A PRE-IMPOUNDMENT STUDY OF THE SABIE-SAND RIVER SYSTEM ,MPUMALANGA WITH SPECIAL REFERENCE TO PREDICTD IMPACTS ON THE KRUGER NATIONAL PARK

VOLUME ONE

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THE ECOLOGICAL STATUS OF THE SABIE-SAND RIVER SYSTEM

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The name of the region where this work was done was changed from
EASTERN TRANSVAAL
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during the publication of this report.
Where the name Eastern Transvaal appears in the text, please read
Mpumalanga

EXECUTIVE SUMMARY

Section numbers in the executive summary relate to the chapter headings and subsections in the main report.

1. INTRODUCTION

1.1 This project was begun in January 1990 in response to a need to characterise the fauna of the Sabie-Sand River system for which plans were already advanced to build impoundments. During the course of the project, the region was subjected to the worst drought on record. As a result the scope and duration of the project was extended.

This is the first of three volumes of the project report, and describes the physico/chemical status of the rivers, and the status of the fish and invertebrate communities in the river. These conditions are compared with those in the Letaba River, and the hydraulic habitat preferences of the main fish species and invertebrate groups are described. The second volume documents the effects of the 1991-92 drought, and the third volume assesses the probable effects of planned impoundments on the downstream biota, and includes recommendations for the environmental management of the dams, as well as for the continued monitoring of the Sabie-Sand River system.

This project forms part of the multi-disciplinary Kruger National Park River Research Programme (KNPRRP), whose goals are:

- To inform researchers, system managers and stakeholders about the water quality and quantity requirements to sustain the natural environments of rivers which flow through the Kruger National Park.
- To develop, test and refine methods for predicting the responses of the natural environments of rivers in southern Africa to changing water quality and patterns of supply.

The Sabie River is at present the least impacted of the six rivers which flow through the Kruger National Park (KNP). A catchment study by Chunnett *et al.* (1990) identified 8 possible new dam sites on the Sabie and its major tributary the Sand River. The main objectives of this project were to characterise the present instream chemical, physical and biological conditions in the Sabie-Sand River system, and to predict the consequences of impoundment and increased water abstraction on the riverine biota. The precise aims of the project were defined as follows:

1. To characterise the present chemical, physical and biological conditions in the Sabie-Sand River system before any of the planned impoundments are built. (This volume)
2. To assess the probable extent of ecological disturbances and advantages resulting from future regulation (particularly within the Kruger Park), and to recommend management guidelines to minimise impacts and to maximise new opportunities for water management. (Volume 3)
3. To collect basic biological and hydro-geomorphological data which will allow the calculation of instream flow requirements for the system. This will include the identification of target organisms and their distributions, flow and substratum preferences, as well as modelling the habitat changes caused by different flow regimes. This last component will involve the generation of data to be supplied to the instream flow incremental methodology model (IFIM) being developed by Dr J M King and Ms R Tharme of the Freshwater Research Unit at the University of Cape Town. Instream flow requirements will be calculated within the framework of maintaining maximum natural biological diversity and with respect to the requirements of sensitive key species. (This volume, chapters 6 and 7, and volume 3, chapter 3)
4. To assess the probable effects of river regulation in the Eastern Transvaal Lowveld against those already measured for regulated systems in the western Cape (Palmiet River), and eastern Cape (Buffalo River). This will broaden

our knowledge of the general ecological consequences of impoundment on Southern African river systems. (Volume 3)

5. To develop a long-term surveillance system which will provide information on key changes within the Sabie-Sand River system (for example, the invertebrates, the riparian vegetation, channel morphology, etc.), in order to distinguish between natural cyclical changes and those which may result from river regulation and other disturbances. (Volume 3)

6. To develop a collaborative methodology which will allow comparisons to be made between data-sets on different Kruger National Park river systems. Collaboration will take place between this programme and those of Dr Chutter and Mr Heath on the Letaba system, and Dr King and Ms Tharme's development of instream flow methodologies. Further collaboration will also be developed between this Programme and the Foundation for Research Development Programme on the rivers of the Kruger National Park which will be led by Dr Rogers of the University of the Witwatersrand, the general Kruger National Park Rivers Programme, and researchers and managers of the Transvaal Provincial Administration, and the Department of Water Affairs and Forestry.

Additional objectives added to these original aims were to:

7. Characterise conditions during the 1991-92 drought, and assess its effects on the water quality and fauna of the river. (Volume 2).

8. Monitor the effects of the collapse of the Zoeknog Dam on the Mutlumuvi River in February 1993. (Volume 3).

The remainder of this section provides a brief summary of which of the aims of the project were achieved:

1. This aim has been achieved. Volume 1 describes the fish, invertebrates, water quality, hydrology and habitat conditions at more than twenty sites from the headwaters to the Mozambique border, including seasonal changes during dry and wet periods.
2. This aim has been partially achieved. Chapter two of volume 3 reviews the effects of previous research on existing impoundments in South Africa, predicts as far as possible the effects of proposed dams on the Sabie and Sand Rivers, and describes the effects of construction and the collapse of the Zoeknog Dam.
3. This aim has been partially achieved. Chapters 6 and 7 of this volume identify target organisms and describe their distribution, flow and substratum preferences, and hydro-geomorphological data for the calculation of habitat changes has been collected at three sites in the Sabie and Sand Rivers. However, due to difficulties with the IFIM procedure (King and Tharme, 1994), calculations of instream flow requirements using this procedure have not been carried out. Chapter 3 of volume 3 reviews previous estimates of instream flow requirements for Sabie and Sand Rivers, and relates the ecological information collected in this project to those previous estimates in order to refine them.
4. This aim has been achieved. Chapter 2 of volume 3 provides a comparison of previous impoundment studies with the likely effects of impoundments on the Sabie and Sand Rivers.
5. This aim has been partially achieved. Chapter 4 of volume 3 describes some of the requirements necessary to monitor the condition of the rivers, and changes which may be caused by the proposed impoundments. A design for a complete monitoring system will have to await the completion of projects currently underway on the geomorphology and riparian zone of the system.
6. This aim has been achieved within a wider context than this project alone. The development of the KNP Rivers Research Programme, of which this

project has been a part, has resulted in a decision support system and a series of sub-programmes designed to integrate all the research on the rivers of the KNP. Chapter 9 of this volume compares conditions in the Sabie-Sand with the Letaba River.

7. This aim has been achieved. Volume 2 describes in detail the effects of the 1991-92 drought at three sites in the lowveld and the beginning of recovery of the fauna following rains in November 1992. Fieldwork had to stop in April 1993, before recovery was complete, and it would have been desirable to have continued recovery monitoring in order to assess the long term effects of the drought.

8. This aim has been achieved. Chapter 2.4 of volume 3 describes the effects of the construction and subsequent collapse of the dam, the effect on the fish and invertebrates and the initial stages of recovery.

2. THE SABIE-SAND RIVER SYSTEM

2.1 The Sabie-Sand River system forms part of the Incomati system, an international drainage basin lying across several political boundaries - the Republic of South Africa, the former homelands of Gazankulu, Lebowa and KaNgwane, the Kingdom of Swaziland and Mozambique (Fig. 2.1; Chunnett *et al.*, 1990). The catchment of the Sabie-Sand covers some 709 600 ha, rising at 2 130 m AMSL on the eastern escarpment and reaches the Mozambique border at an altitude of 120 m AMSL, some 175 km from source.

The catchment is underlain by Basement Complex traversing the lower Middleveld and upper Lowveld portions of the basin (from the Drakensberg to the Lebombo Mountains), the Karoo Sequence in the eastern sector of the Lowveld, and the Transvaal Sequence which lies on the mountainous western extremes of the basin, separated from the Basement Complex by a Dolomite intrusion. The soils of the catchment tend generally to be resistant to erosion, particularly when compared to other regions of southern Africa, with sediment yields varying from 400 to 600 t km^{-2} yr^{-1} (Chunnett *et al.*, 1990).

The mean annual precipitation (MAP) falls from 2 000 $mm.yr^{-1}$ on the escarpment to *ca* 600 $mm.yr^{-1}$ for the Lowveld. Most rain falls between November and March, with peaks usually occurring in January, but the region is also subject to unpredictable tropical cyclones and to drought. Evaporation varies between 1 400 $mm.yr^{-1}$ in the west, to 1 700 $mm.yr^{-1}$ towards the east, with gross evaporation of the Middleveld and Lowveld respectively being 40% and 60% higher during summer than winter. Details of rainfall and evaporation patterns may be found in Gertenbach (1980) and Pienaar (1985). Chunnett *et al.*, (1987, 1990) report minimum and maximum summer temperatures (January) at Skukuza, as 32° and 20°C respectively, while for winter (July) they are 26° and 6°C respectively.

2.2 The rivers flow through more than 74 000 ha of commercial forestry plantations (pine trees and eucalypts) (Chunnett, *et al.*, 1990). The middle catchment is predominantly made up of the former homelands - Gazankulu, Lebowa and Kangwane, and the river supplies potable water together with irrigation water on a limited basis. Further downstream, it provides the main water supply for the southern part of the KNP where water uses are primarily for potable supply to the tourist industry associated with the Park, as well as water for conservation purposes. A very large dam, the Corumana, has been built by Mozambique on the eastern boundary of the KNP.

2.3 Pienaar (1985) and Joubert (1986) have both provided informative accounts of the historical development of the KNP. Due to gold-mining effluents from the upper reaches, pollution had become so bad that "the Sabie River virtually changed to a sterile stream" (Pienaar, 1985). Since the 1940's the river has recovered to become biologically the most diverse in South Africa (Pienaar, 1985). Moore and Chutter (1988) have provided a review of the more recent biological research on the rivers of the KNP up to the inception of the KNP Rivers Research Programme (KNPRRP), and surveyed the benthic invertebrates of all the major rivers of the Park, concluding that the Sabie contained the most diverse fauna, and appeared to have been least affected by man.

Since Moore and Chutter's (1988) review a considerable amount of research has been undertaken on the rivers of the KNP and the Sabie/Sand in particular, as part of the KNPRRP. A resurvey of the fish fauna of all the rivers by Russell and Rogers (1989) provided the background information on changes since Pienaar's (1978) survey. They found that there had been little observable change in the fish communities of the Sabie River, although there appeared to have been losses of up to 20% of the species from the other rivers (the Letaba and Luvuvhu) (Russell and Rogers, 1989). Venter and Bristow (1986) described five geomorphological zones in the Sabie within the KNP, and Vogt (1991) assessed the short-term geomorphological changes in the KNP rivers, effects that are likely to be accelerated as flow patterns change in the future. Chunnett *et al.* (1990) undertook a catchment study of the Sabie/Sand system which summarised the physical attributes and socio-economic environment of the catchment, analyzed seasonal water availability at a number of sites, and suggested possible new impoundment sites on the system.

A number of research projects on the Sabie River are currently under way or being written up as part of the KNPRRP. These include investigations of the movement of water into and out of the riparian zone, the riparian vegetation, relationships between riparian vegetation and the geomorphology, and attempts to predict the water use of the riparian vegetation. An assessment is also being made of the potential responses of the geomorphology of the Sabie River to changes in the flow regime.

3. MATERIALS AND METHODS

3.1 The methods for this study were based on a three tiered approach, in which physico-chemistry, fish and macro-invertebrates were sampled annually at 21 sites, to provide an overview of community changes throughout the system. At 9 of the 21 sites, similar samples were taken quarterly to assess seasonal changes, and to collect hydraulic habitat information. At 3 of the 9 sites, hydraulic transects were surveyed in order to map available habitats for inclusion in IFIM. When it became evident that a severe drought was in progress, three of the 9 quarterly sites were designated for drought monitoring at monthly intervals.

3.2 To ensure that all habitats/conditions were represented by the sample sites, the rivers were divided into reaches on the basis of topography, geology, water quality, and species distribution parameters (as recommended by Bovee & Milhous, 1978). Details of flow regime, channel morphology and channel pattern were also considered (Bovee 1982). The catchment was stratified into segments on the basis of Chunnett *et al.* (1990). River zonation, natural vegetation types (Acocks, 1975) and topography were initial considerations for the choice of sites.

3.3 A photograph from a fixed point was taken each time a station was surveyed, and a permanent flow transect was established at each study site. At all the monitoring sites, the transects were eventually extended to include the riparian strip. The transects included all features that were depositional, and the presence of any vegetational elements associated with the river. A list of station particulars are provided in Table 3.1. Details of each site are described in this section.

3.5 Water samples for chemical analysis of nutrients were collected, and river discharges were measured at each site. Macro-invertebrates were sampled in the following habitats: stones-in-current; sediments; and marginal vegetation using a surber sampler, a hand net and a Van Veen Grab. Fish were sampled using three complementary techniques: electro-fishing; valved minnow traps; and gill-nets. Macro-invertebrates were preserved in formaldehyde and later identified in the laboratory. Fish were identified to species in the field or a sample was collected for identification. PRIMER version 3.1a (Plymouth Routines in Multi-variate Ecological Research; Field *et al.*, 1982) was employed to analyze pattern in distribution and abundance.

3.6 Microhabitat use and preference, as defined by the hydraulic parameters of flow, depth, substrate and cover were collected. Flow and depth data were represented as suitability index (SI) curves (Bovee, 1986) while substrate and cover were encoded (Bovee, 1986; Brusven, 1977, in Bovee, 1986) and presented as histograms.

4. HYDROLOGY OF THE SABIE-SAND SYSTEM

4.1 Under present developmental conditions, the Sabie River remains t! e only perennial, largely pristine and unregulated river traversing the Kruger National Park (KNP). It has a mean annual runoff (MAR) of some 762 hm^3, 91.2% of which originates in the eastern escarpment and foothill region, the headwaters of the catchment (Fig. 4.1) (Chunnett *et al.*, 1990). Six hydrological reaches were identified in the catchment (Table 4.1).

Flow in the Sabie and Sand rivers varies seasonally (Fig. 4.2), with summer peaks (February) and low flows at the end of the dry season (October). No-flow conditions have never previously been recorded for the Sabie River. The present runoff for different sub-catchments has been reduced by between 11% and 75% (Table 4.2). Baseflow is most reduced in the Sand sub-catchment.

Runoff during the 1991 hydrological year closely followed the seasonal pattern and magnitude expected for the Sabie River (Fig. 4.3b & 4.4) while runoff during the 1992 hydrological year was reduced to drought conditions. Base-flows were reduced by 50% in the upper Sabie River (Fig. 4.3b), and even more noticeably in the mid and lower reaches. Base-flows in September 1992 were at their lowest in recorded history, with the lower Sabie reduced to 0.33 m^3s^{-1}. The lower Sand River reaches stopped flowing during the worst of the drought.

5. PHYSICO-CHEMICAL STATUS OF THE SABIE-SAND SYSTEM

Water quality in the Sabie/Sand River is generally considered to be good to excellent, with the exception of elevated turbidity in the Sand River, but the pH is relatively low, and the system is therefore poorly buffered and sensitive to changes in the catchment. Tables 5.1 to 5.8 list the water quality data analyzed from 11 sample sites during the present project.

5.1 Concentrations of dissolved salts generally increased downstream, but were never high (Table 5.1). The maximum concentration (220 -250 µS/cm) occurred in the Lowveld Sand River during periods of no-flow at the height of the 1992 drought. The maxima recorded in the Sabie/Sand have been 368 µS/cm at North Sand (X3M04), and 360 µS/cm at Phabene (X3M12). These concentrations are well within even the most stringent user guidelines.

5.2 Levels of pH fluctuated widely, particularly in the upper Sabie, (4.0 to 9.1) (Table 5.2). Although the Sabie/Sand is generally an alkaline river, the high values are greater than had previously been recorded (8.5 in the Mac Mac tributary, Chunnett *et al.*, 1990).

5.3 The turbidity of water in the catchment is low during low flows (tables 5.3 and 5.4), with sediment yields in the catchment posing no serious threat to large reservoirs (Chunnett *et al.*, 1990). Occasional turbidity readings greater than 200 and concentrations of TSS over 0.1 g/l (Tables 5.3 and 5.4) were usually associated with high flow spates in the river. The Sand River experiences higher average turbidities (Table 5.4) than the Sabie, as might be expected of a more temporary system, but lower concentrations of suspended solids (Table 5.3). The construction of the Zoeknog Dam resulted in the highest turbidities ever recorded (1400 NTU and 0.888 g/l). Very high turbidities were also measured in the Sand River following the collapse of the central section of the Zoeknog Dam.

5.4 DO concentrations were on average at or around 100%, although some very low DO concentrations were measured during this project, generally associated with isolated pools during the 1991-92 drought, shortly before the pools dried out (Table 5.5).

5.5 Considerably hotter maximum flowing water temperatures (up to 37°C, Table 5.7) than the maximum quoted by Chunnett *et al.* (1990) (31.1°C), were recorded. Low temperatures (down to 5.6°C, Table 5.8), were not as cold as those quoted by Chunnett *et al.*, (1.7°C), but were sufficient to cause fish kills in 1990 when a hail storm on the escarpment led to a sudden drop in water temperature. It appears that the absolute temperature is less important than the rate of temperature change.

5.6 Nutrient concentrations for PO_4, NO_3, $N0_2$ and NH_4, in the Sabie and Sand Rivers were generally very low. Phosphate concentrations higher than those previously recorded (0.217 mg/l) were measured during this project: 1.16 mg/l at site 6 in the Sabie in April 1993; and 1.41 mg/l at site 9 in the Sabie in May 1993. Concentrations in excess of 1 mg/l are not only high for the Sabie, but for freshwaters in general, and would be likely to give rise to eutrophic conditions, especially in downstream impoundments.

5.7 The results of this project generally confirm the prevalent view that the water quality in the Sabie/Sand is adequate for all uses, but they do raise some disturbing concerns in relation to turbidity and nutrient concentrations. Water quality effects due to past gold-mining are still seen today. It was not until the 1940's that the sources of pollution were cleaned up and the river began to recover. Traces of mercury were still found in the sediments as late as 1968.

The Sabie has been subjected to major water quality problems in the past, and the fauna has recovered due to the presence of unimpacted tributaries. The deterioration of flows and water quality in these tributaries would seriously impair the resilience of the river system to cope with further stress.

6. INVERTEBRATE COMMUNITY STRUCTURE

6.1 This Chapter aims to: Describe the invertebrate communities found in the Sabie, Sand, and other major tributaries; assess the changes in the invertebrate fauna from 1990 to 1993, and particularly in the drought conditions of 1992 (section 6.2); describe the differences between the fauna of different habitats (section 6.3); and define the microhabitat preferences of major groups of invertebrates in terms of substrate, water depth and current speed (section 6.4).

Invertebrates have previously been sampled at two sites in the Sabie River during 1985 and 1986. These samples are discussed and compared with those collected from the Letaba River *at the same time, and during a subsequent survey in 1990 and 1991, in chapter 9 of this* volume.

We have concentrated our analysis of the invertebrate fauna on the riffle communities, as those most likely to indicate differences between different zones of the river, different seasons, or different years of the study. The cluster analysis in figure 6.1 indicates five major groups of samples, of which four describe a progression from a wet period (1990), through a drier year (1991), through the worst drought on record (until November 1992), and finally into the reestablishment of good flow conditions from November 1992 until the end of the sampling programme in May 1993. The most obvious feature of both the clusters and the multi-dimensional scaling (MDS) (figure 6.2) is that the sample groups are closely related to the changing flow conditions throughout the three and a half years of the study, rather than to seasonal changes, or to different river zones. It is apparent from figure 6.3 that the highest flows were associated with the 1990 and "recovery" periods, whilst the lowest flows were associated with the drought groups. The drought had a very severe impact on invertebrate abundance, with a decrease of almost an order of magnitude between 1990 and the height of the drought in 1992.

As might be expected, the pre-drought 1990 samples were by far the most diverse in terms of numbers of taxa per sample, averaging 29.4, compared to 14.8 for the drought upper samples, and 15.8 for the drought lower. The "recovery" samples were also depauperate, with an average of 14.3 taxa per sample. It seems clear that the drought halved the diversity of the riffle fauna, while recovery seems to take longer than the seven months of good flows which were sampled at the end of the project.

11 of the 36 taxa common in the 1990 pre-drought samples disappeared from the riffle habitat during the drought:
Trichoptera: *Chimarra* sp.; Philopotamidae; *Aethaloptera* sp.

Ephemeroptera: *Cloeon* sp.; *Trichorythus* sp.; *Acentrella* sp.
Demoulina sp.
Hemiptera: Pleidae.
Diptera: Tabanidae.
Mollusca: Sphaeridae.

There were 6 taxa which occurred in the drought samples but did not occur in the wetter 1990 conditions:
Annelida: Lumbriculidae; Hirudinea.
Trichoptera: Hydropsyche longifurca.
Ephemeroptera: *Povilla adusta.*
Diptera: Orthocladiinae.
Mollusca: *Burnupia* sp.

The recovery period was characterised by the presence of large numbers of small hydropsychid caddis larvae and two taxa which were absent during the drought, including one that appeared for the first time:
Ephemeroptera: *Trichorythus sp.*
Diptera: Culicidae (sampled for the first time)

6.3 The marginal vegetation contained the most taxa (189), and the sediments the least (120). Abundances were high for all three habitats, and were particularly high for the sediments (2638 individuals per grab sample of 0.00225 m^3). The marginal vegetation contained the highest number of taxa which were restricted to one habitat (24, Table 6.1), compared to 13 in riffles and only one in soft sediments. An analysis of the most abundant groups in each habitat is presented in Tables 6.3a-c. Key groups which are abundant in one habitat, but less common in the others, are:
In riffles: Rhagionidae; Hydroptilidae; *Cheumatopsyche afra; C. thomasseti; Hydropsyche longifurca*; and *Cloeon* complex.

In marginal vegetation: Cladocera; Pleidae; Culicidae; *Demoulina* complex; *Caenodes* sp.; and *Caridina nilotica.*

In sediments: Protoneuridae; Lumbriculidae; Tubificidae; Gomphidae; *Afrocaenis* sp.; *Tomichia* sp.; and *Sphaerium* sp.

Sediments in pools and slow-flowing areas form by far the largest area of benthic habitat, especially in the lowveld, followed by bedrock, which harbours lower densities and diversities of invertebrates than riffle. Marginal vegetation is probably the next most common habitat, since it is present all the way along the river, at least during medium and high flows. Riffle, which forms the habitat for the most consistent and best indicator community, is by far the least common habitat, especially in the middle and lower reaches of the river.

6.4 An analysis has been made of the microhabitat occurrences of two of the major insect groups - the Trichoptera and the Ephemeroptera, in terms of substrate type, depth and current speed. It is clear that the Ephemeroptera have less specific requirements than the Trichoptera. Figure 6.4 indicates a wider preference by Ephemeroptera with distribution occurring fairly widely across 6 of the 7 habitat types.

As in the case of the Ephemeroptera, habitat 1 (the sandy substratum, Fig. 6.5) was not favoured by the Trichoptera but, unlike the Ephemeroptera, the Trichoptera showed a distinct preference for the riffle habitat (habitat 2, Fig. 6.5) whilst shying away from both emergent reeds and overhanging vegetation (respectively habitats 5 and 6, Fig. 6.5).

An examination of Figures 6.6 (Ephemeroptera) and 6.7 (Trichoptera) shows that both groups occurred both in highest densities of individuals and in numbers of taxa at depths between 0-30cm. The Trichoptera showed very clear preferences for stronger current speeds (Fig. 6.9) both in terms of numbers of taxa and individual densities, but the Ephemeroptera (Fig. 6.8) were distributed throughout a wide range of flows which ranged from 0.25 to >1 $m.s^{-1}$.

6.5 Invertebrate communities living in riffles in the Sabie/Sand are extremely sensitive to flow conditions. The similarity analysis described in section 6.2 indicates that different communities are far more closely related to the progression of the rivers into, through and out of the 1992 drought than they are to other factors such as altitude, river order, tributary, or season.

The diversity of the communities was drastically reduced with the reduction in discharge in the river, both in terms of the number of taxa (reduced by half) and the density (reduced by almost an order of magnitude). This survey showed that the Sabie/Sand communities had not recovered after 7 months.

The marginal vegetation is the first habitat to be lost when flows are reduced, and we therefore consider it to be the critical habitat for conservation. Communities of the sediments were the least diverse, but sediments are by far the most common habitat, especially in the lowveld, and also form the final refuge habitat in pools when flow ceases.

Trichoptera were the most habitat-specific group in both riffles and marginal vegetation, with 6 families/genera unique to each. In comparison to the Ephemeroptera, the Trichoptera as a group seem to prefer a remarkably narrow set of conditions in terms of habitat utilisation, depth and flow, and it is recommended that this group be targeted for further microhabitat preference work.

From our analysis, it appears that 30 cm of medium to fast flowing water - between 0.63 to 1 $m.s^{-1}$, but not below the former - through the riffle, would provide ideal conditions, conducive to the maintenance of the maximum diversity and abundance of invertebrates.

7. *FISH ASSEMBLAGES OF THE SABIE-SAND SYSTEM*

7.1 This chapter describes the fish fauna in the Sabie-Sand from 1990 to 1993, and is structured with the following aims:

To assess the diversity of fishes in the system, to describe species distribution and abundance (sections 7.2-7.3); to identify representative target species (section 7.4.1); and to describe the habitat requirements of these species (section 7.4.2).

7.2 Forty-nine species of fish were recorded, or are known to have populations within the Sabie-Sand catchment, of which four are alien species. This makes it the most species rich river system in the country, comparable only to the Phongolo River. The diversity is roughly twice that expected for a catchment of this size (6252 km^2) (Welcomme, 1985). This high diversity is partly explained by the presence of clear zonation spanning two eco-regions, its historic affinities, and proximity to the rich east African fish faunas. These ichthyological zones correspond to the Montane-Escarpment and Tropical East-Coast eco-regions respectively (Skelton, 1993). Of the two, the cooler Montane-Escarpment eco-region is less diverse, but it has more regional endemics, (six species) (Skelton, 1993). The tropical East-Coast eco-region is more diverse (Skelton, 1993). *Barbus brevipinnis, Chiloglanis anoterus* and *Serranochromis meridianus* are largely confined to the Incomati system.

Fishes of very small adult size (< 10 cm) make up a high proportion of the Sabie-Sand diversity, both within the low order feeder and potamon reaches (Table 7.1). Cyprinids are the most abundant taxonomic group (48.9%) including 12 minnows and 8 large cyprinids, 5 of which are mudfishes (Appendix III). Catfish account for 20% of the total diversity, including 7 specialised small species with both *Amphilius* and *Chiloglanis* spp (Appendix III). Cichlids make up 11.1% (5 spp) of the species diversity, and are very important ecologically at times. *Oreochromis mossambicus* in particular is reported to dominate assemblages in many studies during times of drought.

7.3 Three patterns in the distribution and abundance within the Sabie-Sand Rivers can be discerned:

1) Two broad ichthyological river zones are identifiable, where one group of species replaces another within a narrow temperature range in the Sabie and

Sand Rivers. Gradient analysis, classification and ordination techniques all clearly demonstrate the zones.

2) Within each zone, additional species appear with distance downstream, due to increased habitat diversity and depth as the river gets bigger.

3) Within zones, each tributary sampled in the Sabie-Sand System has a characteristic fish fauna, with variations from a baseline species assemblage. This reflects local habitat availability, and stream profile.

Temperature is the best correlate for pattern 1 (Fig. 7.1). Our measure of spring-temperature (Fig. 7.1), correlates better with the distribution of fish in the catchment, than species tolerance of temperature extremes which are usually invoked to explain fish distribution (Jubb, 1962). Fish species were allocated to five categories of temperature tolerance (Tables 7.2-7.4), namely:

1) Cold Stenothermal Species (species always restricted in the catchment to cool waters).
2) Warm Stenothermal Species (species only ever found in warm waters).
3) Cold Species (cold water species marginally tolerant of warmer waters).
4) Warm Species (warm water species marginally tolerant of cool waters).
5) Eurythermal (species that show wide tolerance to both warm and cold temperatures within the system).

Gradient analysis identified two fish assemblages: those of the foothill (FHZ), and lowveld zones (LZ).

Fourty two species were collected in the Sabie River, (Table 7.2) the longest river in the Sabie-Sand System. The FHZ within the Sabie River is particularly developed, with a cold-finger of water penetrating the lowveld. Fish diversity in the FHZ is highest at the interface with the LZ. Some overlap of warm cold-tolerant species is found, including many minnow species. At least 6 fish species are missing from the middle reaches (Table 7.5) probably as a result of historic pollution from gold mining activities, and isolation of the upper reaches of the Sabie River by waterfalls. The LZ stretches downstream from site 6 (402 mASL), and supports more than 20 species.

The Marite River is a major tributary of the Sabie River and important as a cold water refuge for FHZ species. Fish were numerous, with substantial populations of cold-stenothermal species including *B.argenteus*, *A.natalensis*, *V.nelspruitensis* and the locally abundant and localised *B.brevipinnis*.

The Sand River has a very limited FHZ with a very sudden FHZ/LZ transition. The full complement of LZ species was present downstream of Site 11. Because this reach was close enough to the headwaters to be perennial, two flow sensitive species absent in the seasonal Sand River were resident, the warm cold-tolerant *Opsaridium zambezense* and the cold warm-tolerant *C.anoterus*. These examples show that both temperature, flow regimes, and microhabitat requirements need to be considered when explaining a species distribution. Diversity in the Sand River LZ was high (above 20 spp per site), and most species were small with larger riffle/run species appearing (*Labeo molybdinus*, *Labeo cylindricus*, & *B.marequensis*) when deeper habitats became available. The larger pool dwelling Labeos (*Labeo rosae* and *Labeo ruddi*) were restricted to a few hippo pools.

C.anoterus and *Barbus viviparus* were identified as the indicator species of the FHZ and LZ zones respectively. The classification of all 44 quarterly monitoring samples shows two groups (Fig. 7.3). Group 1 represents all the cool water samples (FHZ) and group 2 the lowveld surveys (LZ). Within these two main groups, the strongest sub-divisions are spatial rather than seasonal. While temperature-altitude is the strongest axis determining the presence or absence of species, spatial changes at smaller scales (within zones) are probably a consequence of habitat changes down the rivers. Classification of 31 species for 67 samples taken annually in May over four years show 3 main clusters: Species typical of the FHZ (group 1), the LZ (group 2), and an outlying group of species of the LZ, common only during drought recovery in the lower reaches (group 3). Further sub-groups relate to hydraulic habitat types, and specific temperature preferences. MDS of this same data reveals a clear distinction between FHZ and LZ fish assemblages (Fig. 7.6). Temperature tolerant species from both fish zones tend to be classified close together, as are minnows and cichlids. There are no clear separations between groupings within the LZ.

7.4 Baseline or typical fish assemblages were defined for the Sabie-Sand Rivers by using only samples taken prior to the 1991-92 drought. To isolate drought samples, a core group of fish species were selected, which constituted 6% or more of the survey for May. Differences in ranked percentage contribution of the core species were tested using Spearman's Coefficients. Samples taken between May 1990 and August 1991 were similar, best discribing the pre-drought fish assemblages. Using only these pre-drought samples, baseline assemblages were identified for both the Foothill (Fig. 7.7) and Lowveld Zones (Fig. 7.8). Within the FHZ, 6 ecologically important species accounted for 92.3% of the average catch. *C.anoterus* dominated the FHZ baseline catch (70%) with the cyprinids *V.nelspruitensis*, young of *B.polylepis*, *B.marequensis* and the minnow *B.eutaenia* accounting for a further 27%. Eleven ecologically important species made up 82.6% of the average baseline assemblage of the LZ, including a suite of cyprinids (7 species comprising 56%), five of which are minnows. *B.viviparus* was the most numerous and ubiquitous of the LZ species occurring at all LZ sites. Together with *B.marequensis*, *L.molybdinus* and to a lesser degree *C.anoterus*, they exploit areas in or adjacent to flow. The remainder of the sizable minnow component (25%) exploits quiet pools, and together with *B.viviparus* totaled 46% of the LZ small species baseline assemblage. Three pool and backwater cichlids species, (*O.mossambicus*, *T.rendalli* & *P.philander*), made up 26% of the average annual catch.

Seasonal changes within the FHZ baseline assemblage were not marked (Figs. 7.7b-e). The cyprinids increased in percentage proportion of the catch by the end of the wet season (e), probably as a result of summer breeding and the presence of many young fish. Seasonal changes within the LZ were very marked (Figs. 7.8b-e). At the start of the dry season (May;

Fig 7.8b), 75% of the core species catch was typically cyprinid and the cichlids; *O.mossambicus*, *T.rendalli* and *P.philander* together made up only 11% of the CPUE on average. By August, most groups remained unchanged. At the end of the dry cycle (November), and with the onset of the wet season, cichlids increased to over 50% of the fish sampled. Changes in species abundance and composition were not confined to zones and season, but included the effects of disturbance, both natural (the drought) and anthropogenic (the failure of Zoeknog Dam).

After temperature, drought was one of the major determinants of species pattern, particularly within the LZ (Fig. 7.9). Here the relative proportions of the LZ fish assemblage changed, rather than the presence or absence of species. However, prolonged or repeated drought would result in species loss. Most species showed reductions with the failure of the 1992 wet season, but the proportion of cichlids increased (Table 7.7). Cyprinids were reduced from 78% (May 1992; Fig. 7.12c) to less than 50% of the catch, while cichlids increased to over half the CPUE.

The LZ fish assemblage, typical of the end of the dry season in November (pie diagram; Fig. 7.8d), and the pie diagrams characteristic of the drought years are strikingly similar (Figs. 7.12c & 7.12d). This is important as it suggests that the response of the biota is both similar and predictable. The pattern seen is governed by the early summer breeding of the cichlid species irrespective of the success of the seasonal rains. Cichlids were more abundant than cyprinids throughout the drought.

Fish assemblages during the recovery phase were quite different from both pre-drought and drought LZ assemblages (Fig. 7.12d). *O.mossambicus* numbers were greatly reduced following the first rains, but persisted in greater numbers than in pre-drought samples. Others species remained at low numbers, notably *C.anoterus*, *B.marequensis*, and *B.unitaeniatus*. *B.viviparus* remained at roughly half its pre-drought density. Although the drought was severe, a few species had made an early comeback. Young *L.molybdinus* were very numerous and *L.rosae* and *B.afrohamiltoni* were numerous at lower sites for the first time during the projects inception. Some minnows recovered early by surviving well in refuge pools (*B.annectens* & *B.radiatus B.trimaculatus*).

7.6 One of the aims of this project was to identify a set of species whose life-cycles and habitat requirements would be representative of the range of characteristics of all the fish fauna. Sixteen target species were selected on the basis of representativeness, diversity of requirements, importance, and abundance: (Three are common to both zones)

a) **FHZ:** *Barbus eutaenia*
Barbus marequensis
Barbus polylepis
Chiloglanis anoterus
Pseudocrenilabrus philander
Tilapia sparrmanii
Varicorhinus nelspruitensis

b) **LZ:** *Barbus annectens*
Barbus marequensis
Barbus radiatus
Barbus trimaculatus
Barbus unitaeniatus
Barbus viviparus
Chiloglanis anoterus
Labeo molybdinus
Micralestes acutidens
Oreochromis mossambicus
Pseudocrenilabrus philander
Tilapia rendalli

Two species were added to the list due to their status as indeterminate-rare and rare respectively (Skelton, 1987).

Opsaridium zambezense
Serranochromis meridianus

The microhabitat variables flow, depth, substrate and cover were used to characterise those aspects of habitat which would be most affected by changes in the flow regime. The habitat curves presented here are the first comprehensive set of species microhabitat use, and preference, within any African aquatic ecosystem (Figs 7.14-7.40), besides those of King and Tharme (1994) for the fishes of the Olifants River, western Cape. Each species is discussed in detail under the headings: general distribution; within the Sabie-Sand system - distribution; abundance; microhabitat needs; and management considerations.

Flow was arguably the strongest factor structuring the use of habitat by the biota. Flow preference was used to divide the baseline shallow-water fish assemblage into habitat groups which included:

a) **Fishes of Backwaters and Pools;** 8 lifestages of 6 species preferred zero flow to all other flow velocities (Table 7.10). This included all the target cichlids and two deep pool minnows (*B.annectens* & *B.radiatus*). All these species were widespread from the coastal plain to the low-order warmwater streams of the lowveld. Most backwater cichlids preferred waters of shallow to medium depths (>20-80cm deep; Table 7.11) except *P.philander* which preferred very shallow waters (10cm deep) while the two minnows preferred the deepest of pools sampled (>90cm deep). Most species and their lifestages preferred some type of direct instream cover (Table 7.13) provided by all types (Table 7.12) of substrates.

b) **Fishes Marginal to Flowing Waters;** 6 life stages of 5 fish species (Table 7.10) preferred quiet waters (zero velocity), but mostly in close proximity to flow (velocities of >0.2m.s^{-1} 0.6 suitable). They were all small minnows or juveniles of the larger cyprinid, *V.nelspruitensis*, except for juveniles of the characin *M.acutidens*. This group preferred shallow water (>20-90cm deep) in marginal flows, and direct instream cover (Table 7.13). These minnows share a substrate preference (Table 7.12) for boulder, except for adult *B.viviparus* which preferred gravel/pebble.

c) **Fishes of Runs;** 5 lifestages of four species (Table 7.10) preferred slow to moderate velocities in runs (>0-0.4 m.s^{-1}). They were also all medium sized minnows or juveniles of large cyprinids (*B.polylepis*) excepting adults of the characin *M.acutidens*. They all preferred some cover (Table 7.13), mostly instream velocity, visual and the cover of marginal vegetation/roots (Table 7.12).

d) **Fishes of Riffles and Rapids;** 6 lifestages of four species preferred the high velocities and turbid flows of riffles and rapids (>0.4->1.5 ms^{-1}) (Table 7.10). They included riffle specialists and the two species known to be sensitive to low-flow conditions (*C.anoterus* & *O.zambezense*). Depth preference for these fishes (Table 7.11) probably reflects the shallow nature of riffle habitat (20-50 cm deep) with only adults of the large cyprinid *L.molybdinus* preferring waters deeper than generally sampled (>90 cm deep). Cover preferred by riffle species (Table 7.13) is influenced by the combined velocity and visual cover offered by turbid flows. Both *C.anoterus* and *L.molybdinus* juveniles and adults preferred the combined cover of riffles with a gravel/pebble substrate (except the large adult labeos which preferred boulder) (Table 7.12).

8. COMPARISONS OF CONDITIONS IN THE SABIE-SAND WITH THE LETABA RIVER

8.1 A report of a two year study of the relationship between low flows and the river fauna of the Letaba River (Chutter and Heath, 1993) has recently been produced, and this chapter compares their findings for the Letaba with those for the Sabie-Sand from the present study.

8.2 The Sabie is a perennial river, while the Letaba is now a temporary system, although it was a perennial system in its natural state. The Sand River, the major tributary of the Sabie system, was probably perennial along most of its length in its natural state, but is now often reduced to pools during the dry season, and the sandier reaches may dry up completely during severe droughts, as in 1992. The Letaba is a larger system than the Sabie, having a channel length 105 km longer than the Sabie to the Mozambique border, and a catchment area more than twice as big. Table 8.1 summarises the main physical characteristics of the two rivers.

8.3 The water quality of both the Sabie and Letaba systems is good to excellent. Table 8.2 summarises some of the main water quality variables available from sites on the western and eastern boundaries of the KNP. Total dissolved salts in the Sabie are at exceptionally low concentrations. Total phosphate and nitrogen concentrations are similarly low. In the Letaba River dissolved salts are 4 to 6 times as high as in the Sabie. Nutrient concentrations are also higher, but are still well within acceptable limits.

8.4 Thirty-nine fish species have been recorded from the Letaba River, and 33 of these were sampled during the recent study by Chutter and Heath (1993) (see Table 8.3). In comparison, 49 fish species have been recorded from the Sabie-Sand system, and during the current study 37 of these were sampled in the middle and lower reaches of the Sabie-Sand. Thirty species from the present studies were common to the Letaba and Sabie Rivers, and 27 species were common to the Letaba and Sand Rivers (Table 8.3). Three species of fish were sampled in the Letaba but not found in the middle Sabie or the Sand.

8.5 At common taxonomic levels, 135 macro-invertebrate taxa have been recorded from the Sabie-Sand system compared to 110 from the Letaba (Table 8.4). Of these, 35 groups were exclusive to the Sabie-Sand, and 8 were exclusive to the Letaba. The animals found only in the Sabie-Sand were mainly insects (Table 8.4). Once again this comparison highlights the greater diversity of the Sabie-Sand system, but also confirms that the fauna of the Letaba is far from impoverished. It would be rash to ascribe the differences in invertebrate communities in the two rivers simply to differences in the flow regimes, since the Sand River has a seasonal flow regime similar to the Letaba, and yet appears not to be 'nhabited by the 8 groups exclusive to the Letaba (Table 8.4).

8.6 The results presented here confirm the generally-held opinion that the Sabie River contains a more diverse fauna than the Letaba. However, the fauna of the Letaba is still diverse, and appears to have improved since the surveys reported by Russell and Rogers (1989) on fish, and by Moore and Chutter (1988) on invertebrates. These two earlier surveys were done in the wake of severe droughts in the early 1980's. Chutter and Heath (1993) consider that too much emphasis may have been placed on flow as the determining factor for fish and invertebrate communities, and it is probable that the differences in diversity between the Sabie and the Letaba are the consequence of a number of factors, including habitat diversity, the lack of instream barriers in the Sabie, lower turbidity in the Sabie, as well as the constant flow of water.

From this comparison, several species emerge as possible indicators of good conditions: Among the fish, *Chiloglanis anoterus*, *Opsaridium zambezense*, *Barbus eutaenia* and *Labeo congoro* might be the best species for further study. Of the invertebrates, the habitat requirements of the mayflies and caddisflies which are confined to the Sabie-Sand system should be identified, as should those of the stone-fly *Neoperla spio*.

9. CONCLUSIONS: THE CONDITION AND COMMUNITIES OF THE SABIE-SAND SYSTEM

9.4 For the Sabie River, the results of this three year survey have shown that all the species that were recorded in the river during Pienaar's (1978) survey are still present in the river, and that the riverine fauna of the Sabie still appears to be as diverse as ever. The communities had yet to recover from the drought when sampling stopped in May 1993, so it is difficult to say how long full recovery may take. It is certain that, if low flow conditions become the norm, the communities in the Sabie will change considerably.

Water quality in the Sabie is still excellent, and in some aspects is considerably better than the drinking wa*er supplied in much of South Africa. It is important to remember that we are not dealing with an original state of the river, since mine dump pollution virtually wiped out the natural fauna in the middle reaches earlier in the century. The recovery of the fauna has been remarkable, and has only been possible because of the presence of refuge tributaries in the system. One cannot help wondering if the same level of recolonisation would be possible if similar pollution were to reach the Sabie now.

9.5 The middle reaches of the Sand River have been reduced to seasonal flow during most years, with the result that the communities are significantly different from those of the perennial reaches. This makes the maintenance of the perennial upper warm tributaries of vital importance as refuges for recolonisation. The drought, the construction and subsequent collapse of the Zoeknog Dam on the Mutlumuvi, and the diversion of the upper Sand by the Champagne Castle Citrus Estates during 1991, all combined to degrade conditions in these upper reaches. If such multiple events and conditions were to become more frequent, the survival of natural communities in the upper and middle portions of the Sand River would be put at risk.

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minute. Cut levels divide the abundance of each species at each site into categories termed pseudospecies, allowing presence or absence of each abundance category to be compared quantitatively (section 3.5.3.2). Indicator species for each division are listed together with the respective pseudospecies preferential values responsible for the classification.

Figure 7.3: Dendrogram showing that the fish assemblages of the Sabie-Sand system can be classified according to river zones. Data has been reduced from 44 quarterly monitoring surveys by season in the Sabie-Sand catchment over four years (1990-93). Abundances for 44 species were root-root transformed, standardized and compared using the Bray-Curtis measure. The dendrogram was formed using group averages sorting. Two main groups are distinguished at an arbitrary similarity index of 20%, showing the FHZ and LZ. The FHZ can be sub-divided into two site specific groups while the LZ can be divided into 3 groups possibly reflecting river profile and order. Further divisions in both groups are strongly dependent on sample sites themselves. Samples are numbered by site.

Figure 7.4: Zonation in the Sabie-Sand system reflected by the distribution of fish assemblages. Ordination using multi-dimensional scaling (MDS) on the same similarity matrix as Fig. 7.3. Quarterly samples of 44 fish species from 44 sites reduced by season for three years were used. Clusters and sub-divisions distinguished in the dendrogram are delimited. Data reduction masked seasonal assemblage differences thus strengthening site specific interpretation. Clusters 1 & 2 and 1a & 1b are spatially distinct. This results from FHZ/LZ division and the separation of impacted site 3. Clear divisions within cluster 2 (LZ) are not marked although two gradients are proposed.

Figure 7.5: Dendrogram of inverse analysis comparing 31 fish species (cutoff at 4% dominance in any of the 67 samples) in the Sabie-Sand catchment between May 1990 & May 1993. Species abundances were standardized and compared using the Bray-Curtis measure with group average sorting. At the 8% similarity level cluster 1 & 2 are cool and warm species respectively with cluster 3 an outlier. Warm species can be divided at the 30% similarity level into three groups and a series of cold tolerant species (2d). The first group of species (2a) breed during drought, group 2b are margin or run species, while group 2c are minnows typical of pools and include their associated predator *Serranochromis meridianus*.

Figure 7.6: MDS inverse ordination for 31 fish species from the Sabie-Sand catchment using standardized abundances and Brey-Curtis measures. Main species groups delineated from Fig. 7.5 (previous dendrogram). FHZ species (1) & LZ species are distinct. Eurythermal species from both zones concentrate closer to the interface between clusters 1 & 2. Cluster 3 contained two species associated with the recovery floods in the catchment post drought.

Figure 7.7: Baseline pie diagrams for small fish electrofished in the foothill zone (FHZ), upper Sabie and Marite rivers, during pre-drought conditions (1990-91). Pies

index species make up between 87.3% to 91.8% of the catch. Pies are percent averages for species standardized (STD unit = fish/min). Pie (a) is the pre-drought baseline for May where *Chiloglanis anoterus* is the most numerous (60% of index species). After the failed 1991-92 wet season (b) catches of *Chiloglanis anoterus* were reduced to their lowest (19%) while *Barbus marequensis* increases to 35%. Recovery by May 93 shows pie (c) similar to the 91 baseline pie except for *Varicorhinus nelspruitensis* which had been relatively more numerous than *Barbus polylepis*.

Figure 7.12: May pie diagrams for small fish electrofished in the lowveld zone (LZ), Sabie and Sand rivers over four years. Pies are percent averages for species standardized (STD unit = fish/min). Pre-drought pies (a) & (b) are very similar, with cyprinids making up over 75% of the index species catch and minnows comprising about 50%, (*Barbus viviparus* was the most numerous at 30%). The cichlids *Oreochromis mossambicus, Pseudocrenilabrus philander* & *Tilapia rendalli* made up only 10-15%. After the failed wet season of 1991-92 (c) and prior to the severe dry season, cichlids made up over 50% of the index species while minnows were reduced. By May 93 (d), some recovery in the catch of *Labeo molybdinus* is evident while *Barbus viviparus* remains less abundant.

Figure 7.13: Distribution and abundance of the Lowveld Zone (LZ) indicator species, *Barbus viviparus* in the Sabie River system. Abundance is shown as average station CPUE (fish/minute), at different altitudes (mASL). *B.viviparus* was typically the most abundant lowveld fish found at all LZ stations within the Sabie-Sand River. It was particularly abundant within the lower order Sand sub-catchment streams (max CPUE, 2.9). Abundance decreases towards the lower Sabie River. *B.viviparus* is absent in the lower Incomati system.

Figure 7.14: Distribution and abundance of the Foothill Zone (FHZ) indicator species, *Chiloglanis anoterus* in the Sabie River system. Abundance is shown as average station CPUE (fish/minute), at different altitudes (MASL). *C.anoterus* was the most abundant species at higher altitudes within the FHZ in both the Sabie (max. CPUE, 1.8) and Sand sub-catchments (max. CPUE, 2.2). The species is absent in the lower Sabie-Sand system. It does penetrate the Sabie River in suitable habitats to 220 mASL. It is limited in FHZ in the smallest or first order streams surveyed.

Figure 7.15: Availability and bias curves for velocity and depth as well as substrate/cover histograms for the Foot Hill Zone (FHZ) and Lowveld Zone (LZ) sites. In the FHZ, relatively higher flows were recorded (above 0.75 $m.s^{-1}$ (a), peaking at 0.95 $m.s^{-1}$). At LZ sites (d) slow to no-flow velocity predominated. Slightly deeper waters were sampled at FHZ sites (b) (52 cm) with a bias towards deeper waters (>90 cm) compared to LZ sites where there was a bias towards shallower waters (e) (<20 cm deep). Channel Index codes (CI) (section 7.6.2) for the FHZ (c) show that combined cover predominated with boulder in flow the most commonly available substrate/cover type. All cover types were available at LZ sites (f), with combined velocity/visual cover relatively more

common. Bedrock and sandy runs with marginal vegetation and cobble in flow were the most common substrate/cover types sampled in shallow waters. Compared to FHZ sites, there was a bias towards exposed and some sheltered bedrock.

Figure 7.16: Utilization and preference curves for velocity and depth, as well as substrate/cover histograms for *Barbus annectens* juveniles. Juveniles preferred quiet waters (zero flow) mostly below 0.1 $m.s^{-1}$ (0.8 suitability) (a). They preferred deep waters in pools (b) not generally accessible to electrofishing (>80 cm deep). *Barbus annectens* was often found taking cover from flow in marginal vegetation or in quiet waters in cobble or in deep pools with no cover bar depth. They preferred quiet deep pools with soft substrates or cobble (c) or if with flow, a pebble substrate. * = excluded substrate codes not possible within cover type.

Figure 7.17: Utilization and preference curves for velocity and depth, as well as substrate/cover histograms for *Barbus eutaenia* juveniles. Most juveniles were found in flows between 0.1 & 0.5 $m.s^{-1}$ (a) and in shallow water (22 cm) (b). Juveniles preferred combined velocity and visual cover although some shade cover was used (c). Preferred substrates ranged from pebble & cobble to vegetation over bedrock. * = excluded substrate codes not possible within cover type.

Figure 7.18: Utilization and preference curves for velocity and depth, as well as substrate/cover histograms for *Barbus eutaenia* adults. Like juveniles, adults preferred a flow (a) of 0.35 $m.s^{-1}$ and were mostly in flows < 0.7 $m.s^{-1}$. They preferred shallow waters (12 cm) (b). Adults preferred velocity shelter but some combined cover was used (c). Substrates utilized were mostly cobble but cobble and vegetation and some gravel were preferred to other cover. * = excluded substrate codes not possible within cover type.

Figure 7.19: Utilization and preference curves for velocity and depth, as well as substrate/cover histograms for *Barbus marequensis* juveniles. Juveniles preferred moderately high flows (a) of 0.75 $m.s^{-1}$ in rapids and shallow waters (22 cm) (b). They utilized a variety of cover and substrates types (c) particularly cobble in flow, but preferred open bedrock runs. * = excluded substrate codes not possible within cover type.

Figure 7.20: Utilization and preference curves for velocity and depth, as well as substrate/cover histograms for *Barbus polylepis* juveniles. Juveniles most preferred sluggish flows (a) (0.15 $m.s^{-1}$) and relatively deeper waters (72 cm) (b). Although most utilized boulders in currant (c), they preferred roots mats both marginal to (visual instream cover) and in flow (combined cover). * = excluded substrate codes not possible within cover type.

Figure 7.21: Utilization and preference curves for velocity and depth, as well as substrate/cover histograms for *Barbus radiatus*. Fish collected preferred zero flow (a) almost exclusively as well as the deepest waters sampled (> 90 cm)

(b). They *utilized and preferred marginal vegetation in bedrock pools (c)*. * = excluded substrate codes not possible within cover type.

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Figure 7.25: Utilization and preference curves for velocity and depth, as well as substrate/cover histograms for *Barbus viviparus* juveniles. Juveniles preferred quiet waters or cover adjacent to moderate flows mostly below 0.3 m.s^{-1} with flows of 0.95 m.s^{-1} still suitable) (a). Shallow waters were preferred (32 cm) (b). Although they utilized all cover and substrate types (c) particularly marginal vegetation, they preferred boulders in flow (instream velocity shelter), pebbles and shade. * = excluded substrate codes not possible within cover type.

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Figure 7.27: Utilization and preference curves for velocity and depth, as well as substrate/cover histograms for *Chiloglanis anoterus* juveniles. Juveniles preferred the fastest of flows (>1.4 m.s^{-1}) (a) which were limited within the

All cover and substrate types were utilized (c) except overhead cover. Although they utilized cobble in flow they preferred gravel/pebble, a limited substrate type in the head of downstream pools in the lowveld. * = excluded substrate codes not possible within cover type.

Figure 7.34: Utilization and preference curves for velocity and depth, as well as substrate/cover histograms for *Oreochromis mossambicus* juveniles. Juveniles prefer shallow waters (32 cm) (b) with zero flow (a). Cover and substrate use is ubiquitous (c). Besides vegetation bordering sandy runs with flow, preference is for visual cover in all substrates excluding boulders. * = excluded substrate codes not possible within cover type.

Figure 7.35: Utilization and preference curves for velocity and depth, as well as substrate/cover histograms for *Oreochromis mossambicus* adults. Adults prefer zero flow (a) with some tolerance of higher flows at lower suitability and shallow to deeper waters (33-63 cm) (b). Like juveniles, they mostly utilized marginal vegetation over sand (c) with combined cover. Adults preferred marginal cover over sand without flow or adjacent to flow, over bedrock. * = excluded substrate codes not possible within cover type.

Figure 7.36: Utilization and preference curves for velocity and depth, as well as substrate/cover histograms for *Pseudocrenilabrus philander* juveniles. Most preferred quiet backwaters in zero flow (a) and very shallow waters (<12 cm) (b). Juveniles utilized cover both instream velocity and visual (c). All substrates, but particularly marginal vegetation over fines/sand was used. Juveniles preferred a gravel/pebble substrate in backwaters to all others. * = excluded substrate codes not possible within cover type.

Figure 7.37: Utilization and preference curves for velocity and depth, as well as substrate/cover histograms for *Pseudocrenilabrus philander* adults. Like juveniles, adults preferred quiet backwaters with zero flow in shallow waters (mostly below 8 cm depth). They utilized visual cover both in and out of flow and particularly marginal vegetation over sand. They preferred visual cover in backwaters over most substrate types. * = excluded substrate codes not possible within cover type.

Figure 7.38: Utilization and preference curves for velocity and depth, as well as substrate/cover histograms for *Serranochromis meridianus* juveniles. Juveniles fish preferred shallow (32-42 cm) (b) backwaters with zero flow (a). They utilized mostly marginal vegetation adjacent to flow (combined cover) but they preferred backwaters in both vegetation over sand and within boulders (instream visual cover) (c). * = excluded substrate codes not possible within cover type.

Figure 7.39: Utilization and preference curves for velocity and depth, as well as substrate/cover histograms for *Tilapia rendalli* juveniles. Juveniles preferred shallow (32 cm) backwaters (b) in zero flow (a). They were mostly collected in marginal vegetation over both fines and bedrock (c) adjacent to flow

SUMMARY LIST OF TABLES

LIST OF ACRONYMS

CPUE:	Catch Per Unit Effort
DO:	Dissolved Oxygen
FHZ:	Foothill Zone
GIS:	Geographical Information System
KNP:	Kruger National Park
mASL:	Meters Above Sea Level
KNPRRP:	Kruger National Park Rivers Research Programme
LZ:	Lowveld Zone
MLA:	Maximum Level of Acceptability
NOEL:	No Observed Effect Level
NT:	Number of Taxa
NTU:	Nephelometric Turbidity Unit
SL:	Standard Length
SRP:	Soluble Reactive Phosphorous
STW:	Sewage Treatment Works
TNI:	Total Number of Invertebrates
TSS:	Total Suspended Solids

1. INTRODUCTION

1.1 RATIONALE AND OBJECTIVES FOR THIS PROJECT

This project forms part of the multi-disciplinary Kruger National Park River Research Programme (KNPRRP), whose goals are:

- To inform researchers, system managers and stakeholders about the water quality and quantity requirements to sustain the natural environments of rivers which flow through the Kruger National Park, and
- To develop, test and refine methods for predicting the responses of the natural environments of rivers in southern Africa to changing water quality and patterns of supply.

