.

In alkaline streams it was concluded that when SASS4 ranged between 50 and 100 and ASPT was less than 6, water quality was slightly to moderately impacted. Below SASS4 50, ASPT should be ignored and the lower the SASS4 score, the greater the degree of water quality deterioration in the range moderate to severe. In acid streams, because the unimpacted guideline has been raised to SASS4 >125 and ASPT >7, it is necessary to place the slight to moderate water quality deterioration between 125 and about 60 and the ASPT to less than 6.

In an acid stream the lower the SASS4 score below 60, the greater the degree of water quality deterioration. The data for the western Cape include several instances of the unreliability or volatility of ASPT when SASS4 scores are low, as found in other parts of South Africa (**Appendices A, B, C**, etc). These have been pointed out in the results section as they have been found.

Results from the western Cape have confirmed other findings regarding the impact of missing habitats on SASS scores. Thus when stones in current or fringing vegetation habitats are not found at sampling points on unpolluted rivers, the SASS4 score is markedly lower, but the ASPT does not change sufficiently for change to be recognised. It is by no means clear that the absence of sand and mud habitats can be detected in either SASS4 or ASPT scores, for the diversity (at family level) of the fauna of these habitats is not great.

There is no evidence in the western Cape results that SASS4 scores are sufficiently sensitive to respond in a detectable manner to general changes in river channel conditions, unless these changes result in the disappearance of stones in current or marginal vegetation habitats. Certainly the bridge building activity on the Molenaars River did not result in changes measurable by SASS4. It is necessary to keep in mind that the taxa scores in SASS4 were allocated on the basis of consensus of sensitivity to water quality change and not on the basis of sensitivity to physical conditions (other than pH, which is a physical measure of water quality). However, the conclusions regarding the impact of high sediment loads on SASS scores in Lesotho streams (**Appendix E**) indicate that SASS results are susceptible to high sediment loads.

As postulated in the introduction, few lowland streams or rivers were found in which water quality, assessed from SASS, was not impaired. The Palmiet is an exception in that it is a river whose lower catchment is in a protected (no agriculture and direct abstraction for agricultural purposes) high rainfall area, which allows water quality to recover from the large agricultural and dam impacts upstream. The Berg River at Piketberg and Sanddrift farm are also possible exceptions.

The Great Berg River tributary sampling points illustrate that unusual SASS scores may be expected when rivers cease flowing towards the end of the dry season. This was expected and is the reason why streams which cease flowing have otherwise been omitted from the SASS study. The tragedy of South African river ecosystems is that so many perennial streams have become intermittent. The unrecorded loss of species must be great. The country seems to be incapable or unwilling to control direct abstraction, though there is law to prevent misuse of water resources.

4. CONCLUSIONS

SASS4 results from the western Cape confirm that this method of assessing water quality is sensitive to water quality changes due to trout farms (Kraalstroom), to urban and industrial effluent (Eerste River and Plankenberg stream) and to dams (Palmiet River). Low scores can be expected in streams which are no longer perennial.

The fauna of unpolluted acid streams (pH <6) in this area results in SASS4 scores and ASPT values similar to those found in unpolluted acid streams in the southern Cape. These scores and values are higher than in mildly acid to alkaline streams (pH >6). Guideline values for the assessment of water quality from SASS4 and ASPT have had to be slightly modified for acid streams.

The SASS results from mildly acid to alkaline streams (pH >6) in the western Cape are similar to those from mildly acid to alkaline streams in other parts of the country.

5. REFERENCES

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