There are six major rivers which transect the Kruger Park: The Luvuvhu in the North; the Shingwedzi; the Letaba; the Olifants; the Sabie-Sand; and the Crocodile which forms the southern boundary of the Park. All these rivers rise outside the western boundary of the Park, and their upper catchments are therefore outside the jurisdiction of the National Parks Board. Commercial forestry, mining, impoundment, water abstraction, irrigation, and growing populations in the former homelands, have all caused water quality and quantity problems for the rivers of the KNP.

The Sabie River is at present the least impacted of the six rivers. It still maintains a perennial flow and contains good quality water at all times. It is probably the least-impacted of the larger rivers of southern Africa, and contains the most diverse fish and invertebrate fauna of any known in the region. Because of the growing demand for water in the catchment, in particular in Gazankulu and Lebowa, and because of the demands of commercial forests in the upper catchment, flow in the river has been constantly reduced. A catchment study by Chunnett *et al.* (1990) identified 8 possible new dam sites on the Sabie and its major tributary the Sand River (although all 8 are unlikely to be built). Such impoundments will alter the hydrological and temperature regimes, sediment loads and water chemistry downstream, and these physico-chemical changes will inevitably cause impacts to the riverine biota. Some of these impacts may be harmful to the biota, reducing diversity and abundance, while others may be beneficial, for example, providing the capacity to augment flows during droughts.

The main objectives of this project were therefore to characterise the present instream chemical, physical and biological conditions in the Sabie-Sand River system, and to predict the consequences of impoundment and increased water abstraction on the riverine biota. The precise aims of the project were defined as follows:

1. To characterise the present chemical, physical and biological conditions in the Sabie-Sand River system before any of the planned impoundments are built. (This Volume)
2. To assess the probable extent of ecological disturbances and advantages resulting from future regulation (particularly within the Kruger Park), and to recommend management guidelines to minimise impacts and to maximise new opportunities for water management. (Volume III)
3. To collect basic biological and hydro-geomorphological data which will allow the calculation of instream flow requirements for the system. This will include the identification of target organisms and their distributions, flow and substratum preferences, as well as modelling the habitat changes caused by different flow regimes. This last component will involve the generation of data to be supplied to the instream flow incremental methodology model (IFIM) being developed by Dr J M King and Ms R Tharme of the Freshwater Research Unit at the University of Cape Town. Instream flow requirements will be calculated within the framework of maintaining maximum natural biological diversity and with respect to the requirements of sensitive key species. (This Volume, Chapters 6 and 7)

4. To assess the probable effects of river regulation in the eastern Transvaal Lowveld against those already measured for regulated systems in the western Cape (Palmiet River), and eastern Cape (Buffalo River). This will broaden our knowledge of the general ecological consequences of impoundment on southern African river systems. (Volume III)
5. To develop a long-term surveillance system which will provide information on key changes within the Sabie-Sand River system (for example, the invertebrates, the riparian vegetation, channel morphology, etc.), in order to distinguish between natural cyclical changes and those which may result from river regulation and other disturbances. (Volume III).
6. To develop a collaborative methodology which will allow comparisons to be made between datasets on different Kruger National Park river systems. Collaboration will take place between this programme and those of Dr Chutter and Mr Heath on the Letaba system, and Dr King and Ms Tharme's development of instream flow methodologies. Further collaboration will also be developed between this Programme and the Foundation for Research Development Programme on the rivers of the Kruger National Park which will be led by Dr Rogers of the University of the Witwatersrand, the general Kruger National Park Rivers Programme, and researchers and managers of the Transvaal Provincial Administration, and the Department of Water Affairs and Forestry.

In addition to these objectives, subsequent modifications to the programme took place on a response and need-to-know basis. These additions placed enormous additional burdens on the Project research staff, who none-the-less not only coped, but gathered unique and enormously valuable information. The first addition was necessitated by the fact that during 1992, the eastern Transvaal lowveld experienced the worst drought in living memory and as the river went into drought stress, experiencing complete cessation of flow in the Sand River, the team was asked to intensify their field research effort in order to examine the response *of the river and its biota to drought stress, followed by a drought-recovery monitoring period* (See Volume II).

A further burden was placed on the team in early 1992 when the Zoeknog Dam on the Mutlumuvi tributary of the Sand River collapsed during the early filling phase. Since the project team had a two year database of biological and physico-chemical information from sites up- and downstream of the dam site, the Department of Water Affairs requested an assessment of the effects of the dam failure on the fish and invertebrates, particularly in response to increases in silt transport and habitat smothering (Section 2.4, volume 3).

This is the first of three volumes of the project report, and describes the physico-chemical status of the rivers, and the status of the fish and invertebrate communities in the river. These conditions are compared with those in the Letaba River, and the hydraulic habitat preferences of the main fish species and invertebrate groups are described. The second volume documents the effects of the 1991-92 drought, and the third volume assesses the probable effects of planned impoundments on the downstream biota, and includes recommendations for the environmental management of the dams, as well as for the continued monitoring of the Sabie-Sand River system.

2. THE SABIE-SAND RIVER SYSTEM

2.1 TOPOGRAPHY, GEOLOGY, SOILS AND CLIMATE

The Sabie-Sand River system forms part of the Incomati system, an international drainage basin lying across several political boundaries - the Republic of South Africa, the former homelands of Gazankulu, Lebowa and KaNgwane, the Kingdom of Swaziland and Mozambique (Fig. 2.1; Chunnett *et al.*, 1990). Stretching from the Drakensberg Escarpment of the eastern Transvaal, across the Lebombo Mountains to the east, its confluence with the Incomati occurs 45 km beyond the Mozambique border with South Africa. From its sources to the Incomati confluence, the catchment of the Sabie-Sand covers some 709 600ha (Chunnett *et al.*, 1987, 1990; Wells, 1992). The Sabie River comprises the mainstem of the system, with the Sand and Marite Rivers acting as major tributaries (Figures 2.1, 2.2); for the purposes of this report, the Sand River is regarded as a sub-catchment of the Sabie, while the Marite and Mac Mac rivers are considered to be tertiary drainages (Fig. 2.2).

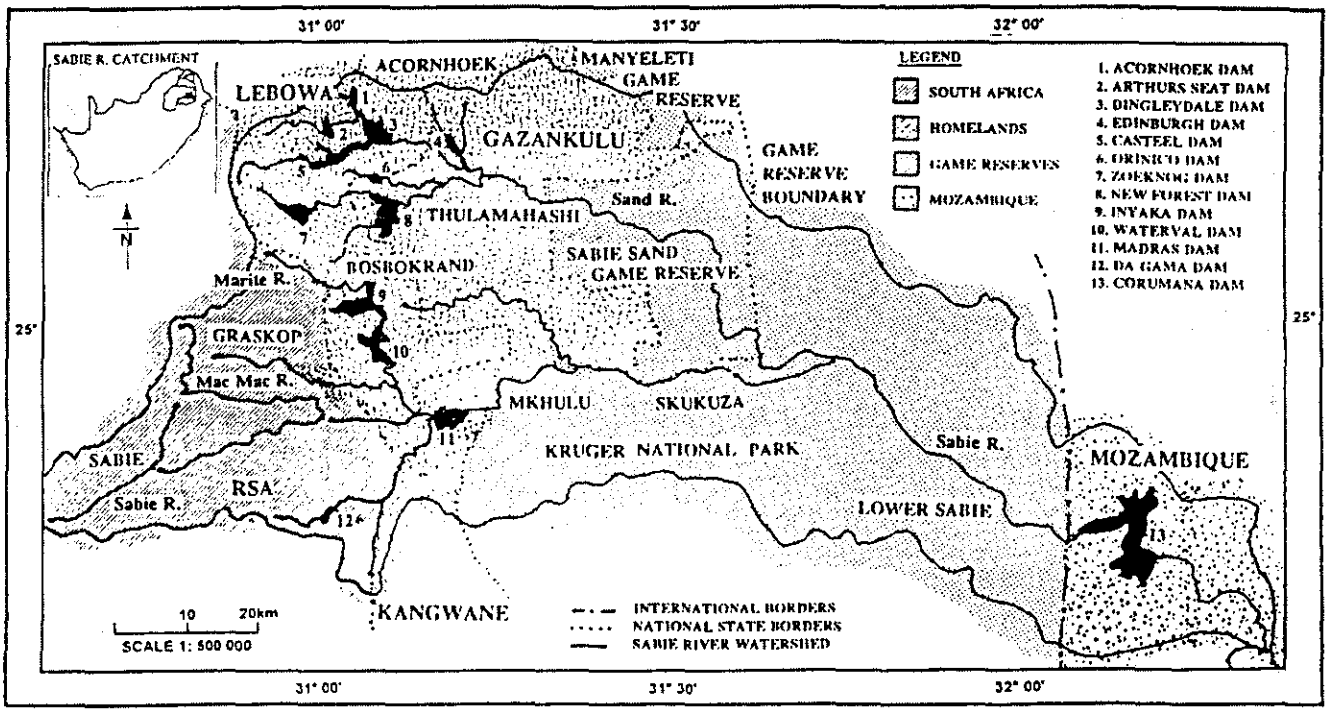

Figure 2.1 Map of the Sabie-Sand system showing major political boundaries at the time of the survey, land-use and proposed and current dam sites.

The topography of the catchment is such that the Sabie River arises at 2 130 mAMSL on the eastern Escarpment. Dropping precipitously, it reaches its confluence with the Sand River, some 125km to the east, inside the western boundary of the KNP, and then reaches the Mozambique border at an altitude of 120 mAMSL, some 175km from source, after passing

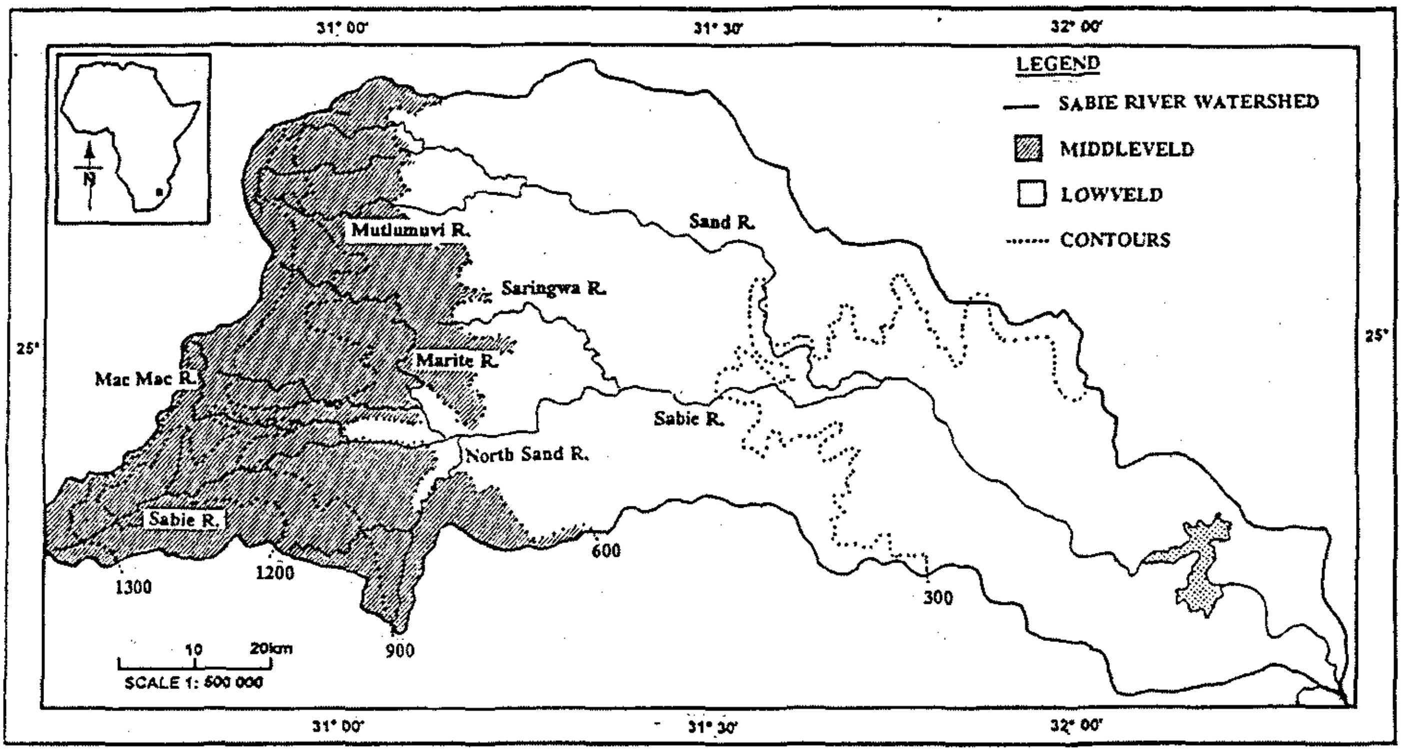

Figure 2.2 Major tributaries and topographical map of the Sabie-Sand River system up to the Mozambique border at the eastern boundary of the Kruger National Park.

through the south-central sector of the KNP (Fig. 2.2). Effectively, the system starts in the "Middleveld", the steep and frequently undulating eastern face of the Drakensberg Escarpment that plummets from the Highveld Plateau; slopes are generally in excess of 15% in this region. At the 600 m contour, the system enters the hotter "Lowveld" which is gently-sloping-to-flat countryside covered in thorn trees, and with the exception of the transit of the system through the Lebombo Mountains, slopes are generally far less than 15%. On average this Lowveld component of the system lies at *ca.* 300 mAMSL and gently slopes towards the east. No large floodplains, swamps or wetlands of significance occur in the entire catchment of the Sabie-Sand system (Chunnet *et al.*, *1987, 1990*).

Figure 2.3 illustrates the simplified geology of the catchment which may be divided into three major subsets: Basement Complex traversing the lower Middleveld and upper Lowveld portions of the basin (from the Drakensberg to the Lebombo Mountains), the Karoo Sequence in the eastern sector of the Lowveld, and the Transvaal Sequence which lies on the mountainous western extremes of the basin, separated from the Basement Complex by a Dolomite intrusion (Fig. 2.3). The Basement Complex comprises granite and granodiorite rocks with patches of diabase and gabbro intrusions towards the south west, and a larger tonalite intrusion towards the centre of the basin. There are no mineral deposits of economic significance within this sector.

The western-most Transvaal Sequence of the steep escarpment slopes comprises a wide variety of rock types that vary from shales, quartzite, dolomite, breccia, chert, lava, tuff, basalt and conglomerates. Gold occurs frequently in this region and has led to some mining activity in the Graskop and Sabie areas of the catchment (Chunnett *et al.*, 1990). For the Karoo Sequence of the Lebombo Range, the rocks comprise mainly basalts and rhyolite of the Lebombo Group with coal, sandstones, shales and mudstones of the Ecca and Beaufort Groups. In addition, sandstones and siltstones of the Clarence Formation also occur with some granophyre and dolerite intrusions. The geological details of the KNP sector of the catchment can be found in Venter & Bristow (1986) and Venter (1990).

The soils of the catchment tend generally to be resistant to erosion, particularly when compared to other regions of southern Africa, with sediment yields varying from 400 to 600 $t.km^{-2}.yr^{-1}$ (Chunnett *et al.*, 1990).

Essentially they change from lithosols in the upper, high-lying parts of the catchment, to ferrallitic clays and arenosols lower down. On the western boundary of the KNP, the rivers flow through gabbro overlain by red and black clays, while within the KNP, the soils of the sandy crests are predominantly shallow in nature. Sodic duplex soils dominate the lower lying areas.

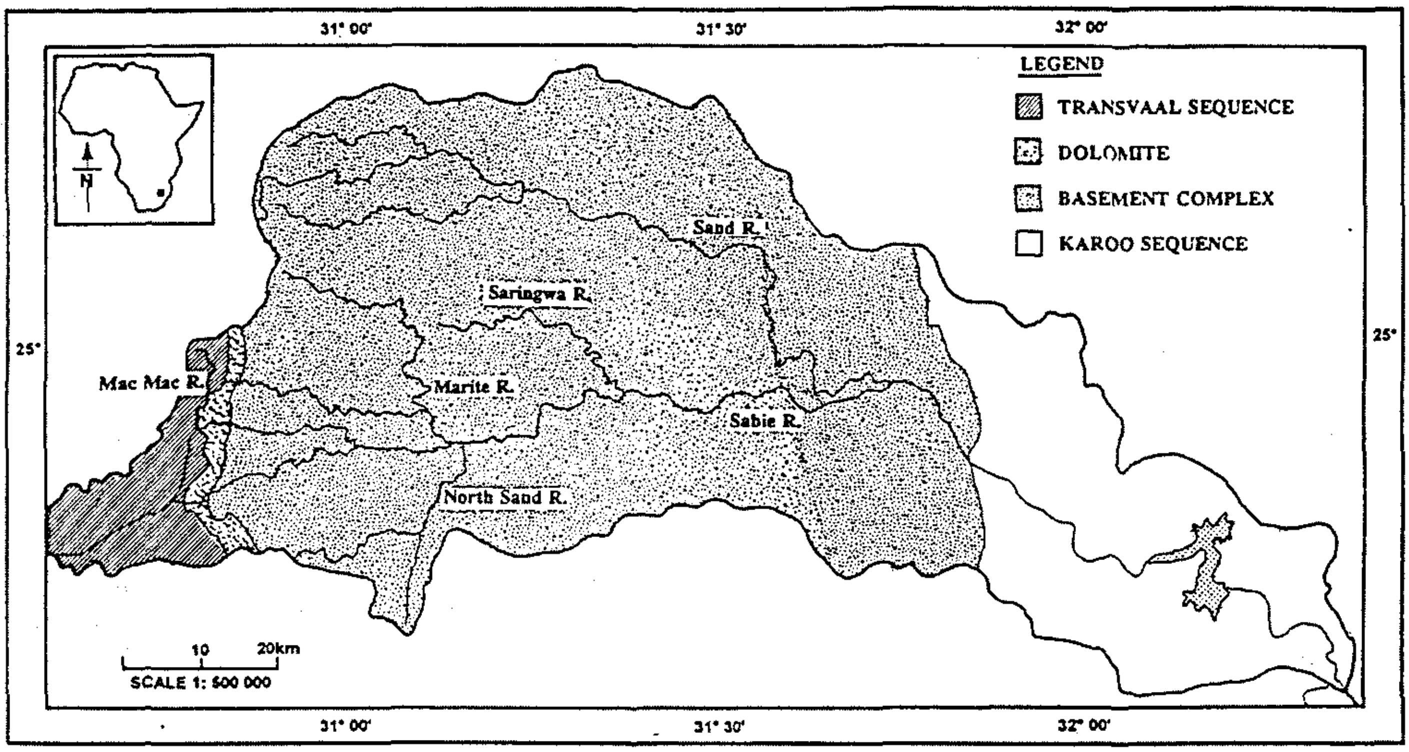

Figure 2.3 Geology of the Sabie-Sand River system up to the Mozambique border at the eastern boundary of the Kruger National Park.

The climate of the region is typical of the eastern Transvaal Lowveld: warm to hot sub-tropical summers, with variation according to altitude (Chunnett *et al.*, 1987). The mean annual precipitation (MAP) falls from 2 000 mm.yr^{-1} on the Escarpment to *ca.* 600 mm.yr^{-1} for the Lowveld (Fig. 2.4). Most rain falls between November and March, with peaks usually occurring in January, but the region is also subject to unpredictable tropical cyclones and to drought. Symons Pan evaporation is generally high, outstripping MAP throughout most of the catchment, with the exception of the upper zones of the Escarpment. Evaporation varies between 1 400 mm.yr^{-1} in the west, to 1 700 mm.yr^{-1} towards the east, with gross evaporation of the Middleveld and Lowveld respectively being 40% and 60%

higher during summer than winter. Details of rainfall and evaporation patterns may be found in Gertenbach (1980) and Pienaar (1985).

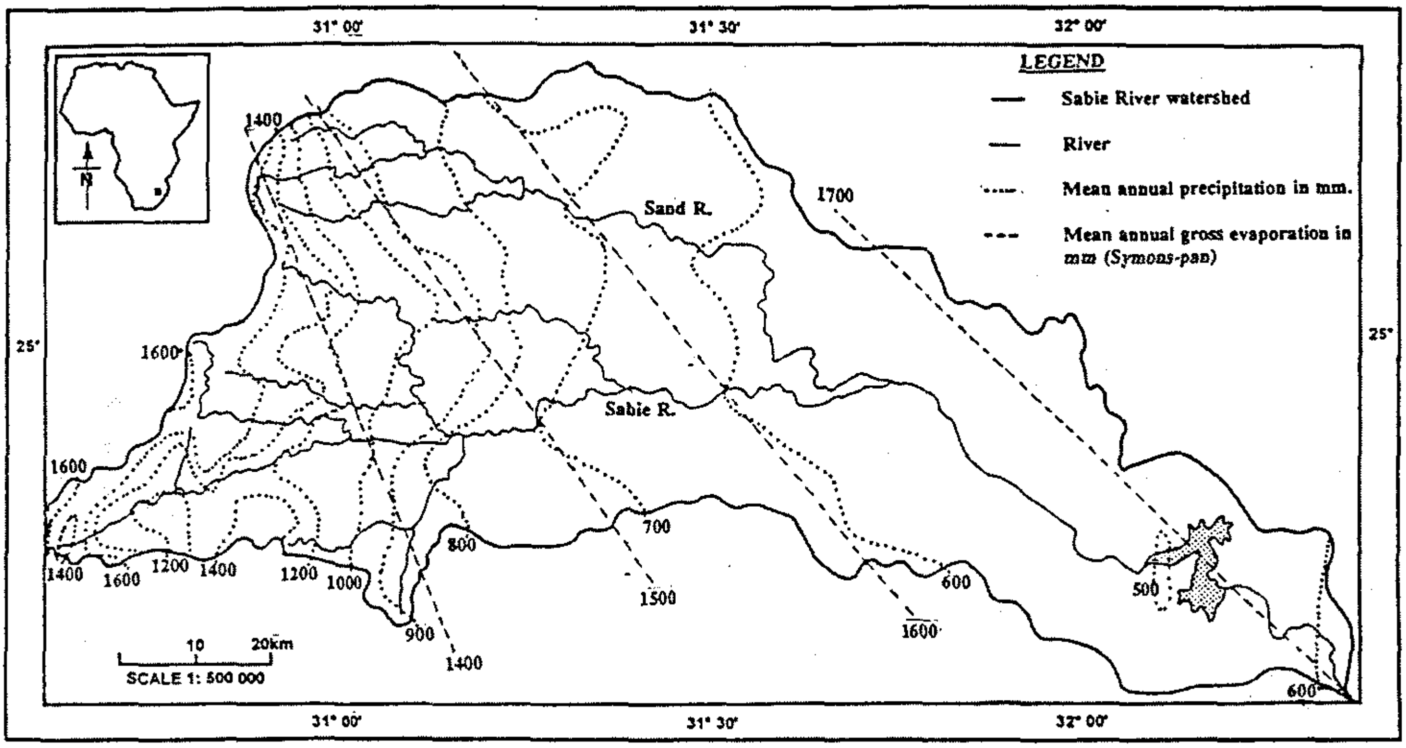

Figure 2.4: Mean annual precipitation and mean annual gross evaporation of the Sabie-Sand River system up to the Mozambique border at the eastern boundary of the Kruger National Park.

Temperatures obviously vary with altitude and given the steep gradient of the system, there are considerable changes from the Middleveld through to the Lowveld. Chunnett *et al.* (1987, 1990) report maximum and minimum summer temperatures (January) at Skukuza, as 32° and 20°C respectively, while for winter (July) they are 26° and 6°C respectively. Moving towards the Middleveld, temperatures at Bosbokrand (lower Middleveld) are recorded by these authors as: January maximum, 28°C and minimum, 18°C, while for July they are respectively 22° and 9°C. For the upper Middleveld region represented by Graskop they are: January maximum, 23°C and minimum, 14°C, while for July the maximum is 17° and the minimum, 4°C (Chunnett *et al.*, 1987, 1990).

2.2 CATCHMENT LAND USE

The upper catchment has already been exploited as far as possible for forestry, and the rivers flow through more than 74 000 ha of commercial forestry plantations (pine trees and eucalypts) (Chunnett *et al.*, 1990). Water demand from the plantations is considerable and the river has several other priority uses, not all of which are strictly compatible. In the middle catchment, predominantly made up of the former homelands - Gazankulu, Lebowa and Kangwane - it supplies potable water together with irrigation water on a limited basis, increasing towards the western boundary of KNP. Further downstream, it provides the main water supply for the southern part of the KNP where water uses are primarily for potable supply to the tourist industry associated with the Park, as well as water for conservation purposes. In terms of the afforested upper catchment, the degree of monoculture plantation has already reduced the MAR by 115×10^6 m^3 (20.5%) (South African Department of Water Affairs and Forestry, 1990). Dense and rapidly growing human populations are placing increasing demands upon the river for domestic consumption and irrigated agriculture and, to meet this, there are five existing dams on the tributaries of the Sand River and one on a tributary of the Sabie. In addition, seven further potential sites for impoundment have been identified by the South African Department of Water Affairs and Forestry in the Sabie and in its major tributaries, the Sand and Marite rivers (Fig. 2.1). A very large dam, the Corumana, has been built by Mozambique on the eastern boundary of the KNP. If the growing demands are met in full, the Sabie would cease to flow during most dry seasons (June-October), as has already occurred in the Luvuvhu and the in Letaba (Davies, 1989) over many years. The third priority use is water for nature conservation in the KNP, downstream from the other two main users.

2.3 SUMMARY OF PREVIOUS RESEARCH

Pienaar (1985) and Joubert (1986) have both provided informative accounts of the historical development of the KNP, including anecdotal evidence of the state of the rivers. Col. J Stevenson-Hamilton, perhaps the most famous warden of the KNP, was convinced in the early 1900's that the Park was becoming progressively dessicated, and he attributed these changes to large-scale deforestation in the catchments, and uncontrolled grass fires. In his 1912 annual report, Stevenson-Hamilton remarked that the Sand River had shrunk since 1902, and that in the Sabie River, islands which were barely noticeable in 1902 were heavily colonised by bush and rank grass by 1912 (Pienaar, 1985). In 1913, a well had to be sunk at Sabi Bridge to provide water for the warden and his staff, because of the polluted state of the Sabie River, due to gold-mining effluents from the upper reaches. By 1922, Stevenson-Hamilton noted that the pollution had become so bad that "the Sabie River virtually changed to a sterile stream" (Pienaar, 1985). In 1933, a survey by Mr. F.B. Jeary indicated that "micro-organisms" (presumably macro-invertebrates and algae) were non-existent in the Sabie. By the mid-1940's, the Mining Department had taken steps to stop the pollution, and the river has recovered to become biologically the most diverse in South Africa (Pienaar, 1985). This can only be the result of gradual recolonisation from the tributaries, such as the Sand and Marite, which were unaffected by mining. In the late 1960's there were still mercury deposits in the benthic silts of the Sabie River (Pienaar, 1985).

Moore and Chutter (1988) have provided a review of the more recent biological research on the rivers of the KNP up to the inception of the KNPRRP. They concluded that published information on the rivers of the KNP up to the mid-1980's related mainly to specific taxonomic groups of the fauna. Major groups of vertebrates such as the fish (Pienaar, 1961), Hippotami (Pienaar, 1966) and reptiles (Pienaar *et al.*, 1978) have been studied. Of the insects, some of the dipterans which have an aquatic larval stage have been investigated (Schulz *et al.*, 1958; Braack *et al.*, 1981), although the publications were concerned with the terrestrial adult stages and larvae from non-permanent pools.

Previous research published on the river fauna includes a checklist of Decapoda and fresh-water fish which is combined with amphibians, reptiles and small mammals (Pienaar, 1961). Another list of species is a preliminary list of dragonflies (Odonata) (Balinsky, 1965). A publication by Oosthuizen (1979) concerning the leech species *Placobdella multistrata*, makes several references to specimens collected from the KNP and Sciacchitano (1961) published a paper (in Italian) on the leeches of the KNP, Oberholzer and Van Eeden (1967) undertook an extensive survey of the freshwater molluscs of the KNP with particular reference to the vectors of bilharzia. In 1978 the five major rivers flowing into the KNP (Crocodile, Sabie, Olifants, Letaba and Luvuvhu Rivers) were monitored for pesticide residues. The results of that survey indicated that pesticides had not yet posed a serious threat to wildlife in the KNP (Van Dyk, 1978). Other than newspaper articles, reviews such as Joubert (1986) and Anon (1986), and occasional popular articles in Custos (van Jaarsveld, 1985; Van Niekerk, 1986; Cilliers *et al.*, 1987) little information has been published on KNP rivers.

In 1959 the Hydrobiology Division of the National Institute for Water Research (NIWR) collected benthic invertebrates from the Crocodile River at Malelane in July and November and from the Sabie River at Lower Sabie in November only. This study was executed as part of a research project on "South African Hydrobiological Regions" by Dr. A.D. Harrison and J.D. Agnew and their findings are recorded in Report 2 and 3 on NIWR file W6/6/8H. Many previously un-recorded Ephemeroptera (mayflies) and Trichoptera (caddisflies) were found, particularly at Lower Sabie. The fauna of the Sabie River was far more diverse than that of the Crocodile. It was concluded that the fauna has strong links with that of Central Africa. The collected material was catalogued and later donated to the Albany Museum, Grahamstown.

Moore and Chutter (1988) surveyed the benthic invertebrates of all the major rivers of the Park, and concluded that the Sabie contained the most diverse fauna, and appeared to have been least affected by man.

Since Moore and Chutter's (1988) review a considerable amount of research has been undertaken on the rivers of the KNP and the Sabie-Sand in particular, as part of the KNPRRP. A resurvey of the fish fauna of all the rivers by Russell and Rogers (1989) provided the background information on changes since Pienaar's (1978) survey. They found that there had been little observable change in the fish communities of the Sabie River, although there appeared to have been losses of up to 20% of the species from the other rivers (the Letaba and Luvuvhu) (Russell and Rogers, 1989). This implied that there had been little degradation of the Sabie system, and confirmed its conservation status as one of the highest in the country.

The geomorphology and channel forms of the Sabie have also been the subject of important research recently, since the availability of habitat is crucially dependent on geomorphological and hydrological processes. Venter and Bristow (1986) described five geomorphological zones in the Sabie within the KNP, and Vogt (1991) assessed the short-term geomorphological changes in the KNP rivers, effects that are likely to be accelerated as flow patterns change in the future.

Chunnett *et. al.*, (1990) provided a catchment study of the Sabie-Sand system which summarised the physical attributes and socio-economic environment of the catchment, analysed seasonal water availability at a number of sites, and suggested possible new impoundment sites on the system. This is to date the most comprehensive analysis of the water resources of the Sabie system.

The water quality of the Sabie system, as of the other rivers of the KNP, is the subject of long-term monitoring by the Department of Water Affairs. There has also been an attempt to define water quality guidelines for the KNP rivers (Moore *et al.*, 1990). The provisional guidelines were set in relation to the historical water chemistry database, this being the best available information at present, in the absence of knowledge about the water quality tolerances of the riverine biota.

A number of research projects on the Sabie River are currently underway or being written up as part of the KNPRRP. These include investigations of the movement of water into and out of the riparian zone, the riparian vegetation, relationships between riparian vegetation and the geomorphology, and attempts to predict the water use of the riparian vegetation. An assessment is also being made of the potential responses of the geomorphology of the Sabie River to changes in the flow regime.

At present, the Sabie River is one of the most studied rivers in the country, and a very useful database has been and continues to be built on the physical, chemical and biological components of the system. Once the current research projects have been completed, a synthesis of this information in relation to the decision support system being developed by the KNPRRP will provide an excellent level of understanding of the potential effects of further development of the water resources of the rivers. The recommendations of this report will need to be reviewed within the context of the information synthesis and simulation model to be developed in 1995.

3. MATERIALS AND METHODS

3.1 GENERAL APPROACH

3.1.1 PROBLEMS OF SCALE AND TIME

Any study that hopes to explore and understand the processes at play in running waters today needs carefully to consider the appropriate time and spatial scales, both to design the most effective sampling programme, and to interpret the data correctly. It is important to select scales that are ecologically meaningful and relevant to the questions being asked, especially considering that the full range of possible scales spans over 16 orders of magnitude (Minshall, 1988)!

Central to this study was the need for a base-line understanding of the whole Sabie-Sand system against which the effects of proposed dams could be measured. This task is complicated by the multitude of unpredictable natural variations in habitat condition and the responses of the fauna in space and time. It seems reasonable therefore to suspect that base-line conditions can only be defined to a certain level and that patterns that do exist (such as seasonal changes) may be masked by disturbances on different spacio-temporal scales such as drought, local flood events and existing anthropogenic effects (ie afforestation and dam construction). This chapter discusses how the study sites and frequency of sampling were selected, describes the location and characteristics of the sites, and gives details of the methods used to collect information on the fish, invertebrates, and physico-chemical conditions in the river. In this kind of study, which attempts to characterise many aspects of the whole river system, the number of sites and the frequency of sampling is always a compromise between the required resolution of the data, and the resources available.

3.1.1.1 THE CATCHMENT

Over the last two decades, river ecologists have realised that the catchment is the basic unit of lotic ecology (Cummings, 1992). At this level the principle factors governing the condition of the river include geological history, basin erosion, climax vegetation, drainage density, flow regime and mean annual temperature (Minshall, 1988). Catchment processes typically operate on a scale of the order of 100 km^2.

The initial aim of the study was to classify the Sabie-Sand catchment in its regional context, and explore the suspected longitudinal zonation of the associated biota. Previous studies of the Sabie-Sand River have neglected such an approach as emphasis on political and conservation boundaries stunted ecological understanding of lowveld rivers. At the first level of resolution, annual survey stations were established catchment-wide. These were surveyed in May, at the start of the dry season, when river reaches were both easily workable and were expected to reflected the passage of the past wet season.

3.1.1.2 BASE-LINE BIOLOGICAL DATA

The base-line referred to in this study, is an attempt to describe typical conditions in the different regions of the river, and the characteristic biota associated with habitat types under typical hydrological conditions. While acknowledging the variability of these rivers, it is still important to get an idea of a base-line community against which to compare the changes caused by perturbations, both natural and unnatural. We are in agreement with Cummings (1992) that the species assemblages have evolved hand-in-hand with the particular flow conditions and channel patterns available, and with Southwood (1977) who suggests that habitat acts as the template onto which species have adapted.

The annual samples at 21 sites provided a general view of the communities throughout the river system. To explore seasonal patterns in community changes, 9 of the stations were sampled quarterly. This provided the second level of resolution. Fish were sampled at the scale of the reach (about 100 m), each reach being divided into a series of habitat types (such as pools and riffles). Macroinvertebrate samples were collected at a slightly smaller scale from the variety of substratum patches available within the study reach (scale in m^2).

3.1.1.3 BIOLOGICAL AND HABITAT DATA FOR INSTREAM-FLOW RECOMMENDATIONS

The third level of resolution for data collection addressed the specific microhabitat use of the ichthyofauna and invertebrates. Microhabitat was defined by the hydraulic parameters of flow, depth, substrate and cover, and a detailed description of the methods is given in section 3.6.

3.1.1.4 DROUGHT STUDIES

The drought of 1991-92 provided the opportunity to study conditions in the rivers during the worst drought on record. A series of sites representing the lowveld were monitored on a monthly basis from June to November 1992. Reaches where flow stopped were mapped and pools monitored. Pool volume, chemical characteristics and initial species assemblage were recorded and the evolution and fate of pools were closely monitored using the methods described in section 3 (Vol. II). Volume II of the report describes the effects of the drought.

3.2 STUDY SITE SELECTION

To ensure that all habitats/conditions were represented by the sample sites, the rivers were divided into segments on the basis of topography, geology, water quality, and species distribution parameters (as recommended by Bovee & Milhous, 1978). Also considered were details of flow regime, channel morphology and channel pattern (Bovee 1982). The catchment was stratified into segments on the basis of Chunnett *et al.* (1990). River zonation, natural vegetation types (Acocks, 1975) and topography were initial considerations.

3.2.1 SURVEY SITES

We use the term station for points on the rivers that were repetetively s.ampled. The term sites refers to any point on the river, whether it was visited once or frequently. Twenty sites were initially identified on 1:50 000 maps before being verified in the field. The positions of the eight potential dam sites were also considered in the choice of sample sites, so as to include stations above and below dam sites. Point sources of pollution (such as sewerage works) and existing weirs were avoided for the purposes of the routine surveys, because we wished to characterize the typical fauna of each segment. Separate samples were collected from these sites to assess their effects on the biota. Site 18 was replaced by station 21 as the former site was situated at a citrus irrigation canal which drastically affected discharge readings. Following the initial site selection, two levels of survey stations were established. The first level constituted the catchment-wide annual survey sites, nine of these sites were chosen as quarterly monitoring stations.

As the study progressed, further sites were identified as needs or problems arose. Sites 22-24 were chosen in reaches with large pools, to allow gill-netting. Station 25 was established to monitor the effects of the construction of the Zoeknog Dam. Site 26 was surveyed for detailed hydraulic habitat studies, as an alternative to site 13, where access was denied by an uncooperative land owner. Site 27 was surveyed following the Zoeknog Dam burst, while Site 28 was surveyed to help explain a gap in some fish distributions in the upper Sabie River. A full list of sites is given in Table 3.1.

3.2.2 MONITORING SITES

Nine monitoring stations were sampled quarterly to provide information on seasonal changes. These stations included three headwater sites (Station 3, 5 & 21), and six lowveld sites. Three stations were on the Sand River (Stations 11, 13/14 & 19) and three on the Sabie (Stations 6, 7/9, & 20). Hydraulic habitat measurements were also taken at these sites. Quarterly monitoring changed from site 13 to 14 and sites 7 to 9 because of logistical and suitability problems respectively.

Table 3.1: A complete list of names, locations, altitude and gradient for all field sites *surveyed, monitored or mentioned in this study.*

STATION No.	LOCALITY	ALTITUDE masl	GRADIENT m/km	LATITUDE	LONGITUDE
1	Above Sabie	1270	44.0	25°09'04S	30°39'39E
2	Mac Mac	1328	9.1	24°57'35S	30°49'52E
3	Rocky Boulder	867	18.2	25°03'48S	30°51'28E
4	Bandits	619	8.7	25°02'11S	30°59'06E
5	Hazyview	488	4.9	25°01'48S	34°01'21E
6	Mkhuhlu	402	3.3	25°01'93S	31°14'40E
7	Lisbon	320	3.3	24°58'12S	31°24'14E
8	Skukuza	265	1.7	24°58'35S	31°35'05E
9	Confluence	220	2.5	24°57'47S	31°44'28E
10	Welgevonden	745	30.8	24°42'38S	30°55'46E
11	Rooiboklaagte	538	2.7	24°41'09S	31°03'39E
12	Dinglydale	458	4.9	24°42'25S	31°10'37E
13	Exeter	384	3.5	24°45'10S	31°20'22E
14	Londolozi	315	4.0	24°47'31S	31°31'32E
15	Mala Mala	275	1.8	24°55'08S	31°35'44E
16	Maritsane	785	5.3	24°50'37S	31°02'50E
17	Inyaka	715	9.5	24°53'25S	31°05'27E
18	Citrus Bridge	480	14.3	25°00'25S	31°06'58E
19	New Forest	499	4.8	25°45'34S	31°07'41E
20	Mlondozi	140	3.7	25°09'35S	31°59'52E
21	The Gums	620	9.6	24°56'18S	31°04'43E
22	Coffee Dam	635	-	24°55'35S	31°05'32E
23	Hippo Pool	550	-	24°41'30S	31°05'07E
24	New Weir	281	-	24°58'05S	31°30'25E
25	Zoeknog	660	16.7	24°45'22S	31°00'30E
26	Meat Factory	260	1.8	24°57'58S	31°37'27E
27	Above Zoeknog	708	13.6	24°45'35S	30°58'30E
28	Sabie Sewage	955	8.5	25°05'20S	30°48'01E

3.3 STUDY SITE DESCRIPTION

3.3.1 FIXED POINT PHOTOGRAPHY

A photograph from a fixed point was taken each time a station was surveyed. This provided an indication of the appearance of habitats typical of the station and recorded the major physical changes. Furthermore, the photographs also furnished details of different flow regimes at the different reaches (Vol. III, Appx. I).

3.3.2 TRANSECTS

A permanent flow transect was established at each study site using cement headstakes. These transects were selected to describe the flow conditions, and habitat availability associated with different discharge rates.

3.3.3 RIPARIAN STRIP AND MARGINAL VEGETATION COMPOSITION

At all the monitoring sites, the transects were eventually extended to include the riparian strip. The transects included all features that were depositional, and the presence of any vegetational elements associated with the river. Vegetation was classed into the following groups: riparian tree and shrub, reed, grass or herbs. The marginal vegetation was further described by employing a 50 m x 1 m vegetation transect along the water's edge.

A further three stations (6, 9 & 26) were selected for detailed hydraulic measurements and were described using 6 to 8 transects, for eventual use in the PHABSIM model.

3.3.4 SITE PROFILES

A list of site particulars are provided in Table 3.1. Stream order was assigned by employing Strahler's (1956) ordering system (Fig. 3.1).

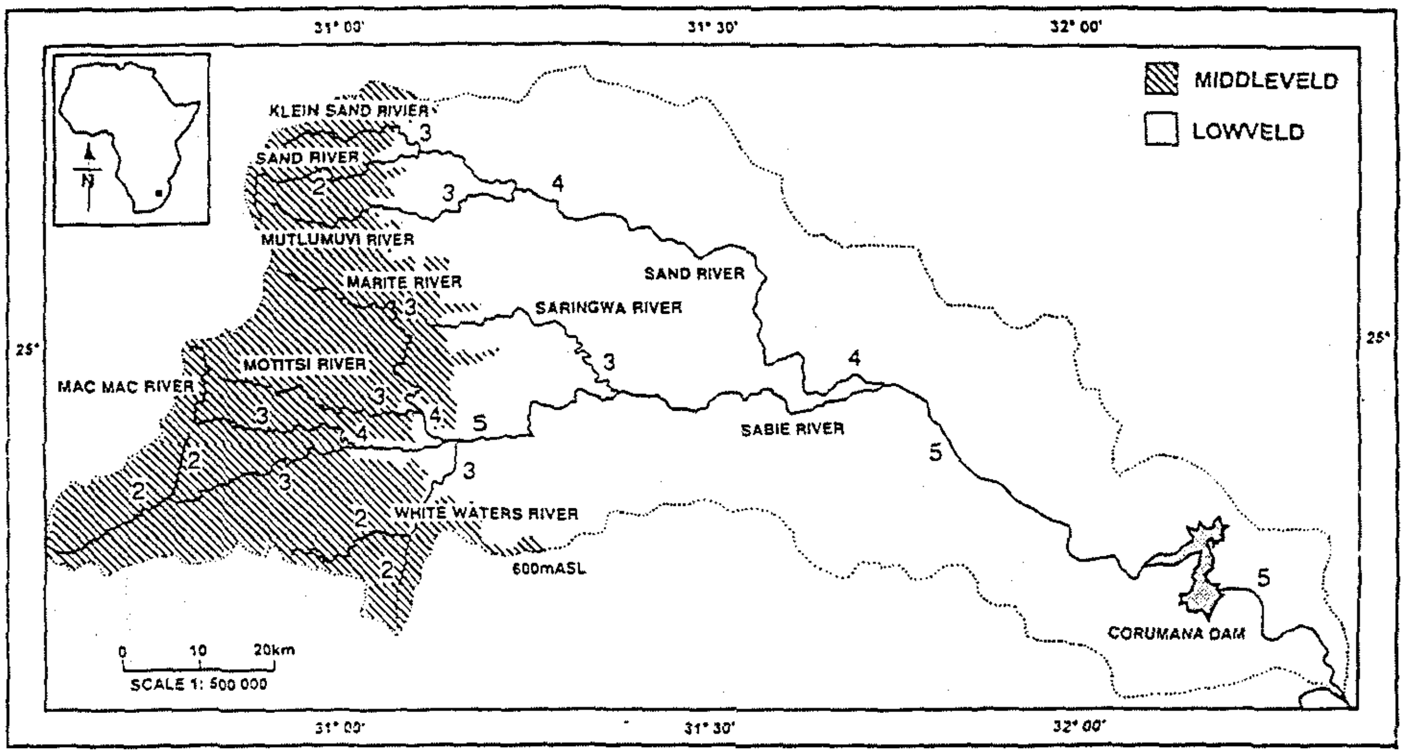

Figure 3.1 Stream ordering within the Sabie River system using Strahler's (1957) classification. Standard 1:50 000 maps were used.

Site 1: (25°09'04S, 30°39'39E)

An annual survey station, situated on a first order, clear and cold mountain stream with a steep gradient (44 m.km^{-1}) (Fig. 3.2-3). Site 1 is located ±4 km from the source at an altitude of 1270 mAMSL within the "mountain source & waterfall" zone of Chunnett *et al.* (1987).

The river flows through a narrow natural ribbon of forest surrounded by pine plantations. Introduced trout were the only fish present. The river bed substratum consisted mainly of boulder and cobble with short riffle-run sequences averaging 7.1 m.

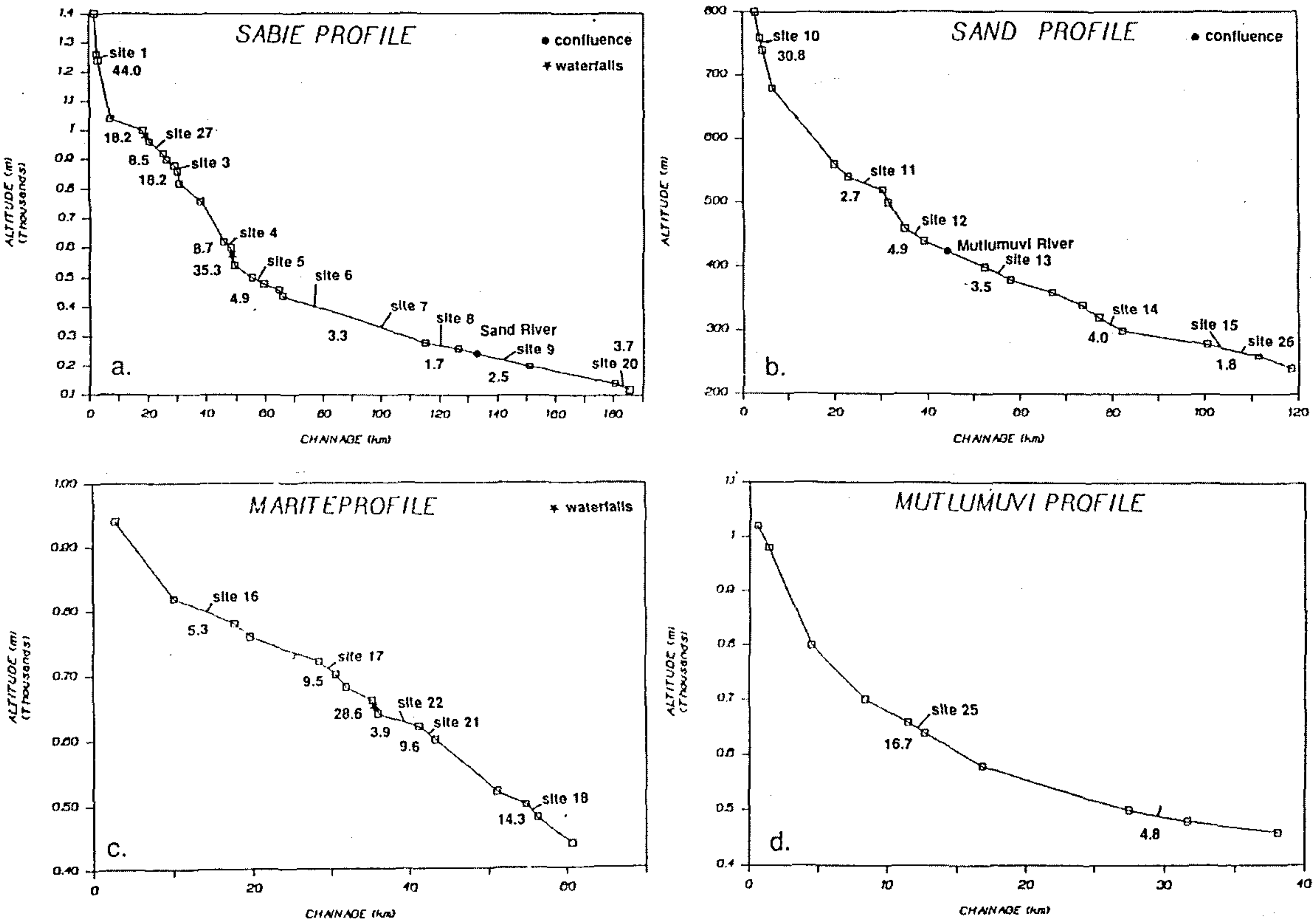

Figure 3.2 River profiles with gradients of associated sampling sites for; (a) Sabie River, (b) Sand River, (c) Marite River & (d) Mutlumuvi River. Waterfalls and confluence points are marked.

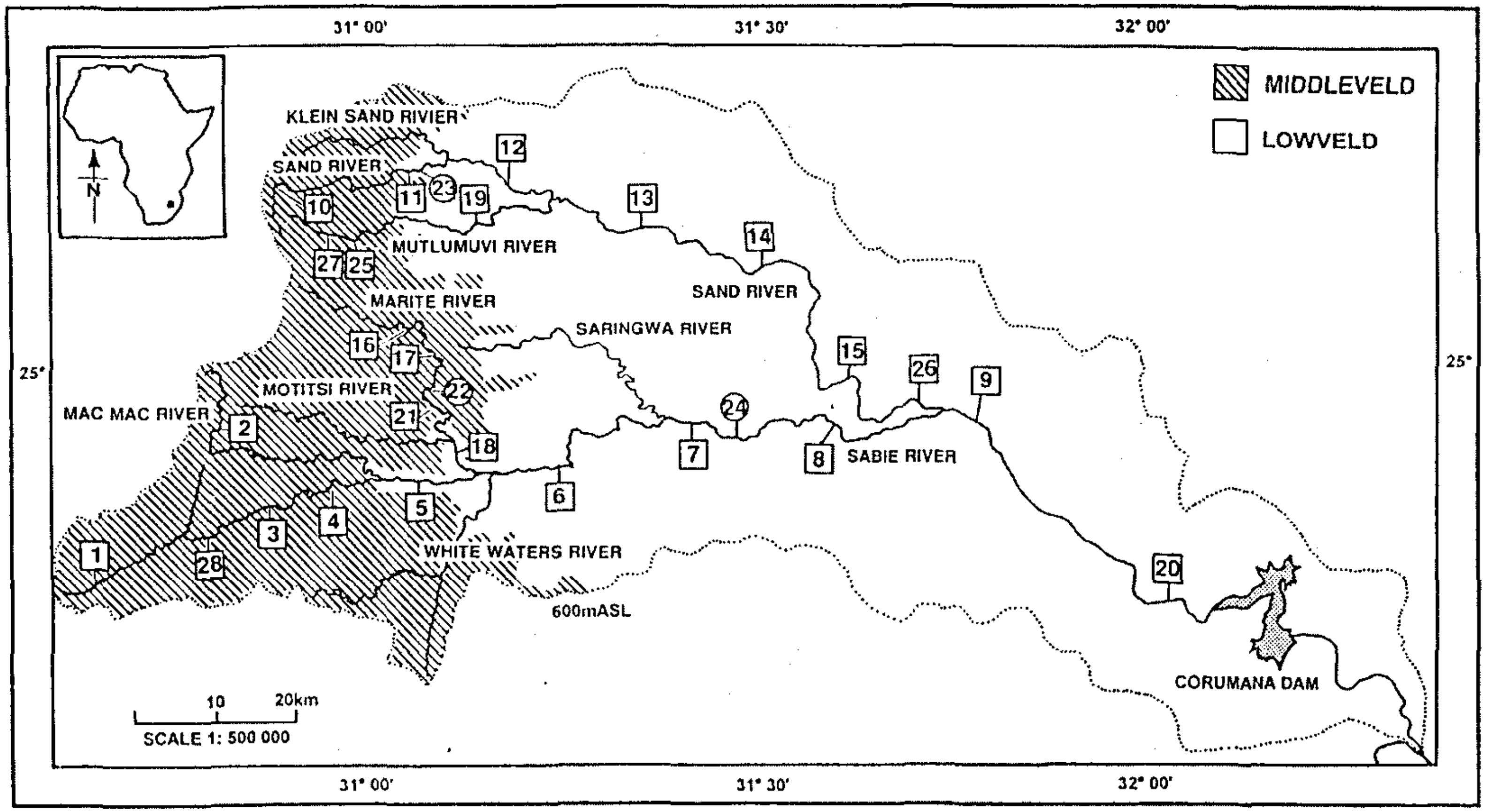

Figure 3.3 Station locality map for all sites sampled over the study period, including annual survey, quarterly monitoring and once-off sites. Gill-net stations shown as circles.

Site 2: (24°57'35S, 30°49'52E)

A survey site on the Mac Mac River above the falls (Fig. 3.3) at an altitude of 1328 mAMSL and with a moderate gradient (9.1 m.km^{-1}) (Fig. 3.2). This first order stream is characterised by bedrock run and rapid sequences averaging 22 m, with only occasional sand and loose substrates. No fish were found. The reach occurred within the "mountain source & waterfall" zone of Chunnett *et al.* (1987). The riparian strip was open with shrubs and grasses. The catchment area is planted with young pine trees.

Site 3: (25°03'48S, 30°51'28E)

A third order monitoring site on the Sabie River at 867 mAMSL, 10 km downstream of Sabie Town (Fig. 3.3). The site is moderately steep (gradient; 18.2 m.km^{-1}, Fig. 3.2) and is bounded

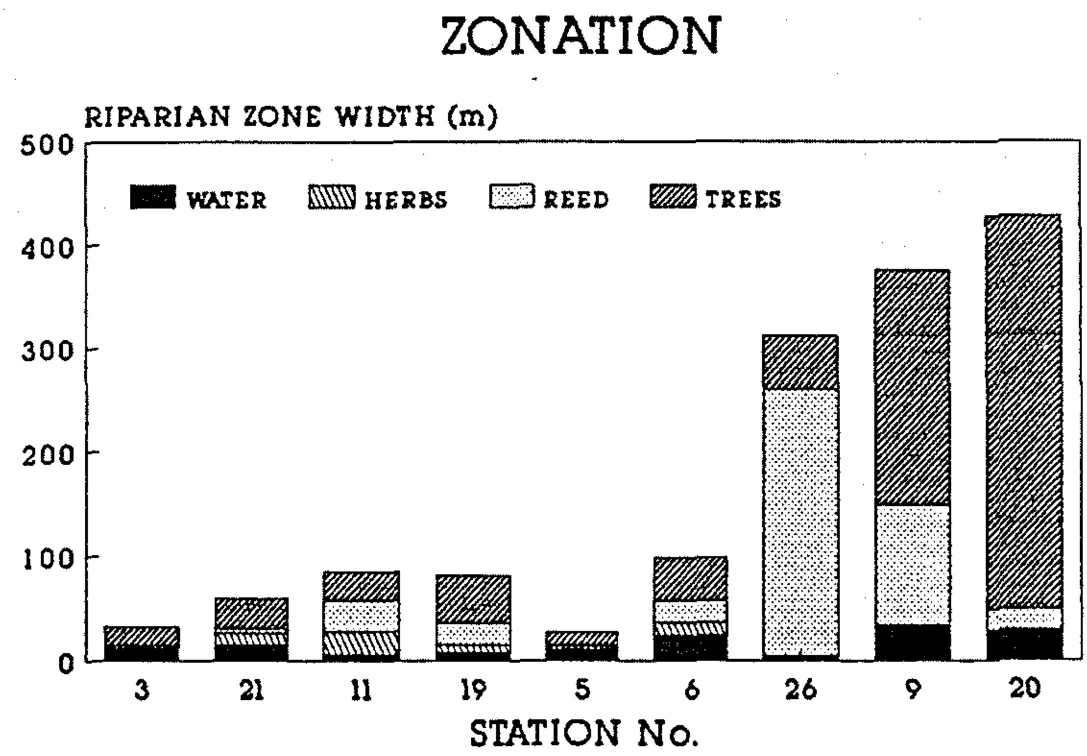

Figure 3.4: Riparian zone dimensions and composition of the 9 quarterly monitoring sites by altitude. The upper sites 3, 5 & 21 were narrow with tall riparian forests. Sites 11, 19 (higher altitude) & 6 are lowveld sites of about one hundred meters wide with reed contributing 20-30%. Downstream sites 9, 20 & 26 are wider (300-420m). They range from site 26, typical of reaches in the lower Sand River with extensive reedbeds and a sandy floodplain, to site 20, a complex braided reach with many riparian trees and little reed.

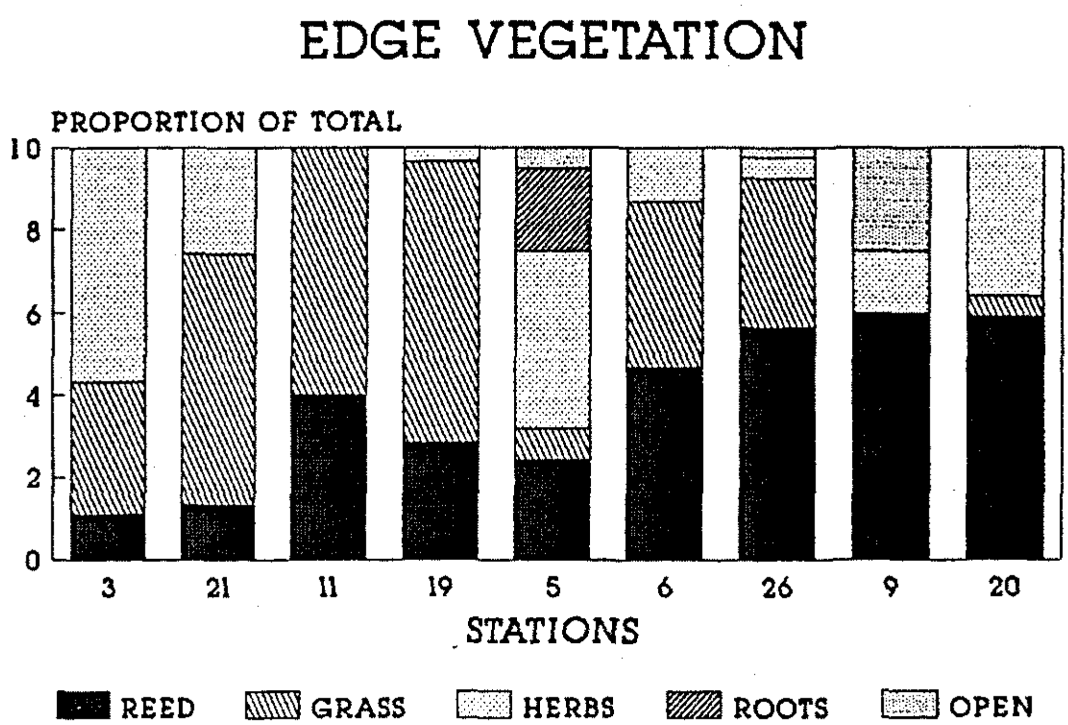

Figure 3.5: The proportional contribution of river edge vegetation types at 9 quarterly monitoring sites by altitude. Generally, marginal vegetation in the upper Sabie sub-catchment was herbaceous with grasses (sites 3, 5 & 21) while grasses dominated bank verges at intermediate Sand River sites (11 & 19). Reeds generally increased in importance down the river profile and contributed less to cover at lower flows.

by a steep valley. Flow cascades over large boulders between deeper pools with riffle-run sequences on average 177 m in length. Substratum consists of a full range of cobble to boulder. The riparian zone is narrow (Fig. 3.4) and consists of indigenous forest that partly shades the channel. The riparian strip is invaded by pine and gum, and surrounded by exotic afforestation. The vegetation bordering the stream is predominately herbaceous with grasses (Fig. 3.5 & 3.6a) with trailing roots. The site falls within the "mountain stream zone" classification of Chunnett *et al.* (1987).

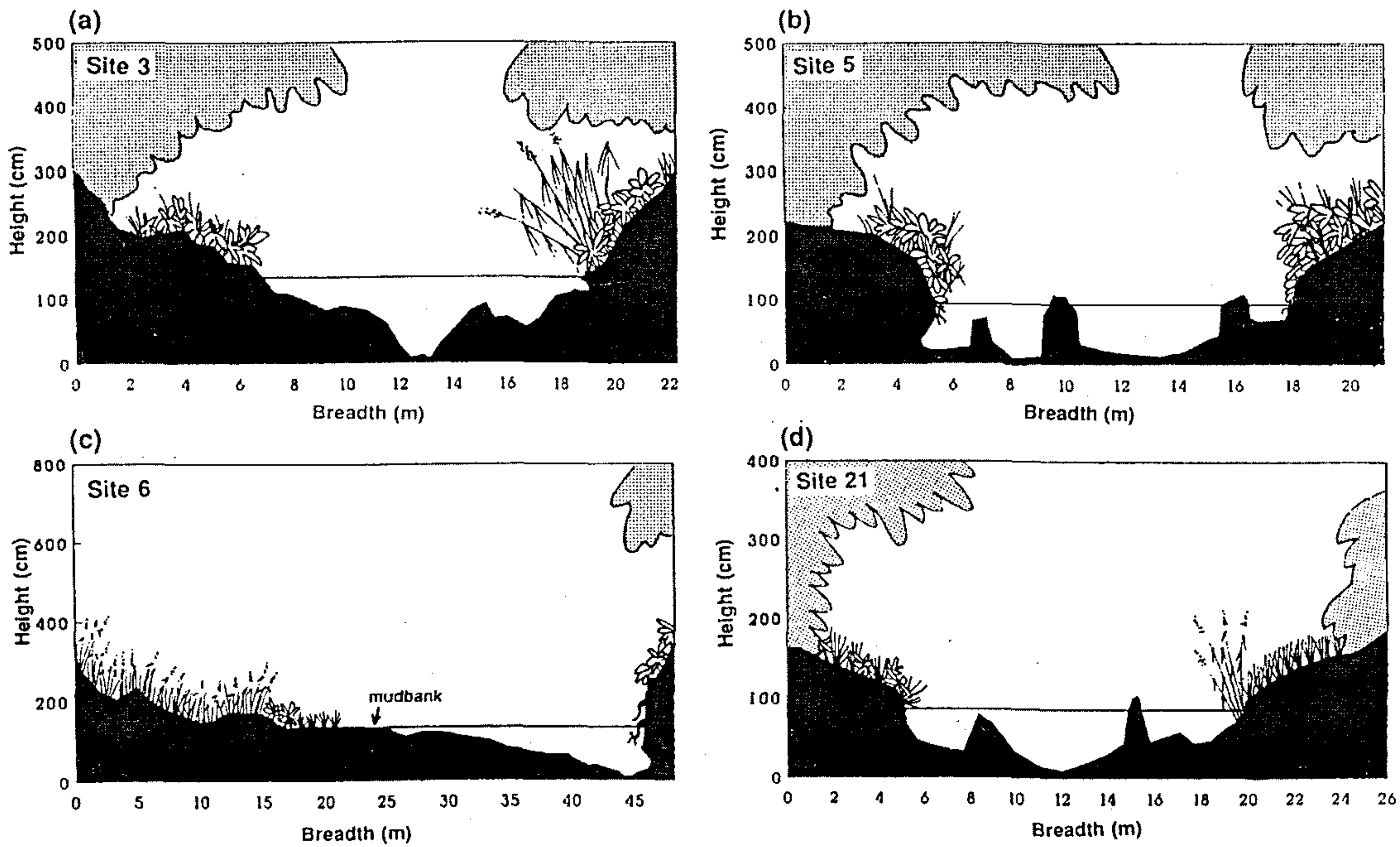

Figure 3.6 Typical channel profiles for upper Sabie sub-catchment sites. Vegetation categorized as grasses (ⴥ), herbs (ⴥ), reed (ⴥ) or trees (⁞⁞). Upper sites 3,5 & 21 have cobble and bedrock substrates with grasses and herbs providing good edge cover at most flows. Trees generally shade the reaches to some degree. Banks are often undercut but stabilized. Lower Sabie River site 6 is sandy, with sandbars.

Site 4: (25°02'11S, 30°59'06E)

A survey site on the third order Sabie River approximately 20 km below Sabie Town (Fig. 3.3). It has a moderately steep gradient (8.7 $m.km^{-1}$), (Fig. 3.2) and high altitude (619 mAMSL). The site lies upstream of a four meter-high waterfall. Long sluggish pools are sandwiched between cobble riffles. Pool banks are stabilised by roots of the narrow riparian forest and are often undercut. The riparian zone is continuous with surrounding indigenous forests lying in the steep valley. The reach falls within the "mountain stream" zone of Chunnett *et al.* (1987).

Site 5: (25°01'48S, 34°01'21E)

A monitoring station on the fourth order Sabie River near the town of Hazyview (Fig. 3.1 & 3.3) at an altitude of 488 mAMSL with a gradient of 4.9 $m.km^{-1}$ (Fig. 3.2). Here the Sabie River enters the middleveld, within the "lowland and midland river" zone of Chunnett *et al.* (1987).

The narrow riparian forest of old growth (Fig. 3.4) stabilizes the banks (which are often undercut), and partly shades the reach (Fig. 3.6b). The reach is characterised by extensive bedrock runs and slow deep pools with sequences averaging 175 m. Edge vegetation consists mainly of herbs at the waters edge (Fig. 3.5 & 3.6b) with some reed and large areas of tree roots offering excellent instream cover.

Site 6: (25°01'93S, 31°14'40E)

A monitoring site on the fifth order Sabie River at the western edge of the KNP (Fig. 3.1 & 3.3). The site is classified within the "lowland and midland river" zone of Chunnett *et al.* (1987), and surrounded by tropical bushveld (Acocks, 1975) at an altitude of 402 mAMSL. It has a gentle gradient of 3.3 $m.km^{-1}$ (Fig. 3.2).

The river is large, with a moderate riparian zone of some hundred meters (Fig. 3.4) and mature riparian forests stabilizing undercut banks but seldom shading the stream (Fig. 3.6c).

Reed-beds grow in exposed and sandy areas and during low-flows extensive beds of herbaceous plants developed on exposed sand (Fig. 3.6c). The river flows over sandy runs, rapids and through deep pools with sequences typically over 500 m. The first signs of braiding and sand bars appear.

Site 7: (24°58'12S, 31°24'14E)

Initially a monitoring site surveyed quarterly, it was later downgraded to an annual survey site. This site was situated on the fifth order Sabie River bordering the KNP and Lisbon Citrus Estates, downstream of the confluence of the Saringwa River (Fig. 3.1 & 3.3). The site was within the "lowland and midland river zone" of Chunnett *et al.* (1987), lying well into the lowveld (alt; 320 mAMSL) and of gentle gradient (3.3 $m.km^{-1}$) (Fig. 3.2).

The reach flows over massive granite intrusions with boulder and bedrock slabs followed by deep sandy pools with hippo. It is often locally braided into channels. Reeds and high riparian forest fringe the river. Loose stones are limited, as is accessible riffle habit. During high flows sampling is effectively confined to the banks.

Site 8: (24°58'35S, 31°35'05E)

A survey site on the fifth order Sabie River near Skukuza village in the KNP (Fig. 3.1 & 3.3). It lies at 265 mAMSL and falls in the "lowland and midland river" zone of Chunnett *et al.* (1987).

This is a relatively low-gradient site (2.5 $m.km^{-1}$, Fig. 3.2), consisting of some bedrock, pools and sandbars. Tall riparian trees dominate the banks, with reeds occurring in open areas.

Site 9: (24°57'47S, 31°44'28'E)

A monitoring, hydraulic habitat and drought monitoring station on the fifth order Sabie River, 2 km downstream of the confluence with the Sand River (Fig. 3.1 & 3.3). Situated within the "lowland and midland river" zone of Chunnett *et al.* (1987), it was surrounded by tropical bushveld (Acocks, 1975) lying at an altitude of 220 mAMSL and with a gentle gradient (2.5 $m.km^{-1}$) (Fig. 3.2).

A broad riparian zone (appx. 400m) of trees and shrub borders extensive reed-beds along the main channel (Fig. 3.4 & 3.5). The transect (Fig. 3.7a) shows that the reed-beds are within, while the riparian trees are removed from, the active channel. The river is braided, with both a slow deep-flowing channel and a broad chute over unfractured bedrock. The reach was sandy with isolated large bedrock boulders, and some loose cobble.

Site 10: (24°42'38S, 30°55'48E)

A survey site on the first order Sand River in the Welgevonden State Forest (Fig. 3.1 & 3.3), at an altitude of 745 mAMSL. The gradient is steep (30.8 $m.km^{-1}$) (Fig. 3.2), and is within the "mountain stream" zone of Chunnett *et al.* (1987). The water is crystal clear and very cold.

The channel consists of short riffle-pool sequences (average length 8.5 m) with a few large sandy pools. A thin strip of relict natural riparian forest remains and totally shades the stream. The surrounding area is covered in pine with much recent disturbance.

Site 11: (24°41'09S, 31°03'39E)

A low-gradient (2.7 $m.km^{-1}$) (Fig. 3.2) monitoring site on the second order Sand River between two potential dam sites. Although it lies at an altitude of 538 mAMSL it is relatively warm. Typical of the "foothill sandbed zone" (Chunnett *et al.* 1987), the riparian zone of some 100 meters has elements of bushveld, reed and grasses (Fig. 3.4). Grasses, sedges and reeds crowd the banks (Fig. 3.5 and 3.7b). The substratum of the riffle areas ranged from cobble to bedrock with deep silty pools between. Sand was the predominant benthic substratum throughout the site.

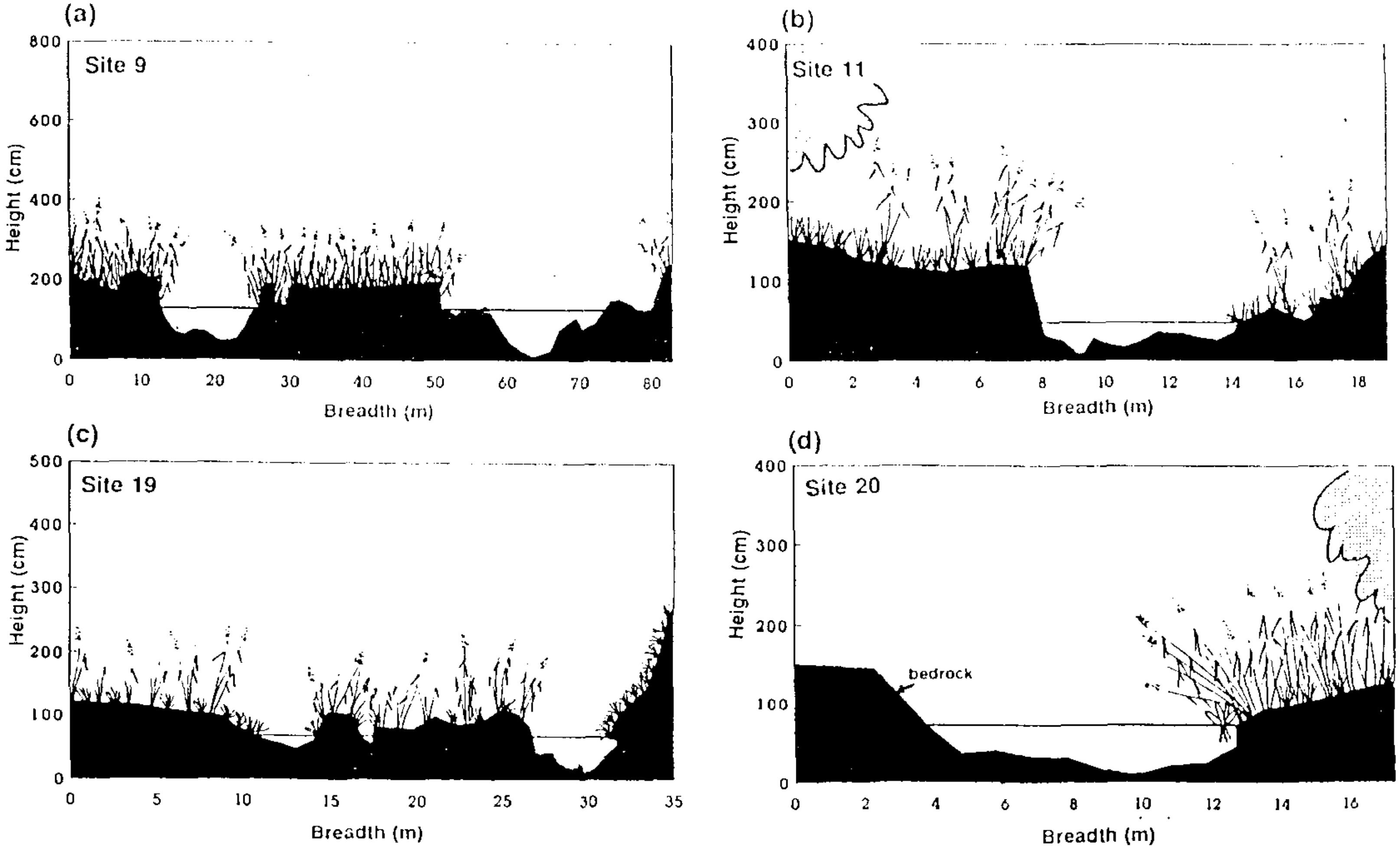

Figure 3.7: Typical channel profiles for lowveld sites. Vegetation categorized as grasses (), herbs (), reed () or trees (). Channels are sandy, less stable and open. Reeds predominate in the lowveld (19) while grasses are more noticeable at the middleveld sites (11 & 19). Riparian trees fringe the channel in rocky controlled and often braided areas (site 20). (Only one of two braids is drawn for site 20).

Site 12: (24°42'25S, 31°10'37E)

A survey site on the third order Sand River near Dingleydale at an altitude of 458 mAMSL and a gradient of 4.9 $m.km^{-1}$ (Fig. 3.1 & 3.3), within the "foothill sandbed zone" (Chunnett *et al.* 1987). A canal diverts a significant volume of water to the Edinburgh Dam from the river upstream of this site. Many people make use of the river for washing clothing. This reach of the river may be a Bilharzia transmission site.

The stream reach is very sandy with the occasional bedrock dyke, stones and riffle are limited. Few riparian trees remain and a sparse but extensive reedbed is present.

Site 13: (24°45'10S, 31°20'22E)

Used as a monitoring station in 1990, but afterwards as a survey site. It is situated on the fourth order Sand River just into the Sabie Sand Game Reserve (alt: 384 mAMSL & grad: 3.5 $m.km^{-1}$) (Fig. 3.1 to 3.3) in the "lowland and midland river zone" as classified by Chunnett *et al.* (1987). The surrounding vegetation was tropical bushveld (Acocks, 1975).

The river flows over massive granite boulders and deep sandy pools, where numerous fish were visible during low flows, and through a channel confined to one bank of an extensive reed-filled river bed. Much sand deposition filled in pools during the study. True riffle areas were limited.

Site 14: (24°47'31S, 31°31'32E)

A monitoring and drought programme site on the fourth order Sand River (alt: 315 mAMSL & grad: 4 $m.km^{-1}$) at Londolozi in the Sabie Sand Wildtuin (Fig. 3.1 to 3.3). It is situated within the "lowland and midland river" zone of Chunnett *et al.* (1987), and surrounded by tropical bushveld (Acocks, 1975). Very similar characteristics to those of Site 13 and 26.

The river flows through a massive granite outcrop, resulting in a series of deep pools, small bedrock runs and complex braids. The riparian zone is a broad (appx 400 m) floodplain, which is generally reed covered with a scattering of small riparian trees along the water edge. For details of the substrate and reach structure see volume 2, section 2.

Site 15: (24°55'08S, 31°35'44E)

A low-gradient survey site (1.8 $m.km^{-1}$, alt: 275 mAMSL) on the fourth order Sand River at Mala Mala, Sabie Sand Wildtuin (Fig. 3.1 to 3.3), within the "lowland and midland river" zone of Chunnett *et al.* (1987).

This reach consists of large sandy pools interlinked with protruding bedrock runs on a wide (some 500 m) reedy floodplain. Riparian trees are confined to the outer edge of the riparian zone.

Site 16 (24°50'37S, 31°02'50E)

A second order survey station on the Maritsane River (Fig. 3.1 & 3.2) (alt: 785 mAMSL & grad: 5.3 $m.km^{-1}$) (Fig. 3.2) in the "mountain stream zone" (Chunnett *et al.* 1987).

The stream is clear with riffle pool sequences of approximately 25 m. Boulders and cobble are abundant. The riparian vegetation spans some 30 m, and the channel is open with weedy side channels and some shading.

Site 17: (24°53'25S, 31°05'27E)

A third order survey stream on the Marite River (alt: 715 mAMSL) immediately below the planned Inyaca Dam (Fig. 3.1 & 3.3).

It flows through an area of massive granitic boulders with extensive rapids and bedrock runs of a relatively steep gradient (grad: 9.5 $m.km^{-1}$) (Fig. 3.2) which are linked by deep sandy pools.

Site 18: (25°00'25S, 31°06'58E)

A fourth order survey reach on the lower Marite River (Fig. 3.1) at an altitude of 480 mAMSL which falls within the "lowland and midland river" zone of Chunnett *et al.* (1987) (Fig. 3.3). The river is relatively steep (grad: 14.3 $m.km^{-1}$) (Fig. 3.2) flowing over extensive bedrock .

The riparian strip is narrow with well developed riparian forests flanking the river. Massive granitic boulders dominate the reach which has shallow bed-rock runs and some pools.

Site 19: (25°45'34S, 31°07'41E)

A third order monitoring station 16 km below the Zoeknog dam at the confluence of the Mutlumuvi and the Nwarele Rivers at New Forest (Fig. 3.1 & 3.3). It lies at an altitude of 499 mAMSL, has an intermediate gradient (4.8 $m.km^{-1}$) (Fig. 3.2) and falls in the "foothill sandbed" zone of Chunnett *et al.* (1987), surrounded by tropical bushveld (Acocks, 1975). The Dwarsloop municipality pumps water from this reach to their supply dam on the Nwarele River.

The reach consisted of deep sandy pools linked by extensive shallow cobble runs. The riparian zone of some 100 m width consists of broad parallel riparian forest with reeds and grasses surrounding the stream (Fig. 3.4). At the water's edge grasses predominate and the channel is largely unshaded (Fig. 3.5 & 3.7c).

Site 20: (25°09'35S, 31°59'52E)

A monitoring and drought monitoring station on one of the three braids at Mlondozi 60 km below the confluence of the Sabie and the Sand Rivers and some 5 km upstream from the Mozambique border (Fig. 3.1 & 3.3). It is the lowest altitude site at 140 mAMSL, but has a higher gradient (3.7 $m.km^{-1}$) than other lowveld sites (Fig. 3.2) as the river rejuvenates through the Lebombo mountains. It falls within the "lowland and midland river zone" of Chunnett *et al.* (1987), and is surrounded by tropical bushveld (Acocks, 1975).

The site is highly braided and only one channel is accessible and was sampled (Fig. 3.7d). Flow in this channel stopped during the study while there was always flow in the main channel. The substratum of the sample site ranged from roughened bedrock slabs to patches of gravel with deep sandy pools. The riparian zone was more than 400 m wide (Fig. 3.4) and complex, consisting mostly of open forest with sparse reeds. Reeds predominated at the channel's edge (Fig. 3.5 & 3.7d). Although some channels were shaded, the reach was generally open.

Site 21: (24°56'18S, 31°04'43E)

A monitoring third order stream on the Marite River at an altitude of 620 mAMSL with a gradient of 9.6 $m.km^{-1}$ (Fig. 3.1 to 3.3).

The riparian strip of approximately 65 m comprised mostly trees with some grasses (Fig. 3.4). Riparian trees partially shaded the reach while grasses and herbs crowded to the water's edge (Fig. 3.5 & 3.6d). Substrate was predominately cobble and boulders of different sizes, arranged in riffle pool sequences of *ca.* 113 m.

Site 22: (24°55'35S, 31°05'32E)

On the Marite River, this was a natural deep pool, reed and tree lined, which served as a gill netting site for station 21. (alt: 635 mAMSL) (Fig. 3.3).

Site 23: (24°41'30S, 31°05'07E)

An irrigation dam that overflows into the Sand River below station 11 and served as a gill-netting site (Fig. 3.3). One resident hippopotamus.

Site 24: (24°58'05S, 31°30'25E)

A new weir on the Sabie river between stations 7 and 8 (Fig. 3.3) that served for flow records of these sites and as a site for gill-netting.

Site 25: (24°45'22S, 31°00'30E)

A survey site on the second order Mutlumuvi River 2 km downstream of the Zoeknog Dam at an altitude of 660 mAMSL (Fig. 3.1 to 3.3). It is situated within the "mountain stream" zone of Chunnett *et al.* (1987) and bordered by tropical bushveld (Acocks 1975). With the breaching of the Zoeknog Dam, this site was completely smothered in sand and gravel.

The stream flows over short riffle-pool sequences (ave. 27 m), made up of cobble and boulders. The riparian strip was generally open.

Site 26: (24°57'58S, 31°37'27E)

A fourth order reach on the Sand River just prior to its confluence with the Sabie River in the KNP (Fig. 3.1 to 3.3) at an altitude of 260 mAMSL. It was established for the measurement of hydraulic transects after the landowner refused access to Site 13.

The reach was very sandy with a riparian zone of over 300m, largely covered in reed-beds, and a narrow ribbon of riparian trees beside the floodplain (Fig. 3.4). Grasses and some reeds grew along the water's edge (Fig. 3.5).

Site 27: (24°45'35S, 30°58'30E)

Site 27 lies upstream of the Zoeknog Dam. It was surveyed following the dam breach as a comparison to station 25, to which it was very similar (Fig. 3.3).

Site 28: (25°05'20S, 30°48'01E)

Site 28 was surveyed to fill in our knowledge of fish distribution in the upper Sabie in the region of the old gold mines (Fig. 3.3).

3.4 FIELD SAMPLING REGIME

Sampling was undertaken from May 1990 to May 1993 (Table 3.2), during which time four different regimes were employed to meet the differing objectives. In the first instance, a catchment wide survey was undertaken annually at stations 1 to 20, while quarterly sampling at nine stations (sites 3, 5, 6, 7/9, 11, 13/14, 21, 19 & 20) was developed to monitor seasonal changes.

Table 3.2 Sampling regime for: (M) annual May survey, (Q) quarterly monitoring, (D) drought monitoring programme and the Zoeknog Dam focus (Z).

	SURVEY TRIP No. & TYPE			
DATE	1990	1991	1992	1993
JAN				Z1 & D7
FEB		Q4	Q8	Z2 D8 & Q12
MAR				
APR				
MAY	Q1 & M1	M2 & Q5	M3 & Q9	Z3 M4 D9 & Q13
JUN			D1	
JLY			D2	
AUG	Q2	Q6	D3 & Q10	
SPT			D4	
OCT			D5	
NOV	Q3	Q7	D6 & Q11	
DEC				

Two additional sampling regimes were later developed. The first of these regimes was initiated when the drought intensified. The team was redirected to design a monitoring programme which would best define the effects of the drought as it progressed. The drought focus was continued until after the drought broke in an attempt to gauge some measure of recovery. The sites selected for this research included 6, 9, 14 and 20. At sites 14 & 20, flow stopped and pools developed as the channel or backwater reaches were isolated, while at site 9, offstream pools were isolated within the sandy river bed (Vol II; Fig. 1 & Table 1). The drought sites were sampled on five occasions, and on a further three occasions after the drought broke.

Secondly, the collapse of the Zoeknog Dam on the Mutlumuvi tributary of the upper Sand River, required that an emergency monitoring programme was set up at sites 25, 19, 14, and at a new site above the dam (site 27). Site 11 was used as a comparison. During this programme the sites were sampled on three occasions, the first immediately after the collapse of the structure (see Vol III).

3.5 FIELD SURVEY METHODS

3.5.1 PHYSICO CHEMICAL METHODS

Water samples for chemical analysis of nutrients were collected at all sites, filtered through Whatman GF/F filters (4.5 µm pore size) and preserved using a 1% solution of mercuric chloride. The samples were then analyzed for nitrite, nitrate, sulphate, soluble reactive phosphate (SRP) and ammonium ions by WATERTEK of the Council for Scientific and Industrial Research (CSIR), Pretoria, using a Technikon II Auto-Analyzer.

Total suspended solids (TSS) were determined by weight difference after the passage of a known volume of water through a pre-combusted (450°C, 5 hours), tared, Whatman GF/F filter which was dried at 105°C for a minimum of three hours. The organic fraction was determined after further combustion at 500°C for 2h. Dissolved oxygen and water temperature were measured using an Aqua-lytic Oxi 921 oxygen meter, calibrated against atmospheric pressure in order to correct for altitude. Salinity was determined as electrical conductivity using a DiST 3 ATC dissolved-solids tester (Hanna instruments), while pH was measured using a Hanna instruments pHep pH meter. For turbidity, an Analite 150 Mk 2 nephelometer, pre-zeroed in distilled water, was used. Minimum and maximum temperatures were recorded using concealed thermometers submerged at selected sites.

River discharge measurements were achieved by the measurement of detailed "panel" flow transects at each site. This involved a minimum of 20 measurements of river depth across each transect, together with simultaneous records of flow velocity using a Price AA Current Meter. These records were subsequently integrated for each transect, in order to develop discharge (V m^3s^{-1}) data for each profile using the equation:

$$V = \sum_{i=1}^{n} (di \times wi \times vi)$$

where,
i = panel number, according to intervals measured,
d = depth (m),
w = width (m), and
v = velocity ($m.s^{-1}$).

3.5.2 MACRO-INVERTEBRATES

3.5.2.1 DATA COLLECTION

As a result of staff changes, macro-invertebrate sampling was disrupted, and the intensity and frequency had to be varied during the course of the project. Riffle samples were taken using a Surber-sampler (net mesh size 80 μm; surface area 625 cm^2). The sampler was settled on the substratum to isolate the sample area, and organisms contained within the box were brushed into the catching net using a light-weight shoe brush. At sites with vegetation, samples of the macro-invertebrate fauna were taken using a hand net (mesh size 250 μm), sweeping five times over an estimated 1 m stretch of vegetation. Samples of "soft" substrates (essentially sand and surface detritus) were taken with a Van Veen Grab (bite area, 2250 cm^3). The contents of the Grab were washed in a bucket by swirling water (10 times) and passing it through a 80 µm net after each wash. Sand and gravel samples were inspected afterwards for molluscs and for other large invertebrates. This method follows that of Maitland & Hudspith (1975) who statistically demonstrated its adequacy for the sandy substrata of Loch Leven.

All faunal samples were fixed in 4% buffered formaldehyde and were later transferred to 70% alcohol in the laboratory. Each sample was then separated into the following size fractions (>2000 µm, 850-2000 µm, 500-850 µm, and 250-500 µm) to facilitate sorting and identification of the fauna. Where possible, taxa were identified to species level. However, as the taxonomy is at present inadequate, many were only identified to genus, family or even broader categories.

With the onset of the drought, a more intensive sampling regime was adopted, concentrating on sites 6, 9, 14 and 20 (see section 3.4). Samples were collected on eight occasions; every month for five months during the drought and every two months for six months following the end of the drought.

For the Zoeknog monitoring programme, three habitat types (riffle, sandy substratum and vegetation) were sampled at several sites down the river, above and below the dam. These included site 27 upstream of the reservoir, site 25 on the Mutlumuvi River, just below the dam, site 19, at the confluence of the Mutlumuvi and Nwarhele Rivers, site 14 at Londolozi on the Sand River, and site 9 below the confluence of the Sabie and the Sand Rivers. Because background data on these sites were available, comparisons could be made to the pre-dam construction state of the river. As the drought masked the effects of the dam burst to some extent, it was decided to include site 11, on the Sand River (comparable in position and river size) especially for rate of recovery after good rains in November 1992. In order to gauge the rate of recovery of the river after the dam burst, another set of samples was taken two months after the event, during May 1993.

The sampling methods adopted for both the macro-invertebrates and physico-chemistry in the drought and the Zoeknog Dam phases were the same as those used in the main study (see Section 3.5).

3.5.2.2 TREATMENT OF DATA

Data analyses in this report were undertaken employing the computer programme "PRIMER" Version 3.1a (Plymouth Routines in Multi-variate Ecological Research) developed by the Plymouth Marine Laboratory of the UK in conjunction with Professor J G Field of the Department of Zoology at the University of Cape Town (Plymouth Marine Laboratory, 1993). PRIMER has specifically been developed for the analysis of complex community-structure data bases and is therefore ideally suited for this study. Species abundance data were transformed using the root-root transformation of Stephenson & Burgess (1980). Transformed data were then standardised to produce the percentage contribution of each taxon to the overall invertebrate community, in order to compare different sampling techniques. The Bray-Curtis measure of similarity (Bray & Curtis, 1957) was then applied in order to construct a triangular similarity matrix, which were then employed in the development of ordination and cluster analyses.

Dendrograms using group-average linking were subsequently constructed by means of a hierarchical agglomerative method. Ordination plots were constructed by means of non-metric multi-dimensional scaling (MDS) (Shepard, 1962). The relationships between data points were represented on a two-dimensional scatter plot, with similarity between points given as the physical distance between them (Field *et al.*, 1982). Differences between macro-invertebrate species clusters illustrated using classification and ordination techniques, are further explored by information statistics (I-) tests (Field *et al.*, 1982) through PRIMER's sub-routine SIMPER.

3.5.3 ICHTHYOFAUNA

3.5.3.1 SURVEY METHODS

Three complementary sampling techniques were adopted to effectively sample most species and size of fish present. A prerequisite was that the technique had to be manageable by two people in the field. This precluded seining as a standard technique.

a) ELECTRO-FISHING

Figure 3.8: *Valved minnow trap design used to sample cichlids* and minnows at survey and monitoring sites.

Fish were sampled using a portable 550 watt Robin generator with coiled copper electrodes 20 cm long and 50 cm apart. A single handnet with a mesh size of 1 cm was used. Both operators wore rubberised wading pants and boots. This method is effective in shallow waters (less than 1 m deep), especially in riffles and runs where flow facilitates transport of the fish into the handnet. It can be used in backwaters and in marginal vegetation with some success. Each electro-fishing session lasted 20 minutes and covered the full range of shallow habitats available in the reach being sampled. Small species (≤10 cm) are the most diverse group in the system (section 7.2.2) and electro-fishing in shallow waters effectively sampled most small species. An attempt was made to fish the same habitat patch on each field trip. This was the most widely employed method of fish sampling used in this study.

b) VALVED MINNOW TRAPS

Traps were employed to sample small fish in deeper waters (greater than 1 meter in depth), specifically in pools and in reedy backwaters. This method is selective in that it captures minnows and to a lesser degree cichlids effectively. The design of the traps resembles those of Lalancette (1981) (Figure 3.8). Traps are 70 cm in diameter, constructed of 4 mm fencing wire and are covered with plastic fly-screening with a mesh size of 2 mm. The traps were baited with bread and set for at least three hours. Where possible, traps were set overnight.

The depth as well as flow, substrate, distance-to-cover, and cover type (turbidity, marginal vegetation or boulders) of each trap was recorded. Macrohabitat type (pool, dam or run) was also recorded.

c) GILL-NETTING

Gill-nets were used to sample fish in deep habitats. Each 25 m x 2 m net comprised four 7.5 m panels which had stretched mesh sizes of 60 mm, 75 mm 100 mm and 144 mm respectively. Whereas electro-fishing and trapping was conducted at all sites sampled, gill-nets were used at the monitoring sites only. When suitable deep habitats were not present, complementary sites were established in the vicinity (Fig. 3.3).

3.5.3.2 DATA CAPTURE & ANALYSIS

Fish were identified to species in the field or a sample was collected for later identification. Lengths (SL), and sex where possible, of all fish were recorded. Representative numbers of each species were weighed using 50 g and 100 g Pesola spring- or 500 g and 1000 g Salter balances. Large sized fish caught in the gill-nets were butchered and their reproductive condition recorded as a Gonadotropic Index (GI) and fat and gut content scored. Spines and scales were also collected and stored should ageing these fish prove necessary. During the last year of the project the reproductive condition of minnows was checked by stripping eggs and milt. Fishing effort was recorded as minutes fished for electro-fishing and as hours set for traps and gill-nets.

TWINSPAN and PRIMER was employed to analyze pattern in distribution and abundance. TWINSPAN (Hill, 1979) was used in preliminary analyses. TWINSPAN is a divisive two-way classification which uses both species and samples to produce a two-way table comparable to Braun-Blanquet tablework. The programm further identifies the species indicative of each division in the classification. Pseudospecies cut levels are used in the analysis. Cut levels are selected categories of abundance that best describes the range of species abundances, while pseudospecies are the presence or absence of each species at each cut level of abundance. The method of pseudospecies allows for quantitative values to be used for what is in essence a scale of abundance values. PRIMER is described under the macro-invertebrate data analyses (section 3.5.2.2).

3.6 ESTABLISHING THE MICROHABITAT REQUIREMENTS OF FISH

3.6.1 DATA COLLECTION

Microhabitat was defined by the hydraulic parameters of flow, depth, and substrate, with the additional recording of the type of cover available. This information is typically represented as suitability index (SI) curves (Bovee, 1986).

Data were collected using standard techniques as developed largely for the application of IFIM (Bovee, 1986). Quadrats of 1 m^2 were electro-fished for one minute and marked with a weighted float. The hydraulic microhabitat data was subsequently measured and recorded at the position of the float. We followed a stratified random sampling technique, designed to sample habitats according to their proportional availability. Quadrats were spaced five paces from each other along transects crossing from bank to bank. Microhabitat data were collected whether fish were captured in a quadrat or not. The total data set was used to calculate habitat availability curves. Altogether, 999 quadrats at nine quarterly monitoring stations were fished over a period of 15 months. The procedure is intensive and extremely time consuming, and generally restricted us to 20 quadrats per day. Data was recorded for all species captured. Fishing always proceeded upstream with minimal splashing. The same sites were revisited and fished with similar effort each sampling trip.

Besides measuring flow and depth, cover and substrate were encoded. Cover is easier to codify than to quantify. Cover codes used were those of Bovee (1986), while the substrate code system used was developed by Brusven (1977, in Bovee, 1986). A modified, but detailed Wentworth scale was used for substrate type. This system describes the dominant and sub-dominant particle size, with the relative proportion of the two known as embeddedness.

3.6.2 SUITABILITY INDEX (SI) CURVE DEVELOPMENT

The microhabitat variables flow, depth, substrate and cover (Slauson, 1988) are arguably the most important in defining the habitat needs of riverine organisms. Although these variables are interactive, each can be analyzed and represented graphically for each species and each life stage.

SI curves describe the use or preference of a particular variable by a target species. Suitability values are relative and are scaled between most utilized (1.0) to not utilized (0.0). Utilization curves (category II criteria) together with availability curves (category I criteria) are used to construct preference curves (category III criteria) using the simple formula:

$$P_i = U_i/A_i$$

where: P_i = the unnormalized index of preference at x_i, Ui = the relative frequency of fish observations at x_i, A_i = the relative frequency of x_i availability during the observation period, and x_i = the interval of the variable (x), (from Bovee 1986).

3.6.2.1 DATA MANIPULATION.

King and Tharme (1994) proved a useful aid to the techniques and pitfalls of SI curve construction in the South African context.

Target species were selected according to the objectives of the study focus (see section 7.5) and included both ecologically important and sensitive species. After separation of the data by species and life-stage, data sets of at least 30 observations could be used to construct the SI curves for all microhabitat variables. Recorded numbers per variable would not have been sufficient to further subdivide the data sets by season. Data for each species from all sites in the Sabie-Sand system were pooled, including those from tributaries.

3.6.2.2 SI CURVE CONSTRUCTION

a) **FREQUENCY ANALYSIS.** Of the four techniques available for the creation of SI curves (Bovee, 1986; King and Tharme, 1994) we initially used non-parametric tolerance limits to construct utilization and availability curves. Although more time consuming, we later used histogram or frequency analysis to construct more robust preference curves.

b) **CURVE SMOOTHING.** Because SI curves are fed into the PHABSIM model as more or less monotonic response curves, smoothing techniques are invariably needed. After selecting an appropriate size class, smooth curves were achieved by grouping adjacent classes. Where necessary a three point running mean was used. As a rule no curve was ever smoothed more than twice. Smoothing details are recorded with each graph. Care was taken to estimate the first and last data point which running filters do not adjust. We used the simple but objective method described by Velleman and Hoaglin (in Slauson, 1988).

c) SHOALING SPECIES. The shapes of histograms are influenced both by the organism's habitat preference and its behaviour (Bovee, 1986). Schooling behaviour in particular was considered important as large numbers of fish could be recorded in a single observation. We adopted the coding system suggested by King and Tharme (1994) in which:

- for all singly occurring species:
each individual was coded as 1

- for schooling species:
one individual was coded as 1
2-10 individuals were coded as 2
more than ten individuals were coded as 3

The use of these codes effectively reduced the number of records in utilization SI curve construction.

d) CHANNEL INDEX (CI) CODES. The detailed substrate codes taken in the field were reduced and combined with cover codes to form channel index (CI) codes which were restricted to two digits. Our CI codes are similar to those used by King and Tharme (1994). The decimals 10-50 encoded cover type, from zero cover to high quality cover. The units from 1-5 encode substrate size from fines, gravels and cobbles to boulders and bedrock.

4. HYDROLOGY OF THE SABIE-SAND SYSTEM

4.1 HYDROLOGY

4.1.1 HISTORICAL RUNOFF PATTERNS AND SEASONAL VARIATION

Under present developmental conditions, the Sabie River remains the only perennial, largely pristine and unregulated river traversing the Kruger National Park (KNP). The Sabie-Sand catchment is relatively small (709 600 ha) in comparison to other lowveld rivers, but it has a mean annual runoff (MAR) of some 762 hm^3 (Chunnett *et al.*, 1987). Most of this runoff (91.2%), originates in the headwaters of the catchment, the eastern escarpment and foothill region (Fig. 4.1). The Sabie headwaters alone account for 81.9% of the runoff (Chunnett *et al.*, 1990).

Chunnett *et al.* (1990) provide an simplistic overview of the hydrology of the Sabie catchment, analyzing simulated monthly runoff sequences spanning 64 years at five key points for both historic and various developmental conditions. In this study three key points (Fig. 4.1) were used to further explore the catchment hydrology in an effort to understand specific flow conditions for each study site used throughout this survey. Six hydrological sections were identified (Table 4.1) which lie between the major tributary confluences and reflect both base-flow and peak-flow magnitude. These were:

(1) The Marite
(2) The upper Sabie (both 1 & 2 were cool-water sections)
(3) The mid-Sabie (below the confluence of the Marite and Sabie rivers)
(4) The Lower Sabie (below the confluence of the Sabie and Sand Rivers)

(5) The upper Sand River (including the two similar Sand River tributaries)

(6) The mid-Sand (downstream of the Mutlumuvi and Sand River tributaries)

Table 4.1: Six hydrological sections were defined by zone, stream order and the magnitude of both base- and peak-flows. All reaches are highly seasonal with base-flows in October and wet season peaks in February. The further from the foothills, i.e. the lowveld zone (LZ), the greater the seasonal range. Sections closer to the source streams are perennial. The mid-Sabie has the highest base-flow under present development conditions. The Sand River has very low base-flow and is prone to stop flowing in severe dry seasons.

HYDROLOGICAL SECTION	ZONE	STREAM ORDER	RUNOFF RANGE (avg. mean monthly)		STATION No.
			Base flow m^3s^{-1} (October)	Flow peak m^3s^{-1} (February)	(monitoring)
1. Marite	FHZ	3-4	1,266	11,064	21
2. Upper Sabie	FHZ	3-4	2,156	18,840	3 & 5
3. Mid-Sabie	LZ	5	3,980	34,771	6 & 7
4. Lower Sabie	LZ	5	3,342	58,671	9 & 20
5. Upper Sand	LZ	3	0,177	7,680	11 & 19
6. Mid-Sand	LZ	4	0,355	15,360	13 & 14

1. Seasonal Flow

The Sabie and Sand rivers are highly seasonal (Fig. 4.2), and best described by a hydrological year that runs from October to September. Both rivers show summer peak flows (February) and lowest low-flows at the end of the dry season (October). Using the seven seasonal flow patterns associated with South African rivers as described by King and Tharme (1994), the Sabie system is classified as having a "seasonal moderate mid-summer flow" (group 6).

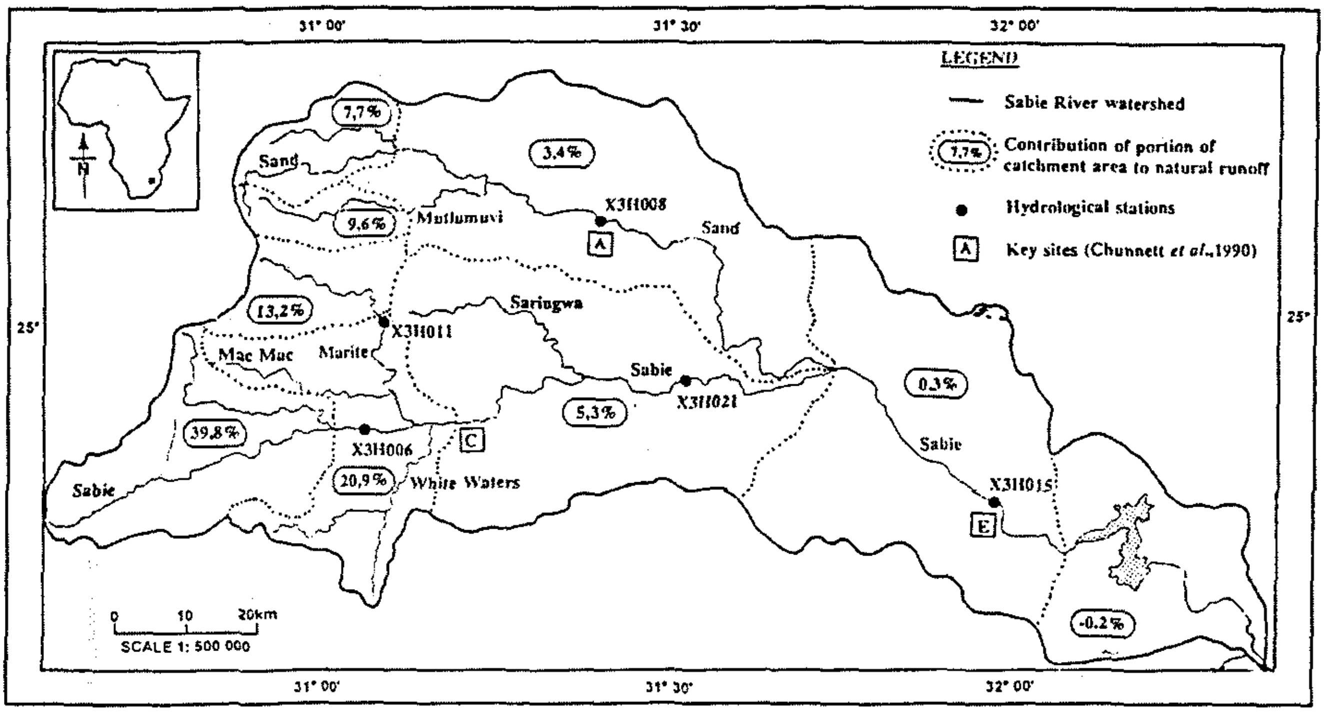

Figure 4.1: Locality map for weirs and sites used in the drawing of flow hydrographs of identified hydrological sections. Also shown is the percentage contribution of discrete catchment areas to the natural runoff. The headwaters account for 91.2% of the Mean Annual Runoff (MAR) of the Sabie-Sand catchment, with the headwaters of the Sabie sub-catchment contributing 81.9% of runoff.

The lower lowveld reaches (Lower Sabie) show the highest monthly peak flows of about 58.7 m^3s^{-1}, with the mid-Sand and mid-Sabie at 15.4 m^3s^{-1} and 34.8 m^3s^{-1} respectively. Base-flows at the end of the dry season (October) are moderately higher in the mid-Sabie (4.0 m^3s^{-1}) compared to lower Sabie sections (3.3 m^3s^{-1}), due to the proximity of the mid-Sabie to the headwaters where most of the runoff is generated. Mean base-flows in the mid-Sand River are presently very low (0.35 m^3s^{-1}), with frequent no-flow conditions. No-flow conditions have never been recorded for the Sabie River.

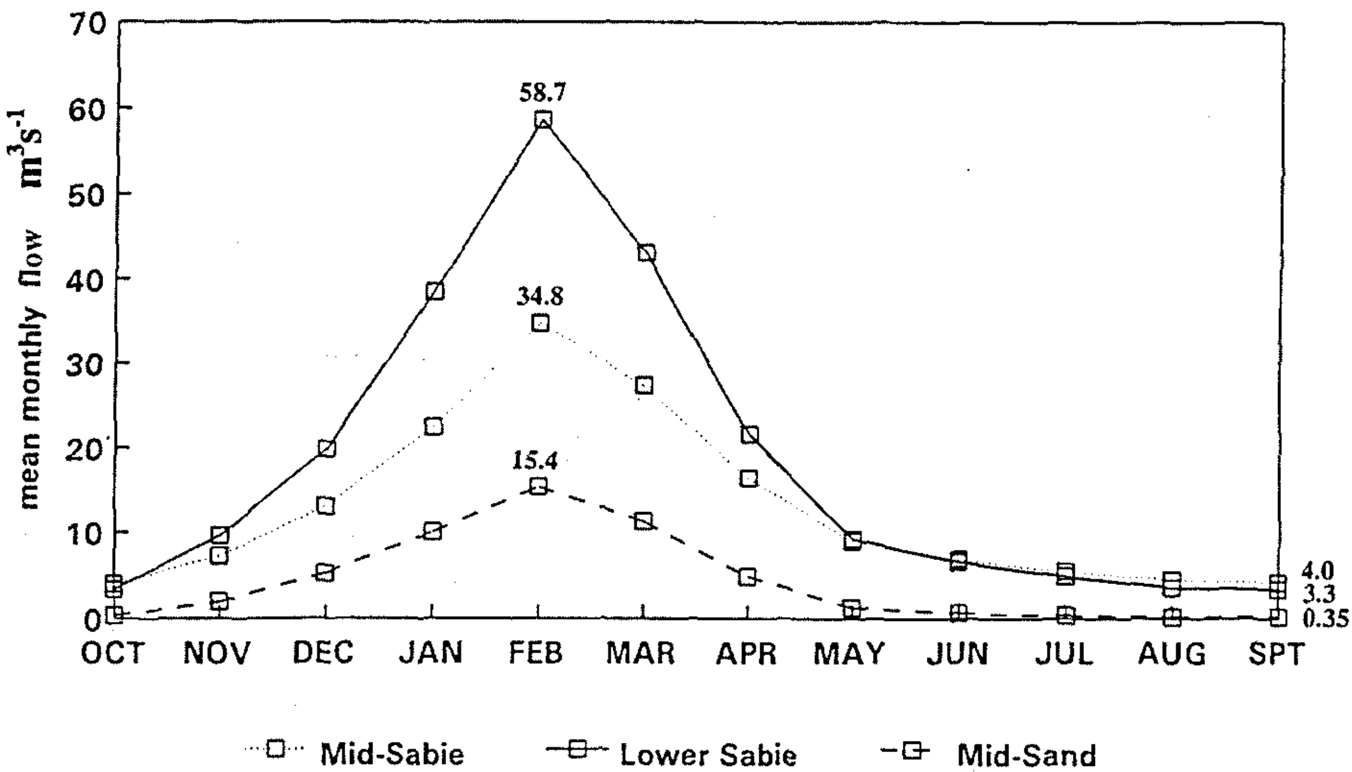

Figure 4.2: The mean monthly flow for a hydrological year (Oct-Sept) at three lowveld key points of the Sabie-Sand rivers at present development conditions. The mean monthly flow was calculated from simulated hydrological data spanning 64 years (1921-1985). Flow or runoff is highly seasonal. All three hydrological sections have peak flow in February and lowest low-flows in October. Present base-flows are very low in the Sand sub-catchment. *Base-flows for the mid-Sabie are moderately higher. Summer peak flow at Lower Sabie is* roughly the summation of flows for the two upstream reaches.

2. Historic Versus Present Runoff

The present runoff of the Sabie-Sand rivers is very different to that simulated for natural conditions. Flow reductions range between 11% and 75% depending on the time of year and location within the catchment (Table 4.2).

Peak flows have been most reduced in the Sabie River (40-48%), particularly within the mid-Sabie section (48%), while the mid-Sand River summer flow peak of 21.5-17.2 hm^3 is least

Table 4.2: Simulated runoff in million cubic meters (hm³) in the Sabie and Sand rivers over 64 years under natural and present development conditions. Month and magnitude of maximum mean flow, minimum mean flow and mean annual flow (MAR) are shown. Percentage reduction in runoff for the two rivers is tabulated. The MAR at the Sabie River LZ sites has been reduced by 25 to 28%, whereas the Sand River LZ has lost only 15% of its natural runoff. Maximum runoff in the Sabie River shows the highest reduction (40%-48%), whereas minimum runoff is most reduced in the Sand River (75%).

Runoff Measure	River Reaches	Natural Condition		Present Condition		Change
		Runoff (hm^3)	Period	Runoff (hm^3)	Period	
Max	Mid-Sand River	21.5	Feb	17.2	Feb	20%
	Mid-Sabie River	67.5	Feb	35.2	Mar	48%
	Lower Sabie River	91	Jan	55	Jan	40%
Min	Mid-Sand River	0.8	Sept	0.2	Sept	75%
	Mid-Sabie River	2.7	Sept	2.4	Oct	11%
	Lower Sabie River	1.7	Sept	1.3	Oct	24%
MAR	Mid-Sand River	158.34	Annual	134.07	Annual	15%
	Mid-Sabie River	562.73	Annual	403.81	Annual	28%
	Lower Sabie River	764.39	Annual	576.96	Annual	25%

adapted from Chunnett *et al* (1990) using frequency analysis of monthly runoff at three lowveld locations (A, C & E).

affected (20%). Conversely, dry season base-flows are most reduced in the mid-Sand River reach (0.8-0.2 hm³: 75%). Winter base-flows in the Sabie River sections are less affected with the mid-Sabie MAR reduced by 11% (2.7-2.4 hm³) and the lower Sabie 24% (1.7-1.3 hm³) respectively. These flow reductions may explain why the mid-Sand River frequently stops flowing under present conditions, approaching that of a seasonal system. The headwaters of the Sand sub-catchment remain perennial.

The major reductions in runoff within the Sabie sub-catchment may be attributed to the large afforested (72100 ha to 7600 ha) and irrigated (11300 ha to 2900 ha) areas. The marked low-flow conditions in the mid-Sand could be due to planting of winter tree crops (citrus) in a natural low base-flow area. Political and economic conflicts of interests surrounded the use of base-flows in the Sand River during the 1992 drought. The whole base-flow of the Sand River (0.58 m^3s^{-1}) was intercepted for many months by Champaign Citrus Estates. Threatened with court action by downstream game ranches, water was subsequently released but failed to reach further than Thulamahashe were it was again diverted to the off-stream Edinburgh Dam. The classification of the Sand River as a seasonal or perennial river is very important as it governs the rights of downstream users to base-flows.

4.1.2 RUNOFF DURING THE SURVEY

Describing specific flow conditions at study sites was considered important for the interpretation of biotic patterns and processes. Monthly flow records from gauging weirs (where available), or simply spot-flows (from quarterly monitoring sites) were used for comparison with the expected mean monthly discharge calculated from Chunnett *et al.* (1990) simulated flow data. Flow hydrographs were prepared for each of the six hydrological sections identified (Fig. 4.3-4.5). It must be stressed that these values are merely rough estimates intended to extend flow magnitudes simulated for the lowveld sections to upland sites.

Runoff during the 1991 hydrological year approximated the typical seasonal pattern and magnitude simulated for the Sabie River (Fig. 4.3b & 4.4). Mean base-flows for all Sabie River sections during 1991 were comparable with those for an average year, while peak flows were lower, probably because of floods that occurred seasonally in the lower reaches, which are included in the 64 years of simulated monthly discharge. Discharges recorded during 1991 for the Marite River did not compare well with those of an average year, derived from the upper Sabie River.

The 1992 drought is marked in all river sections. Failure of seasonal summer high runoff was recorded from the upper to lower Sabie sections. Base-flows were reduced by 50% in the upper Sabie River (Fig. 4.3b), and even more noticeably in the mid- and lower sections. Base-flows in September 1992 were at their lowest ever, with the lower Sabie section

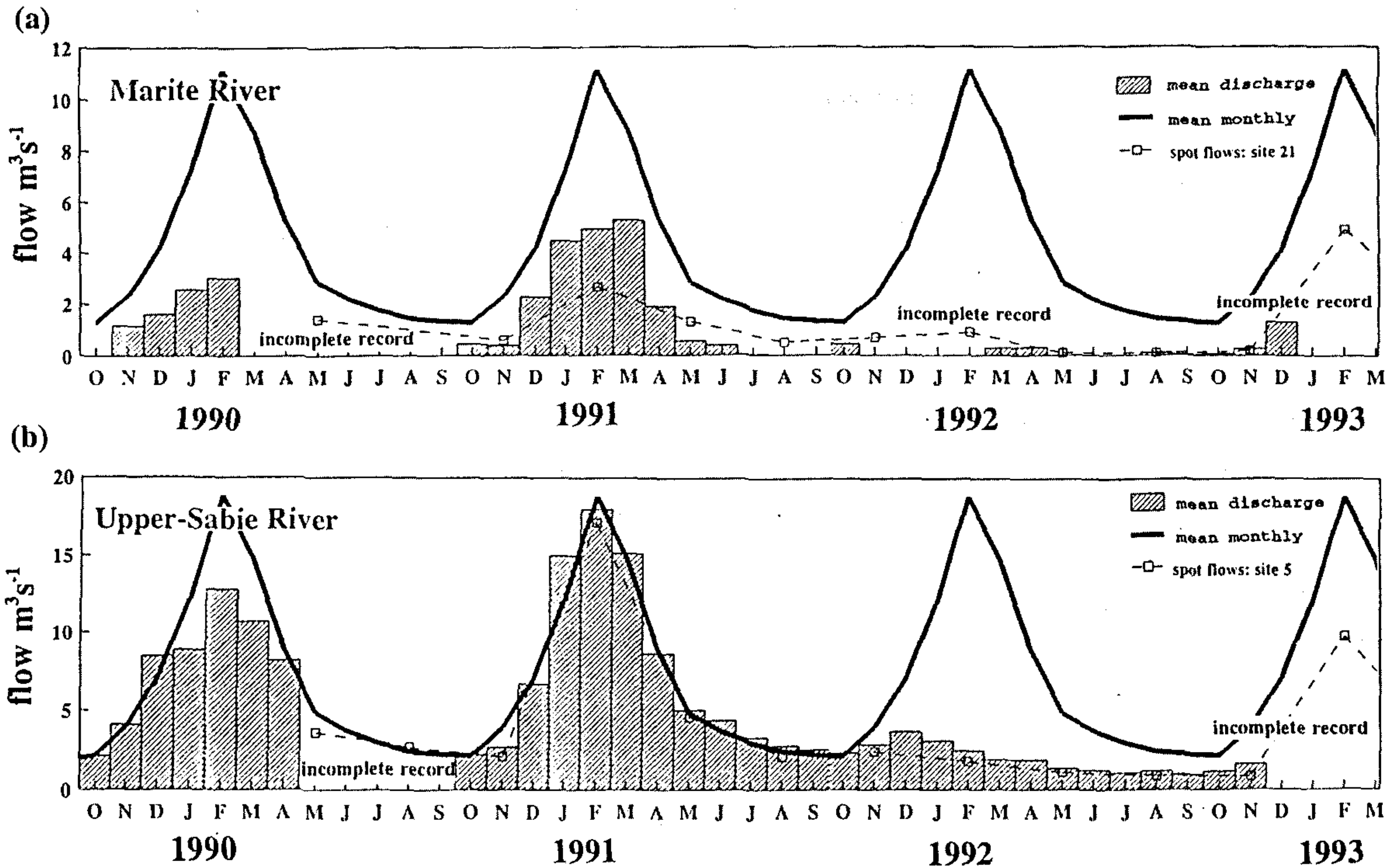

Figure 4.3: Gauged discharges (mean discharge) and spot-flows from 1990 to 1993, compared with the average seasonal discharge pattern (mean monthly) from simulated data for the past 64 years (Fig 4.2), for (a) the Marite River (weir X3H011) and (b) the upper Sabie (weir X3H006). The 1991 drought is noticeable in both these foothill sections.

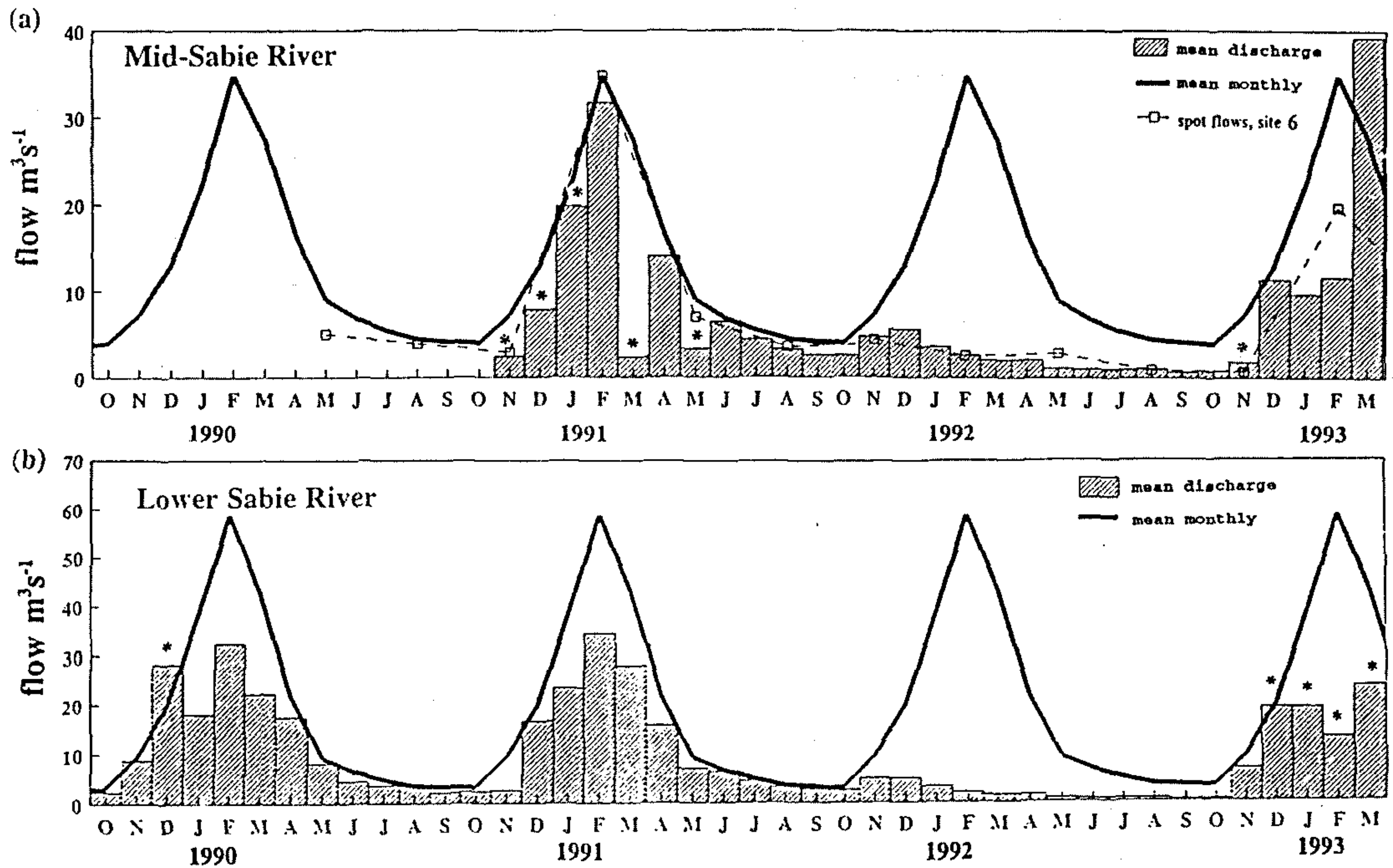

Figure 4.4: Gauged discharges (mean discharge) and spot-flows from 1990 to 1993, compared with the average seasonal discharge pattern (mean monthly) from simulated data for the past 64 years (Fig 4.2), for (a) the mid-Sabie River (weir X3H021) and (b) Lower Sabie (weir X3H015). The asterisk marks reading known to be under-measured. The drought of the 1991 hydrological year is noticeable in both sections. Base-flows were low but the river did not stop flowing in either reach throughout the drought.

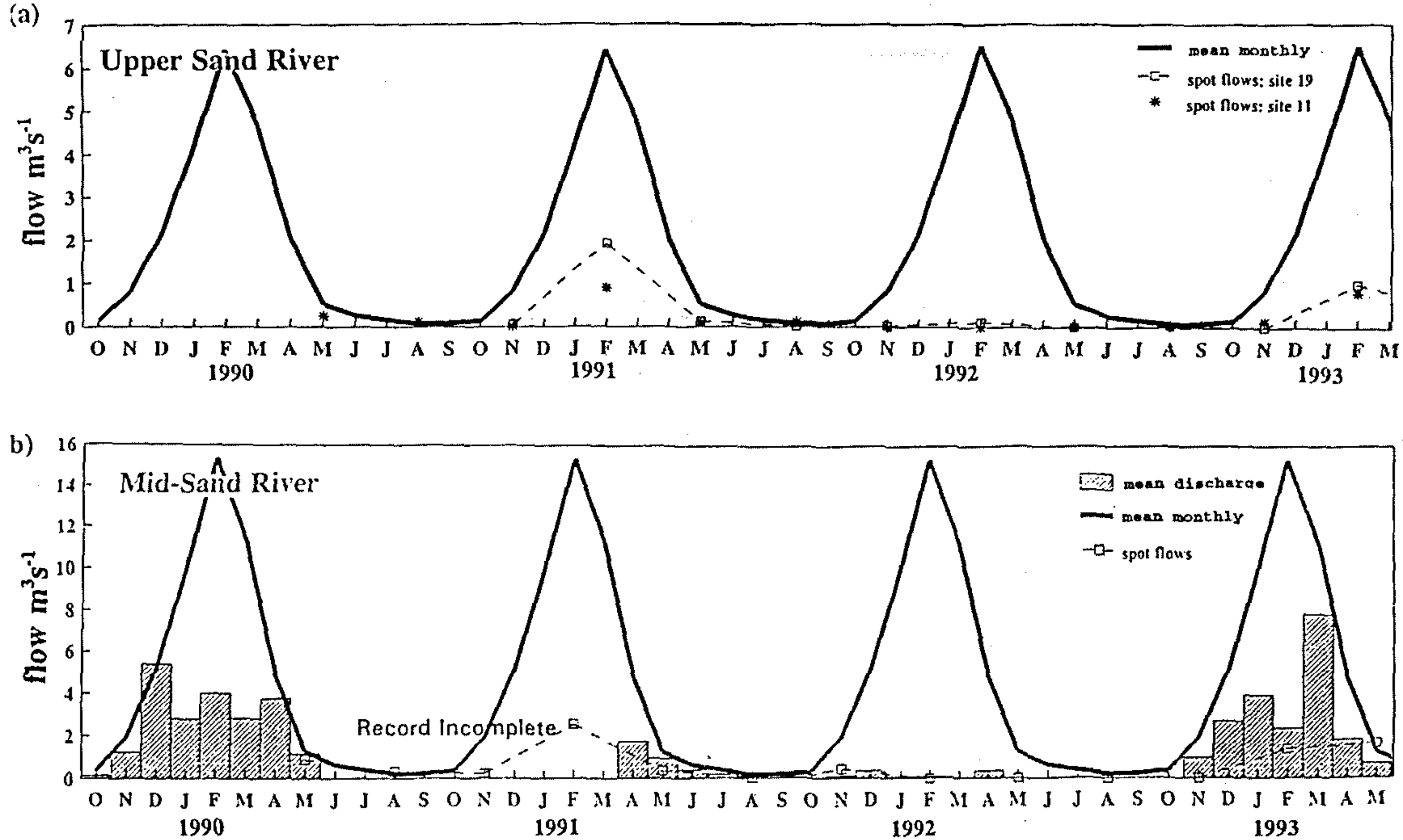

Figure 4.5: Mean discharge hydrographs for the duration of the study period (May 1990 -May 1993) for the upper and mid-Sand River. Mean monthly flow was calculated from simulated hydrological data (Fig 4.2). The mean monthly discharge for the upper Sand sections, were derived from mid-Sand River values. Monthly flow data was recorded at the weir X3H008 at Exeter on the Sand River. There was a gap in the gauged flow record between June 1990 and March 1991. Spot-flows for site 11 (Sand River) and site 19 (Mutlumuvi River) taken by transect during quarterly field trips are plotted for the upper Sand River lowveld to indicate base-flows. The drought of the 1991 hydrological year is noticeable in both reaches. The Mutlumuvi at site 19 stopped flowing during Oct-Nov 1992.

recording only 0.33 m^3s^{-1}. The lower Sand River section is prone to no-flow conditions under present developmental conditions and stopped flowing for five months during the drought (June-October, Fig 4.5b).

The flow profiles for the six identified sections and their respective monitoring stations (Table 4.1) are as follows:

a. **Headwaters and Foothills**

1) Marite River: Mean monthly discharge for the Marite was calculated from mid-Sabie values and the calculated contribution to total MAR of specific catchment areas taken from Chunnett *et al.* (1990). Eighty six percent of the mid-Sabie runoff is derived from the upper Sabie and Marite rivers (excluding the North Sand River), with the Marite River accounting for 37,3% of this runoff. Mean discharge recorded during the study period, particularly peak flows, were generally lower than predicted from Figure 4.3a. The 1992 drought is clearly seen with base-flows reduced almost to extinction. Quarterly spot-flows for monitoring site 21 are shown in Table 4.3.

2) Upper Sabie River: Mean monthly discharge was calculated for this reach as for the Marite, given that the upper Sabie accounts for 62,3% of the Marite-Sabie runoff. The recorded mean discharge closely approximates expected flows (Fig. 4.3b). The 1991-1992 drought is clearly seen. Base-flows were generally reduced to 50% of predicted flows, although the Sabie River remained perennial. Quarterly spot-flows for monitoring sites 3 and 5 are shown in Table 4.3.

b. **Lowveld**

3) Mid-Sabie River: Pre-drought runoff in the Sabie lowveld closely approximates expected flows. The 1991-1992 drought is clearly visible, with base-flows proportionately more reduced than flow of

Table 4.3: Spot-flows (m^3s^{-1}) recorded during quarterly field trips. The flows recorded at sites 3, 11 and 20 are partial flows at sampling sites, and are not representative of the whole river channel. Above site 3, the old Sabie Hydroelectric power station diverts a minimum of 1.1342 m^3s^{-1}. Above site 11 a citrus estate dam diverts 0.58 m^3s^{-1}. Site 20 straddles a single braid in the Sabie channel. Figure 4.6 relates actual flows in the braid to those for the whole channel.

		Monitoring Sample Sites										
		Foothill zone, Sabie			Lowveld zone, Sabie				Lowveld zone, Sand			
Field Trips		3	5	21	6	7	9	20	19	11	13	14
	May	1.220	3.566	1.360	5.070	7.220	-	1.194	-	0.257	0.863	-
90	Aug.	0.854	2.687	-	-	3.935	-	0.791	-	0.132	0.328	-
	Nov.	0.808	2.061	0.583	2.933	19.680	-	0.992	0.058	0.004	0.234	-
	Feb.	9.362	17.098	2.748	-	34.790	-	14.569	1.943	0.898	2.556	-
91	May	2.341	4.596	1.287	7.047	7.618	-	2.294	0.136	0.109	0.375	0.329
	Aug.	1.045	2.064	0.511	3.533	-	-	0.583	0.018	0.121	-	0.094
	Nov.	0.540	2.423	0.690	4.412	-	6.483	2.294	0.034	0.004	-	0.447
	Feb.	0.811	1.818	0.883	2.583	-	2.053	0.121	0.119	ZERO	-	ZERO
92	May	0.323	1.073	0.087	2.894	1.028	0.592	ZERO	0.010	0.006	0.001	0.002
	Aug.	0.617	0.906	0.144	0.953	-	0.659	ZERO	0.030	0.019	-	ZERO
	Nov.	0.018	0.855	0.207	0.729	-	13.151	3.475	ZERO	0.141	-	0.001
	Feb.	4.747	9.807	4.861	19.614	-	16.540	7.650	0.300	-	-	1.402
93	May	1.866	3.197	1.786	9.638	6.31	6.310	1.185	0.457	0.304	1.298	1.680
Min.		0.018			0				0			
Mean		2.417			5.814				0.095			
Max.		17.098			34.790				2.556			

higher sections, although at no stage did the river stop flowing (Fig. 4.4a). Quarterly spot-flows for monitoring sites 6 and 7 are given in Table 4.3.

4) Lower Sabie River: Peak flows did not approach those expected, possibly as higher seasonal runoff was anticipated, and due to the influence of extreme flood years on the mean monthly discharge (Chunnett *et al.*, 1990). Base-flows followed pre-drought levels (Fig.

4.4b). Drought base-flows were proportionately reduced in the lower Sabie reach. Quarterly spot-flows for monitoring sites 9 and 20 are shown in Table 4.3.

5) Upper Sand River Lowveld: The two main tributaries that form the upper Sand reach contribute similar runoffs. Their flows are comparable to half those calculated from the mid-Sand reach at Exeter (Fig. 4.5a). The magnitude of peak flows recorded during this study did not compare well with those calculated for the reach. Although the base-flows in the upper Sand were higher due to its proximity to the headwaters, the Mutlumuvi showed very low-flows throughout the drought. In November 1992 the Mutlumuvi was stopped downstream of site 19 by municipal abstraction for Dwarsloop. Quarterly spot flows for monitoring sites 11 and 19 are given in Table 4.3.

6) Mid-Sand River: Below average peaks of mean discharges were recorded for pre-drought years, suggesting that like the lower Sabie reach, the effect of extreme flood years on calculated peak flows are high (Fig. 4.5b). With the failure of the 1991-1992 wet season, the reach first stopped flowing for a short period in March 1992 at site 14. A local thunderstorm reactivated the reach, which finally stopped flowing again in May. The river did not flow again until 5 months later in November. The lower Sand River must have stopped flowing some time earlier, cutting the mid-Sand from the Sabie River. Quarterly spot flows for monitoring sites 13 and 14 are given in Table 4.3.

4.1.3 INTERPRETING SPECIFIC SITE FLOWS

Three sites need special mention when interpreting them in the context so far discussed.

Site 3:

Situated in the upper Sabie, the study site was found to be downstream of the old Sabie hydroelectric power station that consistently diverted at least 1.1342 m^3s^{-1}. During the height of the drought (Oct-Nov 1992), the whole base-flow of the reach was at times abstracted.

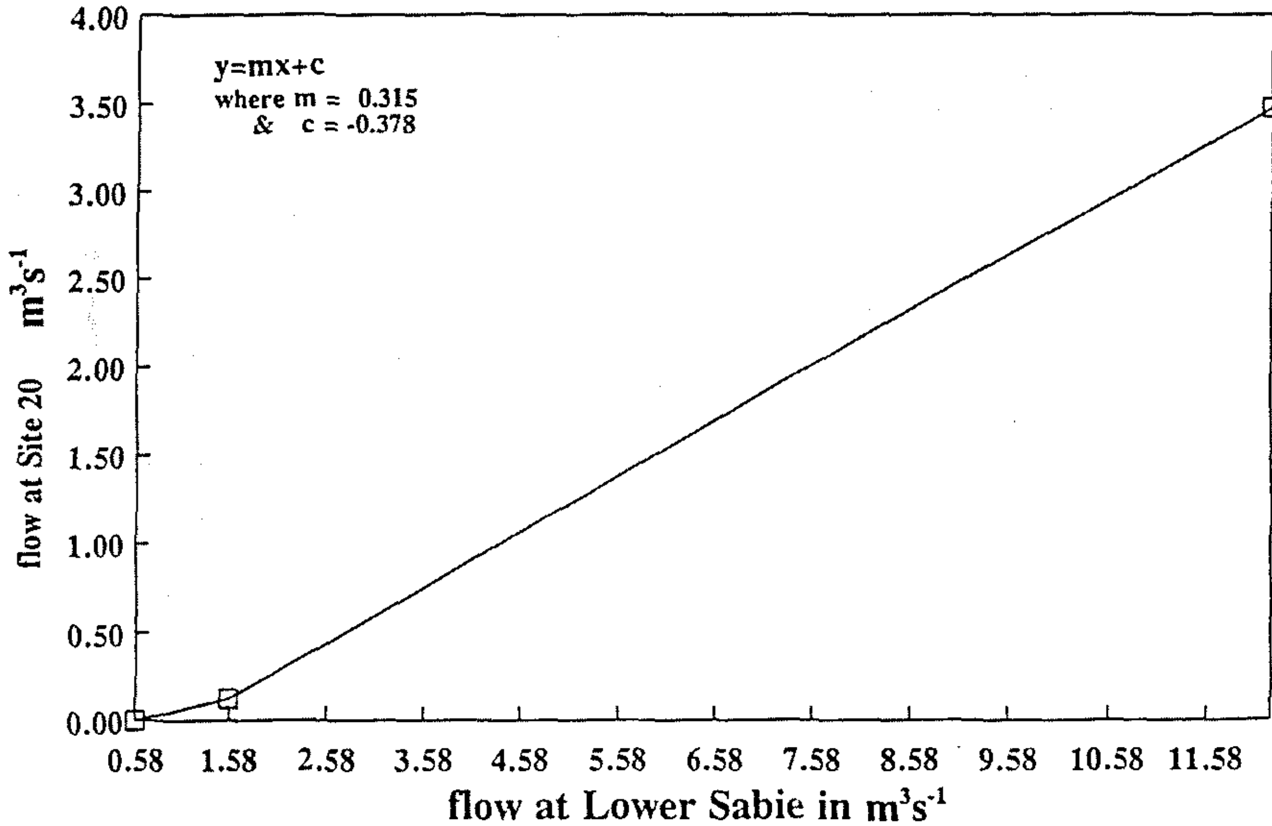

Figure 4.6: Flow calibration graph for Mlondozi, site 20. Discharge is measured from the upstream weir at Lower Sabie and the flow in the sampled braid calculated.

Site 11:

Similarly an inland irrigation canal parallel to site 11 was found late in the project. It explained the apparent low-flows recorded in the upper Sand in November 1990, well before any reach showed the effects of the drought. 0.58 m^3s^{-1} was continuously diverted by this canal.

Site 20:

Spot-flows measured are not directly comparable to those on the lower Sabie as the site is situated on a braid. The relationship of runoff at this site is presented in Figure 4.6.

4.1.4 DAILY FLOWS

Chunnett *et al.* (1990) acknowledged the importance of failing to deal with daily flow variations. This proved to be an important limitation in the hydrological analysis as daily flow variations, in conjunction with base-flows and drought, are probably the driving force in describing the distribution and abundance of the riverine biota. Mean discharges are useful in addressing flow consistency and low-flow quantification, but they mask the flushing flows typical of summer high-flow spates. Figure 4.7 traces the daily flow recorded in the mid-Sand reach from the breaking of the drought in November 1992 to early February 1993. In this lowveld reach, daily flows increased remarkably and rapidly for a limited period. These can be termed flushing-flows. Base-flows are re-established with an exponential decrease in flow in a few days, but remain elevated if flushing flows occur in close succession.

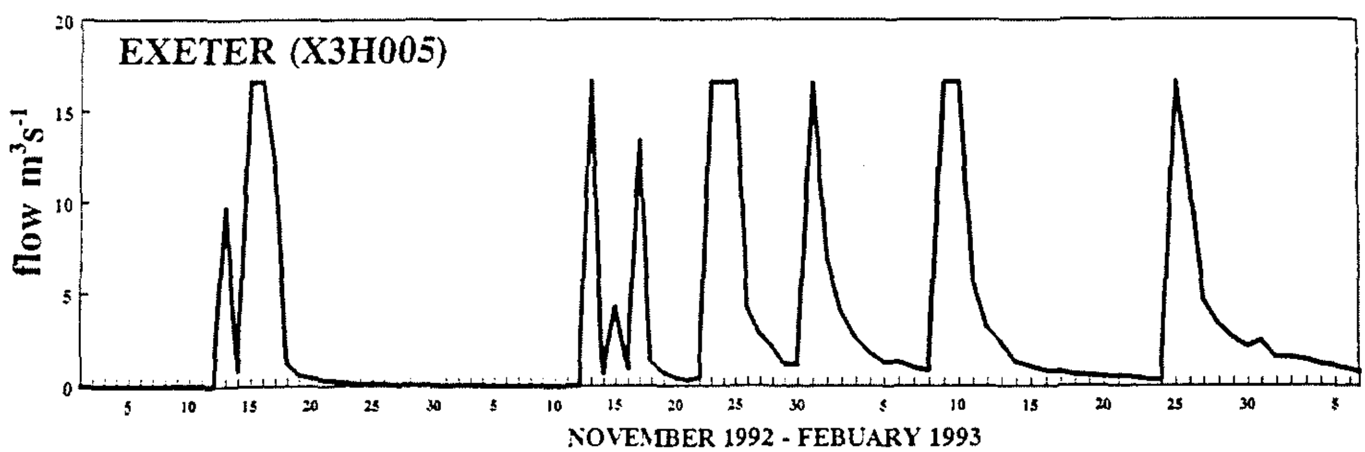

Figure 4.7: Flow readings at Exeter (Station X3H008) for the Sand River. Illustrated are spot-flows readings (at 6 am) or flood peak. Flow is "flashy" with a rapid rise and exponential fall in discharge. Six flow peaks were recorded between November 1992 and February 1993 where flow often exceeded the maximum calibrated discharge of 16.614 m^3s^{-1}.

5. PHYSICO-CHEMICAL STATUS OF THE SABIE-SAND SYSTEM

Water quality in the Sabie-Sand River is generally considered to be good to excellent, with the exception of elevated turbidity in the Sand River. Regular water chemistry samples have been analyzed since 1983 at four sites within the Kruger Park, and an analysis by van Veelen (1990) concluded that the river is not mineralised, and that the water quality has been stable over the period of record, but that the pH is relatively low, and the system is therefore poorly buffered and sensitive to changes in the catchment. This last statement is not confirmed by the pH measurements during 1990 to 1993 which were consistently higher than seven, apart from occasional readings in the upper section sites (Table 5.2).

Outside the Kruger Park, water chemistry samples have been analyzed regularly at 10 sites in the Sabie, Sand, and their main tributaries since the mid to late 1970's, with occasional samples from the 1960's. According to Chunnett *et al.* (1990), these samples show that all the surface waters in the catchment are suitable for irrigation, livestock watering, and after conventional treatment, for domestic supply.

Tables 5.1 to 5.8 list the water quality data analyzed from 11 sample sites during the present project, and the following sections relate the results to previous water quality measurements, and to general standards for different uses. The nutrient concentrations measured during this project are not presented in tables, since they were sampled only sporadically and the analyses of some samples had to be discarded due to contamination or spillage during transit.

Table 5.1: Salinity (measured as electrical conductivity in µS/cm) at sites in the Sabie and Sand Rivers. Site 21 is in the Marite River, and site 19 is in the Mutlumuvi River.

		CONDUCTIVITY (µS/cm) at monitoring sample sites										
		Foothill zone, Sabie			Lowveld zone, Sabie				Lowveld zone, Sand			
Field trips		3	5	21	6	7	9	20	19	11	13	14
90	May	-	-	-	-	-	-	-	-	-	-	-
	Aug.	-	-	-	-	-	-	-	-	-	-	-
	Nov.	-	-	-	-	-	-	-	-	-	-	-
91	Feb.	60	60	30	-	60	-	80	70	60	110	-
	May	100	80	40	80	80	-	80	70	70	130	120
	Aug.	100	100	40	100	-	110	110	90	80	170	160
	Nov.	120	100	50	90	140	150	150	100	110	180	180
92	Feb.	120	100	50	110	110	120	130	90	100	-	250
	May	120	95	50	120	130	150	-	100	90	220	180
	Aug.	100	100	50	150	-	-	-	100	90	-	-
	Nov.	170	150	80	180	-	120	210	220	140	-	-
93	Feb.	60	70	30	80	-	110	120	-	-	-	130
	May	90	90	40	120	100	120	130	130	90	135	120
Min.		30			60				60			
Mean		81.5			118				125.3			
Max.		170			210				250			

Table 5.2: pH measurements at sites in the Sabie and Sand Rivers. Site 21 is in the Marite River, and site 19 is in the Mutlumuvi River.

		pH at monitoring sample sites										
		Foothill zone, Sabie			Lowveld zone, Sabie				Lowveld zone, Sand			
Field trips		3	5	21	6	7	9	20	19	11	13	14
90	May	9.1	8.1	-	8.1	8.2	-	7.8	8.4	7.8	8.2	8.1
	Aug.	8.5	7.7	8.1	-	7.4	-	8.0	-	8.1	8.6	-
	Nov.	8.5	4.0	8.0	-	8.0	-	7.8	8.7	7.8	-	-
91	Feb.	7.8	7.4	7.4	-	7.4	-	7.3	8.0	7.5	7.8	-
	May	8.2	8.1	7.6	7.9	8.0	-	7.7	7.9	7.7	8.1	8.0
	Aug.	7.8	8.6	7.9	8.0	-	8.5	8.0	8.5	7.9	8.7	7.9
	Nov.	8.3	8.1	7.6	7.8	7.8	7.8	7.3	8.6	7.4	9.0	7.7
92	Feb.	-	8.3	7.2	7.9	7.8	8.3	7.7	7.2	7.2	-	9.0
	May	8.0	7.7	7.9	7.1	7.9	7.6	-	8.4	7.0	7.3	7.9
	Aug.	8.3	8.1	7.4	8.2	-	-	-	8.6	7.6	-	-
	Nov.	8.2	7.8	8.3	7.7	-	7.7	7.6	9.2	7.4	-	-
93	Feb.	5.8	6.7	7.2	7.4	-	7.5	7.6	-	-	-	8.0
	May	8.0	7.9	7.5	7.4	7.9	8.1	7.7	7.5	7.9	7.9	7.6
Min.			4.0				7.1				7.0	
Mean			7.8				7.8				8.2	
Max.			9.1				8.5				9.2	

Table 5.3: Total suspended solids (TSS) measured at sites in the Sabie and Sand Rivers. Site 21 is in the Marite River, and site 19 is in the Mutlumuvi River.

		TSS (g/l) at monitoring sample sites										
		Foothill zone, Sabie			Lowveld zone, Sabie				Lowveld zone, Sand			
Field trips		3	5	21	6	7	9	20	19	11	13	14
90	May	0.0014	0.0033	-	0.0043	0.0068	-	0.0071	0.0039	0.0024	0.0016	0.0057
	Aug.	0.0034	0.0042	0.0047	-	0.0061	-	0.0056	-	0.0041	0.0031	-
	Nov.	0.0016	0.0022	0.0029	-	0.0173	-	0.0545	0.0266	0.0076	0.008	-
91	Feb.	0.012	0.0148	0.0114	-	0.0524	-	0.0482	0.006	0.006	0.0136	-
	May	0.0011	0.0018	0.0031	0.0014	0.0016	-	0.0053	0.0025	0.0026	0.0015	0.0024
	Aug.	0.0004	0.0057	0.0027	0.0015	-	0.0034	0.0093	0.0073	0.0019	0.0015	0.0052
	Nov.	0.0014	0.0022	0.008	0.0216	0.0452	0.0622	0.204	0.0016	0.0025	0.0068	0.0182
92	Feb.	0.0017	0.0013	0.0208	0.0053	0.0047	0.0044	0.0033	0.888	0.0066	-	0.0137
	May	0.0037	0.0015	0.0031	0.0043	0.0036	0.0064	-	0.0057	0.0028	0.0044	0.0062
	Aug.	0.0016	0.0022	0.0031	0.0023	-	-	-	0.004	0.0023	-	-
	Nov.	0.0026	0.002	0.0126	0.0065	-	0.138	0.228	0.0124	0.0068	-	-
93	Feb.	0.0148	0.012	0.0216	0.0258	-	0.0573	0.0608	-	-	-	0.036
	May	0.0053	0.0034	0.007	0.1716	-	-	-	0.1408	-	-	0.052
Min.			0.0004				0.0014				0.0015	
Mean			0.0097				0.0377				0.0349	
Max.			0.0216				0.228				0.888	

Table 5.4: Turbidity (measured as Nephalometric Turbidity Units) at sites in the Sabie and Sand Rivers. Site 21 is in the Marite River, and site 19 is in the Mutlumuvi River.

Field trips		TURBIDITY (NTU) at monitoring sample sites										
		Foothill zone, Sabie			Lowveld zone, Sabie				Lowveld zone, Sand			
		3	5	21	6	7	9	20	19	11	13	14
90	May	-	-	-	-	-	-	-	-	-	-	-
	Aug.	-	-	-	-	-	-	-	-	-	-	-
	Nov.	-	-	-	-	-	-	-	-	-	-	-
91	Feb.	16	25	15	-	64	-	86	68	14	32	-
	May	1	2	7	2	2	-	14	10	5	7	9
	Aug.	3	4	7	2	-	3	7	10	4	-	7
	Nov.	6	1	18	27	64	75	469*	7	7	3	23
92	Feb.	13	2	30	8	6	5	7	1400**	6	-	9
	May	2	1	7	5	5	3	-	15	9	3	23
	Aug.	1	1	3	2	-	-	-	2	4	-	-
	Nov.	2	1	15	3	-	126	220	12	13	-	-
93	Feb.	17	2	9	22	-	52	51	-	-	-	50
	May	1	2	10	200	2	10	22	220	16	48	70
Min.			1				2				2	
Mean			7.5				45.5				70.2	
Max.			30				469				1400	

* Localized spate in Mlondozi tributary of Sabie.
** Zocknog dam construction.

Table 5.5: % Dissolved oxygen measured at sites in the Sabie and Sand Rivers. Site 21 is in the Marite River, and site 19 is in the Mutlumuvi River.

		OXYGEN (% saturation) at monitoring sample sites										
		Foothill zone, Sabie			Lowveld zone, Sabie				Lowveld zone, Sand			
Field trips		3	5	21	6	7	9	20	19	11	13	14
90	May	102	102	-	104	95	-	102	105	104	115	106
	Aug.	108	121	107	-	100	-	94	-	91	130	-
	Nov.	102	100	103	-	105	-	87	118	101	88	-
91	Feb.	97	97	96	-	101	-	89	107	94	103	-
	May	100	101	106	100	110	-	95	100	95	117	114
	Aug.	-	96	104	92	-	100	94	116	97	107	88
	Nov.	*106*	*116*	*106*	*101*	*95*	*100*	*83*	*97*	*133*	*115*	*81*
92	Feb.	103	110	99	93	102	115	93	88	81	-	122
	May	104	101	107	93	103	109	-	109	95	67	94
	Aug.	106	101	110	103	-	-	-	116	98	-	-
	Nov.	113	100	123	97	-	95	99	119	100	-	-
93	Feb.	98	98	98	107	-	95	95	-	-	-	100
	May	103	116	100	94	112	99	98	93	-	100	101
Min.			96				83				67	
Mean			104.3				98.6				102.7	
Max.			123				115				133	

Table 5.6: Spot temperatures measured during sampling trips in the Sabie and Sand Rivers. Site 21 is in the Marite River, and site 19 is in the Mutlumuvi River.

		SPOT TEMPERATURE (°C) at monitoring sample sites										
		Foothill zone, Sabie			Lowveld zone, Sabie				Lowveld zone, Sand			
Field trips		3	5	21	6	7	9	20	19	11	13	14
90	May	14.6	14.7	-	16.4	18.7	-	18.3	18.9	16.1	13.6	14.0
	Aug.	13.0	14.1	15.0	-	16.1	-	15.2	-	17.0	16.4	-
	Nov.	20.7	21.5	25.9	-	24.0	-	24.5	31.0	25.9	21.8	-
91	Feb.	17.2	19.6	25.4	-	23.5	-	25.2	28.4	24.9	27.6	-
	May	14.1	15.3	15.5	16.5	19.6	-	19.3	17.6	16.6	15.4	16.9
	Aug.	-	16.0	16.2	17.0	-	21.4	21.5	22.3	20.9	20.6	19.5
	Nov.	19.6	22.7	24.0	23.8	22.4	23.9	26.4	29.6	29.7	33.0	26.9
92	Feb.	22.2	26.1	21.9	25.5	28.8	32.1	29.7	25.0	26.6	-	28.4
	May	12.7	12.8	16.9	14.2	18.4	18.7	-	23.1	14.1	19.9	24.7
	Aug.	15.1	15.3	14.5	19.4	-	-	-	22.5	18.4	-	-
	Nov.	20.3	24.0	26.7	27.9	-	28.3	28.3	33.6	27.4	-	-
93	Feb.	19.2	21.3	21.7	21.4	-	26.1	27.5	-	-	-	27.5
	May	20.3	21.3	20.1	22.8	22.0	24.4	24.2	21.3	-	23.7	28.1
Min.			12.7				14.2				13.6	
Mean			18.9				22.5				22.8	
Max.			26.7				32.1				33.6	

Table 5.7: Maximum temperatures measured between sampling trips by means of minimum/maximum thermometers in the Sabie and Sand Rivers. Site 21 is in the Marite River, and site 19 is in the Mutlumuvi River.

		MAXIMUM TEMPERATURE (°C) at monitoring sample sites										
		Foothill zone, Sabie			Lowveld zone, Sabie				Lowveld zone, Sand			
Field trips		3	5	21	6	7	9	20	19	11	13	14
90	May	-	-	-	-	-	-	-	-	-	-	-
	Aug.	16.4	16.5	-	-	21.0	-	-	-	18.7	25.0	-
	Nov.	24.1	24.8	26.8	31.6	28.9	-	30.5	-	29.2	33.6	-
91	Feb.	22.3	24.6	25.3	-	27.0	-	31.8	-	29.9	34.5	-
	May	22.3	23.5	23.8	27.0	27.1	-	24.8	-	27.0	32.9	-
	Aug.	-	16.2	18.0	18.4	-	24.0	21.4	23.1	20.4	-	-
	Nov.	20.8	22.8	25.8	28.2	-	-	28.5	32.5	27.7	34.8	-
92	Feb.	23.5	25.4	28.8	29.5	-	-	32.0	34.6	33.2	-	-
	May	21.2	26.2	-	30.1	31.5	-	-	34.8	30.8	-	32.8
	Aug.	13	16.9	17.5	20.8	-	-	-	-	17.2	-	-
	Nov.	20.2	26.0	30.8	-	-	-	-	34.0	28.8	-	-
93	Feb.	22.2	-	-	27.3	-	-	-	-	-	-	-
	May	-	26.8	-	-	-	-	-	-	-	-	-
Min.			13				18.4				17.2	
Mean			22.5				27.1				29.3	
Max.			30.8				32.0				34.8	

Table 5.8: Minimum temperatures measured between sampling trips by means of minimum/maximum thermometers in the Sabie and Sand Rivers. Site 21 is in the Marite River, and site 19 is in the Mutlumuvi River.

		MINIMUM TEMPERATURE (°C) at monitoring sample sites										
		Foothill zone, Sabie			Lowveld zone, Sabie				Lowveld zone, Sand			
Field trips		3	5	21	6	7	9	20	19	11	13	14
90	May	-	-	-	-	-	-	-	-	-	-	-
	Aug.	11.1	11.5	-	-	13.0	-	-	-	12.0	10.0	-
	Nov.	12.1	13.0	13.9	12.0	15.3	-	16.7	-	14.9	13.2	-
91	Feb.	-	19.3	19.0	-	24.0	-	25.0	-	20.0	20.4	-
	May	14.4	16.0	15.6	16.4	17.6	-	19.7	-	16.3	13.4	-
	Aug.	-	12.4	10.4	12.3	-	12.2	13.7	11.0	12.1	-	-
	Nov.	16.2	16.3	16.0	17.3	-	-	18.7	16.0	17.4	15.9	-
92	Feb.	18.7	20.0	20.0	22.2	-	-	20.2	18.5	20.5	-	-
	May	10.4	14.2	-	16.2	14.8	-	-	16.0	14.0	-	15.0
	Aug.	7.5	10.6	9.5	5.6	-	-	-	-	11.6	-	-
	Nov.	12.2	14.7	15.2	-	-	-		10.2	17.0	-	-
93	Feb.	17.2	-	-	21.2	-	-	-	-	-	-	-
	May	-	18.0	-	-	-	-	-	-	-	-	-
Min.			7.5				5.6				10.0	
Mean			14.5				16.7				15.0	
Max.			20.0				25.0				20.5	

5.1 SALINITY

Concentrations of dissolved salts generally increased downstream, but were never high (Table 5.1). The maximum concentration (220 -250 µS/cm) occurred in the lowveld Sand River during periods of low-flow during the 1992 drought. Such concentrations are not as high as some recorded prior to this project in flowing water. The maxima recorded in the Sabie-Sand have been 368 µS/cm at North Sand (X3M04), and 360 µS/cm at Phabene (X3M12). In relation to general guidelines, these concentrations are well within even the most stringent. For example, DWAF (1993) states "No health, aesthetic or treatment effects associated with the electrical conductivity of water are expected below 45 mS/m, equivalent to 450 µS/cm". There are at present no environmental guidelines for water quality, but preliminary experiments being carried out on selected invertebrates from the Sabie do not indicate any adverse effects below salinities of 500 µS/cm. It seems highly unlikely, therefore, that elevated salinity in the Sabie-Sand River is a problem at present.

The situation during no-flow is very different. Isolated pools showed marked increases over time. At Londolozi in the mid-Sand River, conductivity had increased to between 300-600 µS/cm after three months and to 590-1720 µS/cm after five months isolation (Vol 2).

5.2 pH

Levels of pH showed considerable fluctuation during the project, particularly in the upper Sabie, where concentrations of 4.0 to 9.1 were recorded from site 3 in the Sabie and site 21 in the Marite respectively (Table 5.2). Values of 9.0 to 9.2 were also recorded from the lowveld section of the Sand River. Although the Sabie-Sand is generally an alkaline river, the high values are greater than had previously been recorded (8.5 in the Mac Mac tributary, Chunnett *et al.*, 1990), and may be cause for some concern, since, for example, the recommended acceptable range for Class 1 irrigation water is 6.5 to 8.4 (DWAF, 1993). the lower value of 4.0 was an isolated measurement at site 5 in the Sabie in November 1990, and is not as low as the minimum of 3.6 measured in the Marite (Chunnett *et al.*, 1990). Pools isolated during the drought tended to become more alkaline. After five months, some instream pools at Londolozi showed pH as high as 8.5-9.7.

5.3 TURBIDITY AND TOTAL SUSPENDED SOLIDS

Water in the upper Sabie is characterised by its clarity and low concentrations of suspended material (Tables 5.3 and 5.4). Chunnett *et al.* (1990) concluded that sediment yields in the Sabie catchment are relatively low and pose no serious threat to large reservoirs. An exception was the very high concentration of suspended material in the Marite River in November 1990. This was a consequence of the clearance of land adjacent to the river for the survey of the Inyaka Dam site and the establishment of new coffee plantations. Vegetation was cleared to the river bank, and the result was an influx of soil to the Marite, which was fortunately localised in time and space (suspended sediments were not elevated downstream at site 7 in the Sabie, Table 5.3).

In the middle Sabie, turbidities and TSS were also low to moderate, with occasional turbidity readings greater than 200 and concentrations of TSS over 0.1 g/l (Tables 5.3 and 5.4). These were usually associated with high flow spates in the river. At site 20 near the Mozambique border readings of 220 NTU and 0.228 g/l were the result of a local spate in the Mlondozi tributary, which joins the Sabie just upstream of the site. The catchment of the Mlondozi is completely contained in the Kruger Park, so that we must consider this to be a natural event, and this, the highest turbidity measured in the main Sabie River during the project, provides a useful benchmark for judging natural high turbidity events in the river.

The Sand River experiences higher average turbidities (Table 5.4) than the Sabie, as might be expected of a more temporary system, but lower concentrations of suspended solids (Table 5.3), presumably because the lower flows in the Sand River carry less sediment. Chunnett *et al.* (1990) however, conclude that the maximum average sediment yield from the Sabie and Sand will be very similar, because the sediment concentrations at high flows will be much higher in the Sand). The one set of very high readings (1400 NTU and 0.888 g/l) was measured at site 19 on the Mutlumuvi tributary, immediately downstream of the Zoeknog Dam site during its construction. This illustrates the effects of construction works in or next to the river bed. Very high turbidities were also measured in the Sand River following the collapse of the central section of the Zoeknog Dam (dealt with in Volume 3 of this report).

5.4 DISSOLVED OXYGEN

Although some very low DO concentrations were measured during this project, they were generally associated with isolated pools during the 1991-92 drought, usually shortly before the pools dried out. These events are described in Volume 2 of this report. Table 5.5 lists the % DO measured at a number of sites during routine sampling trips. Concentrations are on average at or around 100%, as would be expected in the absence of organic pollution leading to high BOD. The lowest concentrations (between 67 and 90%) were measured in mid-1992 at the height of the drought in the Sand River, where flow was reduced or absent. Measurements below 90% at site 20 in the lower Sabie were taken in a side channel which also stopped flowing during the drought, although the main channel did not.

5.5 WATER TEMPERATURES

Temperatures were measured in two ways: as spot temperatures measured whenever the sites were sampled (Table 5.6); and as maxima and minima between visits (Tables 5.7 and 5.8), by leaving a standard max-min thermometer immersed in the water.

Temperature readings for this project indicate a period of unusually hot weather, with maximum water temperatures in flowing water up to 34.8°C (Table 5.7). This is considerably hotter than the maximum quoted by Chunnett *et al.* (1990) (31.1°C), but high temperatures do not appear to have adversely affected the riverine fauna directly. Low temperatures (down to 5.6°C, Table 5.8), are not as cold as those quoted by Chunnett *et al.* (1990) (1.7°C), but were sufficient to cause fish kills in 1990 when a hail storm in the lowveld led to a sudden drop in water temperature right down the river into the Kruger Park. It appears that the absolute temperature is less important than the rate of change, and that fish in particular are unable to cope with sudden reductions in temperature, even down to 10°C, whereas they can manage at very much lower and very much higher temperatures if the change is gradual.

5.6 Nutrients

Nutrient concentrations in the Sabie and Sand Rivers are generally very low, and the maxima in the record previous to this project were as follows (From Chunnett *et al.*, 1990; and van Veelen, 1990):

PO_4	0.217 mg/l
$NO_3 + NO_2$	3.35 mg/l
NH_4	1.27 mg/l

Much higher phosphate concentrations than the above were measured during this project:

1.16 mg/l at site 6 in the Sabie in April 1993

1.41 mg/l at site 9 in the Sabie in May 1993

0.61 mg/l at site 2 in the Mac Mac tributary in May 1992

0.67 mg/l at site 14 in the Sand River in April 1993

These were the highest concentrations measured during routine sampling, and a number of other measurements exceeded 0.3 mg/l. The concentrations above 1 mg/l at sites 6 and 9 are a cause for concern, and may have been a consequence of fertilisers entering the river in irrigation return flows from the farmlands adjacent to the river at these sites. Other causes may have been a consequence of the accumulation of large organic loads during the drought, but the high concentration in the Mac Mac, which did not stop flowing, is hard to explain, and was not an isolated high measurement. Concentrations in excess of 1 mg/l are not only high for the Sabie, but for freshwaters in general, and would be likely to give rise to eutrophic conditions, especially in downstream impoundments.

The highest concentrations for nitrogen species during the project were well below the maxima listed above, with 0.317 mg/l for NH_4, and 1.13 mg/l for NO_3.

A one-off sample from the Sabie immediately downstream of the Sabie sewage treatment works (site 28) in August 1992 gave the following very high concentrations:

PO_4	16 mg/l
$NO_3 + NO_2$	34 mg/l
NH_4	0.32 mg/l

These concentrations were measured at the height of the drought, when the flow of the river was very low, and therefore the dilution factor was minimal. At site 3, some 10 km downstream, conditions had recovered to 0.31 mg/l of PO_4, but the local concentrations were nevertheless unacceptably high. (The DWAF special standard for phosphate in effluents is 1 mg/l).

5.7 CONCLUSIONS

The results of this project generally confirm the prevalent view that the water quality in the Sabie-Sand is adequate for all uses, but they do raise some disturbing concerns in relation to turbidity and nutrient concentrations.

Isolated high turbidity measurements associated with land clearance and construction next to the river are a sign that not enough care is being taken to ensure the preservation of the riparian vegetation which is a very effective filter, preventing material from the catchment from entering the river. On the other hand, the measurement of high turbidities in the Mlondozi tributary is an indication of the levels of natural sedimentation to which we must assume that the biota are adapted.

Elevated nutrient concentrations were common during the period of this project, but could be a consequence of two different trends: the project was carried out during the worst drought on record, and accumulation of organic matter may have contributed to the high nutrient concentrations; and/or there may be a trend of increasing use of fertilisers and effluent disposal in the catchment. The very high phosphate concentrations downstream of the Sabie STW are a result of inadequate effluent treatment which should be addressed as soon as possible.

It is not at present possible to assess environmental water quality requirements adequately, since little is known of the tolerances of the riverine biota. Preliminary experiments underway using a limited number of Sabie invertebrates have indicated that the salinities found in the Sabie-Sand are unlikely to be a problem for the fauna in the river. Apart from phosphates, there do not appear to be trends of increasing concentrations of potential pollutants in the river, and it can be assumed that the biota are adapted to survive the conditions in the river that have pertained to date.

During the 1920's, the main Sabie River was polluted by runoff from gold-mining to the extent that it was described as "virtually changed into a sterile stream" (Pienaar, 1985). It was not until the 1940's that the sources of pollution were cleaned up and the river began to recover. Traces of mercury were still found in the sediments as late as 1968, but the fauna of the Sabie has made a remarkable recovery, presumably from refuge tributaries such as the Marite and the Sand, which were not affected by the mining. The results of this project suggest that there are still some species of fish missing from the middle reaches as a result of their inability to scale cascades and waterfalls and recolonise the river.

We are dealing with a river that has previously experienced extreme water quality problems, and a fauna that has recovered from catastrophic declines in parts of the system. Both the vulnerability of the Sabie to pollution, and its resilience have been demonstrated. Its resilience depends on the maintenance of effective refuge areas from which the fauna can recolonise the rest of the river. The deterioration of refuge areas such as the Marite and Mutlumuvi rivers, both in terms of diminishing flow and deteriorating water quality, is a source of concern.

6. INVERTEBRATE COMMUNITY STRUCTURE

6.1 INTRODUCTION

The macro-invertebrate fauna is the most diverse and abundant group of aquatic animals in a river. The types and densities of invertebrates found at any point along the river are a reflection of the water quality, habitat availability and flow regime of that reach, and could therefore be described as an integrated reflection of the condition of the river. For this reason the invertebrate fauna is most often used to provide an index of conditions, and particularly of water quality.

Although individuals of some species can drift downstream, and the insects have aerial stages during which they travel long distances, the populations living on the river bed tend to be sedentary, and will reflect conditions in the river over the course of their lifetime in the water, which may be between two weeks and several months. The community therefore also provides a time-integrated reflection of conditions in the river, as opposed to water chemistry samples which are only an instantaneous snap-shot of conditions at the time the water is collected.

Invertebrates are also a key community in the ecological functioning of a river - breaking down organic detritus in association with the microflora to recycle nutrients, filtering material out of the water column, grazing algae and fungi from the river bed, turning over the sediments, and serving as important food for other species such as fish.

For these reasons, as well as the intrinsic value which they contribute to the biodiversity and conservation value of rivers, the invertebrate fauna of the Sabie-Sand River was sampled at the same sites, and with the same frequency as the fish fauna. Three different habitats were sampled: stones-in-current (riffles)/bedrock runs; marginal vegetation and sediments. In addition, hydraulic habitat characteristics (current speed and depth) associated with the invertebrate samples were measured at quarterly monitoring sites. The main difficulty with interpreting information from invertebrate samples is that the taxonomy of many of the major groups is either incomplete, or, in the case of the mayflies, being revised. As a result, the analyses presented here are at varying taxonomic levels, from genus for mayflies, caddisflies and some other insects, to family, order, or even phylum level for other groups such as oligochaete worms. This precludes the use of some types of analysis, such as diversity indices, which require that all taxa be described at the same level.

The aims of this chapter are to:

- Describe the invertebrate communities found in the Sabie, Sand, and other major tributaries.
- Assess the changes in the invertebrate fauna from 1990 to 1993, and particularly during the drought conditions of 1992 (section 6.2).
- Describe the differences between the fauna of different habitats (section 6.3).
- Define the microhabitat preferences of major groups of invertebrates in terms of substrate, water depth and current speed (section 6.4).

Invertebrates have previously been sampled at two sites in the Sabie River during 1985 and 1986. These samples are discussed and compared with those collected from the Letaba River at the same time, and during a subsequent survey in 1990 and 1991, in chapter 8.

6.1.1 ANALYSIS OF THE INVERTEBRATE DATA

Cluster and MDS analyses from the PRIMER statistical package (see section 3.5.2.2) were used to establish the similarity of samples in time and space. Analyses were carried out for all the different habitats, but only the analyses from the riffle samples are presented here, since they provided the clearest indications of the changes in the fauna in time and space.

6.2 INVERTEBRATES OF THE RIFFLES

Riffles tend to be the most consistent type of habitat in rivers, providing a comparable range of refuges on, under or around the stones which form the substrate, and a variety of current velocities, and shallow depths. The invertebrate communities of riffles therefore tend to be similar in similar parts of the river, although they are affected by seasonal changes, water quality changes, and changes in discharge. We have therefore concentrated our analysis of the invertebrate fauna on the riffle communities, as those most likely to indicate differences between different zones of the river, different seasons, or different years of the study.

Figure 6.1 is a cluster analysis using the Bray-Curtis similarity index to group all riffle samples for all sites for all seasons, excluding all taxa that make up less than 4% of the total.

The analysis indicates five major clusters at the 37% similarity level or less, with an outlying group (Group VI) of 4 samples which separate at the 20% level or less.

Of the five major clusters, Group V is anomalous, consisting of 6 samples which contained very few animals. Checking the original data, it transpires that these samples were actually taken from rock/slab habitats rather than from riffles. Samples from the other habitats at these sites were rich in species and abundance. Group IV, designated "Drought, lower river reaches", separates at the 29% level; Group III, "1990 pre-drought", separates at the 33% level; and Group II, "Drought, upper river", and Group I, "Recovery", separate at 38%. The "Recovery" group is consistently referred to in inverted commas because, although flow conditions recovered in November 1992, the fauna had not fully recovered by the time sampling ended in May 1993, and these samples were as depauperate as the drought samples.

These four major clusters describe a progression from a wet period (1990), through a drier year (1991), through the worst drought on record (until November 1992), and finally into the

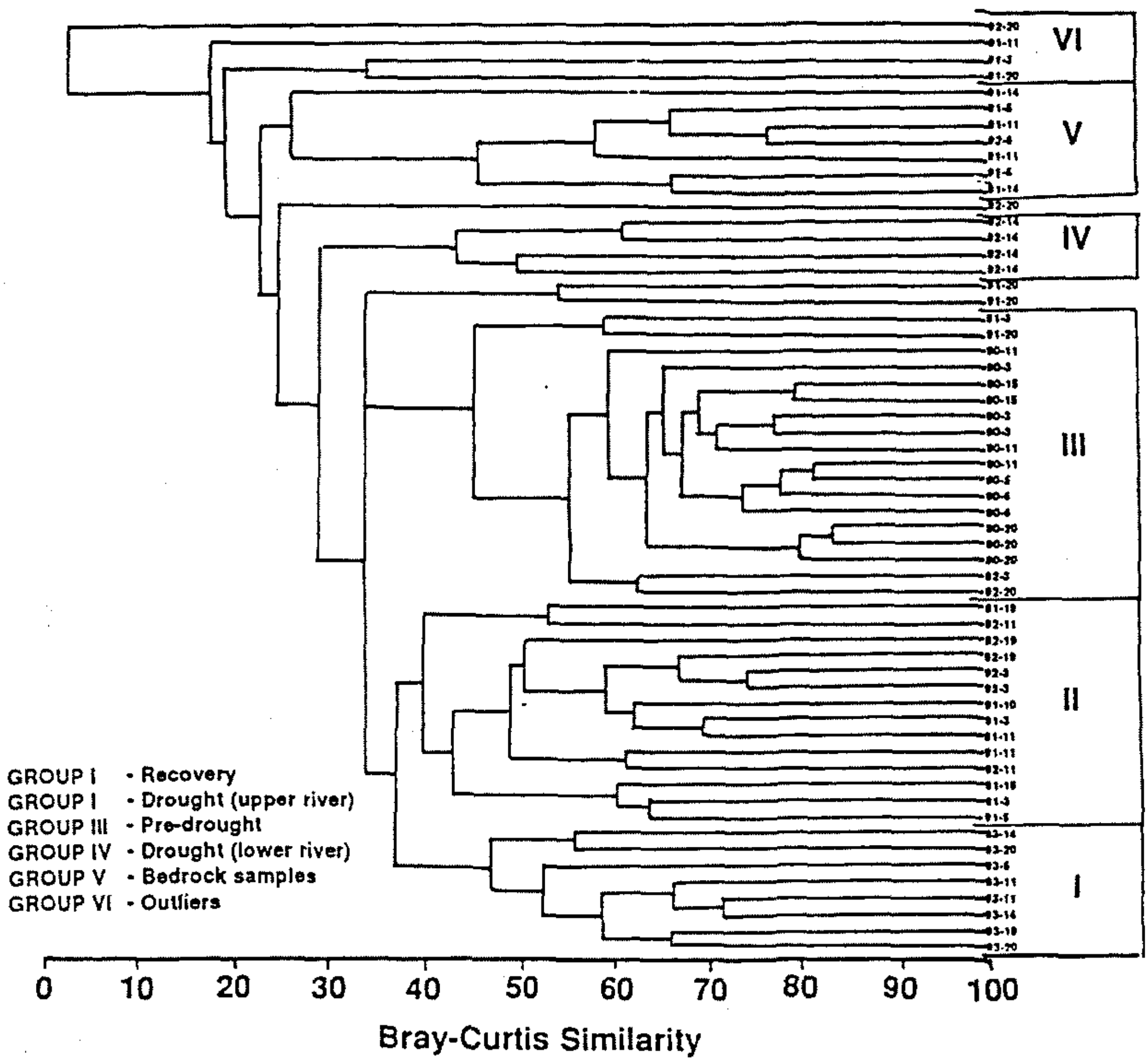

Figure 6.1: Bray-Curtis Similarity dendrograms generated using PRIMER (see text) for all invertebrates recorded from riffle biotopes in the Sabie-Sand River system, for all seasons and all years of the study (1990 - 1993). The divisions, I - VI, have been used to generate the MDS scatter plots illustrated in Figures 6.2 & 6.3. Codes for each sample are: year of sample - field station number; eg. 92-20 = Sample from riffle biotopes in 1992 at site 20.

reestablishment of good flow conditions from November 1992 until the end of the sampling programme in May 1993.

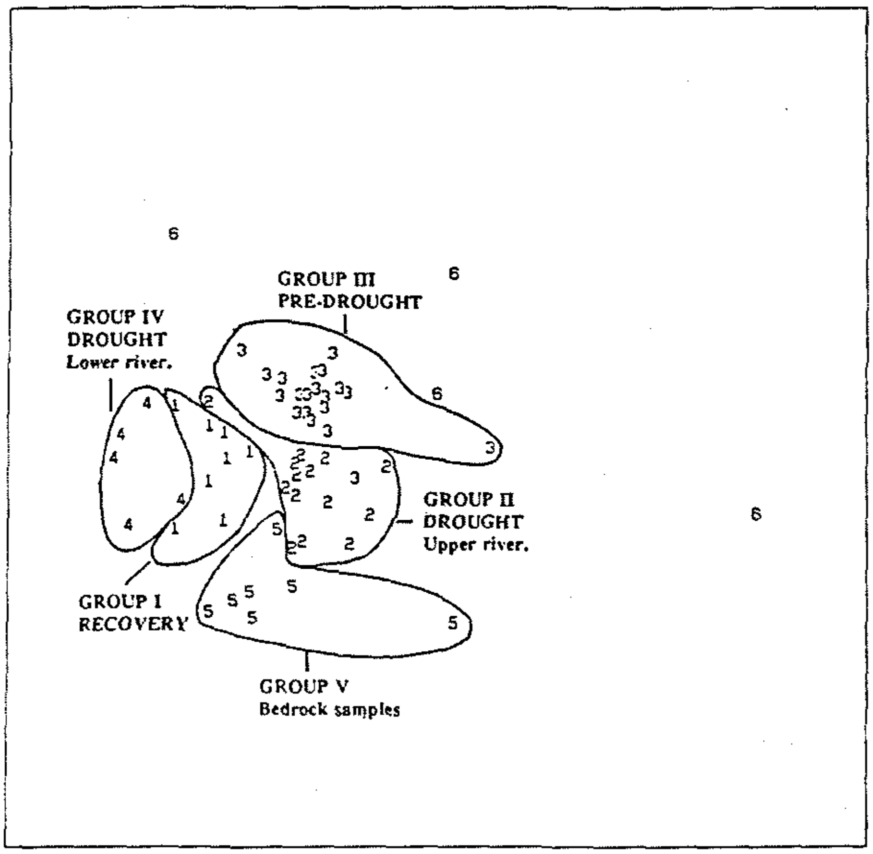

Figure 6.2: MDS scatter plot generated using PRIMER (see text) from the Bray-Curtis Similarity dendrogram illustrated in Figure 6.1. Data cover all invertebrate taxa recorded from the riffle biotopes in the Sabie-Sand River system, for all seasons and all years of the study (1990 - 1993). The samples that fell into each of the divisions (1-6) are circled in order better to identify clusters and their relationships. The stress factor for this plot was calculated at 0.21.

Groupings in the MDS

The MDS plot in Figure 6.2 indicates that the communities in the two wetter years, (Group III, 1990 Pre-drought, and Group V) are distinctly separate. As described above, this is due to the depauperate nature of the Group V samples. The drought, upper river group (Group II), is centrally situated between Groups III and V, so that the vertical axis in the MDS seems to indicate a species richness and abundance gradient.

The most obvious feature of both the clusters and the MDS is that the sample groups are closely related to the changing flow conditions throughout the three and a half years of the study, rather than to seasonal changes, or to different river zones.

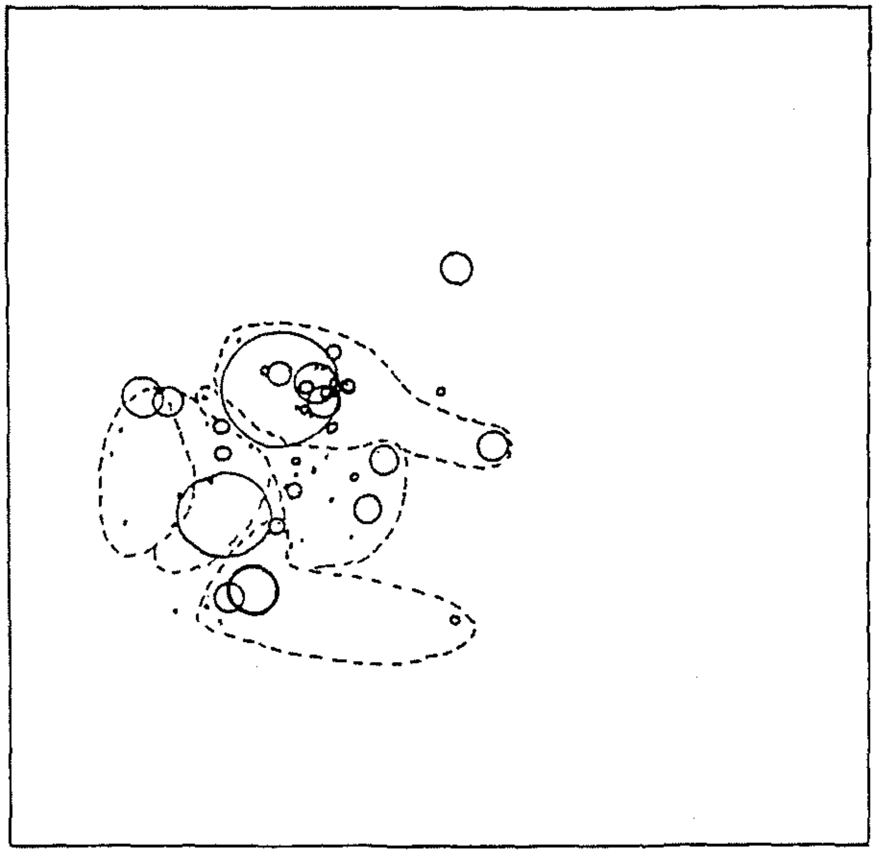

Figure 6.3: MDS scatter plot illustrating all invertebrate taxa for all seasons and all years (April 1990 - May 1993) recorded in the riffle biotope, in relation to flow rates, measured by transect during sampling visits. The size of the continuous line circles is proportional to the flow rate. (Groups of samples, indicated by dashed lines, are the same as for Figure 6.2).

Correlation of groups with discharge

Figure 6.3 is an overlay of discharge conditions (spot measurements at each site on each sampling occasion). In this context, we should preface our conclusions with the observation that the invertebrate communities sampled are more a reflection of antecedent conditions than of the instantaneous discharges measured. However, detailed hydrological measurements for all sites are not available, and we are therefore unable to reconstruct the antecedent conditions between sampling occasions with any degree of confidence. Nonetheless, it is apparent from Figure 3 that the highest flows were associated with the 1990 (III) and "recovery" (I) periods, whilst the lowest flows were associated with the drought groups (II and IV). An apparent anomaly in Group IV is that sample 56 (Site 20, December 1992) was collected during a flow of 3.48 $m^3.sec^{-1}$. However, this discharge had only commenced two days before the samples were collected, and therefore the invertebrate community reflects the antecedent drought conditions, explaining its position in Group IV.

Abundance of Dominant species defining each group

Samples in the 1990 pre-drought group (III) contain by far the greatest numbers of animals (with an average of 5280 per sample), followed by samples from the drought lower sites (IV), with an average of 1164 animals per sample, the upper drought (II) samples averaging 448 per sample. The "recovery" group (I) had the lowest densities of animals, 365 per sample. Clearly, the drought had a very severe impact on invertebrate abundance, with a decrease of almost an order of magnitude between 1990 and the height of the drought in 1992. Although these figures are a reasonable reflection of the densities of invertebrates in the river, it is difficult to draw conclusions about absolute abundances since the shrinking habitat during drought periods may have concentrated the low numbers of survivors into high densities. There may therefore have been an even greater reduction in the abundance of invertebrates between the wet years and the drought. Similarly, the very sparse numbers in the "recovery" samples may be due to dilution effects as the habitat availability increased with increasing flows, as well as the fact that population numbers were very low in the wake of the drought, and had not yet had time to build up again.

A Similarity Percentage Analysis, using Primer clearly shows the Chironomidae to be by far the most abundant taxon in all four of the major clusters illustrated in Figures 6.1-3 (see

Table 6.3). In terms of relative densities of chironomids between groups, the so-called "recovery" group (I) ranks < drought upper river reach (II) < drought lower river reaches (IV) < 1990, pre-drought (III). In the pre-drought samples the chironomids make up 48% of the total numbers, compared to 52 and 35% respectively for the drought upper and lower groups, falling to 33% in the "recovery" period. Other than the chironomids, the two most abundant taxa were the Baetidae, which formed 7% of the pre-drought samples, 7% of the drought upper, 0.5% of the drought lower, but climbed to 12 % of the "recovery" fauna; and the Simuliidae, which formed 14% of the pre-drought, climbing to 31 and 47 % respectively for the drought upper and drought lower samples, but fell to 10% in the "recovery" period. This dominance of the Simuliidae during the drought period compared to the wetter period is surprising, since simulids are filter-feeding animals which normally thrive in fast-flowing waters.

Of the 36 most common taxa recorded in the pre-drought period (1990), elmid beetles comprised 16%, Trichorythus 3.3%, Hydracarina 2.8%, and Cheumatopsyche 2.2%. In the drought upper samples there were 28 common taxa, of which the elmids only made up 0.5%, Cheumatopsyche 2.7%, Hydracarina 1%, and Trichorythus were absent. In the drought lower samples the number of common taxa fell to 13, the elmids were absent, and Hydracarina formed only 0.06%. The most abundant of the remaining taxa were the Ceratopogonidae (6%), the Copepoda (3.85), Lumbriculidae (3.4%), the Culicidae (1.9%), the Corixidae (1.2%), Hirudinae (0.9%), and the burrowing mayfly *Povilla adusta* (0.4%). Many of these taxa preferentially inhabit pools and very slow flowing water, indicating that the riffle habitats were meagre by this stage of the drought. The appearance of *Povilla adusta* (which burrows into wood) in the riffle samples, is also surprising. For the recovery period there were 15 common taxa, of which the Ceratopogonidae comprised 3%, and elmids only 0.8%. Interestingly, the Hydropsychidae, including *C. thomassetti*, made up nearly 15% of the fauna, while the mayfly Trichorythus (an obligate rheophile) was the second most abundant taxon in this group at 23.5%.

Relative taxonomic diversity of groups.

As might be expected, the pre-drought 1990 samples were by far the most diverse in terms of numbers of taxa per sample, averaging 29.4, compared to 14.8 for the drought upper samples, and 15.8 for the drought lower. As we remarked earlier, the "recovery" samples were also depauperate, with an average of 14.3 taxa per sample. It seems clear that the drought halved the diversity of the riffle fauna, while recovery seems to take longer than the seven months of good flows which were sampled at the end of the project.

While these groups may be compared with one another, the variable taxonomic levels to which we were able to identify the fauna precludes comparison with other studies unless the taxonomic levels are equalised. It also precludes the use of diversity indices (which combine taxonomic diversity with abundance) since these all require that animals be identified to the same level.

Drought, wet year, and "recovery" communities

By examining the presence and absence of taxa in the different groups, it is possible to identify those taxa which are characteristic of wet and dry conditions. For example, 11 of the 36 taxa common in the 1990 pre-drought samples disappeared from the riffle habitat during the drought:

Trichoptera:

- *Chimarra* sp.
- Philopotamidae
- *Aethaloptera* sp.

Ephemeroptera:

- *Cloeon* sp.
- *Trichorythus* sp.
- *Acentrella* sp.

Demoulina sp.

Hemiptera:

Pleidae

Diptera:

Tabanidae

Mollusca:

Sphaeridae

While it is predictable that Trichorythus should disappear in slow-flowing conditions, because it is rheophilic, it is less obvious why taxa such as *Cloeon* and Pleidae should be absent from drought samples, since they are inhabitants of pools and marginal areas which are still available at low-flows.

There were 6 taxa which occurred in the drought samples but did not occur in the wetter 1990 conditions:

Annelida:

Lumbriculidae

Hirudinea

Trichoptera:

Hydropsyche longifurca

Ephemeroptera:

Povilla adusta

Diptera:

Orthocladiinae

Mollusca:

Burnupia sp.

It might not be wise to rely too much on these taxa as indicators of drought conditions, since their absence from samples taken in higher flows may be a sampling artifact (for example the annelids may migrate deeper into the sediments during high discharges).

The recovery period was characterised by the presence of large numbers of small hydropsychid caddis larvae and two taxa which were absent during the drought, including one that appeared for the first time:

Ephemeroptera:

Trichorythus sp.

Diptera:

Culicidae (sampled for the first time)

While we would expect the reappearance of *Trichorythus* and small Hydropsychidae as flow increased, the appearance of mosquito larvae in the riffle samples for the first time during the project is baffling, since they are typical of stagnant waters.

6.3 COMPARISONS BETWEEN DIFFERENT HABITATS

The riffle habitat has been used to analyze changes in communities throughout the wet years, drought, and recovery period, because the PRIMER analyses of riffle samples provided the clearest picture of changes caused by reductions in flow. This section concentrates on the differences between the communities of the riffle, marginal vegetation, and sediment habitats, in terms of their diversity and the dominant taxa of each.

For comparisons between the invertebrates of the different habitats, two restrictions have to be observed throughout:

- The habitats cannot be sampled in the same way, or with the same apparatus, and absolute densities of animals cannot be measured without resorting to extremely laborious techniques, such as auguring into riffle substrate in order to sample animals that may be 1 meter deep in the sediment. It is therefore not possible to compare densities in the different habitats, although it is possible to compare the relative diversities.

- It is not possible to identify many of the invertebrate groups to species, and therefore two options are open: To treat all groups at the same level (which would be family or even coarser level); or to retain the maximum information by treating groups at different levels, acknowledging that care has to be taken in any comparisons, and that many types of analysis are then not suitable. We have chosen the latter course, because this study aims to provide baseline data on the diversity of the invertebrates throughout the river.

The taxa listed in Appendix II cannot be equated with those listed in Section 8, where a comparison is made with studies on the Letaba River. In that comparison, the taxonomic levels used had to be converted to those which were common to all the present and historic studies on both rivers.

Appendix II provides a list of all the taxa, and the numbers found in all the samples from the different habitats, identified as far as possible by the project team. Table 6.1 is a summary

Table 6.1: Diversity and abundance of invertebrate taxa in the 3 principle biotopes. "Unique taxa" refers to those which were found in only one biotope. (N.B. Because of different sampling methods, abundance cannot be compared between biotopes.)

	BIOTOPE		
	Riffle	Soft-sediments	Marginal vegetation
Number of taxa	178	120	189
Individuals per sample	5734	2638	3035
Unique taxa	13	1	24

of the number of taxa, which is comparable between habitats, and the average number of individuals per sample, which are not comparable, because of the different sampling methods used for each habitat (see section 3.5.2 for details). The marginal vegetation contained the most taxa (189), and the sediments the least (120). Abundances were high for all three habitats, and were particularly high for the sediments (2638 individuals per grab sample of 0.00225 m^3). Sediments of clean rivers are often very sparsely populated and not very diverse, and those of the Sabie-Sand seem to be an exception, possibly because the sediments are mostly sandy and aerobic, rather than silt and clay, and the drought meant that the sediments in pools were often the only remaining habitats in which large numbers of invertebrates congregated.

The marginal vegetation contained the highest number of taxa which were restricted to one habitat (24, Table 6.1), compared to 13 in riffles and only one in soft sediments. The sediments are usually the habitat of the most tolerant species, and therefore lack the restricted species that are characteristic of the other habitats. Since the marginal vegetation contains the most diverse fauna, and the most unique taxa, this habitat is obviously of great importance in the maintenance of the natural diversity of the river. It is also the habitat which is lost first when water levels drop, and for both these reasons should be considered the critical habitat in the river.

The Trichoptera most characterise both the riffle and the marginal vegetation, with 6 genera/families restricted to each (Table 6.2). In addition, 5 molluscan families are restricted to the marginal vegetation. An analysis of the most abundant groups in each habitat is presented in Tables 6.3a-c. Key groups which are abundant in one habitat, but less common in the others, are:

In riffles:	Rhagionidae; Hydroptilidae; *Cheumatopsyche afra; C. thomassetti; Hydropsyche longifurca*; and *Cloeon* complex.
In marginal vegetation:	Cladocera; Pleidae; Culicidae; *Demoulina* complex; *Caenodes* sp.; and *Caridina nilotica.*
In sediments:	Protoneuridae; Lumbriculidae; Tubificidae; Gomphidae; *Afrocaenis* sp.; *Tomichia* sp.; and *Sphaerium* sp.

The dominance of the three hydropsychid net-spinning caddisflies (*C. afra, C. thomassetti,* and *H. longifurca*) together with hydroptilid caddisflies is typical of flowing water habitats. *Cloeon* spp. are more characteristic of marginal habitats, and they are present in numbers in the marginal vegetation (see Appendix II), so their presence in the riffles may be an effect of the drought. The freshwater shrimp *C. nilotica* is characteristic of the marginal vegetation, and the lumbriculid and tubificid worms are typical of the sediments, as are the burrowing gomphid Odonata.

Table 6.2: Taxa unique to each of the three biotopes surveyed.

Biotope	Taxa	Order
Riffles	Brachyura	(Decapoda)
	Deuterophlebiidae	(Diptera)
	Caenospella sp.	(Ephemeroptera)
	Prosopistoma sp.	(Ephemeroptera)
	Saldidae	(Hemiptera)
	Rhynchocoela	(Nemertinea)
	Platycnemididae	(Odonata)
	Amphisyche sp.	(Trichoptera)
	Glossosomatidae	(Trichoptera)
	Hydropsychidae	(Trichoptera)
	Polycentropodidae	(Trichoptera)
	Stactobia sp.	(Trichoptera)
	Tinodes sp.	(Trichoptera)
Marginal Vegetation	*Cnidaria*	
	Platyhelminthes	
	Georyssidae	(Coleoptera)
	Haliplidae	(Coleoptera)
	Noteridae	(Coleoptera)
	Ephydridae	(Diptera)
	Limnebidae	(Diptera)
	Afrobaetoides sp.	(Ephemeroptera)
	Oligoneuridae	(Ephemeroptera)
	Mesovelidae	(Hemiptera)
	Ancylidae	(Mollusca)
	Corbicula africana	(Mollusca)
	Lanistes sp.	(Mollusca)
	Physa sp.	(Mollusca)
	Succinea sp.	(Mollusca)
	Calopterigidae	(Odonata)
	Chlorolestidae	(Odonata)
	Agapetus sp.	(Trichoptera)
	Calamoceratidae	(Trichoptera)
	Dicercomyzon sp.	(Trichoptera)
	Leptocerina sp.	(Trichoptera)
	Leptocerus sp.	(Trichoptera)
	Leptonema sp.	(Trichoptera)
	Trianodes sp.	(Trichoptera)
Sediments	*Hydrocena* sp.	(Mollusca)

Table 6.3a: Ranked, thirty most abundant taxa collected in the riffle biotope.

Taxa		Ave. Sample Abundance
CHIRONOMIDAE	(Diptera)	3469
SIMULIIDAE	(Diptera)	615
BAETIDAE	(Ephemeroptera)	174
ORTHOCLADIINAE	(Diptera)	146
Baetis sp.	(Ephemeroptera)	135
ELMIDAE	*(Coleoptera)*	101
Trichorythus sp.	(Ephemeroptera)	83
COPEPODA	(Crustacea)	77
HYDRACARINA	(Arachnida)	72
Cheumatopsyche thomasseti	(Trichoptera)	62
Neurocaenis sp.	(Ephemeroptera)	52
CAENIDAE	(Ephemeroptera)	41
RHAGIONIDAE	(Diptera)	35
Choroterpes complex	(Ephemeroptera)	33
other DIPTERA		30
Chironominae sp.	(Diptera)	24
Cheumatopsyche sp.	(Trichoptera)	23
TIPULIDAE	(Diptera)	22
HYDROPTILIDAE	*(Trichoptera)*	21
OLIGOCHAETA	(Annelida)	21
HYDROPSYCHIDAE	(Trichoptera)	21
Cheumatopsyche afra	(Trichoptera)	20
OSTRACODA	(Crustacea)	19
CERATOPOGONIDAE	(Diptera)	19
other TRICHOPTERA		18
Coleoptera sp.	(Coleoptera)	18
Hydropsyche longifurca	(Trichoptera)	17
other PLECOPTERA		15
Cloeon complex	(Ephemeroptera)	15
other EPHEMEROPTERA		15

Table 6.3b: Ranked, thirty most abundant taxa collected in the soft-sediment biotope.

Taxa		Ave. Sample Abundance
CHIRONOMIDAE	(Diptera)	1681
CAENIDAE	(Ephemeroptera)	253
ELMIDAE	(Coleoptera)	102
OLIGOCHAETA	(Annelida)	75
COPEPODA	(Crustacea)	70
CERATOPOGONIDAE	(Diptera)	60
Chironominae sp.	(Diptera)	47
other ANNELIDA		33
OSTRACODA	(Crustacea)	32
HYDRACARINA	(Arachnida)	31
SIMULIIDAE	(Diptera)	30
Baetis sp.	(Ephemeroptera)	20
other DIPTERA		17
BAETIDAE	(Ephemeroptera)	16
GOMPHIDAE	(Odonata)	9
PLECOPTERA		8
Caenis sp.	(Ephemeroptera)	8
ORTHOCLADIINAE	(Diptera)	8
NEMATODA		7
other EPHEMEROPTERA		7
Choroterpes complex	(Ephemeroptera)	7
TUBIFICIDAE	(Annelida)	7
Afrocaenis sp.	(Ephemeroptera)	6
TIPULIDAE	(Diptera)	5
Tomichia sp.	(Mollusca)	5
PROTONEURIDAE	(Odonata)	4
Ecnomus sp.	(Tricoptera)	4
LUMBRICULIDAE	(Annelida)	4
DYTISCIDAE	(Coleoptera)	4
Sphaerium sp.	(Mollusca)	3

Table 6.3c: Ranked, thirty most abundant taxa collected in the marginal vegetation biotope.

Taxa		Ave. Sample Abundance
CHIRONOMIDAE	(Diptera)	1232
OSTRACODA	(Crustacea)	269
SIMULIIDAE	(Diptera)	212
CLADOCERA	(Crustacea)	193
Baetis sp.	(Ephemeroptera)	117
BAETIDAE	(Ephemeroptera)	101
OLIGOCHAETA	(Annelida)	85
HYDRACARINA	(Arachinida)	70
CAENIDAE	(Ephemeroptera)	44
Cheumatopsyche sp.	(Trichoptera)	38
other ANNELIDA		36
COPEPODA	(Crustacea)	36
NEMATODA		31
ORTHOCLADIINAE	(Diptera)	30
ELMIDAE	(Coleoptera)	29
Trichorythus sp.	(Ephemeroptera)	29
CERATOPOGONIDAE	(Diptera)	24
Neurocaenis sp.	(Ephemeroptera)	23
Demoulina complex	(Ephemeroptera)	23
Caenis sp.	(Ephemeroptera)	17
Chironominae sp.	(Diptera)	15
other EPHEMEROPTERA		14
DYTISCIDAE	(Coleoptera)	13
Ecnomus sp.	(Tricoptera)	13
Caridina nilotica	(Crustacea)	12
other MOLLUSCA		12
PLEIDAE	(Hemiptera)	11
CULICIDAE	(Diptera)	11
Choroterpes complex	(Ephemeroptera)	10
Caenodes sp.	(Ephemeroptera)	10

Although no attemps were made to measure the relative abundance of different habitats during this project, it is important to understand the relative availability of the different habitats in the river, since this will govern the total numbers of the various taxa. Section 3.3 describes the nature of the riparian strip and marginal vegetation throughout the catchment, while Figure 7.15 shows the relative difference in substrate type between the upper (LZ) and lower (LZ) reaches of the catchment. In the upper reaches of the river, the substrate is predominantly made up of cobble and boulder, and riffle habitat is therefore common. Interspersed between the riffles are pools with beds of sediment. At medium or high flows, the river margins are inundated, and marginal vegetation habitat is available for colonisation, but is a small area compared to the other habitats. Lower down the river, in the lowveld zone, the riverbed is wider, there is more deposited sediment, larger pools, and fewer riffles. In addition, where flowing water has scoured the riverbed, there is a predominance of bedrock, with few areas of loose cobble or boulder. Consequently, riffle habitat in the lower river is extremely rare. Marginal habitat also forms a smaller proportion of the available substrate, and is also seasonally variable, reducing during low-flows when the water level recedes from the river banks.

Sediments in pools and slow-flowing areas therefore form by far the largest area of benthic habitat, especially in the lowveld, followed by bedrock, which harbours lower densities and diversities of invertebrates than riffle. Marginal vegetation is probably the next most common habitat, since it is present all the way along the river, at least during medium and high flows. Riffle, which forms the habitat for the most consistent and best indicator community, is by far the least common habitat, especially in the middle and lower reaches of the river.

6.4 MICROHABITAT REQUIREMENTS

An analysis has been made of the microhabitat occurrences of two of the major insect groups - the Trichoptera and the Ephemeroptera, in terms of substrate type, depth and current speed. These groups were chosen because they are abundant and diverse, they are better known than many of the other groups, and they showed more habitat specificity than other groups (there were 6 trichopteran families/genera confined to riffles, and 6 to marginal vegetation, and 3 ephemeropteran families/genera were confined to marginal vegetation).

It is clear that the Ephemeroptera have less specific requirements than the Trichoptera. Figure 6.4 indicates a wider preference by Ephemeroptera, which are distributed widely across 6 of the 7 habitat types. The only habitat type that is clearly not favoured by this macro-invertebrate group is the sandy substratum (habitat 1; Fig. 6.4). Although habitat 7 (Fig. 6.4) was sampled on relatively few occasions, it was surprisingly, the most favoured type. Habitat 7 comprises the root zone, of not only emergent vegetation, but also the roots of riparian trees and shrubs as well as the root systems of the invasive floating water plants, *Eichhornia* and *Pistia*. Ephemeroptera were present in this habitat both at high numbers of taxa and high density of individuals. It is possible that "submerged roots" act as an important *refugium* when flow becomes limited.

Both Trichoptera and Ephemeroptera did not favour habitat 1, (sandy substratum; Fig. 6.5), while only the Trichoptera showed a *distinct preference* for the riffle habitat (habitat 2, Fig. 6.5), whilst avoiding both emergent reeds (habitat 5) and overhanging vegetation (habitats 6; Fig. 6.5). Both Ephemeroptera and Trichoptera showed strong preference for the submerged root-zone habitat (habitat 7; Fig. 6.5). Both insect target groups showed the strongest preference for riffle habitat - this is not immediately apparent from Figures 6.4 and 6.5, but habitats 2-4 inclusive are all effectively variations of the theme of "riffle". Habitat 2 comprised gravel and small cobble substrata with fast flowing water, while habitats 3 and 4 comprised medium cobble to boulder and large boulders to bedrock slab respectively; both

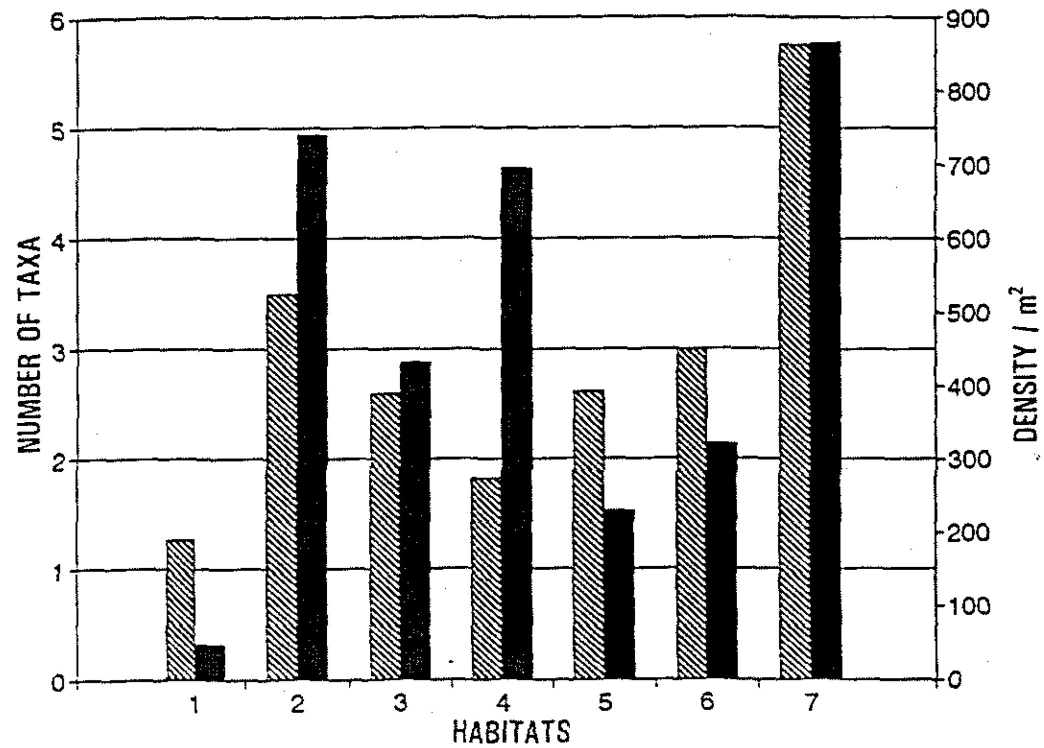

Figure 6.4: Bar chart showing average number of taxa (hatched) and density (solid) of Ephemeroptera per sample in different habitat types in the Sabie-Sand River system. Habitat codes; 1 = sand & silt, 2 = riffle (gravel to small boulder), 3 = riffle (medium cobble to small boulder), 4 = riffle (large boulder to bedrock slabs), 5 = reeds (emergent), 6 = grass (overhanging), 7 = roots (marginal vegetation and floating water plants).

with fast flowing water.

Despite the obvious importance of the root zone for both insect target groups, the paucity of data points for this zone precluded further analysis in term of depth and other preferences. We therefore concentrated on riffles because of their importance to both groups. An examination of Figures 6.6 (Ephemeroptera) and 6.7 (Trichoptera) shows that both groups occurred both in highest densities of individuals and in numbers of taxa at depths between 0-30cm. This is an important observation given the minimum flow recommendation of the Skukuza Workshop (10cm over the riffle; Davies *et al.*, 1991). Representatives of both

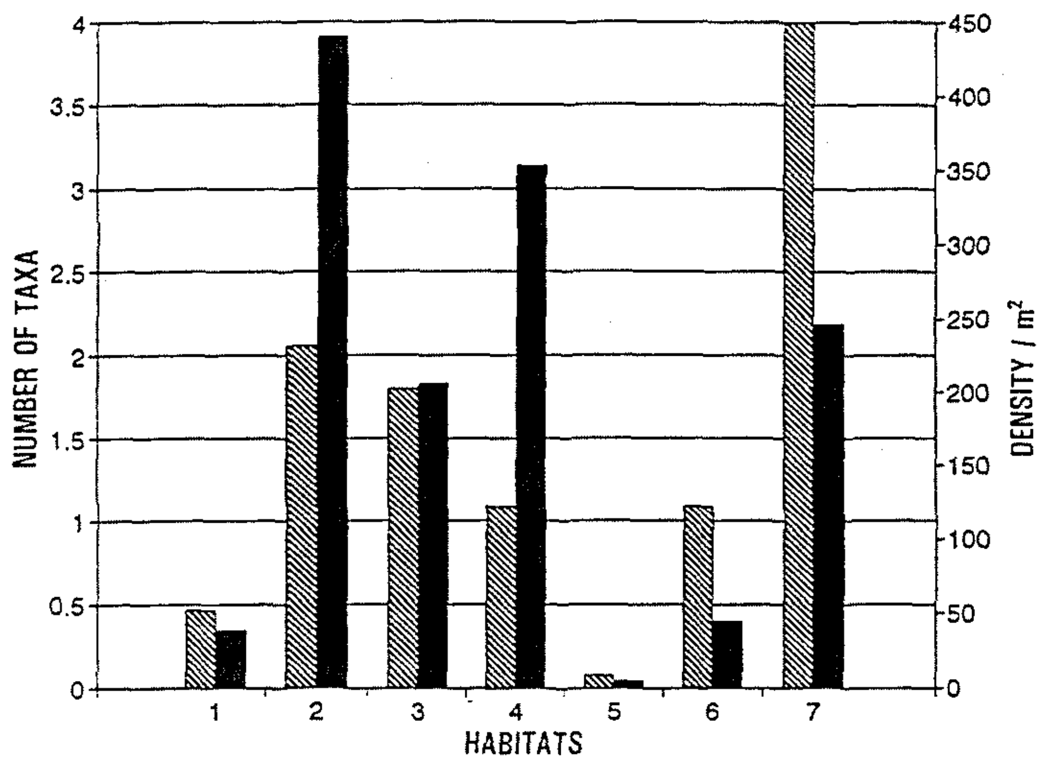

Figure 6.5: Bar chart showing average number of taxa (hatched) and density (solid) of Trichoptera per sample in different habitat types in the Sabie-Sand River system. Habitat codes; 1 = sand & silt, 2 = riffle (gravel to small boulder), 3 = riffle (medium cobble to small boulder), 4 = riffle (large boulder to bedrock slabs), 5 = reeds (emergent), 6 = grass (overhanging), 7 = roots (marginal vegetation and floating water plants).

orders tolerated a wider range of depths with large numbers of taxa (but at low individual densities) occurring at depths between 50-60cm and >60cm. (Fig. 6.6 & 6.7).

The Trichoptera showed a clear preference for higher current speeds (Fig. 6.9) both in terms of numbers of taxa and densities, but the Ephemeroptera (Fig. 6.8) were more evenly distributed across a range of current speeds which ranged from 0.25 to >1 $m.s^{-1}$. Trichopteran densities and number of taxa increased between 0.63 and 1 $m.s^{-1}$, with lower densities at speeds >1 $m.s^{-1}$. On the other hand, the number of Trichoptera taxa recorded generally

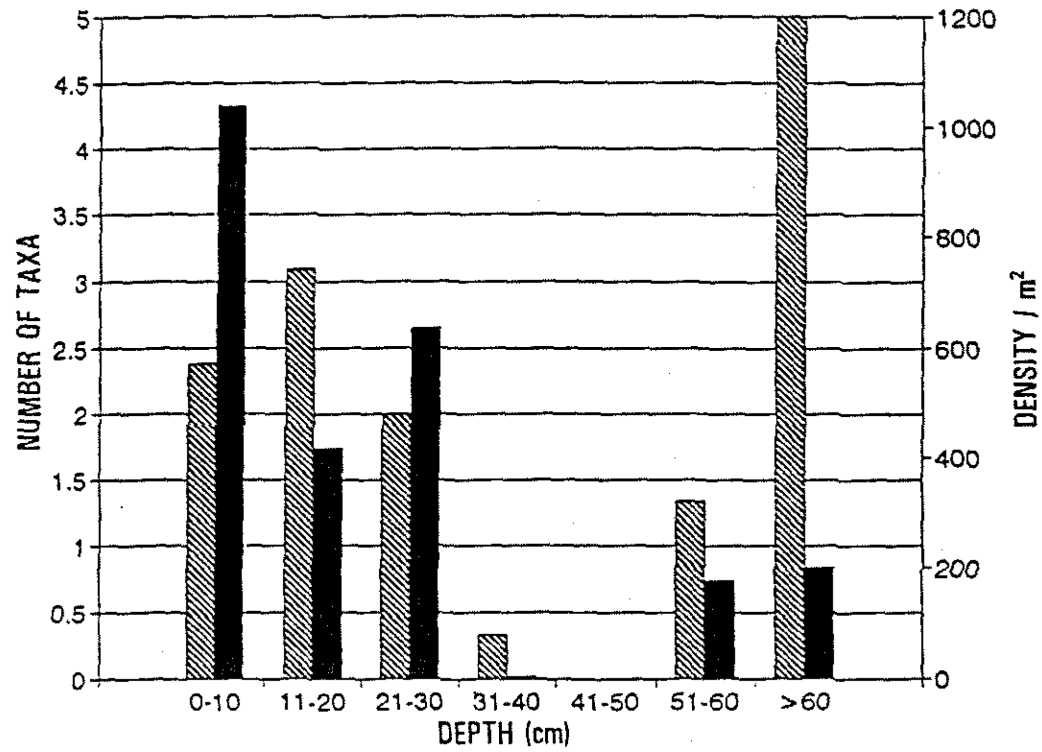

Figure 6.6: Bar chart showing the average number (hatched) and density (solid) of Ephemeroptera in samples at different depths within the Sabie-Sand River system.

showed a stepped increase with increasing flow (Fig. 6.9).

The Ephemeroptera were scarce or absent only at very low-flows. Above 0.040 $m.s^{-1}$ both densities and numbers of taxa were high, with a sudden decrease between 0.25 and 0.63 $m.s^{-1}$, followed by a marked increase at speeds >0.63 $m.s^{-1}$ (Fig. 6.8).

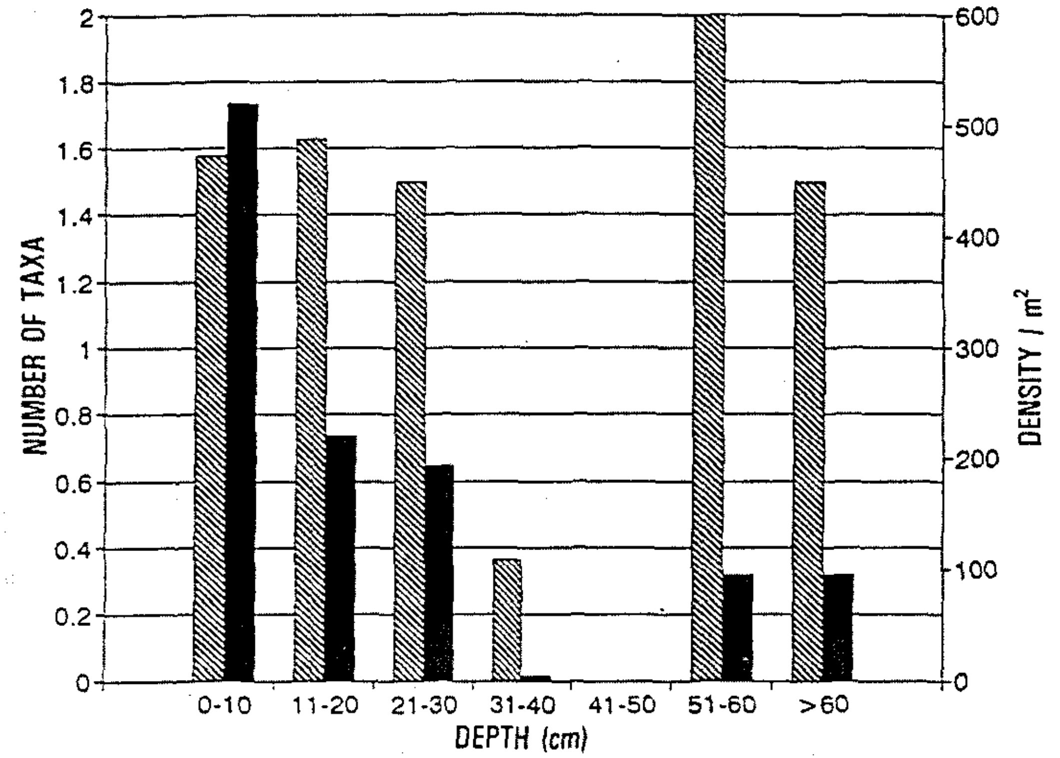

Figure 6.7: Bar chart showing the average number (hatched) and density (solid) of Trichoptera in samples at different depths within the Sabie-Sand River system.

6.5 CONCLUSIONS

6.5.1 EFFECTS OF REDUCED FLOWS

Invertebrate communities living in riffles in the Sabie-Sand are extremely sensitive to flow conditions. The similarity analysis described in section 6.2 indicates that different communities are far more closely related to the progression of the rivers into, through and out of the 1992 drought than they are to other factors such as altitude, river order, tributary, or season.

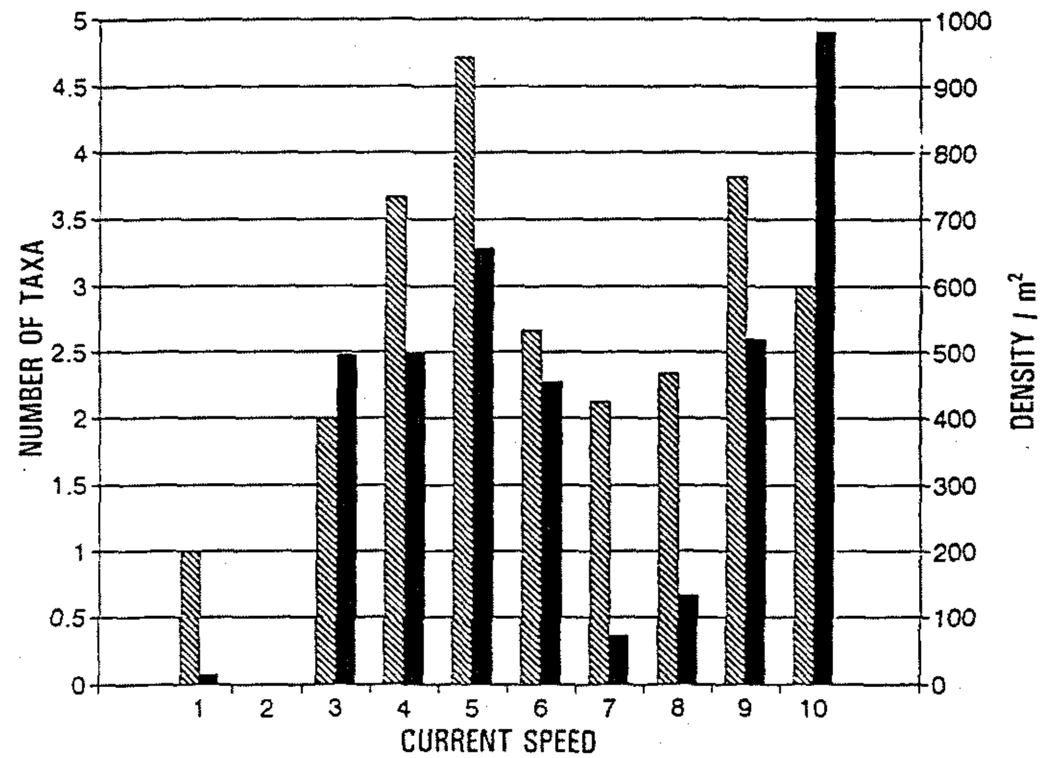

Figure 6.8: Bar chart showing the average number (hatched) and density (solid) of Ephemeroptera in samples at different current speeds within the Sabie-Sand River system. Current increments in $m.s^{-1}$; 1 = <0.025, 2 = 0.025-0.040, 3 = 0.040-0.063, 4 = 0.063-0.100, 5 = 0.100-0.158, 6 = 0.159-0.251, 7 = 0.251-0.398, 8 = 0.398-0.631, 9 = 0.631-1.000, 10 = >1.000.

The diversity of the communities was drastically reduced with the reduction in discharge in the river, both in terms of the number of taxa (reduced by half) and the density (reduced by almost an order of magnitude). When high flows did recommence, in November 1992, there was some evidence of recovery, in the form of the reappearance of the rheophilous mayfly *Trichorythus* and the appearance of large numbers of small net-spinning caddis larvae (Hydropsychidae). However, the recovery was by no means complete by the time the fieldwork ended in May 1993, and this indicates that communities may take much longer than expected to recover from major droughts, if they ever do so completely. Previous studies give conflicting recovery times. Harrison, (1966) suggested that invertebrate communities in annual streams prone to drought recover and resemble perennial stream communities in only

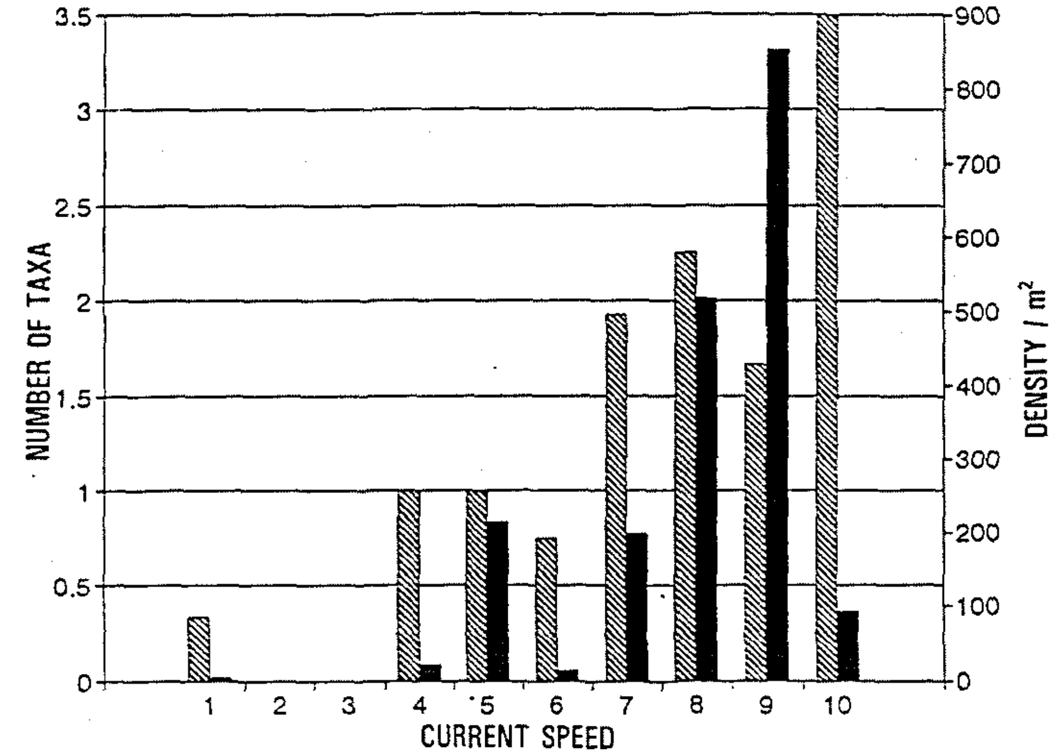

Figure 6.9: Bar chart showing the average number (hatched) and density (solid) of Trichoptera in samples at different current speeds within the Sabie-Sand River system. Current increments in m.s^{-1}; 1 = <0.025, 2 = 0.025-0.040, 3 = 0.040-0.063, 4 = 0.063-0.100, 5 = 0.100-0.158, 6 = 0.159-0.251, 7 = 0.251-0.398, 8 = 0.398-0.631, 9 = 0.631-1.000, 10 = >1.000.

three months while Niemi *et al.*, (1990) found that macro-invertebrates approached predistrubance densities and full recovery in less than 18 months. This survey showed that the Sabie/Sand communities had not recovered after 7 months. This may be an indication of the sensitivity of some of the community to poor flows, the severity of the drought, or the limitation of suitable refuges from which recolonisation can occur.

We have tentatively been able to identify groups of taxa which were indicative of wet and dryer conditions (see section 6.2), simply in terms of their presence and absence from samples. Although we can explain the reasons for some of the presence/absence, our detailed knowledge of the ecology of many of the taxa (and indeed our ability to identify them to a useful ecological level), is still too rudimentary to place much confidence in these groups as indicators.

6.5.2 DIFFERENCES BETWEEN THE COMMUNITIES OF DIFFERENT HABITATS

Of the habitats examined (riffles, marginal vegetation, and sediments), the marginal vegetation contained the most diverse community, and the highest number of taxa restricted to one habitat (section 6.3). Since the marginal vegetation is also the first habitat to be lost when flows are reduced, we consider it to be the critical habitat for conservation. The availability of this habitat will fluctuate seasonally, reducing as flows recede during normal dry seasons, but the aim should be to maintain water in the marginal vegetation for at least the wetter months (November to April). Communities of the sediments were the least diverse, but sediments are by far the most common habitat, especially in the lowveld, and also form the final refuge habitat in pools when flow ceases.

Trichoptera were the most habitat-specific group in both riffles and marginal vegetation, with 6 families/genera unique to each. Taxa typical of each of the habitats have been defined (Table 6.3a-c and section 6.3), both in terms of those unique and those which were most common in each habitat.

6.5.3 MICROHABITAT PREFERENCES

The analysis of microhabitat preferences has been made at the level of order rather than family or genus, because there were too few records to provide coherent patterns at finer taxonomic resolution, and therefore the preferences of individual species and genera are masked. Further, the variety of species' preferences for particular microhabitat conditions may, at this level of taxonomic focus, blur overall trends. It has also to be recognised that the preferences are not adjusted for sampling bias in different conditions. For example, shallower habitats were more commonly sampled than deeper ones, and therefore the average number of taxa and the average density for shallow habitats may be a more accurate reflection than for deeper ones.

Despite these observations and handicaps, in comparison to the Ephemeroptera, the Trichoptera as a group still seem to prefer a remarkably narrow set of conditions in terms of habitat utilisation, depth and flow, and it is recommended that this group be targetted for further microhabitat preference work. At the same time, the Trichoptera are likely to pay dividends as a group for monitoring the physical conditions of the river system.

In terms of ensuring optimum diversity at both the individual and taxonomic levels, it would appear from our analysis that 30 cm of medium to fast flowing water - of between 0.63 to 1 $m.s^{-1}$, but not below the former - through the riffle, would provide ideal conditions, conducive to the maintenance of the maximum diversity and abundance of these invertebrates. This improves on the confessed "thumb-suck" reported by Davies *et al.* (1991).

7. FISH ASSEMBLAGES OF THE SABIE-SAND SYSTEM

7.1 INTRODUCTION

This chapter describes the distribution of the fish fauna in the Sabie-Sand from 1990 to 1993, and is structured with the following aims:

1) To assess the diversity of fishes in the system, to describe species distribution and abundance, and to show how these changed in different parts of the river during different years. (sections 7.2-7.3).

2) To identify target species that are representative of the catchment, zones, reaches or macrohabitats of the system, that can be used to describe the range of ecological requirements of the fish fauna as a whole. (section 7.4).

3) To describe the habitat requirements of these species in terms of water velocity, depth, substrate and cover, which are the conditions which will primarily be affected by changing discharge in the river (section 7.5).

7.2 SPECIES DIVERSITY

The conservation of biotic diversity is central to the mission statements of conservation organizations spanning the IUCN to the KNP. Biotic diversity *per se.* is not in itself a measure of the importance of a system but rather it is important as an indicator of change in the status of the system (O'Keeffe, 1989a).

7.2.1 FISH DIVERSITY IN THE SABIE-SAND SYSTEM

Between May 1990 and May 1993, 44 species of fish were collected in the Sabie-Sand rivers. All species are recorded, and fully named in appendix III. The minnow *Barbus anoplus* is evidently common in the Klein Sabie River (Engelbrecht, 1986) bringing the total of indigenous species with confirmed populations to 45. Until quiet recently, the gobi, *Glossogobius callidus* had been confused with *Glossogobius giuris* by earlier ichthyologists (Greenwood, 1995) (appendix III). Engelbrecht (1986) also recorded *Chiloglanis pretoriae* at a single locality on the White Waters River and noted the eel *Anguilla marmorata*, while we recorded *Anguilla bengalensis*. Four alien species have been recorded to date (*Lepomis macrochirus*, *Micropterus salmoides*, *Salmo gairdneri*, and *Salmo trutta*) bringing the total number of species to 49. Total diversity for the Sabie-Sand system therefore stands at 45 species (49 including the aliens), making it the most species rich river system known in the country, followed closely only by the Phongolo River in Natal.

O'Keeffe *et al.* (1989a) list diversity in representative rivers within Harrison and Agnew's (1959) hydrobiological regions in South Africa, and found in excess of thirty species generally within the tropical lowveld, the highest diversity for the country. The number of fish species inhabiting a river is largely related to the catchment size of the river. The relationship is explained in the shaded box, where N=number of species and A=basin area in km^2 (Welcomme, 1985). The form of the relationship differs slightly for different geographical regions with the equation for African rivers presented here. Using this relationship and the catchment area of the Sabie River (6252 km^2) we would expect a diversity of only 20 species, less than half of what was actually recorded!

$$N = 0.449A^{0.434}$$
$$(n=25 \quad r=0.91)$$

The high diversity of the Sabie and Sand Rivers is partly explained by zonal complexities and its historic affinities. The system straddles two ecoregions in a relatively small catchment.

The montane-escarpment region with its cool headwaters has a poor ichthyofauna (Skelton, 1993) but due to isolation the ichthyofauna is distinctive. Six species are confined to this region with very localised populations of *Varicorhinus nelspruitensis* and *Chiloglanis anoterus*. The diverse tropical east coast region extends through much of Mozambique, up the Zambezi and Limpopo valleys (Skelton, 1993), to Mkuzi, northern Zululand. It contains many species typical of much of the tropical and seasonal Zambezi basin, with a few elements from even further beyond (Skelton *pers comm.*) including *Serranochromis meridianus* which is endemic to the Incomati system and neighbouring coastal plain lakes.

Cyprinids were the most diverse taxonomic group in the catchment (48.9%), with a whole suite of minnows occuring in both the cool and warm waters. The LZ minnow assemblage (appendix III) was particularly diverse, comprising eight species, or nine including the eurythermal *Barbus eutaenia*. Eight large cyprinids were found in deeper pools including *Barbus polylepis* and *V.nelspruitensis*, the widely distributed *Barbus marequensis* and a suite of mudfishes (5 spp).

Catfish were the next most diverse grouping, nine species accounting for 20% of the total diversity. Seven rather specialised and small species of *Amphilius* and *Chiloglanis* are mostly typical of the upper cool reaches (appendix III). Two *Chiloglanis* spp are found in warmer lowveld waters (*Chiloglanis paratus* & *Chiloglanis swierstrai*), and are possibly derived from specialized ancestors, contributing to the high diversity of the tropical east coast region.

Cichlids made up 11.1% (5 spp) of the species diversity, and since they were very numerous at times in the system, they were an ecologically important group. *Oreochromis mossambicus* in particular is reported to dominate assemblages in many studies during times of drought (Jackson, 1989; Merron *et al.* 1993). *O.mossambicus* is phenotypically plastic (Bruton, 1975) and is able to breed in adverse conditions, with behaviourial characteristics of both small and large species.

Further insight into the diversity within the system will be discussed within the context of distribution within the catchment

7.2.2 MINNOWS & SMALL SPECIES

As is generally the case in African rivers, fishes of very small adult size (< 10 cm) make up a high proportion of the ichthyofauna of the Sabie-Sand rivers both within the feeder streams, rocky, and potamon reaches (Welcomme, 1985). Small species have an advantage in that they can mature early (within a year), and can exploit cover within root masses (fringing vegetation) and the interstices of coarse substrates (stoney runs and riffles) (Welcomme, 1985).

Table 7.1: Fish diversity in the Sabie-Sand River system within taxonomic group and between small and large species.

	Small Species (< 10cmSL)	Large Species (>10cmSL)	total	%
Cyprinids	14	8	22	48.9
Catfishes	7	2	9	20.0
Cichlids	2	3	5	11.1
Characins	2	1	3	6.7
Eels	0	2	2	4.4
Gobies	1	1	2	4.4
Snoutfishes	1	1	2	4.4
total	27	18	45	100
%	60	40	100	

Small species are well represented within the Sabie River Catchment (Table 7.1). This is not surprising as the Sabie River system comprises mostly small order streams (1-3) with the fourth order Sand River and fifth order Sabie River making up the lowveld reaches (Fig. 3.1). Our reliance on electrofishing (supplemented with minnow traps) was designed to sample this assemblage, as these methods are particularly effective for sampling small species in shallow habitats.

7.3 DISTRIBUTION AND ABUNDANCE

7.3.1 ZONATION OF THE ICHTHYOFAUNA

Changes in ichthyofauna along upstream-downstream gradients are known to occur and have been described for species number, species richness and even within feeding guilds (Oberdorff *et al.*, 1993). Species number in North American rivers increases rapidly from upstream to downstream by addition of new species rather than replacement of the upstream fauna (Horwitz, 1978) which suggests the addition of habitat. The primary characteristic of fishes within the Sabie and Sand rivers is a replacement of species between upstream and downstream reaches, which suggests a clear zonation. Secondly, species are added within lowland reaches, with distance downstream.

Distribution and diversity at all stations on the Sabie, Marite and Sand Rivers between May 1990 and May 1993 are summarized in Tables 7.2-7.4. Various patterns are discernable:

1) Two broad ichthyological river zones are identifiable, where one group of species replaces another within a short distance in the Sabie and Sand rivers.
2) Within each zone, additional species appear with distance downstream, due to increased habitat diversity and depth as the river gets bigger.
3) Within zones, each tributary sampled in the Sabie-Sand system has a characteristic fish fauna, deviating marginally from a common species assemblage. This reflects habitats locally available and stream profile position.

These patterns are important when positioning of dams and their downstream effects are considered.

7.3.1.1 Temperature and Zonation

Gaigher (1969, 1973) used altitude to describe the distribution of the fish of the Transvaal waters within both the Limpopo and Incomati systems. This is not appropriate, for although temperature and altitude are intimately related, many factors such as steam order, volume, channel structure and riparian cover can affect stream temperatures regionally (Ward,1985).

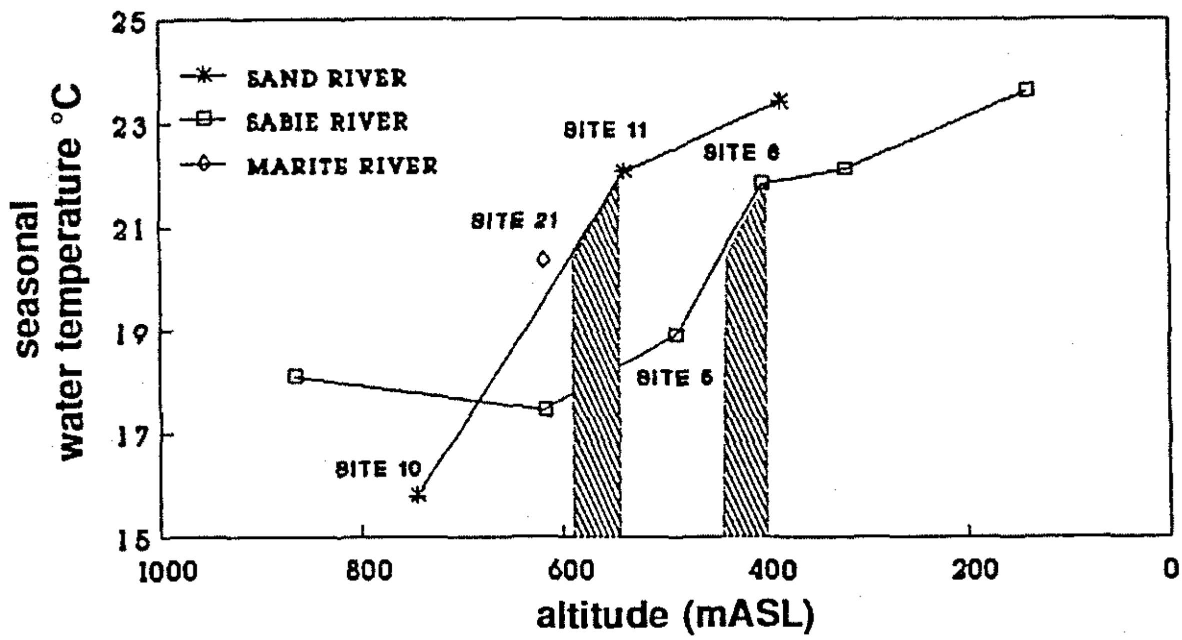

Figure 7.1a: Fish zonation as explained by water temperature and altitude in the Sabie-Sand system in spring (September to November 1990). Water temperature plotted is a three month mean from measurements of minimum and maximum. The transition in fish communities from the FHZ to the LZ, which occurs between sites 5-6 on the Sabie and sites 10-11 on the Sand, appears to be a result of temperature, since the transition zones occur at similar water temperatures, but at different altitudes. Hatched areas delimit the range of water temperature where this transition occurs, taking into account the single FHZ site sampled in the Marite River. A narrow range of temperature (20.5-22°C) could explain the transition in all three rivers.

Temperature best describes the zonation pattern of fish distribution seen within the Sabie-Sand system (Fig. 7.1a & b).

Within the Sabie and Sand rivers and excluding the cool waters of the Marite (site 21), a narrow range of temperature, not altitude, best explains the transition between FHZ and LZ fish assemblages (Fig. 7.1a). FHZ-LZ zonation, as explained by a narrow range of a seasonal water temperature measure, is consistent throughout and between years (Fig. 7.1b).

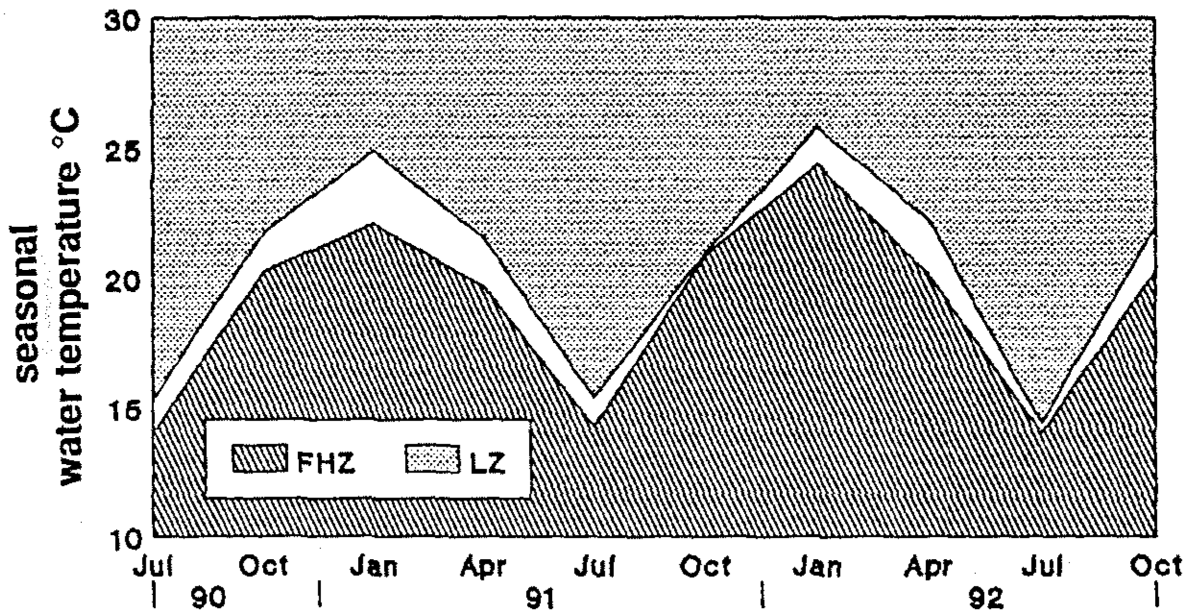

Figure 7.1b: Seasonal water temperature (three monthly mean of min-max) characteristic of the FHZ (hatched area) and LZ (shaded area) as identified by their respective fish assemblages. A narrow range of seasonal temperature (white area) delimits the transition from FHZ to LZ. The characteristic fish fauna of any site can be predicted from its seasonal water temperature and the zonal areas presented.

A species tolerance of the extremes of temperature is often considered paramount when temperature is invoked to explain distribution (Jubb, 1962). Although fish-kills related to low temperatures have been documented for lowveld fishes both due to cold weather (*O.mossambicus*: Jubb, 1962; Bruton and Taylor, 1979) or hail (*Hydrocynus vittatus*: Gaigher, 1970), their importance may only be localized or periodic, only resulting in abundance or distributional shifts.

In an attempt to define temperatures biological effect, Stuckenberg (1969) proposed "effective temperature". Here a measure of summer temperature is used as an ecological factor to explain the distribution of animals. Stuckenberg argues that "summer temperature" is most important in temperate systems as it is then that the biota are seasonally reproductively active, drawing his examples mostly from the distribution of reptiles and anurans as related to air temperature. We have shown that water temperature indeed best explains the distribution of fishes in the Sabie-Sand rivers, if Stuckenberg's ideas are correct, then water temperature above the range of 20.5-22°C (spring) and 22-25°C (summer) would best define the requirements of the LZ fish assemblage.

A: Gradient Analysis

We have classified fish into five categories based on the patterns of fish distribution (Tables 7.2-7.4):

1) Cold Stenothermal Species (species always restricted in the catchment to cool waters).
2) Warm Stenothermal Species (species only ever found in warm waters).
3) Cold Species (cold water species marginally tolerant of warmer waters).
4) Warm Species (warm species marginally tolerant of cool waters).
5) Eurythermal (species that show wide tolerance to both warm and cold temperatures within the system).

Using this classification, two fish assemblages are identified: those of the Foothill (FHZ), and Lowveld Zones (LZ) (Table 7.2-4). These ichthyological zones correspond to the Montane-Escarpment and Tropical East Coast ecoregions respectively (Skelton, 1993).

The Sabie River, (Table 7.2) is the longest river in the Sabie-Sand system and includes the full range of reach types found within the system. Here, 42 species were collected at 11 stations situated between 1270 and 140 mASL spanning 5 stream orders (Fig. 3.1). Diversities at each station range from 1 to 28 species, and increase with stream order.

Table 7.2: Longitudinal distribution of fish in the Sabie River collected between May 1990 and May 1993. Station number, altitude and river zonation are indicated. Species are classified according to their temperature tolerance.

	STATION No.	1	28	3	4	5	6	7	24	8	9	20
	(Altitude)	1270	955	667	519	444	402	320	291	249	229	149
	ZONES	FOOTHILL ZONE					LOWVELD ZONE					
█	*Salmo trutta*	■										
▮	*Tilapia sparrmanii*		■									
█	*Varicorhinus nelspruitensis*		■	■	■	■						
▮	*Chiloglanis anoterus*		■	■	■	■	■	+		+	■	
▒	*Pseudocrenilabrus philander*		■		+	■	■	■	+	■	■	+
▒	*Anguilla mossambicus*			■	+	■	+	+		+	+	
█	*Barbus brevipinnis*				■	+						
▮	*Barbus eutaenia*				■	■	■	+	+	+		
█	*Amphilius uranoscopus*				+	■						
█	*Barbus polylepis*					■						
▒	*Barbus unitaeniatus*					■	■	■	+	+		
░	*Marcusenius macrolepidotus*					■	■	■	■	■	+	■
░	*Micralestes acutidens*					■	■	■	■	■	■	■
▮	*Barbus marequensis*					■	■	■	■	■	■	■
▒	*Opsaridium zambezense*					■	■	■		■	■	
▒	*Chiloglanis swierstrai*					■	■	■	■	■	■	+
	Barbus trimaculatus					+	■	■	■	■	■	■
▒	*Labeo molybdinus*					+	■	■	■	■	■	■
▒	*Clarias gariepinus*					+	■	■	■	■	+	■
▮	*Anguilla bengalensis*						+					
	Schilbe intermedius						■		■			■
	Serranochromis meridianus						■	■	■	■	■	■
	Tilapia rendalli						■	■	■	■	■	■
	Barbus viviparus						■	■	■	■	■	■
	Oreochromis mossambicus						■	■	■	■	■	■
	Chiloglanis paratus						■	■	■	■	■	■
	Petrocephalus catostoma						+	■	■	■		■
	Barbus annectens							■	■		+	■
	Barbus radiatus							■	■		■	■
	Mesobola brevianalis							■		■	■	
	Labeo rosae							+	■			■
	Hydrocynus vittatus								■			■
	Labeo congoro								■			■
	Labeo cylindricus								■			■
	Labeo ruddi								■			
	Glossogobius callidus									■	■	■
	Brycinus imberi											■
	Barbus afrohamiltoni											■
	Synodontis zambezensis											■
	Barbus toppini											■
	Barbus paludinosus											■
	Glossogobius giuris											■
	No. of species	1	4	3	7	17	21	23	24	20	20	28

█ = cold stenothermal
▮ = cold, warm tolerant
▒ = eurythermal
░ = warm, cold tolerant
(blank) = warm stenothermal

■ = population present
+ = marginal records

Table 7.3: Longitudinal distribution of fish for the Marite River collected between May 1990 and May 1993. Station number, altitude and river zonation are indicated. Species are classified as to their temperature tolerance. The Marite River lies within the foothill zone (FHZ).

STATION No.	16	17	21	18
(Altitude)	785	714	620	450
ZONES	FOOTHILL ZONE			
Barbus argenteus	■	■	■	
Amphilius natalensis	■	■	■	+
Barbus brevipinnis	■	■	■	+
Varicorhinus nelspruitensis	■	■	■	+
Chiloglanis anoterus	■	■	■	■
Anguilla mossambica	■		■	■
Anguilla bengalensis	+			
Barbus marequensis	+	■	■	■
Marcusenius macrolepidotus		+	■	■
Amphilius uranoscopus		+	■	■
Tilapia sparrmanii			■	
Barbus polylepis			■	+
Chiloglanis swierstrai			+	■
Barbus unitaeniatus			■	■
Labeo molybdinus			■	■
Barbus eutaenia			■	■
Clarias gariepinus				■
Opsaridium zambezense				■
Pseudocrenilabrus philander				■
No. of Species	8	8	15	16

= cold stenothermal
= cold, warm tolerant
= eurythermal
= warm, cold tolerant
= warm stenothermal

■ = population present
+ = marginal records

The FHZ within the Sabie River is particularly extensive, with cold stenothermal species reaching site 5 within the lowveld at an altitude of 488 mASL. This is the proverbial cold finger of the Sabie River, where relatively cold foothill waters penetrate the lowveld before warming. It is possible that the waters of the Sabie remain cooler than waters in the Sand River at comparable altitudes because of the higher discharge volume, and the shaded nature of the stream at this point, reducing solar insolation. A riffle specialist, the pennant-tailed rock catlet *C.anoterus*, is typical of this zone where it reaches its highest densities. Fish diversity in the FHZ is highest at the interface with the LZ. Some overlap of warm cold-tolerant species is found, including many minnow species. The minnow *B.eutaenia* was restricted to the clear warm-cold water interface on the Sabie and Sand rivers.

Although the Sabie River today is seen as the least developed of the lowveld rivers it suffered major disturbance more than 40 years ago due to gold mining in its upper reaches. Chemical effluent from this process is reported to have totally killed invertebrates (Pienaar, 1985) and affected the ichthyofauna. There has been recovery of invertebrates and fish but fish distributions in the upper reaches of the Sabie may still show effects. Table 7.5 records species that, judging from past records and present distributions in the Marite River are absent, possibly because of their inability to recolonise reaches upstream of cascades and waterfalls. Six species are involved, most noticeably *Barbus argenteus* and *Amphilius natalensis* and *Amphilius uranoscopus*. *A.natalensis* and *B.argenteus* were not recorded during this study in the Sabie River. There is also the possibility that *Barbus treurensis* has been lost from the upper Sabie River although specimens described by Groenewald (in Jubb, 1968) may have been those of the then undescribed *Barbus brevipinnis*. The early collection by Groenewald, now lost (Jubb, 1968), can not be proven as necessarily incorrect.

Niemi *et al.* (1990) conclude in a review on recovery in lotic systems that recovery usually takes three years unless: 1) the pollutant persists; 2) the habitat available was physically altered or; 3) the system is isolated, preventing recolonization. The latter may apply to the upper Sabie River particularly as the missing species are those unable to surmount cascades and waterfalls.

Table 7.4: Longitudinal distribution of fish in the Sand River collected between May 1990 and May 1993. Station Number, altitude and river zonation are indicated. Species are classified by their temperature tolerance. Only site 10 on the upper Sand Rivier lies within the foothill zone (FHZ)

	STATION No.	10	11	12	13	14	15
	(ALTITUDE)	745	538	458	384	315	275
	ZONES	FHZ	LOWVELD ZONE				
	Amphilius natalensis	■					
	Barbus brevipinnis	■	+	+			
	Chiloglanis anoterus	■	■	+			
	Barbus eutaenia	■	■	■	+	+	
	Barbus marequensis	■	■		■	■	■
	Anguilla mossambica	■	■		■	■	■
	Opsaridium zambezense		■				
	Marcusenius macrolepidotus		■	■	■	■	+
	Barbus paludinosus		■		■	+	
	Barbus annectens		■	■	■	■	■
	Barbus radiatus		■	■	■	■	■
	Barbus trimaculatus		■	■	■	■	■
	Barbus unitaeniatus		■	■	+	■	■
	Barbus viviparus		■	■	■	■	■
	Chiloglanis paratus		■	■	■	■	■
	Clarias gariepinus		■	■	■	■	■
	Labeo molybdinus		■	■	■	■	■
	Micralestes acutidens		■	■	■	■	■
	Oreochromis mossambicus		■	■	■	■	■
	Tilapia rendalli		■	■	■	■	■
	Serranochromis meridianus		■		■	■	■
	Mesobola brevianalis		■			■	■
	Pseudocrenilabrus philander			■	■	+	+
	Chiloglanis swierstrai			■	■		■
	Labeo ruddi				■		
	Barbus toppini				■	■	
	Labeo rosae				■	■	■
	Petrocephalus catostoma				■	■	
	Schilbe intermedius				■	■	■
	Anguilla bengalensis					■	
	Synodontis zambezensis					+	
	Barbus afrohamiltoni					+	
	Labeo cylindricus					+	
	Glossogobius callidus					■	■
	No. of Species	6	21	17	24	28	21

= cold stenothermal
= cold, warm tolerant
= eurythermal
= warm, cold tolerant
= warm stenothermal

■ = population present
+ = marginal records

Table 7.5: Checklist for fish occurring in the upper Sabie River. Question marks indicate an apparent gap in the distribution of a series of fish species that are either recorded historically above these stations or are found in the upper Marite River in similar habitats. The absence of these species may reflect the historical effects of gold-mine pollution.

STATION No.	28	3	4	5	6
(Altitude)	955	867	619	488	402
ZONE	FOOTHILL ZONE				LZ
Amphilius natalensis	?	?	?		
Barbus argenteus	?	?	?		
Tilapia sparrmanii	■	?	?		
Barbus brevipinnus	?	?	■		
Amphilius uranoscopus	?	?	?	■	
Barbus polylepis		?	?	■	
Varicorhinus nelspruitensis	■	■	■	■	
Pseudocrenilabrus philander	■	?	■	■	■
Chiloglanis anoterus	■	■	■	■	■
Anguilla mossambicus		■	■	■	■
Barbus eutaenia				■	■
Barbus unitaeniatus				■	■
Barbus trimaculatus				■	■
Barbus maraquensis				■	■
Marcusenius macrolepidotus				■	■
Microlestes acutidens				■	■
Labeo molibdinus				■	■
Clarius garipinus				■	■
Chiloglanis swierstrai				■	■
Anguilla bengalensis					■
Tilapia rendalli					■
Barbus viviparus					■
Oreochromis mossambicus					■
Chiloglanis paratus					■
Serranochromis meridianus					■

? = Species absent, due to passed pollution?

The LZ stretches downstream from site 6 (402 mASL), and supports a diverse assemblage of more than 20 species. Most minnows were recorded by site 7 while the larger *Labeos* were present by site 24 with the appearance of deep pools. Not only did the larger fish make their appearance with the occurrence of deeper habitats, but a series of dwarf or small species were also recorded. By station 20, *Barbus afrohamiltoni, Barbus paludinosus, Barbus toppini, Synodontis zambezensis*, and *G. giuris* had been found. The presence of these species can be related to specific microhabitats that were locally available.

The Marite River is a major tributary of the Sabie River and important as a cold zone refuge for FHZ species with an average of eight species recorded per site (Table 7.3). Fish were numerous, with substantial populations of cold stenothermal species occurring (*B.argenteus, A.natalensis, B.brevipinnis* and *V.nelspruitensis*). The endemic *B.brevipinnis* is largely confined to the cooler waters or the Marite River and its tributaries. The cold warm-tolerant *C.anoterus* is abundant throughout. Warm cold-tolerant species raise the lower reaches diversity to similar high levels as those in the Sabie River (16 as to 17 spp).

The distribution pattern in the Sand River is interesting in that the FHZ assemblage is very restricted and the transition between FHZ and LZ very sudden. Cold stenothermal species were only recorded from station 10. As in the Sabie River, the minnow *B.eutaenia* was once again found straddling the warm-cold water divide in healthy populations.

Site 11 supported the full complement of LZ species even though it was relatively high (538 mASL). Site 11 is an exposed small (second order) low gradient stream and water temperatures were typical of lower altitudes. Station 11 was close enough to the headwaters to be perennial resulting in the presence of two flow-sensitive species, the warm cold-tolerant *Opsaridium zambezense* and the cold warm-tolerant *C.anoterus*, within the LZ. These examples show that the distribution of fish cannot be explained by temperature alone, but that flow regimes, and microhabitat requirements need to be considered as well.

Diversity in the LZ was high (above 20 spp per site) except at site 12 which was always very shallow and sandy. Most species were small with only larger riffle/run species appearing (*Labeo molybdinus*, *Labeo cylindricus*, & *B.marequensis*). The larger pool-loving Labeos (*Labeo rosae* and *Labeo ruddi*) were restricted to a few hippo pools within the reach. Eels were always scarce but widely distributed, occurring from the highest reaches to the Mozambique border.

B: Classification and Ordination

This section presents an analysis of fish assemblages in space and time, using the statistical packages TWINSPAN and PRIMER, which are explained in detail in chapter 3.

Pre-drought species and abundance samples (May 1990-February 1991) were classified using TWINSPAN (Hill, 1980) (Fig. 7.2). Two clear assemblage divisions were initially identified, those of the Foot Hill Zone (FHZ) and the Lowveld Zone (LZ). TWINSPAN identified *C.anoterus* and *Barbus viviparus* as the indicator species of each zone respectively.

Figure 7.3 shows a dendrogram resulting from the classification of 44 samples. Data were reduced by season from quarterly samples for monitoring sites surveyed between Aug 1990 and May 1993. Clusters are based on the standardized abundances of 44 species of fish found in the Sabie System over 4 consecutive annual survey trips, root-root transformed and classified using a Bray-Curtis similarity measure with group-average sorting.

At the arbitrary similarity level of 20%, two groups of samples were define the ichthyological zones were evident by eye, and are clear from the TWINSPAN classification. Group 1 represents all the cool water samples (FHZ) while group 2 the lowveld samples (LZ).

The FHZ (Group 1) can be further divided into two groups. Group 1b comprises FHZ sites of the middle Sabie and Marite rivers while 1a is a series of samples from site 3, a FHZ site within the upper Sabie that supports an impoverished fauna which may still show effects of gold mining (Table 7.5).

TWINSPAN CLASSIFICATION

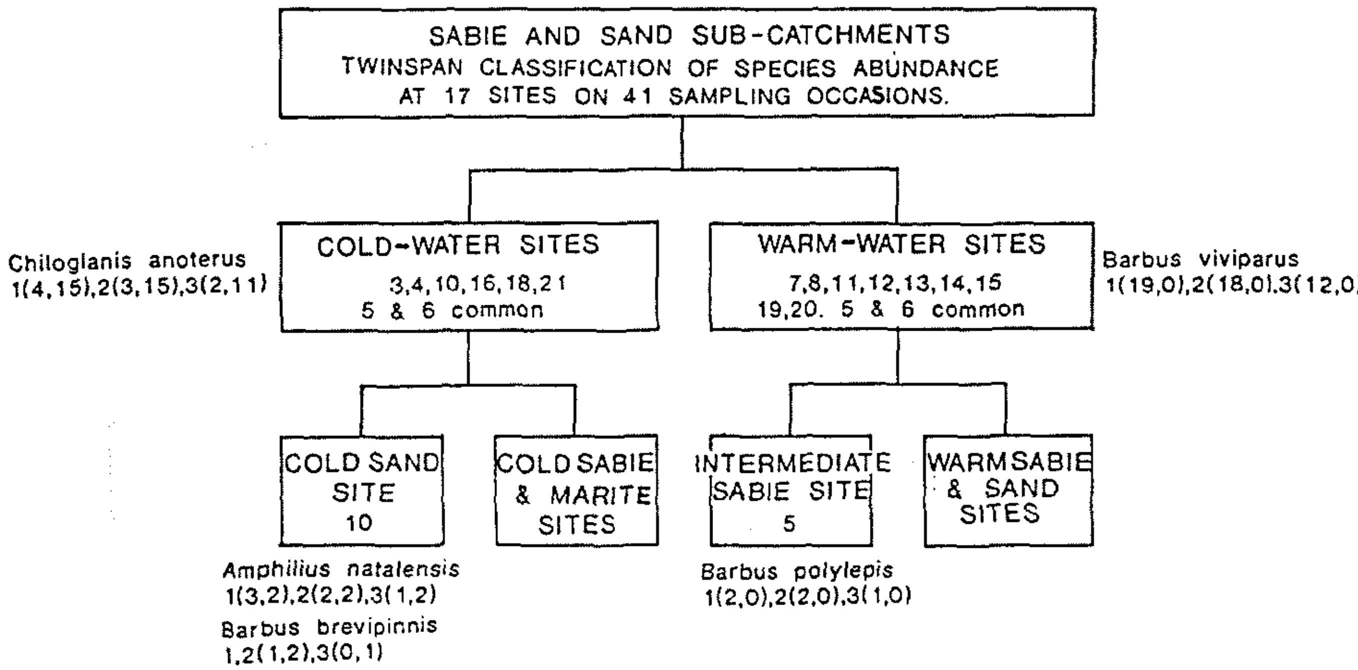

Figure 7.2: TWINSPAN classification of species abundance data for 42 sampling occasions at 17 sites in the Sabie and Sand rivers. The five cut levels used were: 0.03 (1), 0.07 (2), 0.18 (3), 0.44 (4) & 2.00 (5), where CPUE = fish per minute. Cut levels divide the abundance of each species at each site into categories termed pseudospecies, allowing presence or absence of each abundance category to be compared quantitatively (section 3.5.3.2). Indicator species for each division are listed together with the respective pseudospecies preferential values responsible for the classification.

Within the two main groups (1 & 2), the strongest sub-divisions are spatial rather than seasonal. Subsequent analysis showed that the fish assemblage did respond seasonally in the lowveld, but that by reducing data by season over the whole study period, seasonal changes were masked by drought effects. Site differences are strongest in the sub-groups 1a and b. Group 2 can be divided at the 55% similarity level to give three sub-groups: 2a including the Sand River sites, 2b the upper to middle Sabie LZ site while 2c groups the lower Sabie sites.

While temperature-altitude is the strongest axis determining the presence or absence of species, spatial changes at smaller scales (within zones) are probably a consequence of habitat changes down the rivers. Assemblages are not randomly structured but rather deterministic and highly predictable as a result of local habitat structure (Meeffe & Sheldon, 1990). Patterns are probably broadly associated with flow regime and stream order, with different fish assemblages resulting from changing conditions along river profiles, due to different habitat types and abundances.

Figure 7.4 shows the results of Multi Dimensional Scaling (MDS) on the same samples and sites as those used in Fig. 7.3 (stress value = 0.097), and supports the interpretation of clear zonation in the catchment. The FHZ and LZ groups are separate, as are the site 3 samples (subgroup a) from the rest of group 1. Otherwise, samples from the same sites are generally clustered together, but with some overlap, indicating that fish distribution patterns are present, but as gradients rather than clearly discontinuous distributions.

In summary, the strongest pattern seen in the distribution of the fish fauna of the Sabie system, is the clear divide between the FHZ and LZ ichthyological zones. Within the LZ, samples from the Sand River are separable from the Sabie River sub-catchment samples. Within the Sabie River, samples from the middle and lower sites are to a lesser degree separable. Divisions within reaches (ie Sand River stations) reflect site-specific habitat availability.

As station samples were analysed for pattern, so species distribution can be analyzed using PRIMER's classification and ordination techniques. This is called inverse analysis and progressively agglomerates species in association and charts these species groups in two dimensional space through MDS.

Figure 7.5 shows the results for 31 species (cutoff point set at 4% to remove rare species or chance occurrences (Field *et al.*, 1982) for 67 samples taken annually in May over four years.

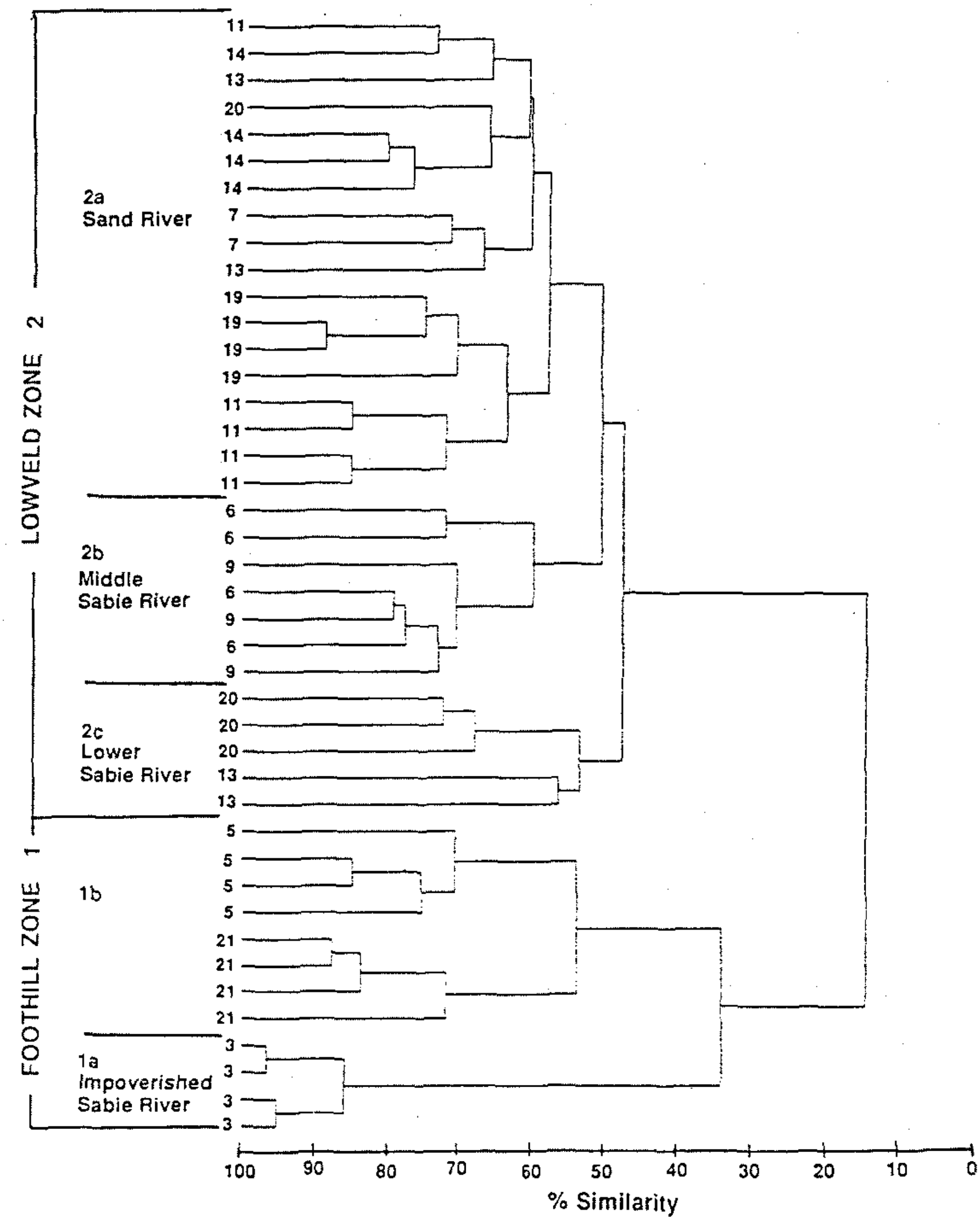

Figure 7.3: Dendrogram showing that the fish assemblages of the Sabie-Sand system can be classified according to river zones. Data has been reduced from 44 quarterly monitoring surveys by season in the Sabie-Sand catchment over four years (1990-93). Abundances for 44 species were root-root transformed, standardized and compared using the Bray-Curtis measure. The dendrogram was formed using group averages sorting. Two main groups are distinguished at an arbitrary similarity index of 20%, showing the FHZ and LZ. The FHZ can be sub-divided into two site specific groups while the LZ can be divided into 3 groups possibly reflecting river profile and order. Further divisions in both groups are strongly dependent on sample sites themselves. Samples are numbered by site.

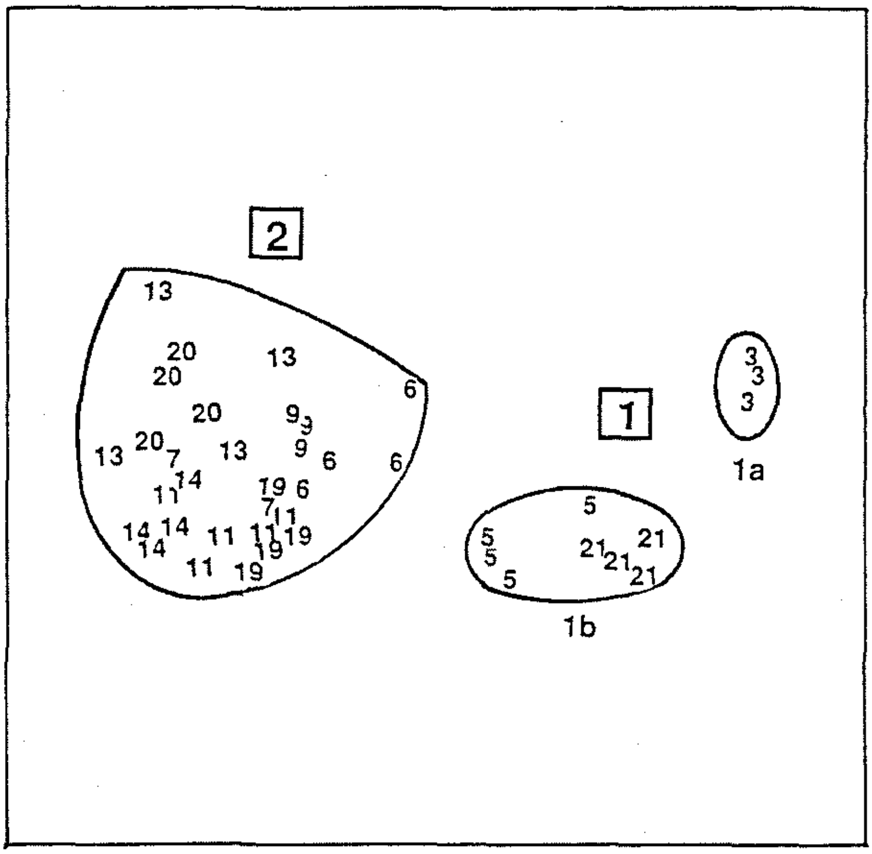

Figure 7.4: Zonation in the Sabie-Sand system reflected by the distribution of fish assemblages. Ordination using multi-dimensional scaling (MDS) on the same similarity matrix as Fig. 7.3. Quarterly samples of 44 fish species from 44 sites reduced by season for three years were used. Clusters and sub-divisions distinguished in the dendrogram are delimited. Data reduction masked seasonal assemblage differences thus strengthening site specific interpretation. Clusters 1 & 2 and 1a & 1b are spatially distinct. This results from FHZ/LZ division and the separation of impacted site 3. Clear divisions within cluster 2 (LZ) are not marked although two gradients are proposed.

At the 8% similarity level three clusters are formed. Group 1 is made up of species typical of the FHZ and group 2 with species typical of the LZ. Group 3 contains two outlying LZ species that were only sampled in large numbers for the first time at the end of the study, and during recovery of the lower reaches of the Sabie River from drought. Group 2 species can be divided at the 30% similarity level into 3 sub-groups related to hydraulic habitat types, and a fourth group related to temperature preferences. Group 2a are species that can breed during

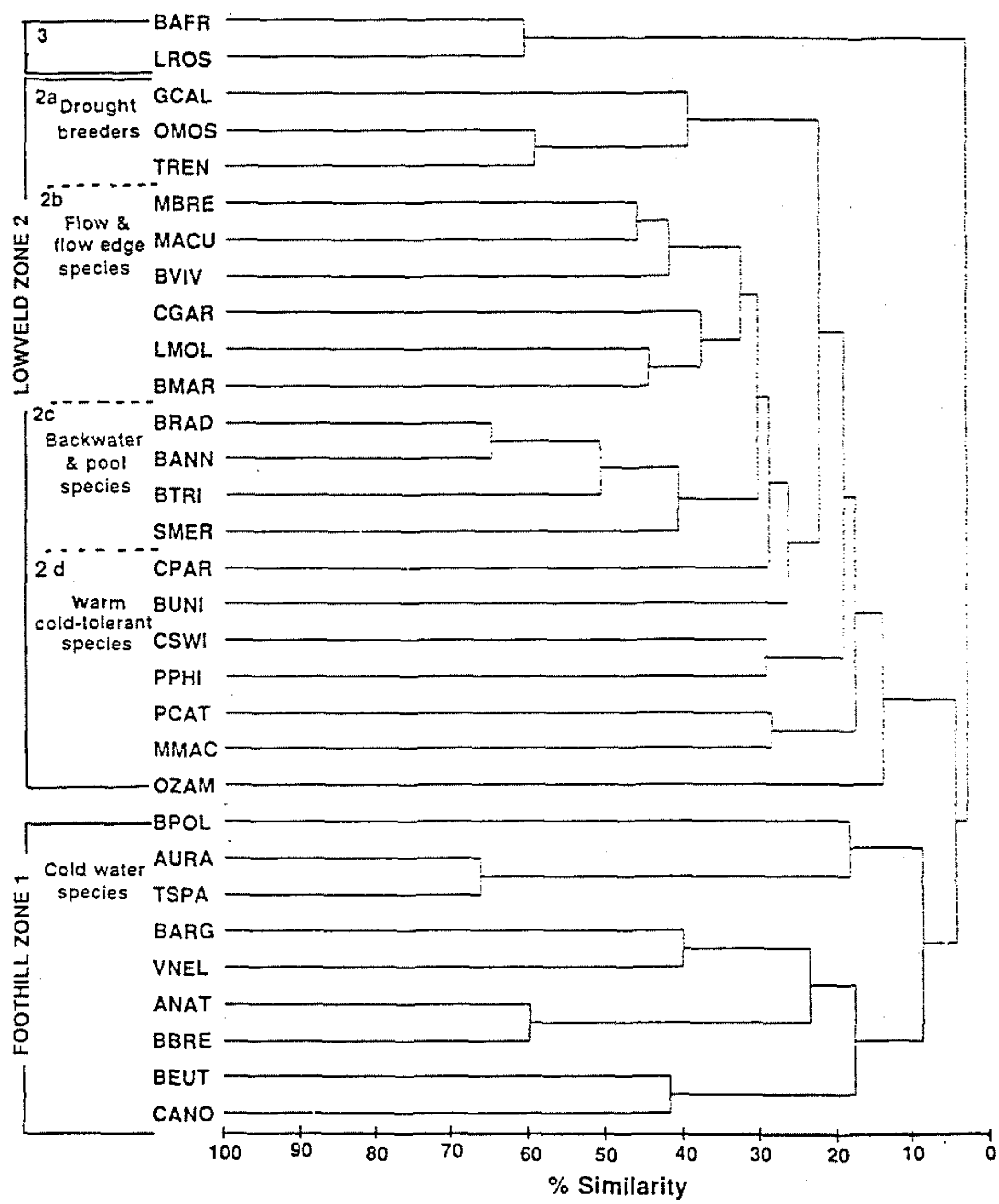

Figure 7.5: Dendrogram of inverse analysis comparing 31 fish species (cutoff at 4% dominance in any of the 67 samples) in the Sabie-Sand catchment between May 1990 & May 1993. Species abundances were standardized and compared using the Bray-Curtis measure with group average sorting. At the 8% similarity level cluster 1 & 2 are cool and warm species respectively with cluster 3 an outlier. Warm species can be divided at the 30% similarity level into three groups and a series of cold tolerant species (2d). The first group of species (2a) breed during drought, group 2b are margin or run species, while group 2c are minnows typical of pools and include their associated predator *Serranochromis meridianus.*

drought conditions, 2b species are widespread and typical of runs, marginal to flow or riffles (*B.marequensis* juveniles & *L.molybdinus*). Group 2c are backwater and pool inhabiting species including the minnows *Barbus radiatus*, *Barbus annectens* and *Barbus trimaculatus* as well the cichlid small fish predator (*S.meridianus*). Species not grouped (2d) are typically cold-tolerant.

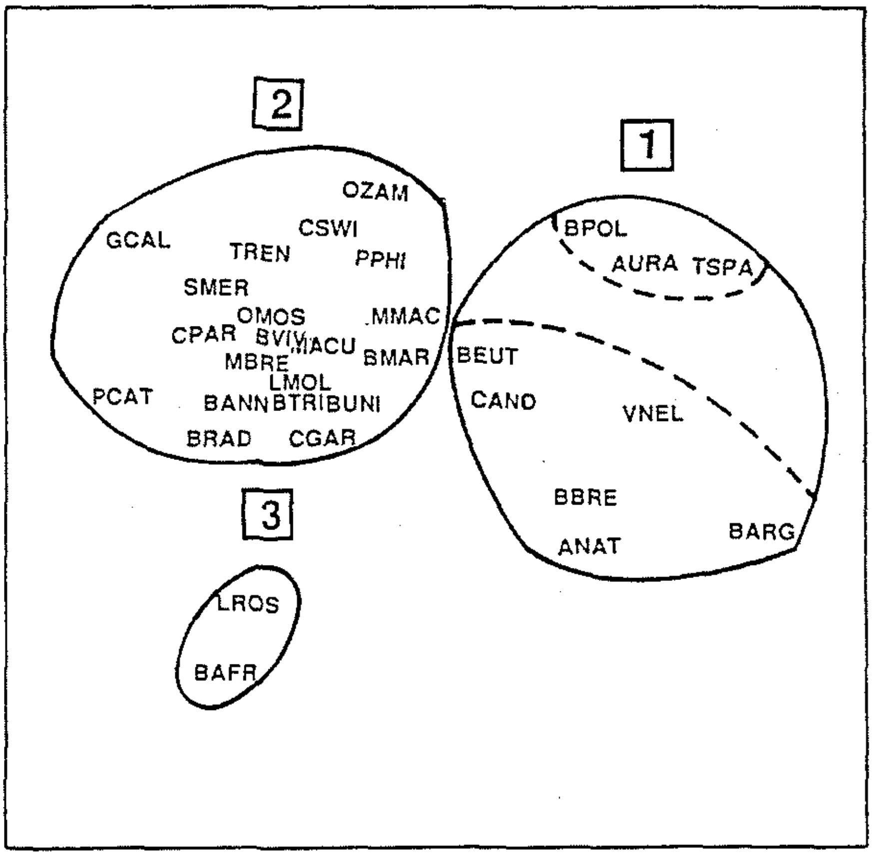

Figure 7.6: MDS inverse ordination for 31 fish species from the Sabie-Sand catchment using standardized abundances and Brey-Curtis measures. Main species groups delineated from Fig. 7.5 (previous dendrogram). FHZ species (1) & LZ species are distinct. Eurythermal species from both zones concentrate closer to the interface between clusters 1 & 2. Cluster 3 contained two species associated with the recovery floods in the catchment post drought.

MDS of this same data reveals a clear distinction between FHZ and LZ fish assemblages (Fig. 7.6). Temperature tolerant species from both fish zones tend to be classified close together, as are minnows and cichlids. There are no clear separations between groupings within the LZ.

In conclusion, classification of fish species distributions confirms the site classifications in terms of a major change in assemblages between the cool water, higher altitude foothill species, and the warm water lowveld species. Subsidiary distinctions tend to be based on habitat preferences within the Lowveld Zone.

7.4 BASELINE SPECIES ASSEMBLAGES

7.4.1 ZONE BASELINE ASSEMBLAGES

A major requirement of a pre-impoundment survey is to gather typical or baseline information on the distribution and abundance of species, against which to assess changes caused by the impoundment. Defining the baseline biotic assemblage for the Sabie-Sand ecosystem is not an easy task as it is a dynamic system. It would comprise the suite of species that are typical (defined as most abundant and therefore ecologically important) of each zone under natural, seasonal conditions prior to the drought. Patterns and processes would therefore be expected to track the seasonal variation and any other natural pattern at different spatial and temporal scales.

Baseline assemblages for the Sabie-Sand, while acknowledging the above limitations, were based on the following assumptions:

1) That the Sabie River is naturally perennial.
2) That the species assemblages seen at the start of the programme were typical of the biota under flow conditions during the past 20 years.

3) That the assemblages found during this project had recovered from major disturbances in the recent past, such as the 1982-83 drought.

4) That the drought significantly affected the fish fauna, and resulted in assemblages atypical of the river during normal years.

To isolate drought years from typical seasonal years, the data from all sites sampled during May 1990,91,92 and 93 were combined and compared. A core group of fish species were selected, comprising those which constituted 6% or more of any one years's May survey. Twelve species were identified (*B.annectens*, *B.brevipinnis*, *B.marequensis*, *B.radiatus*, *B.trimaculatus*, *B.viviparus*, *C.anoterus*, *L.molybdinus*, *O.mossambicus*, *Pseudocrenilabrus philander*, *Tilapia rendalli* & *V.nelspruitensis*). A series of comparisons of the different years (1990-91, 1991-92, 1992-93) was carried out, by ranking the relative abundances of core species during each year (species ranking).

Species rankings between 1990 and 1991 were significantly correlated (Spearmans's coefficient: r_s=0.83: P<0.001), indicating a high degree of commonness between the two years. Species ranking between 1991-92 & 1992-93 were not significantly correlated (r_s=0.14 & 0.22 respectively, both with p>0.05). This shows that the fish assemblages changed between 1991 and 1992, and again between 1992 and 1993. Similarly we looked at Spearman's coefficients between Aug 1990-91, Nov 1990-91 & Feb 1991-92 The fish fauna from May 1990 until August 1991 reflected pre-drought, relatively well-watered conditions in the rivers, and therefore the baseline assemblage has been defined to include only the May 1990 - Aug 1991 Survey data.

A. The Foothill Zone Baseline

Baseline pre-drought results are presented (Fig. 7.7a) for fish electrofished within the FHZ. Pies are percent averages for species standardized to the capture unit fish/min. Six ecologically important species were identified, each constituting 5% or more of the annual catchment-wide samples over four consecutive surveys. Pie (a) is the year average, and pies (c-e) are seasonal averages for the FHZ assemblage. Only six species accounted for 92.3%

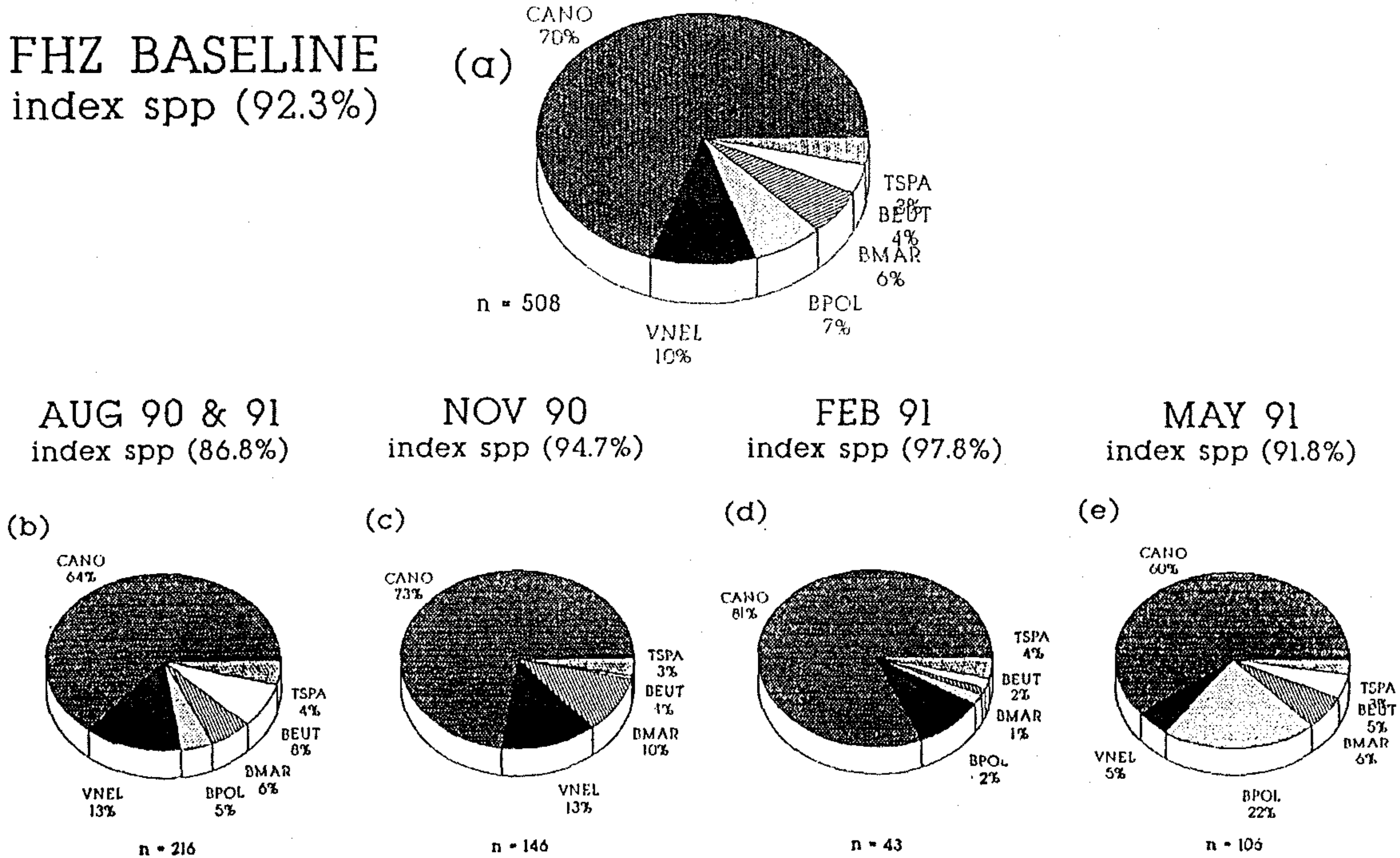

Figure 7.7: Baseline pie diagrams for small fish electrofished in the foothill zone (FHZ), upper Sabie and Marite rivers, during pre-drought conditions (1990-91). Pies are percent averages for species standardized (STD unit = fish/min). Pie (a) is the year average. Pies (b)-(e) are quarterly seasonal averages for FHZ sites. Six species account for 92.3% of the catch with *Chiloglanis anoterus* dominant (70%) and the four cyprinids *Varicorhinus nelspruitensis*, *Barbus polylepis*, *Barbus marequensis* and *Barbus eutaenia*, accounting for a further 27%. Quarterly seasonal pies are similar but the cyprinid, *B.polylepis* was more numerous (e) following the wet season (d). At the start of the wet season (c) CPUE for *B.polylepis* and *B.eutaenia* were reduced while *V.nelspruitensis* and *Barbus marequensis* were higher. Percentage CPUE for the cichlid *Tilapia sparrmanii* remained static.

of the average catch. *C.anoterus* dominates the FHZ baseline catch (70%) with the cyprinids *V.nelspruitensis*, young of *B.polylepis*, *B.marequensis* and the minnow *B.eutaenia* accounting for a further 27%. The cichlid *Tilapia sparrmanii* was only recorded at one of the monitoring stations (site 21) on the Marite River. *C.anoterus* and *V.nelspruitensis* were present at all FHZ monitoring sites.

In summary the FHZ is characterized by the riffle specialist *C.anoterus*. The three larger cyprinids, the regionally endemic *V.nelspruitensis* and young of *B.marequensis* and *B.polylepis* are typical of shallow runs and riffles. This is in line with the structure of the river in this zone where riffle-run sequences are short and substrates are typically broken. Quiet water *B.eutaenia* and *T.sparrmanii* are to be found in the shelter of root and boulders in marginal habitats.

B. The Lowveld Zone Baseline

Using a similar method the yearly average catch or baseline was derived for the LZ (Fig. 7.8). Eleven ecologically important species make up 82.6% of the average baseline assemblage, of which the most dominant is the minnow, *B.viviparus* (bowstripe barb) which accounts for 21% of the electrofished catch. *O.mossambicus* is an important component on average (12%) even before the drought. *B.annectens*, *B.marequensis*, *L.molybdinus*, *C.anoterus* and *T.rendalli* each make up roughly 10% of the assemblage with the minnows *B.trimaculatus*, *Barbus unitaeniatus* & *B.radiatus* constituting 5-6%.

In general, the LZ baseline comprises a suite of cyprinids (7 species comprising 56%), five of which are minnows. *B.viviparus* is the most numerous and ubiquitous of the LZ species occurring at all LZ sites. Together with *B.marequensis*, *L.molybdinus* and to a lesser degree *C.anoterus*, they exploit areas in or adjacent to flow. *C.anoterus* is present in the LZ especially at stations towards the FHZ interface, where broken substrate riffles are still a feature. The remainder of the sizable minnow component (25%), exploits quiet pools, and together with *B.viviparus* totals 46% of the LZ small species baseline assemblage. Three pool

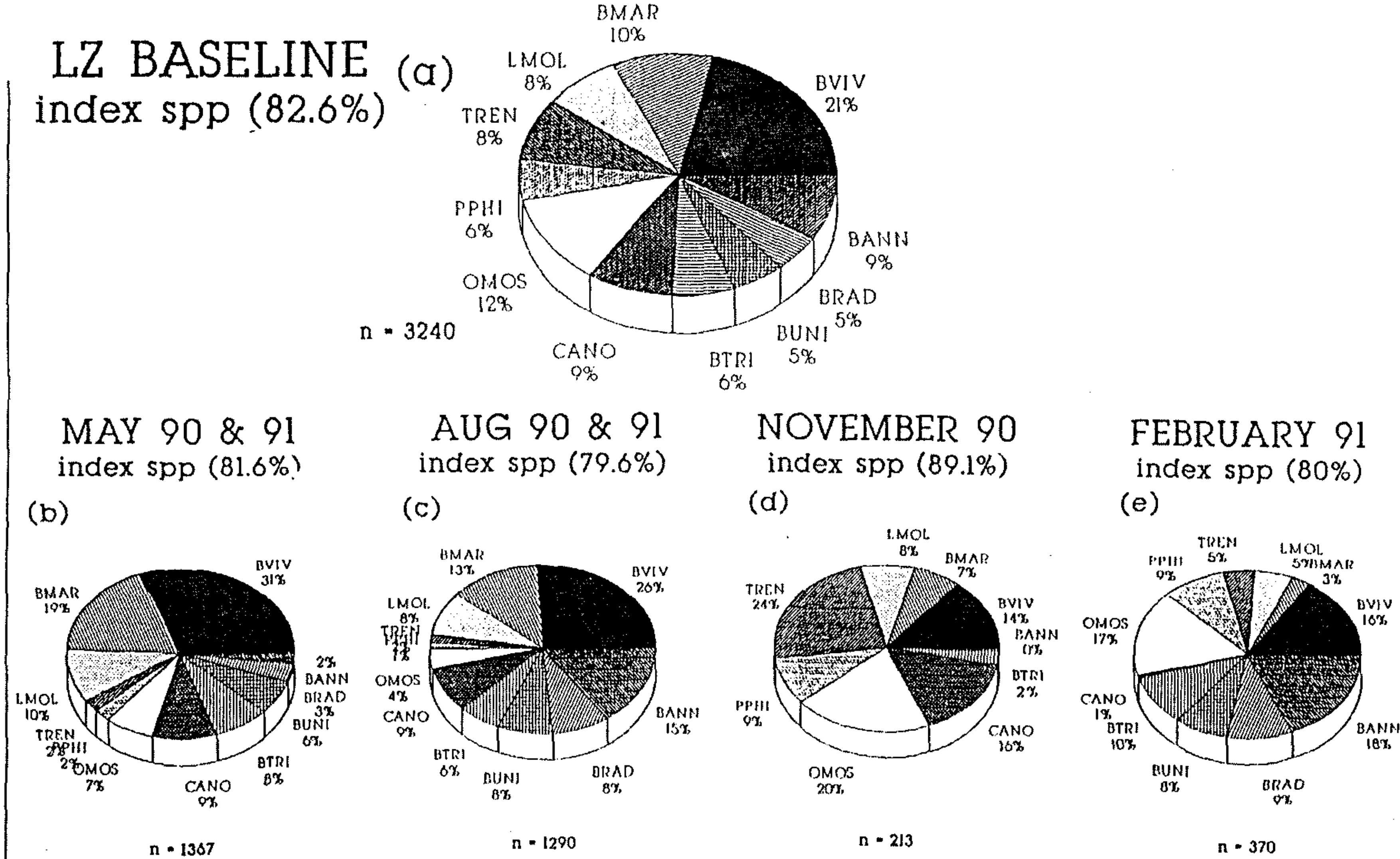

Figure 7.8: Baseline pie diagrams for small fish electrofished in the lowveld zone (LZ), Sabie and Sand rivers, during pre-*drought conditions* (1990-91). *Pies are percent averages for species standardized (STD unit = fish/min). Pie (a) is the season* average. Pies (b)-(e) are quarterly averages for LZ sites. 11 species account for 82.6% of the average quarterly catch (a). Of these, 7 (56%) are cyprinids, 5 of which are minnows. *Barbus viviparus* is the most important (21%). 26% of the average annual catch are cichlids (*Pseudocrenilabrus philander, Tilapia rendalli & Oreochromis mossambicus*). At the start of the dry season (May: (a), 75% of the catch is cyprinid (*Labeo molybdinus-Barbus trimaculatus*) with minnows making up about 50% (*Barbus viviparus, Barbus annectens, Barbus radiatus, Barbus unitaeniatus & Barbus trimaculatus*). By the beginning of the wet season (d) cichlids (*Oreochromis mossambicus, Tilapia rendalli & Pseudocrenilabrus philander*) typically make up 50% of the catch. By February, minnows are typically more than 50%. Riffle loving *Chiloglanis anoterus* are difficult to catch at high flows (e).

and backwater cichlids species, (*O.mossambicus, T.rendalli & P.philander*), make up 26% of the average annual catch.

7.4.2 SEASONAL BASELINE ASSEMBLAGES

Because the Sabie-Sand system is hydrologically highly seasonal, fluctuations in the average baseline species assemblage for each zone need to be examined.

A. Foothill Zone

Figures 7.7b-e illustrate the seasonal average composition of the fish assemblage found during quarterly monitoring trips in the FHZ during the defined pre-drought baseline period. Quarterly baseline pies are similar for all seasons with *C.anoterus* dominating throughout. The cyprinids, including the small & large-scaled yellowfish (*B.marequensis & B.polylepis*), as well as the minnow *B.eutaenia*, increased in % proportion of the catch by the end of the wet season (e), probably as a result of summer breeding and the presence of many young fish.

B. Lowveld Zone

Figures 7.8b-e give the seasonal average for the quarterly monitoring trips the LZ during the defined pre-drought period.

Clear differences are evident in the nature of the seasonal catches:

a) **May:** At the start of the dry season (pie 7.8b) 75% of the core species catch were cyprinids. This included five minnows and the dominant *B.viviparus* (31%), which together made up 50% of the catch. Young *L.molybdinus* and *B.marequensis* are found in shallow runs and even riffle habitats together with *C.anoterus*, particularly at sites closer to the FHZ. The cichlids *O.mossambicus, T.rendalli & P.philander* together made up on average only 11% of the CPUE.

b) **August:** By August (Fig. 7.8c) cyprinids remained abundant at 86%, with minnows especially numerous. This may have been due to their concentration in reduced habitat towards the end of the dry cycle. *B.marequensis* & *L.molybdinus* numbers decreased marginally. *C.anoterus* numbers remained unchanged and the fish were confined to riffles. Cichlids remained scarce in samples (7%).

c) **November:** By the end of the dry cycle (Fig. 7,8d), and with the onset of the wet season composition changed dramatically. Cichlids increased to over 50% of the small fish sampled, while the minnows were all reduced. *B.viviparus* was no longer the most dominant species, but both cichlids *O.mossambicus* and *T.rendalli* were more numerous. The catlet *C.anoterus* remained abundant, although confined to the riffle areas it prefers. *O.mossambicus* is known to commence breeding in September-October independent of summer rains (Bruton, 1985) in lake Sibaya and it seems likely that both *P.philander* and *T.rendalli* do likewise. Early summer breeding, independent of summer rains, would best explain the shift in dominance from cyprinids to cichlids seen November.

d) **February:** February is normally the wettest month in the Sabie system. Summer breeding, flow-dependent fish probably spawn following spates during high flows. Although it would still be too early to expect changes too be complete in three months, some are evident. Cyprinids increased to 69% of the sample, with minnows accounting for the majority of the change (Fig. 7.8e). Cichlid percentages also started to decline again (31%). High flows prevented the sampling of *C.anoterus* in their preferred habitat, which explains the apparent low numbers recorded.

7.4.3 DROUGHT ASSEMBLAGES

Changes in species abundance and composition were not confined to predictable seasonal shifts, they included the effects of disturbance, both natural (the drought) and anthropogenic (the failure of Zoeknog Dam).

Using PRIMER we were able to show that after downstream temperature zonation, drought was one of the major determinants of species pattern, at least within the LZ. Unlike the zonation pattern which reflects generally fixed species distributions, the drought pattern reflects changes within the LZ in species abundance. The dendrogram (Fig. 7.9) represents 67 May samples classified using the Bray-Curtis similarity measure and group-average sorting. At the arbitrary similarity level of 8% two groups can be distinguish - the Foothill Zone group (FHZ) and the Lowveld Zone group (LZ). The role of drought in the secondary patterns in both these zones are discussed:

A. Foothill Zone

The FHZ (Group 1) can be further divided into three sub-groups. Group 1a comprised FHZ sites within the Sand sub-catchment, 1b FHZ sites within the upper Sabie and Marite Rivers while group 1c represents the intermediate Sabie sites 5-6. Any pattern between years was lost as inter-reach/site differences are stronger. In other words, between site similarities obscured differences between samples collected in the first two pre-drought years (B) or during the height of the drought (D) or recovery (R). This means that any changes within the FHZ fish assemblage during the 1991-92 drought were overshadowed by station/reach differences between different tributaries or position along the river profile.

Figure 7.10 supports this interpretation using the same similarity matrix. It delineates groups of stations from Figure 7.9 showing that stations were more related through spatial rather than temporal variation in species distribution and abundance. Groups 1 and 2 are clear although related with transitional samples near their interface. Sub-groups 1a (the upper Sand River) and 1c (the intermediate Sabie River) show distinct differences from each other. Some indication of drought induced assemblage shift can be seen if data for the monitoring stations in the FHZ are combined for each yearly survey for May. Drought is seen to have an effect on the abundance of the baseline species assemblage (Fig. 7.11a-c & Table 7.6).

Table 7.6: Baseline species percentages for May in the aseasonal FHZ. Summer drought flows increased pre-drought cyprinid and cichlid numbers, except the large cold-water yellowfish *Barbus polylepis*. The average percentage of the riffle-dwelling catlet, *Chiloglanis anoterus* was also reduced. Post-drought samples were affected by relatively low and warmer winter flows which appeared to further reduce numbers of *Barbus polylepis* so that, following the normal wet summer season, their numbers had still to recover. All other species in the FHZ recovered to pre-drought percentages although *Varicorhinus nelspruitensis* and *Barbus eutaenia* numbers remained relatively high.

SPECIES	FOOTHILL ZONE		
	Pre-drought	Summer drought	Post drought
Barbus eutaenia	5%	↑ 7%	↑ 9%
Barbus marequensis	6%	↑ 35%	↓ 5%
Barbus polylepis	22%	↓ 15%	↓ 1%
Chiloglanis anoterus	60%	↓ 19%	↑ 69%
Tilapia sparrmanii	3%	↑ 4%	↓ 1%
Varicorhinus nelspruitensis	5%	↑ 19%	↓ 15%

In the more aseasonal FHZ, where many species are shown to be largely seasonally stable in abundance (see section 7.4.2), we would have expected the species present to be less resilient to drought. By May 1992, after the failed wet season, the abundance of the dominant rock-catlet *C.anoterus* had plummetted to only 19%, while the eurythermal *B.marequensis* seemed to increase proportionally. Cyprinids generally increased in importance except for the cool-water yellowfish, *B.polylepis*, which decreased in abundance.

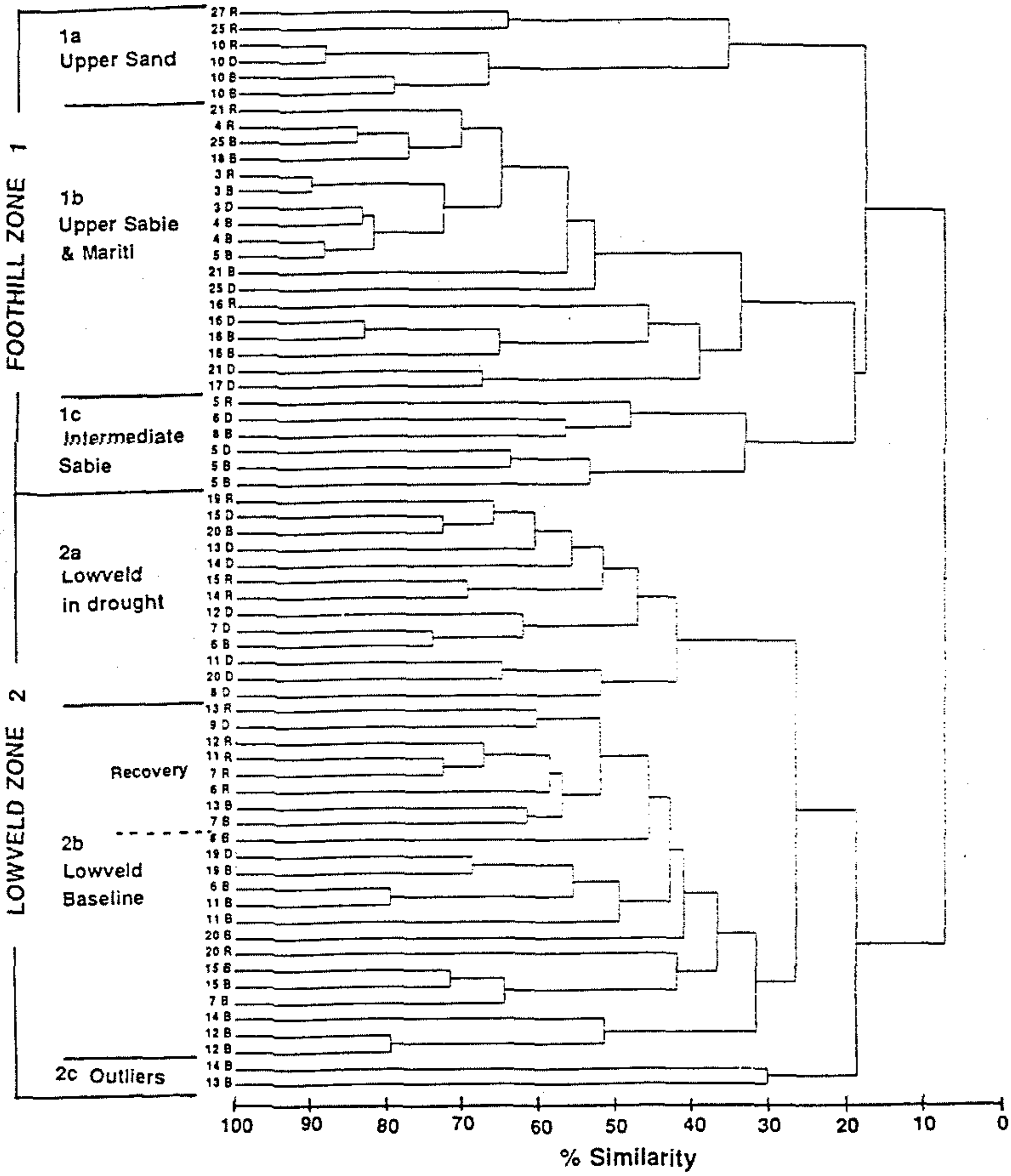

Figure 7.9: Dendrogram showing the spatial and temporal differences of 67 May samples at 20 survey stations for fish assemblages in the Sabie-Sand catchment over four years (1990-93). Abundances for 44 fish species were standardized and compared using the Bray-Curtis measure with the dendrogram formed by group averages sorting. Two main groups are distinguished at an arbitrary similarity index of 8% showing the FHZ and LZ. The FHZ can be divided into three sub-groups which are largely site specific. The LZ can be divided into three groups (2a-c). Group 2a samples are mainly drought affected. Samples are numbered by site and coded as; baseline (B: May 90 & May 91), drought (D: May 92) or recovery (R: May 93).

Besides the reduction of the rock catlet *C.anoterus* which is known to be badly affected by reduced flow, the increase in abundance of certain species in the FHZ alone, was somewhat unexpected. This may be explained by the origins of particular species. During the 1992 drought, FHZ flows remained perennial with waters both warmer (Table 5.6) and slower flowing (Table 4.3). This seemed to have benefitted cyprinids, some of which are widespread in the warmer waters of the catchment, and the cichlid *T.Sparrmanii*. *B.marequensis* had decreased in LZ waters while it increased in FHZ waters. Individuals could have moved upstream from the LZ to escape the extremes of the drought being experienced there, or the more placid stable summer flow conditions may have allowed for successful local spawning. On the other hand, the reduction in the abundance of the Cyprinid *B.polylepis* may relate to its ecological requirements. Biogeographically *B.polylepis* has its origins in the large cyprinids of central South Africa (Skelton, 1994), suggesting that it needs cooler waters.

By May 1993, following both low but perennial winter flows, and a normal summer wet season in the FHZ, most species had returned to pre-drought percentages, except *B.polylepis* which appeared even further reduced. Because of the low fecundity expected from the rock catlet (*C.anoterus*) due to the few extremely large eggs produced (approximately 2.5 mm in diameter), their recovery suggests that numbers were not reduced during the drought but rather that they had taken refuge locally and had avoided capture within our sample reaches.

B. Lowveld Zone

PRIMER analysis showed evidence of the passage of the drought within the FHZ (Fig. 7.9). Group 2 can be divided into a drought group (2a) separated from the baseline LZ assemblage of pre-drought samples. The only drought sample within the heart of the LZ baseline group (2b), was station 19 which had exceptionally high abundances of *O.mossambicus* in an otherwise remnant lotic species assemblage. Within the LZ group (2b), there is a sub-group of predominately recovery samples that were collected after the drought broke in November 1992. We can conclude that between years, differences in species abundance within lowveld sites for May surveys, show the passage of drought. To a lesser degree samples characteristic of recovery can be distinguished, and lie between the baseline LZ assemblage abundances and drought samples.

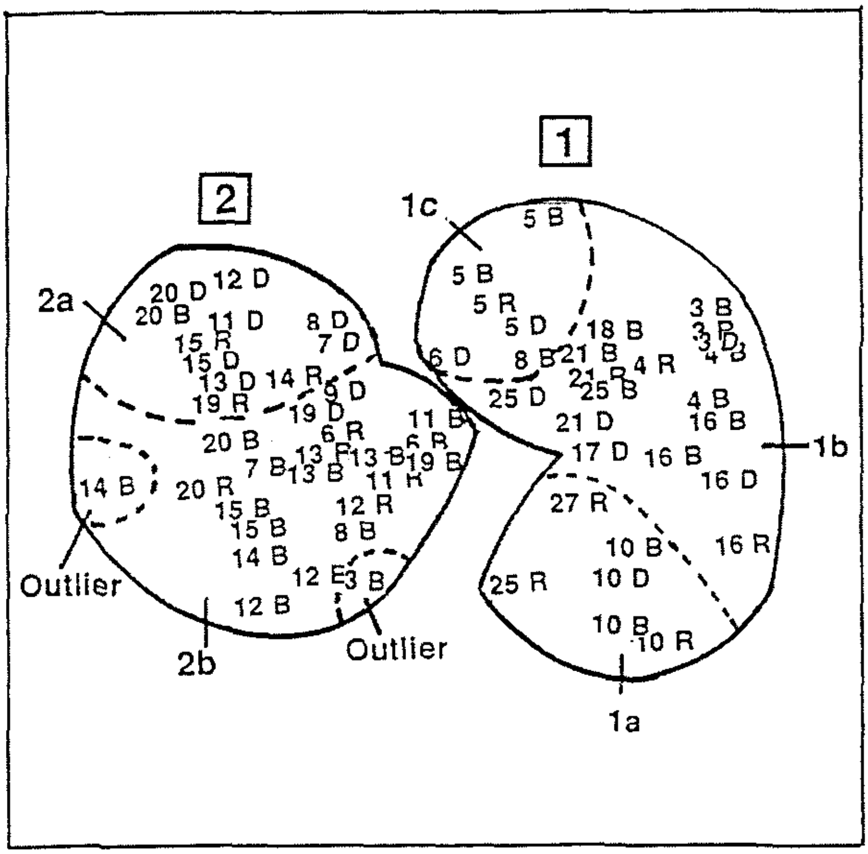

Figure 7.10: Spatial and temporal differences in fish assemblages using multi-dimensional scaling (MDS) on the data in the previous dendrogram (Fig. 7.9). Differences between FHZ & LZ assemblages were more marked than those caused by the 1991-92 drought. Subdivisions within the FHZ cluster show differences between fish assemblages in different sub-catchments and sites. Within the LZ differences are less clear, showing rather a gradient of change best explained by the passage of the 1991-92 drought.

Analysis using MDS shows that the LZ group (Fig. 7.10) is well-defined and different from the FHZ group. This is consistent with the interpretation of the drought shifting the relative proportions of the LZ fish assemblage rather than changing its structure by causing local extinctions. Prolonged or repeated drought would result in species loss and the formation of new dendrogram groupings.

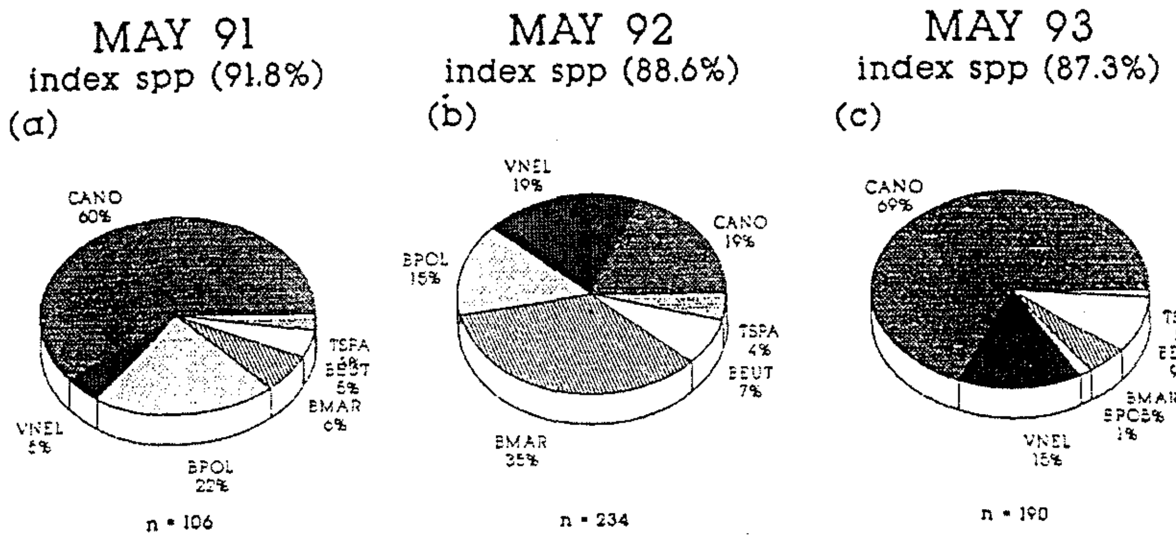

Figure 7.11: May pie diagrams for small fish electrofished in the foothill zone (FHZ), upper Sabie and Marite rivers over three years spanning the 1991-92 drought. Six index species make up between 87.3% to 91.8% of the catch. Pies are percent averages for species standardized (STD unit = fish/min). Pie (a) is the pre-drought baseline for May where *Chiloglanis anoterus* is the most numerous (60% of index species). After the failed 1991-92 wet season (b) catches of *Chiloglanis anoterus* were reduced to their lowest (19%) while *Barbus marequensis* increases to 35%. Recovery by May 93 shows pie (c) similar to the 91 baseline pie except for *Varicorhinus nelspruitensis* which had been relatively more numerous than *Barbus polylepis*.

The relative abundances of core baseline species sampled in May 1991 and 1992 give an insight into the causes of observed changes in the fish assemblages (Fig. 7.12 & Table 7.7). Both May assemblages (Fig. 7.12a & b) within the pre-drought baseline were very similar. With the failure of the 1992 wet season, all species showed decreases in relative percentages excepting cichlids, which increased (Table 7.7). By May 1992 (Fig. 7.12c), cyprinids had

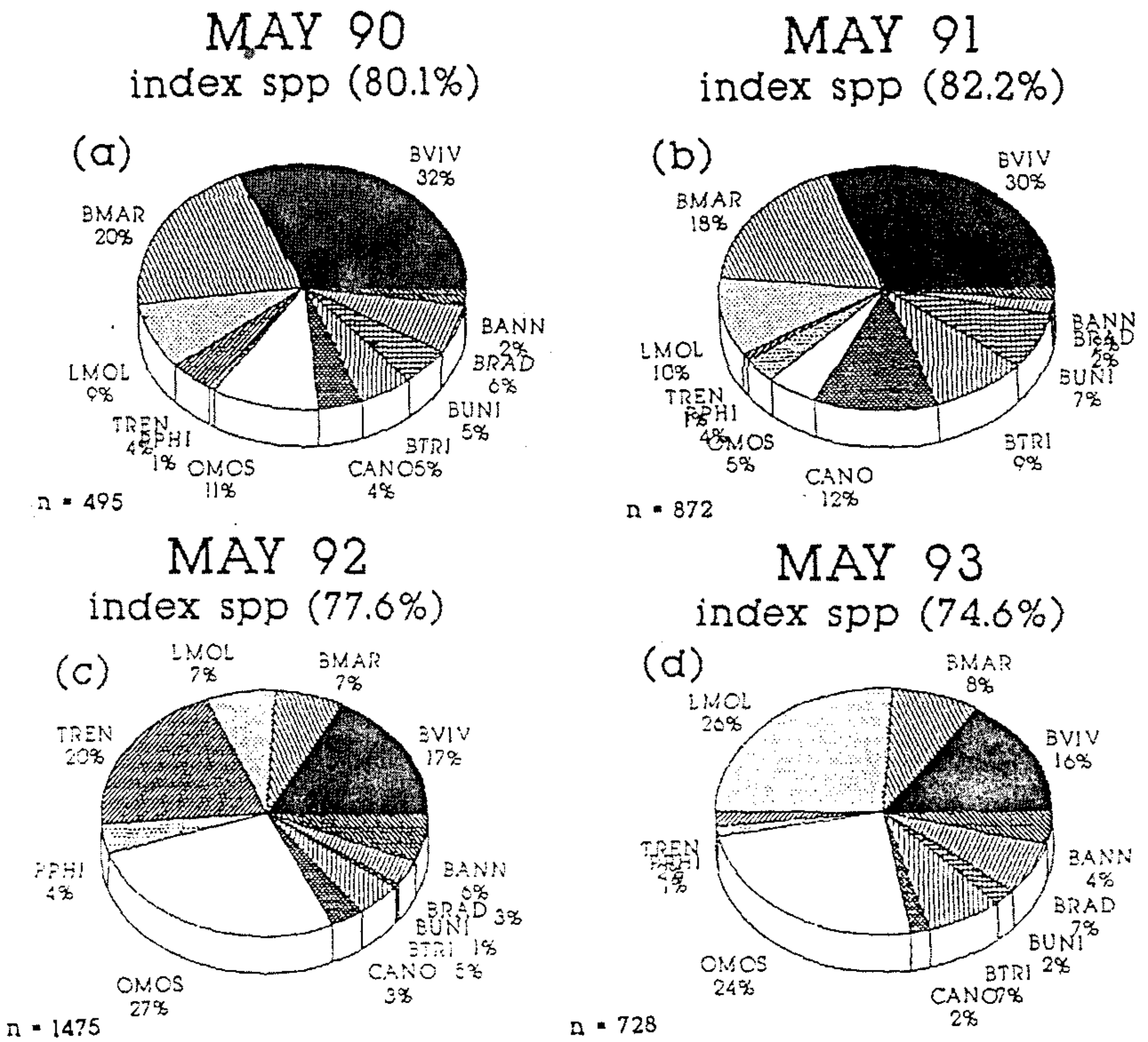

Figure 7.12: May pie diagrams for small fish electrofished in the lowveld zone (LZ), Sabie and Sand rivers over four years. Pies are percent averages for species standardized (STD unit = fish/min). Pre-drought pies (a) & (b) are very similar, with cyprinids making up over 75% of the index species catch and minnows comprising about 50%, (*Barbus viviparus* was the most numerous at 30%). The cichlids *Oreochromis mossambicus*, *Pseudocrenilabrus philander* & *Tilapia rendalli* made up only 10-15%. After the failed wet season of 1991-92 (c) and prior to the severe dry season, cichlids made up over 50% of the index species while minnows were reduced. By May 93 (d), some recovery in the catch of *Labeo molybdinus* is evident while *Barbus viviparus* remains less abundant.

Table 7.7: Baseline species percentages for May in the seasonal LZ. All species showed summer drought-affected decreases in their numbers resulting from lower flows, except for the cichlids and two species of deep pool-dwelling minnows which were sampled more easily (*Barbus annectens* & *Barbus radiatus*). *Chiloglanis anoterus* and *Barbus marequensis*, both riffle species, as well as *Barbus viviparus* and *Barbus unitaeniatus* had failed to recover by May 1993. *Tilapia rendalli* numbers were reduced during the extreme dry season while *Pseudocrenilabrus philander* remained the only target species unaffected by drought or season.

SPECIES	LOWVELD ZONE		
	Pre-drought	Summer drought	Post drought
Barbus annectens	2%	↑ 6%	↓ 4%
Barbus marequensis	18%	↓ 7%	↑ 8%
Barbus trimaculatus	9%	↓ 5%	↑ 7%
Barbus radiatus	2%	↑ 3%	↑ 7%
Barbus unitaeniatus	7%	↓ 3%	↓ 2%
Barbus viviparus	30%	↓ 17%	↓ 16%
Chiloglanis anoterus	12%	↓ 3%	↓ 2%
Labeo molybdinus	10%	↓ 7%	↑ 26%
Oreochromis mossambicus	5%	↑ 27%	↓ 24%
Pseudocrenilabrus philander	4%	4%	↓ 2%
Tilapia rendalli	1%	↑ 20%	↓ 2%

been reduced from 78% of the catch to less than 50%, while cichlids had increased to over half the CPUE. *C.anoterus* was markedly reduced.

Following the extended drought dry season and after the first normal wet season, (May 93, Fig. 7.12d) some recovery was evident, but species abundances were very different from those observed in 1991. The harsh dry season during which the lowveld Sand River stopped flowing for five months reversed early drought increases in the percentages of the cichlid *T.rendalli*, and reduced the abundance of *P.philander*, while *O.mossambicus* persisted in greater numbers than the baseline abundances. Notably, numbers of the riffle loving rock-catlet *C.anoterus* and *B.marequensis* were still markedly reduced in the LZ, the former because it is sensitive and may be limited in recovery potential. The minnow *B.viviparus* remained at roughly half its expected pre-drought catch while *B.unitaeniatus* also remained depressed in numbers.

Although the drought was severe, a few species had made an early comeback. Young *L.molybdinus* were very numerous (as were *L.rosae* and *B.afrohamiltoni* in some sites, for the first time during the project) and some minnows also recovered early (*B.trimaculatus*), or survived well in refuge pools (*B.annectens* & *B.radiatus*).

There is a striking and important similarity between the May 1992 drought sample (Fig. 7.12c) and that of the typical post dry season baseline seen in November (Fig. 7.8d). This suggests that changes in the percentage make-up of the LZ baseline fishes during drought are similar to changes caused by a normal dry season. Here the percentage of early summer breeding cichlids (breeding independent of good wet season flows) eclipses the relative numbers of cyprinids which only breed with the arrival of the seasonal rains in November. Proportions of cichlids compared to cyprinids and abundances of six of the most important core species including *B.viviparus*, *O.mossambicus*, and *T.rendalli* support this similarity. An important exception is the drought impact on the rock-catlet *C.anoterus* which was much reduced. (Low *C.anoterus* numbers in Fig. 7.12a were due the exclusion of a riffle sequence included in subsequent samples at station 6). *B.viviparus* is similarly reduced to half its baseline level.

Ecological theory suggest that species with a fast turnover should be very resilient (Lowe-McConnell, 1979). Because the lowveld rivers are seasonal and naturally prone to periods of drought, the Sabie River fish assemblage can be expected to be resilient. Nevertheless, the maintenance of viable refuge populations in the long term is important. The lowveld species were in general able to survive severe drought as long as pool refuges persisted.

In conclusion, changes seen in species distribution and abundance during the 1991-92 drought mirrored natural dry season changes in species composition. Within lowveld reaches, the relative abundance of species varied rather than their presence. Changes relate to differing breeding success of the summer spawning fish assemblage, with increased flow-dependent and flow-independent species alternating in dominance according to flow conditions. This supports the idea that management should set goals based on species abundances rather than presence or absence. Further, the patterns of abundance seen during drought years are natural and are typical of dry season assemblages which suggests some degree of resilience at least within the LZ assemblage. Providing the drought conditions are not prolonged or repetitive, many of the species concerned can be expected to recover rapidly. Some species such as *C.anoterus* were markedly impacted and they showed little recovery after the first year. Their origins within the more stable headwater stream probably underlies their sensitivity to drought.

What ever the interpretation of changes in fish assemblages from 1990-1993, it is obvious that recovery relies on an adequate refuge population in the long run. The drought focus (vol 2), tries to answer questions as to how and why certain species survive and for how long.

7.5 TARGET SPECIES

One of the aims of this project was to identify a set of species whose life-cycles and habitat requirements would be representative of the range of characteristics of all the fish fauna. These target species were selected on the basis of representativeness, diversity of requirements, importance, and abundance (since not enough information could be gathered

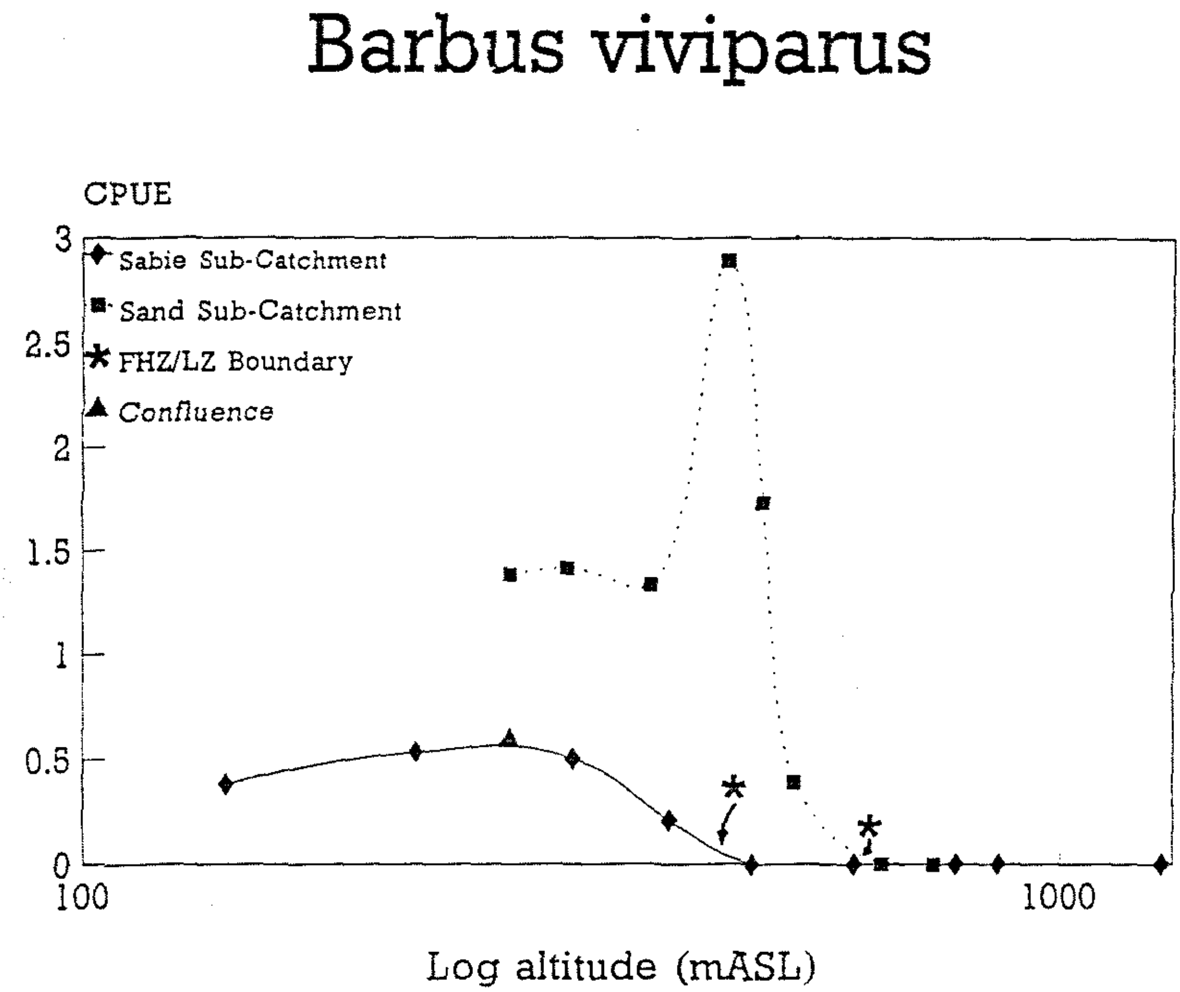

Figure 7.13: Distribution and abundance of the Lowveld Zone (LZ) indicator species. *Barbus viviparus* in the Sabie River system. Abundance is shown as average station CPUE (fish/minute), at different altitudes (mASL). *B.viviparus* was typically the most abundant lowveld fish found at all LZ stations within the Sabie-Sand River. It was particularly abundant within the lower order Sand sub-catchment streams (max CPUE, 2.9). Abundance decreases towards the lower Sabie River. *B.viviparus* is absent in the lower Incomati system.

on scarce species). The following sections identify these target species, describe their habitat requirements, and provide a hand-book of their ecology.

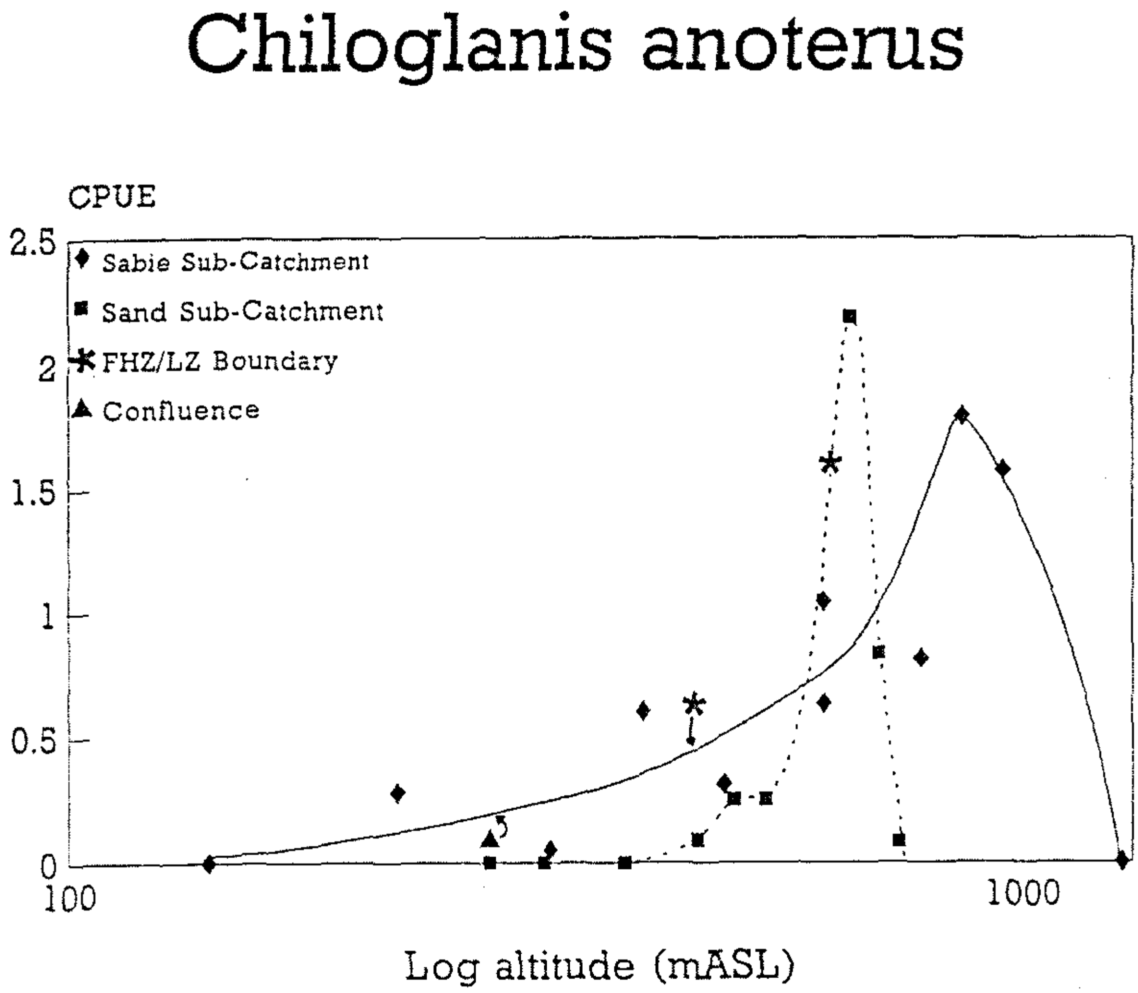

Figure 7.14: Distribution and abundance of the Foothill Zone (FHZ) indicator species, *Chiloglanis anoterus* in the Sabie River system. Abundance is shown as average station CPUE (fish/minute), at different altitudes (MASL). *C.anoterus* was the most abundant species at higher altitudes within the FHZ in both the Sabie (max. CPUE, 1.8) and Sand sub-catchments (max. CPUE, 2.2). The species is absent in the lower Sabie-Sand system. It does penetrate the Sabie River in suitable habitats to 220 mASL. It is limited in FHZ in the smallest or first order streams surveyed.

7.5.1 SELECTION CRITERIA

A. Zone Indicator Species, their distribution & abundance

TWINSPAN (Hill, 1979) was used to identify species representative of the two major zones (FHZ & LZ) (Fig. 7.2). *B.viviparus* was identified as the indicator species of the LZ since it was present at all LZ sites, but at none of the FHZ sites. *C.anoterus* was selected as the indicator species for the FHZ since it provided 60 to 81% of the catch at FHZ sites (see Fig. 7.7), compared with 1 to 16% of the catch at LZ sites (Fig. 7.8).

B.viviparus, as with many of the minnows, was more numerous in the LZ in close proximity to the Drakensberg foothills (Fig.7.13), and was also more numerous in the Sand compared with the Sabie subcatchment. This can probably be explained by microhabitat needs, linked to substrate, flow and depth preferences, which will be dealt with in subsection 7.5.2. Many of the minnows and other small species that required good cover in flowing waters in any of their life stages, are less numerous as the river profile flattens out and are absent in the lower Incomati River (appendix III).

C.anoterus was abundant in the perennial FHZ streams in both the Sabie and Sand rivers (Fig 7.14), but was not numerous in the smallest streams possibly due to microhabitat needs. Numbers were reduced as waters warmed and riffle habitat became scarce.

B. Ecologically Important Species

These are species that during any one year, made up 5% of the catch for the May catchment-wide survey data (appendix IV: Table 1-4). This included pre-drought and drought years as well as a recovery year. Fifteen species were initially identified, including both the river zone indicator species. *Petrocephalus catostoma* was discounted as its high numbers were probably an artifact of collection method. They were sometimes collected in large numbers at site 14 were an unusual rock fracture provided exceptional cover for the species. *Micralestes acutidens* was included because of its wide distribution and abundance. Eighteen species were selected, of which three were important in both FHZ and LZ waters;

a) **FHZ:** *Barbus eutaenia*
Barbus marequensis
Barbus polylepis
Chiloglanis anoterus
Pseudocrenilabrus philander
Tilapia sparrmanii
Varicorhinus nelspruitensis

b) **LZ:** *Barbus annectens*
Barbus marequensis
Barbus radiatus
Barbus trimaculatus
Barbus unitaeniatus
Barbus viviparus
Chiloglanis anoterus
Labeo molybdinus
Micralestes acutidens
Oreochromis mossambicus
Pseudocrenilabrus philander
Tilapia rendalli

C. Red Data Species

Two species were added to the list due to their status as indeterminate-rare to rare respectively (Skelton, 1987).

Opsaridium zambezense
Serranochromis meridianus

Table 7.8: Size limits (mm) of juvenile and adult fish species.

SPECIES	JUVENILE	ADULT
FAMILY: Cyprinidae		
Opsaridium zambezense	< 76[2]	≥ 76[2]
Barbus annectens	< 43	≥ 43
Barbus eutaenia	< 41	≥ 41
Barbus marequensis	< 175[1]	≥ 175[1]
Barbus polylepis	< 235[1]	≥ 235[1]
Barbus radiatus	< 47	≥ 47
Barbus trimaculatus	< 55	≥ 55
Barbus unitaeniatus	< 52	≥ 52
Barbus viviparus	< 32	≥ 32
Varicorhinus nelspruitensis	< 158	≥ 158
Labeo molybdinus	< 146	≥ 146
FAMILY: Characidae		
Micralestes acutidens	< 44	≥ 44
FAMILY: Mochokidae		
Chiloglanis anoterus	< 39*	≥ 39
FAMILY: Cichlidae		
Oreochromis mossambicus	< 80[1]	≥ 80[1]
Pseudocrenilabrus philander	< 37	≥ 37
Serranochromis meridianus	< 135	≥ 135
Tilapia rendalli	< 140[1]	≥ 140[1]

* = Single female of 37mm with eggs.
[1] = Gaigher, 69
[2] = Crass, 64

7.5.2 MICROHABITAT REQUIREMENTS

Any good field biologist can tell you where and when you are most likely to find a familiar species even though it is difficult to quantify their habitat needs exactly. The challenge is to make this information accessible and quantitatively comparable in order to aid the management of rivers. The microhabitat variables flow, depth, substrate and cover were considered those most likely to explain the use of habitat by target species. Data were collected using standard techniques developed largely for use in the American Instream Flow Incremental Methodology (IFIM) (Bovee, 1986) (details of which can be found in section 3.6) and Suitability Index (SI) Curves were developed for the target species.

A. *Suitability Index (SI) Curves*

SI curves quantify the knowledge of a good field naturalist. Details of data manipulation, SI curve construction and perceived limitations are given in section 3.6. The SI curves presented here are the first comprehensive set of species microhabitat use and preference within any African aquatic ecosystem besides those of King and Tharme (1994) for the Olifants River in the Southwestern Cape. They should not be seen as the final word on these species but rather as a first attempt based on limited data. Individual SI curves show microhabitat use for each variable for adults and juveniles of target species within the Sabie-Sand system at the sites where they were found. Table 7.8 lists the division of juvenile and adult size classes used. In some cases, larger numbers of schooling fish were captured at one time. To avoid these data swamping the results from individual fish, schools were treated as individuals for the purpose of SI curve calculation.

The preference curves calculated here include data from comparable tributaries (by zone or stream order), and for all seasons. This necessary lumping of data where numbers of a species were scarce, maximizes the number of observations for each life stage of each species. Data were further combined over seasons as it was felt that the limitations of developing separate seasonal curves without adequate records (a minimum of approximately 30 records is required) would far outweigh any perceived benefit.

Table 7.9: Channel index (CI) codes for cover and substrate for all selected fish species.

TENS	TYPE	REFUGE VALUE
10	No cover	None
20	Offstream overhead	Visual cover (indirect)
30	Instream object	*Velocity shelter*
40	Instream overhead	Visual cover (direct)
50	Combination	Combination (velocity & visual cover)
UNITS	DOMINANT PARTICLE BY PERCENT AREA OR SIZE WHERE AREAS ARE EQUAL	MODIFIED WENTWORTH SCALE (mm)
1	Fines & sand	0-2
2	Gravel	2-75
3	Cobble	75-300
4	Boulder	>300
5	Bedrock	Slabs

B. Interpreting *SI* Curves

It is important to understand that the availability to fish of velocity, depth, cover and substrate types, will be influenced by the changing nature of the stream along its profile. Figures 7.15a-f show the combined habitat availability curves typical for the FHZ and LZ, and what we have termed "bias" curves or bars. Bias curves or bars show the range of velocity, depth substrate or cover that was particular to the FHZ or LZ. These graphs differ from species availability curves and bars because each species had its own unique distributions within the catchment.

Figures 7.16-7.40 give SI curves for 18 target species from the Sabie-Sand system. In the graphs, utilization curves or bars refer to the relative number of individuals making use of any particular current velocity, depth, substrate or cover type. Values are presented as a suitability index scaled between (1.0) and (0.0). We referred to utilization of 0.8 and above as "most utilized" while a suitability above 0.6 was considered marginally "suitable".

However, utilization curves alone give a distorted picture of the species preferences, since, for example, more shallow water (<50 cm) was sampled than deeper water. To show where the greatest densities (as opposed to numbers caught) of a species were found, it was necessary to relate the numbers found at any velocity, depth, substrate or cover, to the relative availability of that type of habitat. The resultant combined curves or bars represent the species preference.

Preference curves are interpreted in a similar way to utilization curves. Utilization curves that closely mirror preference curves suggest that the range used was in fact that preferred. When these two curves differ markedly, this indicates that the species preferred range was limited in availability or infrequently sampled and its true preference is revealed.

An index combining both cover and substrate codes was used. Channel Index codes (CI codes) for substrate and cover are presented as histograms. CI codes used are similar to those used by King and Tharme (1994). The tens (10-50) encoded cover from no to high quality cover. The units 1-5 encode the substrate from fines, gravel/pebbles and cobbles through to boulders and bedrock. CI codes used are summarized in Table 7.9.

Not all cover and substrate code types are possible (for example, "no cover" is only possible where substrate comprises either fines, sand (1) or bedrock (5), since other sized substrates

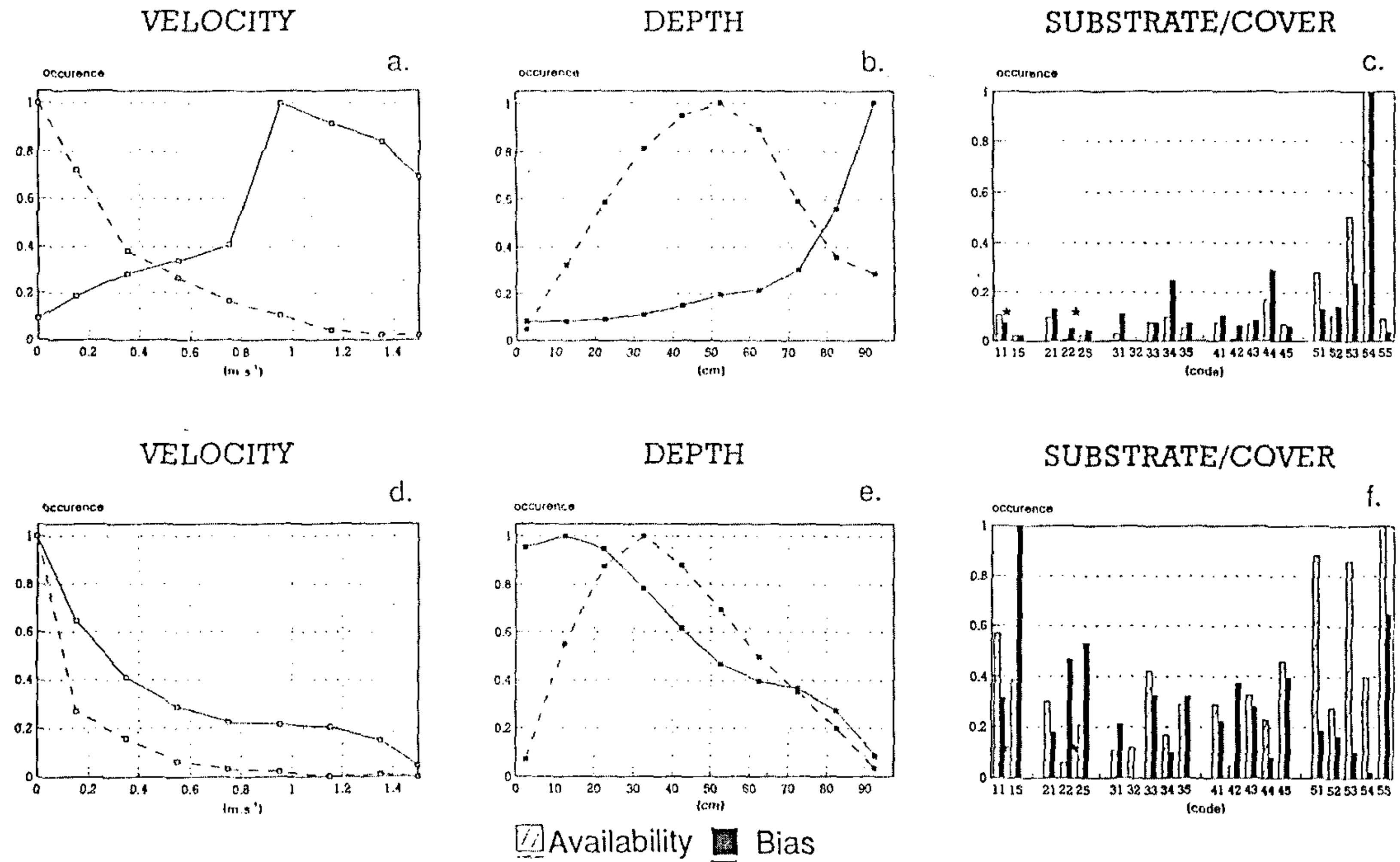

Figure 7.15: Availability and bias curves for velocity and depth as well as substrate/cover histograms for the Foot Hill Zone (FHZ) and Lowveld Zone (LZ) sites. In the FHZ, relatively higher flows were recorded (above 0.75 $m.s^{-1}$ (a), peaking at 0.95 $m.s^{-1}$). At LZ sites (d) slow to no-flow velocity predominated. Slightly deeper waters were sampled at FHZ sites (b) (52 cm) with a bias towards deeper waters (>90 cm) compared to LZ sites where there was a bias towards shallower waters (e) (<20 cm deep). Channel Index codes (CI) (section 7.6.2) for the FHZ (c) show that combined cover predominated with boulder in flow the most commonly available substrate/cover type. All cover types were available at LZ sites (f), with combined velocity/visual cover relatively more common. Bedrock and sandy runs with marginal vegetation and cobble in flow were the most common substrate/cover types sampled in shallow waters. Compared to FHZ sites, there was a bias towards exposed and some sheltered bedrock.

by definition provide cover, so only 11 and 15 are possible). Those excluded are marked by an asterisk and include the substrates pebbles to boulders (units 2-4), with no cover (decimal 10) and cobble to boulder (units 3-4) with indirect visual or off stream cover (decimal 20).

Marginal vegetation, although not classified as a substrate type, was important as a microhabitat variable for many species. Its effects within CI code data are apparent when cover has been coded for over sand and bedrock (where no cover would be expected). Cover over both sand and bedrock was particularly common within the LZ sites (Fig. 7.15) and many species preferred this.

7.5.3 ECOLOGICAL PORTRAITS OF TARGET SPECIES

The following section profiles the 18 target species. Included are aspects of their distribution, abundance and microhabitat requierments. Points relating to the management of each species are also discussed.

Barbus annectens

(broadstriped barb) Figure 7.16

GENERAL DISTRIBUTION

A small minnow species of the lowveld east coast rivers stretching from the Zambezi to the Mkuzi in northern Natal (Skelton, 1993). Gaigher (1969) reports it absent from the Olifants and Luvuvhu rivers within the KNP while Russell and Rogers (1989) suggested that it is now also absent from the lower Letaba and Crocodile rivers.

WITHIN THE SABIE-SAND SYSTEM

■ **Distribution:** *B. annectens* is a warm water species, only found in the lowveld waters. It was recorded throughout the Incomati system as far as the lower Incomati River to the coastal plains (Gaigher, 1969) (appendix. III). Within the Sabie and Sand rivers, fish were found only below 320 mASL (site 7) and 538 mASL (site 11) respectively.

■ **Abundance:** As with other minnows species (Fig. 7.13), they were relatively more numerous in the lower order Sand sub-catchment streams, occurring seasonally and sometimes sporadically in the Sabie collection. Typically they make up 9% of the LZ catch (Fig. 7.8a). *B. annectens* abundance is seasonal, peaking at the height of the wet season, when it is one of the most numerous fish in the lowveld (18% in February) during non-drought years. The seemingly anomalous high of 15% in August, the height of the dry season, is probably explained by increasing CPUE's as fish become concentrated and deeper pools become fishable.

MICROHABITAT NEEDS

Number of records: juveniles 48, adults 16

Number of individuals: juveniles 97, adults 20

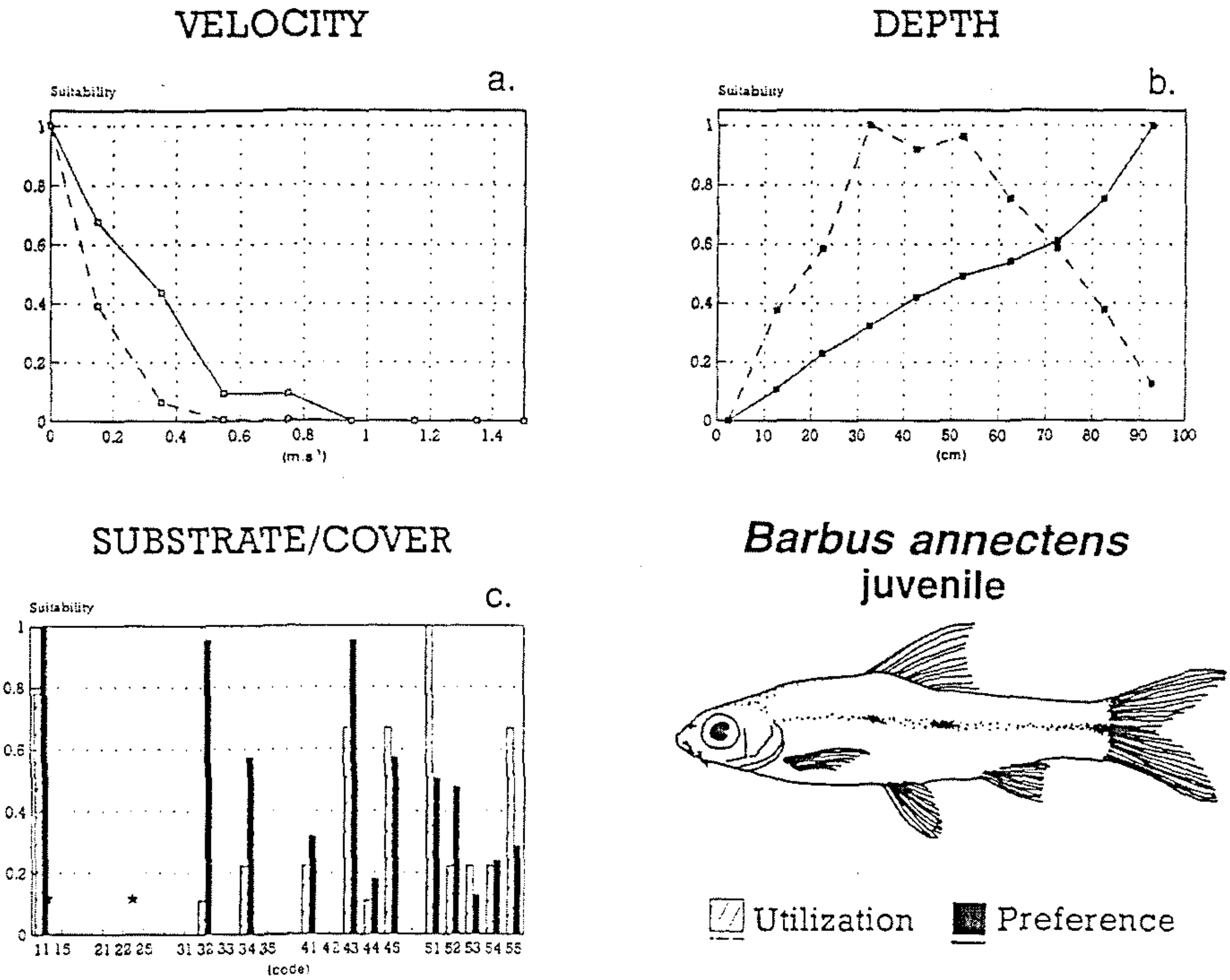

Figure 7.16: Utilization and preference curves for velocity and depth, as well as substrate/cover histograms for *Barbus annectens* juveniles. Juveniles preferred quiet waters (zero flow) mostly below 0.1 $m.s^{-1}$ (0.8 suitability) (a). They preferred deep waters in pools (b) not generally accessible to electrofishing (>80 cm deep). *Barbus annectens* was often found taking cover from flow in marginal vegetation or in quiet waters in cobble or in deep pools with no cover bar depth. They preferred quiet deep pools with soft substrates or cobble (c) or if with flow, a pebble substrate. * = excluded substrate codes not possible within cover type.

Juveniles
Preferred velocity : <0.1 m.s^{-1}
Preferred depth : >80 cm
Preferred substrate: fines, pebble to cobble
Preferred cover : simply depth, visual or velocity cover

B.annectens, together with an associated minnow *B.radiatus*, share a preference for relatively deep pools and quiet waters as preferred by cichlid species (Table 7.10). Skelton (1993) reported that juveniles were often found in marginal vegetation surrounding pools, but they also favoured quiet waters in deep pools with soft-substrate bottoms, where only depth or cobble offer some visual cover (Fig. 7.15c). In marginal flowing waters, like other minnows, they enjoyed gravel/pebbles, a limited substrate type. Preferences identified (Fig. 7.15b) are supported the selection of drought refuge pools by depth, volume and turbidity seen (Vol II Table 9).

Both juveniles and adults probably enjoy similar microhabitat types. *B.annectens*' choice of quiet, deep waters often over fine substrates, probably explains why this minnow, together with *B.radiatus*, penetrates onto the coastal plain and lower Incomati River where other LZ minnows are scare.

MANAGEMENT CONSIDERATIONS

B.annectens is an important element of the small species assemblage in the LZ, second only to *B.viviparus*. Interpreting CPUE for *B.annectens* is particularly complicated, because patterns of abundance are influenced by local movements and by their tendency to aggregate. Because like *B.radiatus*, they prefer the deepest of pools, (May and August, Fig. 7.8b-c), their relative abundance during the dry season may be artificially high due to the greater accessability of their habitat to electrofishing. With this in mind, the influence of the failed wet season of 1992 may be masked, explaining the rise in their relative abundance (2-6%, Table 7.7).

For reasons still unclear, *B.annectens* was not recorded in two of the lowveld rivers within the KNP (Gaigher,1969) and was possibly lost from the lower reaches of two more rivers since (Russell & Rogers, 1989). This suggests sensitivity. *B.annectens* isolated in refuge pools for five months (within the Sand River) persisted well, but as with most fish populations, they suffered extensive reduction (Table 3, Vol II).

B.annectens breeds in summer, responding to flushing flows. Although drought-affected individuals still surviving in October 1992 were very emaciated, they were able to attain breeding condition within a month following the first rains. By May 1993, *B.annectens* numbers appeared to have recovered and numbers were slightly higher than those recorded pre-drought in May 1991. This suggests that B.annectens is resilient, possibly persisting in the deepest of pools in large numbers.

Barbus eutaenia

(orangefin barb) Figures 7.17 & 7.18

GENERAL DISTRIBUTION

B.eutaenia is a small sawfin barb typical of clear flowing streams. They are distributed widely in Africa from the Zaire system to the Okavango River and somewhat patchily in lower order streams of the east coast to the Incomati system (Skelton, 1993). Adults in particular tend to aggregate.

WITHIN THE SABIE-SAND SYSTEM

- **Distribution:** In the Incomati system *B.eutaenia* is eurythermal (Table 7.2 & 7.3) and was confined to the lower foothills of the Sabie-Sand and Crocodile rivers (Gaigher, 1969) (appendix III). In the Sabie and Sand sub-catchments, they were found below 619 mASL (site 4 & site 21) and 745 mASL (site 10) respectively.

- **Abundance:** *B.eutaenia* was an important component of the FHZ assemblage typically making up 4% of the catch (Fig. 7.1a). In the Sabie-Sand rivers they were most numerous in the cool clear waters between the FHZ and LZ with only isolated specimens collected well below site 6 (402 mASL) on the Sabie and sites 12 (458 mASL) and 19 (499 mASL) in the Sand sub-catchment. *B.eutaenia* is characteristic of the less seasonal FHZ where their relative numbers did not fluctuate markedly - only a slight reduction occurred prior to the start of the summer season, before they breed (Fig. 7.7c).

MICROHABITAT NEEDS

Number of records: juveniles 64, adults 58

Number of individuals: juveniles 105, adults 69

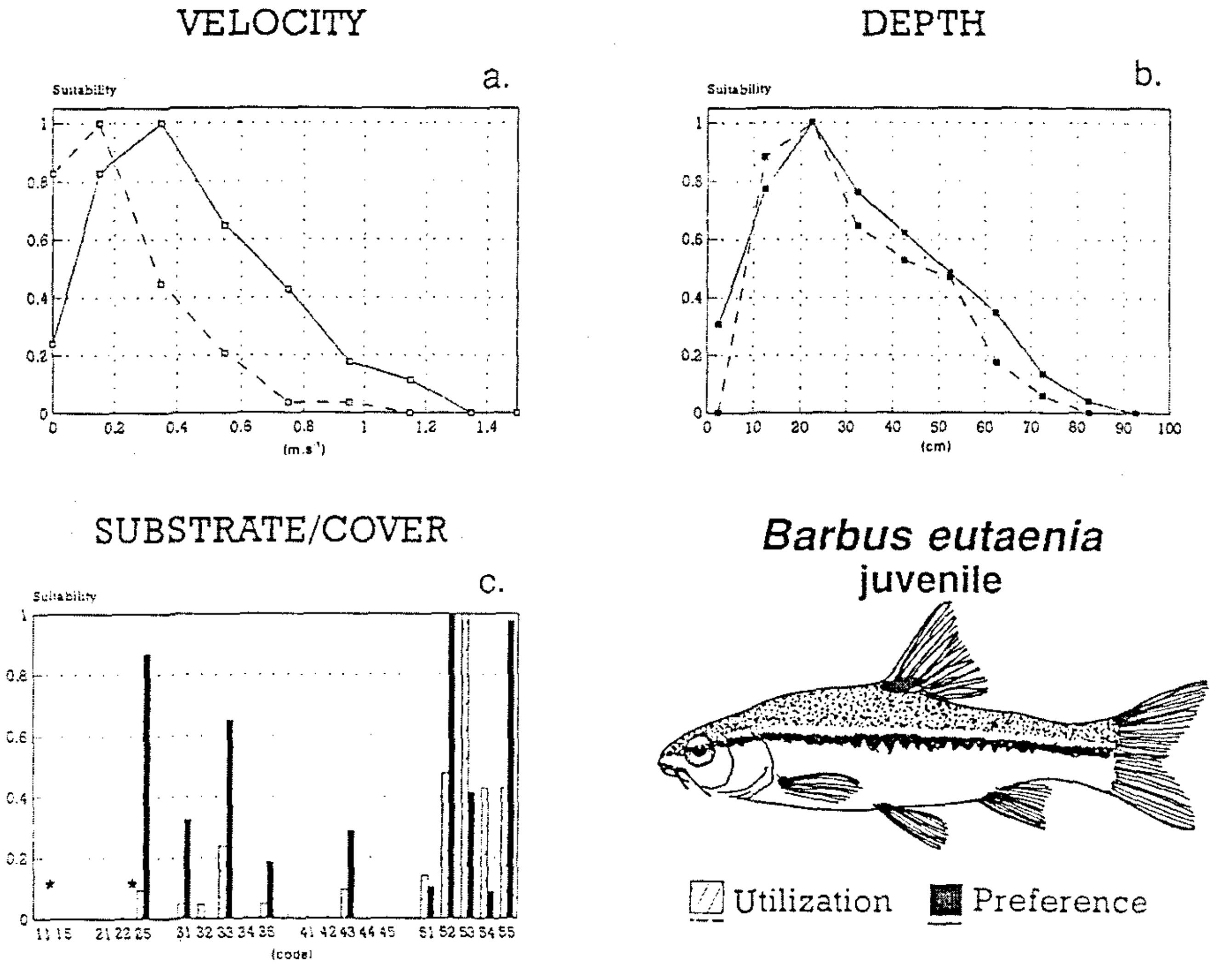

Figure 7.17: Utilization and preference curves for velocity and depth, as well as substrate/cover histograms for *Barbus eutaenia* juveniles. Most juveniles were found in flows between 0.1 & 0.5 $m.s^{-1}$ (a) and in shallow water (22 cm) (b). Juveniles preferred combined velocity and visual cover although some shade cover was used (c). Preferred substrates ranged from pebble & cobble to vegetation over bedrock. * = excluded substrate codes not possible within cover type.

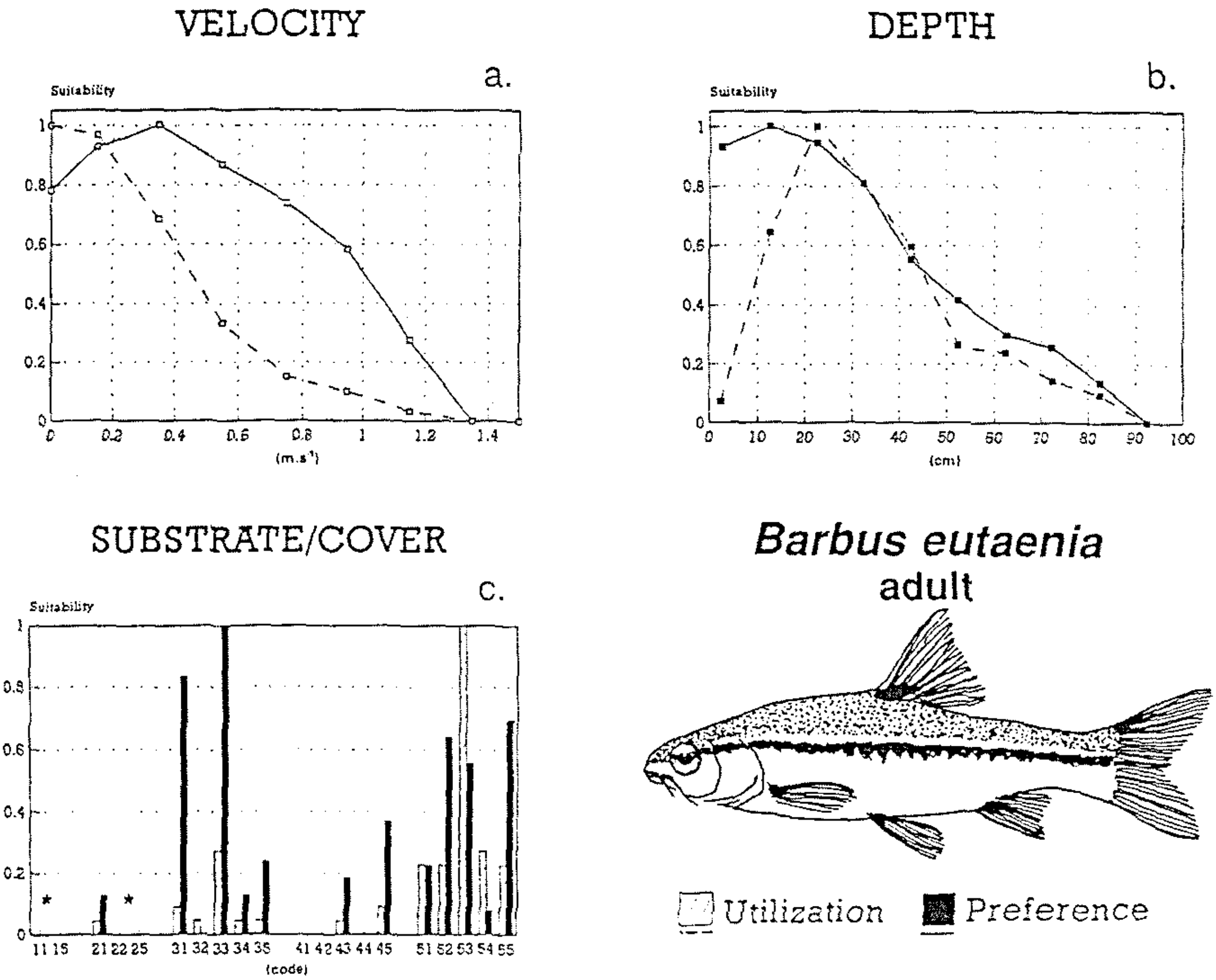

Figure 7.18: Utilization and preference curves for velocity and depth, as well as substrate/cover histograms for *Barbus eutaenia* adults. Like juveniles, adults preferred a flow (a) of 0.35 $m.s^{-1}$ and were mostly in flows < 0.7 $m.s^{-1}$. They preferred shallow waters (12 cm) (b). Adults preferred velocity shelter but some combined cover was used (c). Substrates utilized were mostly cobble but cobble and vegetation and some gravel were preferred to other cover. * = excluded substrate codes not possible within cover type.

Juveniles
Preferred velocity : 0.1-0.5 $m.s^{-1}$
Preferred depth : 15-30 cm
Preferred substrate: roots and pebble
Preferred cover : shade and combined velocity-visual shelter

Adults
Preferred velocity : 0-0.6 $m.s^{-1}$
Preferred depth : 10-35 cm
Preferred substrate: roots and cobble
Preferred cover : velocity shelter

Both juvenile (Fig. 7.16) and adult (Fig. 7.17) *B.eutaenia* were found in runs, preferring flows of 0.35 $m.s^{-1}$. They typically used combined velocity and visual cover in cobble. Both juveniles and adults showed preference for combined cover in marginal vegetation and root mats. Juveniles also enjoyed cover in pebble substrates while adults preferred cobble.

Preferred depths were rather shallow for a species found in runs (Table 7.11) possibly because of their choice of marginal cover. Adults preferred marginally shallower waters but juveniles and adults had similar microhabitat needs.

MANAGEMENT CONSIDERATIONS

B.eutaenia was of minor importance in the Sabie and Sand Rivers with a distribution limited to the lower FHZ largely west of the KNP. Their preference for velocity shelter in slow runs which often includes cobble, pebble and root mats and may explain their distribution in the lower order streams of the system where these microhabitat variables are more prevalent (Fig. 7.15).

B.eutaenia is confined to the less seasonal FHZ waters. As expected, their numbers did not fluctuate seasonally, but surprisingly, their numbers increased slightly with the passage of the drought. (Fig. 7.11, Table 7.6). It appears that the warmer but still perennial and clear flows were more favourable than typical conditions in the catchment, where their distribution is normally limited. By May 1993 following a normal rain season, *B.eutaenia* numbers remained at above pre-drought percentages. This suggests that although apparently tolerant, *B.eutaenia* is limited here at the southern edge of its distribution.

Definite microhabitat preferences include moderate flows, rocky substrate and cover, while both the clarity and water temperature were arguably important. *B.eutaenia*'s distribution largely coincided with the region where most of the potential dam developments are planned, the FHZ-LZ interface.

Barbus marequensis

(largescaled yellowfish) Figure 7.19

GENERAL DISTRIBUTION

A medium sized cyprinid species widespread from the Middle Zambezi to the Phongolo River in the south (Skelton, 1993). It is eurythermal (Table 7.2 & 7.3), typically associated with rocky runs and deep pools (Gaigher, 1973).

WITHIN THE SABIE-SAND SYSTEM

- **Distribution:** It is present in all the main tributaries above the Incomati River (appendix III), in both FHZ and LZ reaches, but absent from the lower coastal plains. *B.marequensis* occurred in the Sabie River from site 5 (488 mASL) to the Mozambique border (site 20: 140 mASL) and throughout the cool Marite River. Within the Sand subcatchment, It is found from the cool site 10 (745 mASL) to the confluence with the Sabie River (Table 7.2-7.3).

- **Abundance:** *B.marequensis* is an important component of the foothill (6% of the catch, Fig. 7.7a) and lowveld zones but was relatively more abundant in the upper LZ (10% of the catch, Fig. 7.8a). Like many cyprinids, abundance decreased with distance downstream. Abundances in the LZ shows seasonal effects, decreasing from 19% at the start of the dry season (May) to 3% by the hight of the wet season (February). In the more stable FHZ seasonal changes do not appear as marked although lowest catches do occur during the wet season (1% in February). Low wet season catches probably reflect a dilution of animals present as habitat availability increases.

MICROHABITAT NEEDS

Number of records: juveniles 317

Number of individuals: juveniles 205

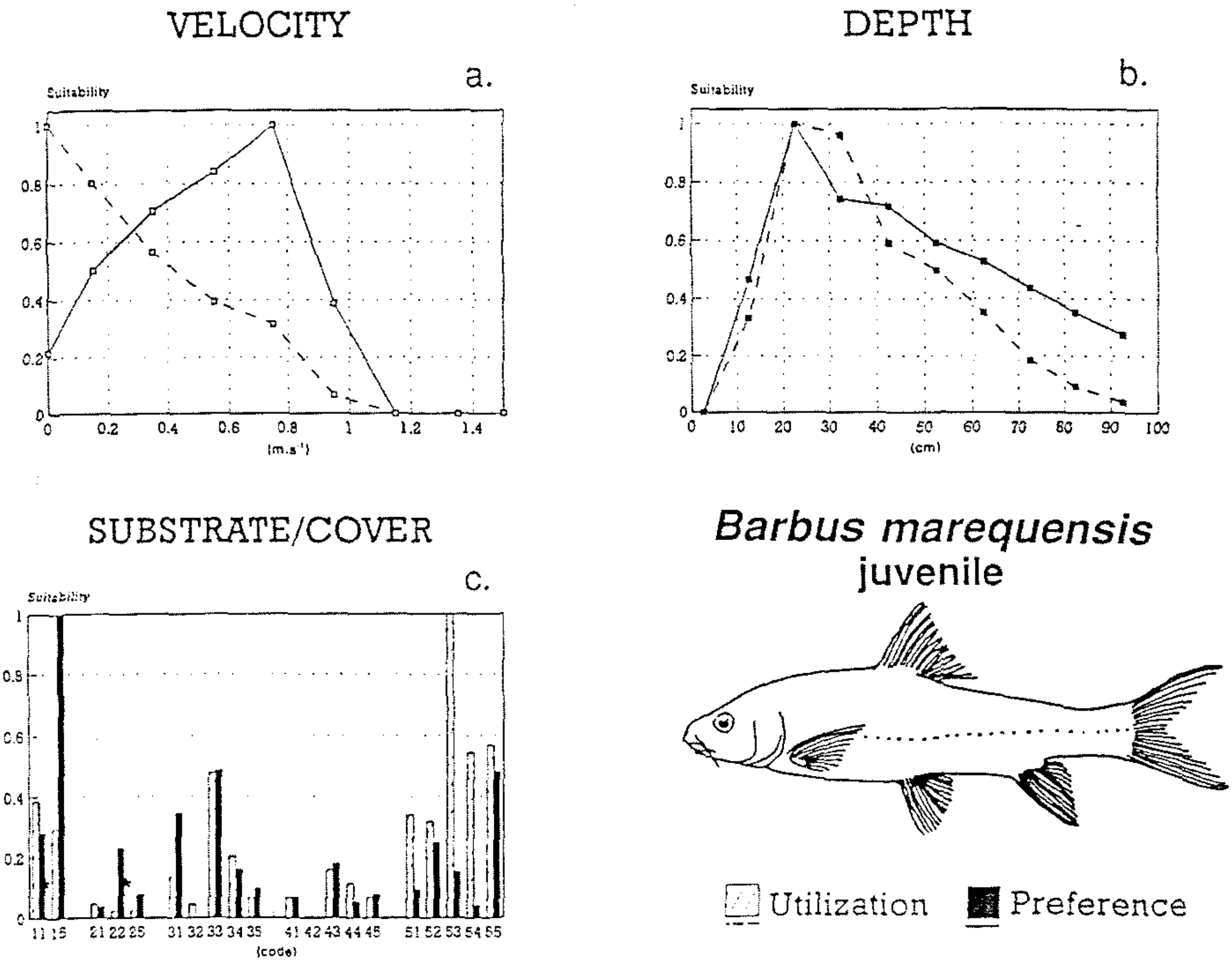

Figure 7.19: Utilization and preference curves for velocity and depth, as well as substrate/cover histograms for *Barbus marequensis* juveniles. Juveniles preferred moderately high flows (a) of 0.75 m.s^{-1} in rapids and shallow waters (22 cm) (b). They utilized a variety of cover and substrates types (c) particularly cobble in flow, but preferred open bedrock runs. * = excluded substrate codes not possible within cover type.

Juveniles
Preferred velocity : 0.5-0.8 $m.s^{-1}$
Preferred depth : 20-30 cm
Preferred substrate: bedrock
Preferred cover : none

Juveniles occupied riffle and run reaches in shallow waters (22 cm), where flows of 0.75 $m.s^{-1}$ were most preferred (Fig. 7.19). They most frequently utilized combined cover, especially over cobble. While *B.marequensis* used all substrate types, exposed bedrock was a preferred substrate type.

Adults were gill netted in deep pools, in waters often too deep to electrofish where their microhabitat requirements could be expected to be different to juveniles.

MANAGEMENT CONSIDERATIONS

Although *B.marequensis* was so widely distributed, these fish were typical of the upper LZ where juveniles were confined to riffle and run reaches over rocky substrates. Their relative abundance in the FHZ assemblage remained static, while their relative CPUE in the LZ appeared to have increased by the dry season.

Like most summer breeding species, *B.marequensis* populations were influenced by the drought. At lowveld sites, where many stations ceased flowing, percentage catches of *B.marequensis* were relatively lower. At Londolozi, *B.marequensis* isolated in small pools during the extremely dry winter, did not survive as well as smaller lowveld species (Table 3, Vol II). In the FHZ where flows were reduced but perennial, this species actually increased in relative numbers. The flow needs of *B.marequensis* juveniles were probably less important here than the higher water temperatures recorded - minimum water temperatures were 0.9-1.8°C higher (Table 5.8) at FHZ transitional sites (sites 5 and 21; July-August 1991). There is the possibility that some local movement of fish from the LZ to the FHZ waters occured. By May 1993 CPUEs recorded in the FHZ were reduced to pre-drought levels while those in the LZ were only starting to recover.

Barbus polylepis

(smallscaled yellowfish) Figure 7.20

GENERAL DISTRIBUTION

A medium sized cyprinid restricted to the southern tributaries of the Limpopo and Incomati rivers in the Transvaal (Skelton, 1993). This is a cool water species which Gaigher (1973) describes as an inhabitant of pools and riffles.

WITHIN THE SABIE-SAND SYSTEM

- **Distribution:** Within the Incomati system *B.polylepis* was restricted to the cold headwater streams of the Sabie, Crocodile and Komati Rivers. In the Sabie River it was only collected at site 5 (499 mASL) and below 620 mASL (site 21) on the Marite River.

- **Abundance:** *B.polylepis* was the third most numerous species within the FHZ assemblage, making up 7% of the catch (Fig. 7.7a) and was the only common FHZ species that appeared to fluctuate in numbers seasonally. *B.polylepis* juveniles were most abundant following the wet season (May = 22%), declining to very low numbers (<1%) at the start of the wet season in November.

MICROHABITAT NEEDS

Number of records: juveniles 29

Number of individuals: 56

Juveniles
Preferred velocity : >0-0.2 $m.s^{-1}$
Preferred depth : 65-80 cm
Preferred substrate: marginal vegetation
Preferred cover : visual

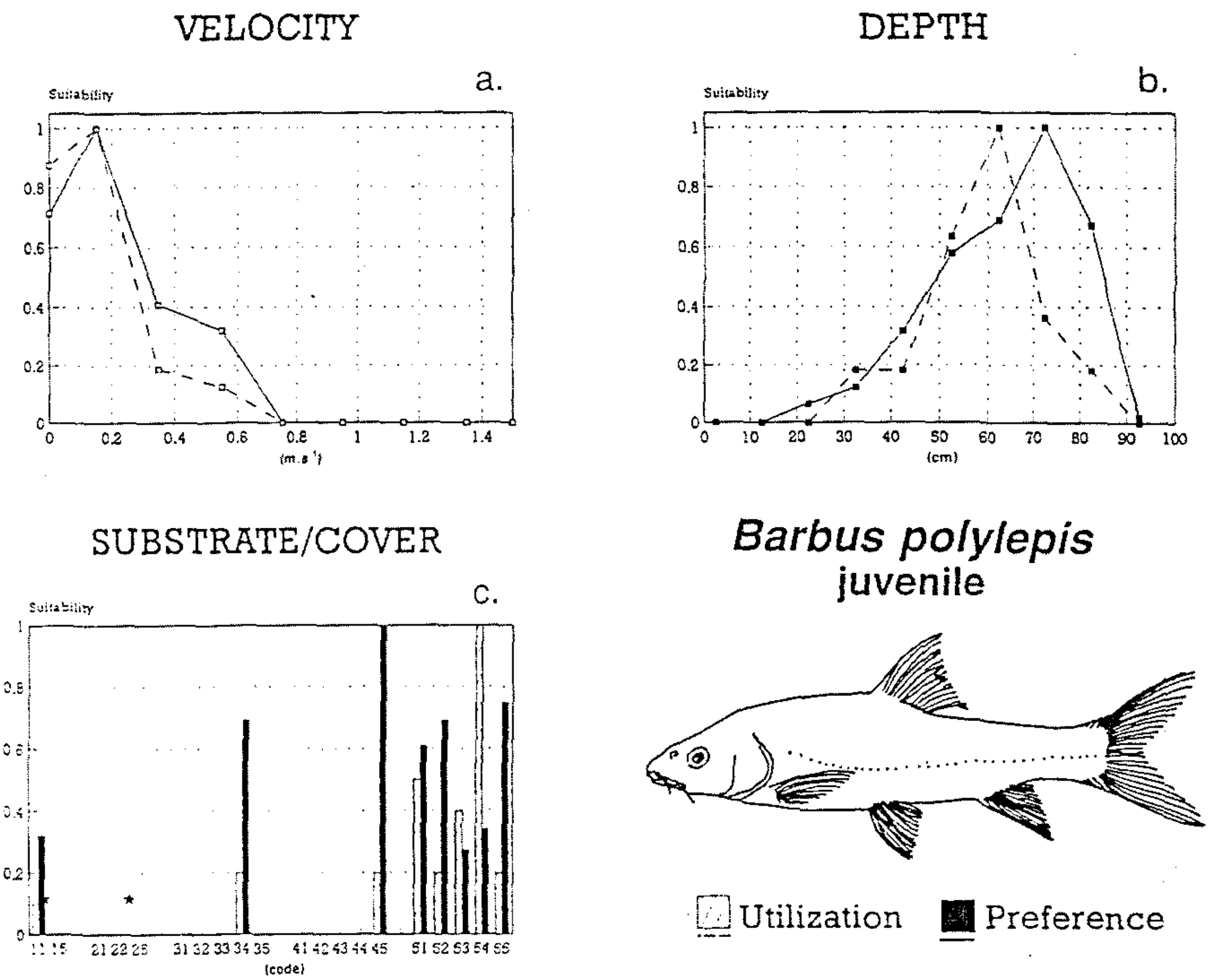

Figure 7.20: Utilization and preference curves for velocity and depth, as well as substrate/cover histograms for *Barbus polylepis* juveniles. Juveniles most preferred sluggish flows (a) (0.15 $m.s^{-1}$) and relatively deeper waters (72 cm) (b). Although most utilized boulders in currant (c), they preferred roots mats both marginal to (visual instream cover) and *in flow (combined cover). * = excluded substrate codes not possible within cover type.*

B.polylepis juveniles (Fig. 7.20) were typically fish of runs preferring sluggish flows of >0-0.12 $m.s^{-1}$ and relatively deeper waters (Table 7.11). Although most utilized boulders in current, they preferred the cover of vegetation both as instream visual cover alone or in flow as combined cover.

MANAGEMENT CONSIDERATIONS

B.polylepis has a restricted distribution in the Sabie and Marite rivers and so is of interest only within the lower FHZ. *B.polylepis* may not be tolerant of reduced summer flows in its limited Sabie River range. Unlike other FHZ species, the relative abundance of *B.polylepis* juveniles fluctuated seasonally which should suggest resilience to changing environments. Unlike *B.marequensis*, that was able to utilize FHZ drought flows to spawn in season, *B.polylepis* juveniles decreased (22 to 15% relative catch) through the drought year and still further by 1993 when other species were showing recovery (Fig. 7.11). The significance of this is not known but may suggest a reduction of suitable adult refuges. One possibility is that the warming of these waters during the drought may have restricted adult habitat still further.

Barbus radiatus

(Beira barb) Figure 7.21

GENERAL DISTRIBUTION

A small minnow species widespread in Africa from Uganda southwards to the Phongolo system (Skelton, 1993) and in all the major rivers of the KNP besides the Levuvhu River (Gaigher, 1969). It is known as a fish of quiet waters, often in vegetation, and active at night (Skelton, 1993).

WITHIN THE SABIE-SAND SYSTEM

- **Distribution:** *B.radiatus* is found in the Komati and its three main tributaries. They are found on the coastal plain together with *B.annectens* where few other minnows are (appendix III). *B.radiatus* is a warm water species occurring at and downstream of site 7 (320 mASL) on the Sabie and site 11 (538 mASL) in the Sand rivers (Table 7.2 & 7.4).

- **Abundance:** *B.radiatus* was the least numerous within an assemblage of five common minnow species within the Sabie-Sand lowveld (5%, Fig. 7.8) but was particularly common in the now annual Sand River. The relative abundance of *B.radiatus* was arguably seasonal with a recovery by the height of the wet season (9% in February) from low numbers at the start of it (<1% in November).

MICROHABITAT NEEDS

Number of records: all 33

Number of individuals: all 55

All
Preferred velocity : 0 m.s^{-1}
Preferred depth : >90 cm
Preferred substrate: marginal vegetation/bedrock
Preferred cover : visual cover

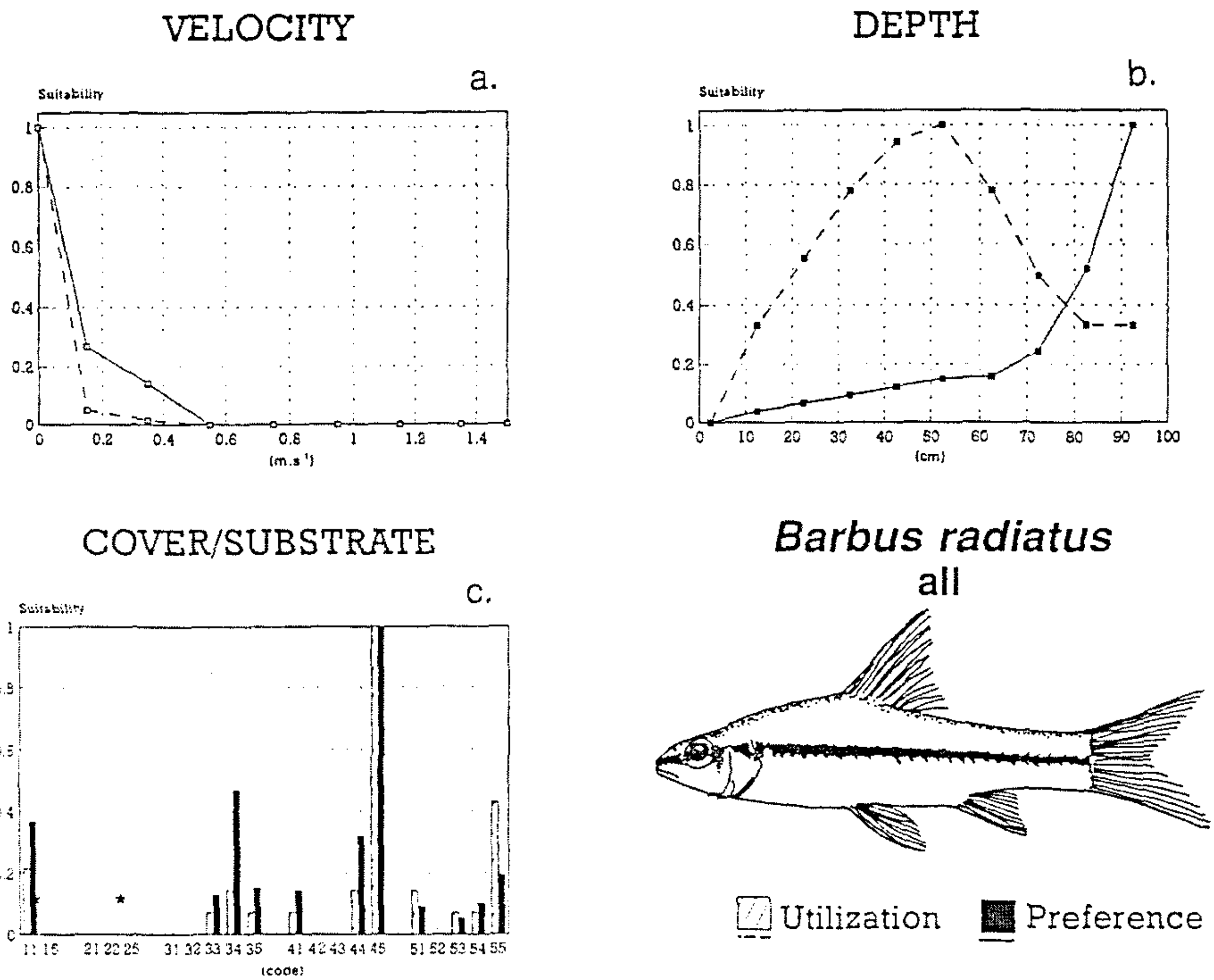

Figure 7.21: Utilization and preference curves for velocity and depth, as well as substrate/cover histograms for *Barbus radiatus*. Fish collected preferred zero flow (a) almost exclusively as well as the deepest waters sampled (> 90 cm) (b). They utilized and preferred marginal vegetation in bedrock pools (c). * = excluded substrate codes not possible within cover type.

B.radiatus is one of only two common non-cichlid species preferring still waters, mostly avoiding any flow (Table 7.10). Like Gaigher, (1973) we found that they preferred deep pools at depths that were limited in this survey, and that were deeper than those preferred by cichlid still water species (Table 7.11). They utilized and preferred marginal vegetation for cover, often in bedrock reaches of the system, particularly in the now annual Sand River at Londolozi where their numbers increased with depth (Table 9, Vol II).

MANAGEMENT CONSIDERATIONS

B.radiatus is typical of the warmer seasonal lowveld rivers and floodplain where populations would be expected to be resilient (Lowe-McConnell, 1979). Although *B.radiatus* numbers may fluctuate seasonally, it is difficult to be sure from this survey, since decreases would have been masked by increased concentration in pools, and greater accessability to their habitat during the drought. At Londolozi *B.radiatus* was associated with the deeper drought pools where they persisted in ever decreasing numbers. They survived in pools for four of five months of extreme drought in very poor conditions (Table 3, Vol II).

Following the drought, relative numbers of *B.radiatus* in the LZ were comparable to pre-drought years suggesting that they not only survived but recovered relatively quickly.

Barbus trimaculatus

(threespot barb) Figures 7.22 & 7.23

GENERAL DISTRIBUTION

B.trimaculatus is a common and hardy, small summer breeding minnow found from southern Uganda to the Umvoti in Natal (Skelton, 1993). It occurs in all the major tributaries of the KNP rivers west of the Lebombo mountains (Gaigher, 1969).

WITHIN THE SABIE-SAND SYSTEM

- **Distribution:** *B.trimaculatus* is a warm water species. Within the Incomati system, *B.trimaculatus* is commonly found in all the reaches of the Incomati and its tributaries within the LZ. They do not extend onto the coastal plain (Gaigher, 1969) (appendix III).
- **Abundance:** *B.trimaculatus* was commonly found at all lowveld sites within the Sabie and Sand rivers particularly within the Sand sub-catchment. Their abundance in the lowveld was typically seasonal with numbers lowest by the start of the wet season (2% in November) and highest by the wet season peak (10% in February) (Fig. 7.8).

MICROHABITAT NEEDS

Number of records: juveniles 49, adults 33

Number of individuals: juveniles 68, adults 41

Juveniles
Preferred velocity : 0-0.3 $m.s^{-1}$
Preferred depth : 60-90 cm
Preferred substrate: cobbles or boulder
Preferred cover : visual or velocity shelter

Adults
Preferred velocity : >0-0.2 $m.s^{-1}$
Preferred depth : 50-90 cm
Preferred substrate: boulders or marginal vegetation
Preferred cover : visual or velocity shelter

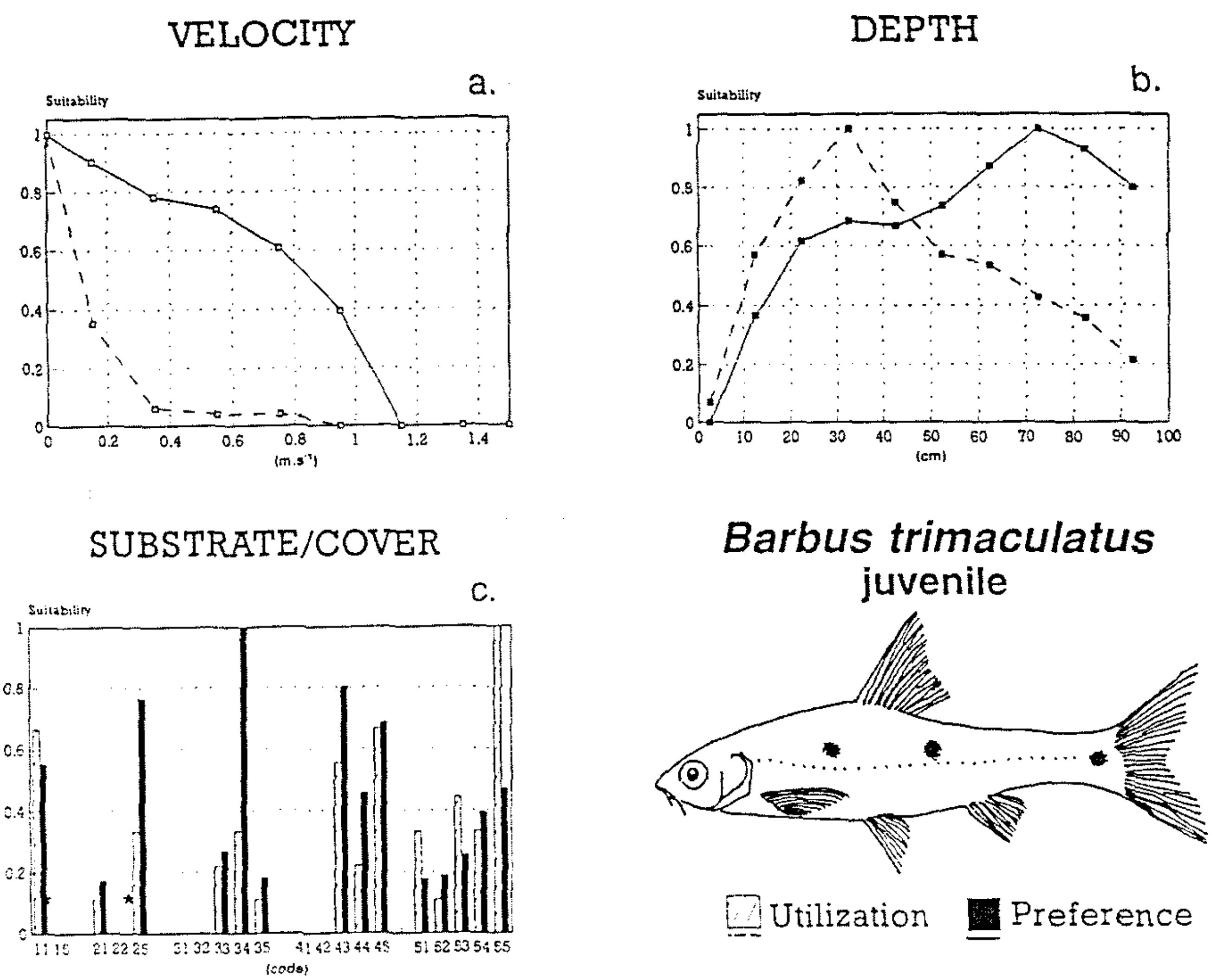

Figure 7.22: Utilization and preference curves for velocity and depth, as well as substrate/cover histograms for *Barbus trimaculatus* juveniles. Although juveniles preferred zero flow (a) and were mostly found below 0.3 $m.s^{-1}$, flows of 0.8 $m.s^{-1}$ were still suitable (0.6 suitability). Juveniles preferred deeper waters (72 cm) than generally sampled (b). Juveniles preferred instream velocity and visual cover (c) and some shade associated with boulder, cobble and vegetation. * = excluded substrate codes not possible within cover type.

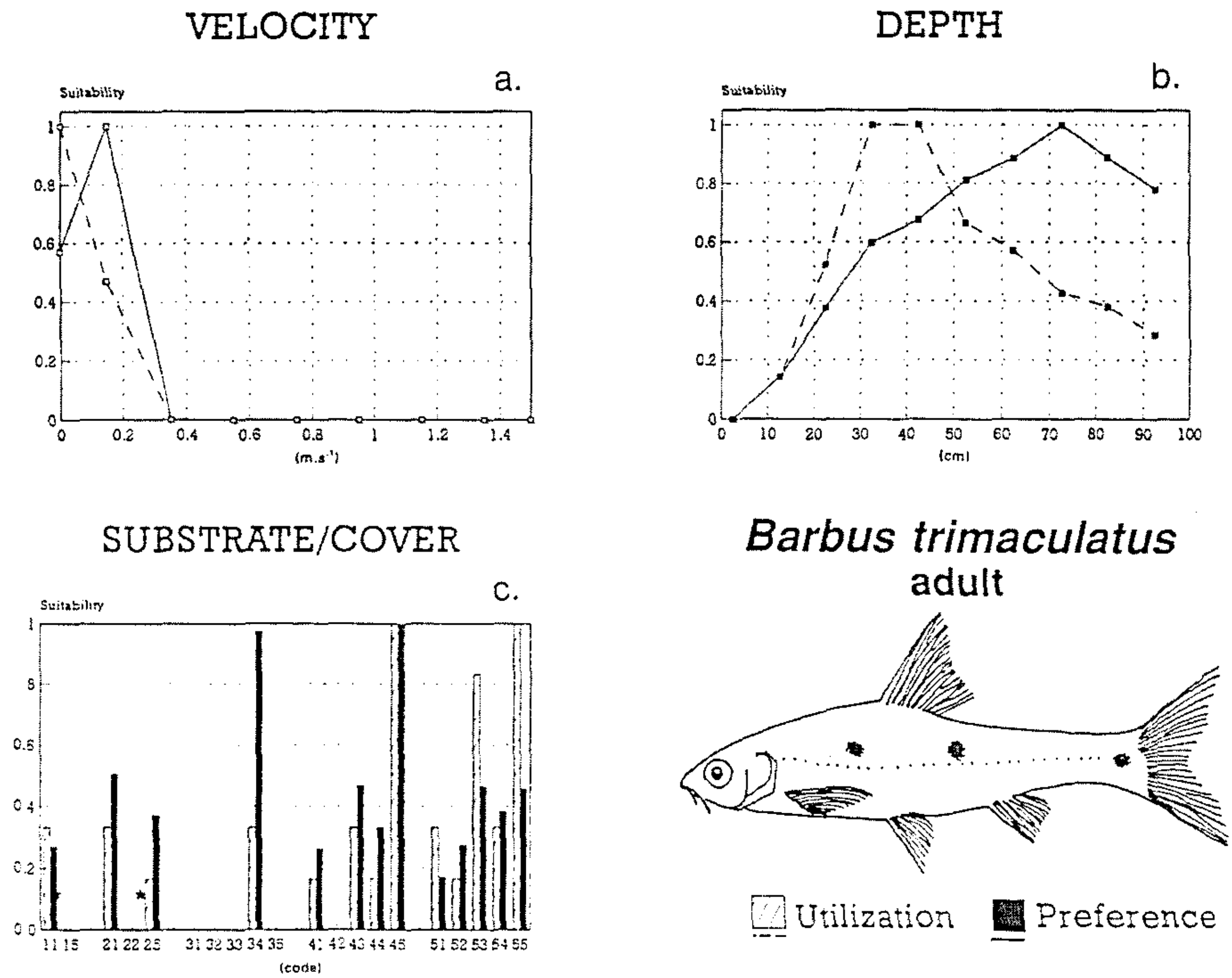

Figure 7.23: Utilization and preference curves for velocity and depth, as well as substrate/cover histograms for *Barbus trimaculatus* adults. Adults preferred marginal sluggish flows (a) of 0.15 $m.s^{-1}$, mostly below 0.2 $m.s^{-1}$. Like juveniles, they preferred deeper waters (b) than generally sampled (72 cm). Adults preferred marginal vegetation (visual instream cover) and boulders (c) in slow current (velocity instream cover) to all others although they utilized most substrate and cover types. * = excluded substrate codes not possible within cover type.

Both juveniles and adults had a preference for deep waters, but their flow preferences differed. *B.trimaculatus* juveniles preferred quiet waters in close proximity to flowing waters, (0.8 $m.s^{-1}$ was still suitable Table 7.10), whereas adults had a definite preference for sluggish runs (0.15 $m.s^{-1}$). Both juveniles and adults utilized a wide range of cover and substrate microhabitat types. Juveniles had some preference for instream velocity and shade cover, associated with boulder, cobble and vegetation while adults preferred marginal vegetation and boulders in sluggish flow. Preference for depth and cover is further supported by positive correlations between fish number and these factors within drought pool refuges at Londolozi (Table 9, Vol II).

MANAGEMENT CONSIDERATIONS

B.trimaculatus is typical of the warmer seasonal lowveld rivers and floodplain where populations would be expected to be resilient (Lowe-McConnell, 1979). Although it may have disappeared from the Luvuvhu River (Russell and Rogers, 1989), it is considered to be a highly tolerant species (Skelton, 1993), a trait supported by our research. Although numbers are definitely seasonal, populations were not unduly influenced by the drought. At Londolozi, *B.trimaculatus* survived all but the most severe conditions almost until the refuge pool dried out. Fry of *B.trimaculatus* were observed late in the season following the last flushing flow in May 1992. Following the drought, they were able to respond rapidly to the first rains of the season. By May 1993 the relative abundance of *B.trimaculatus* was indistinguishable from that of pre-drought years.

Barbus unitaeniatus

(longbeard barb) Figure 7.24

GENERAL DISTRIBUTION

This small minnow species is widespread in southern Africa, in many habitat types, from the Zambian Zaire system through to the Phongolo in Natal, but absent from the east coast lowlands (Skelton, 1993). Gaigher (1969) recorded it from all the lowveld rivers of the KNP bar the Luvuvhu where it had been seen prior to 1966.

WITHIN THE SABIE-SAND SYSTEM

- **Distribution:** *B.unitaeniatus* is a warm, but cold tolerant species within the Incomati and its tributaries. It is commonly found in a narrow band from the lower FHZ (site 5, 488 mASL) in the Sabie and Marite rivers (site 21, 620 mASL) to site 7 (320 mASL) and throughout the Sand River from site 11 (538 mASL) (Table 7.1-3).

- **Abundance:** *B.unitaeniatus* was one of five important minnow species within the LZ (Fig. 7.8) typically making up 5% of the catch. Like *B.radiatus*, their numbers were relatively stable with reductions over the dry season made up during the following wet season. Their numbers never exceeded 8% of the catch. *B.unitaeniatus* is relatively more abundant in the upper LZ, decreasing with increasing stream order. It is not found far beyond the Lebombo mountains (Gaigher, 1969).

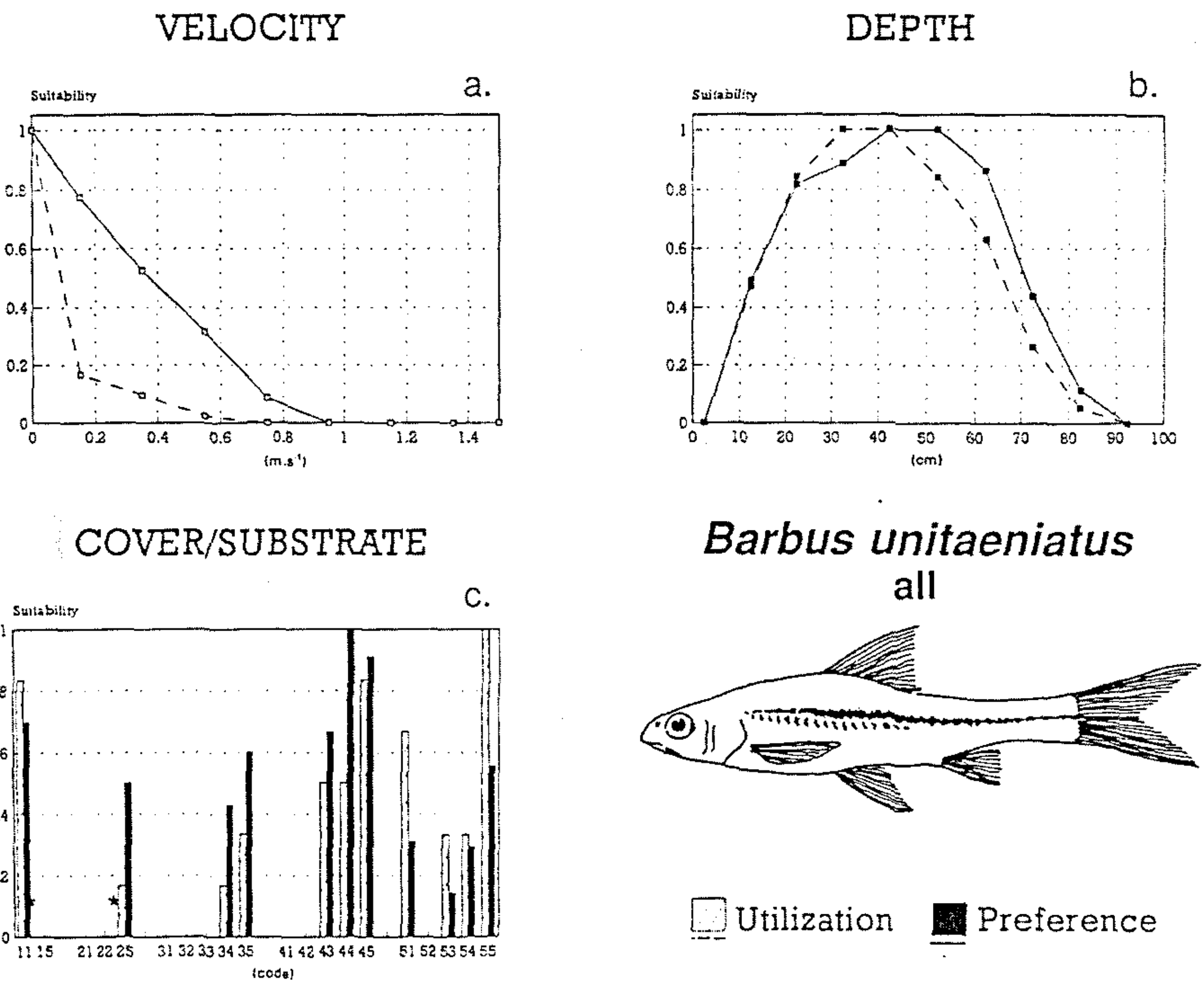

Figure 7.24: Utilization and preference curves for velocity and depth, as well as substrate/cover histograms for *Barbus unitaeniatus*. Fish collected preferred zero flow (a) although flows below 0.3 $m.s^{-1}$ were suitable. They preferred moderately shallow waters (48 cm) (b). They preferred instream visual cover associated with boulder, vegetation and cobble (c). Vegetation cover in bedrock and sand pools was often utilized as well as some soft bottomed coverless pools. * = excluded substrate codes not possible within cover type.

MICROHABITAT NEEDS

Number of records: all 33

Number of individuals: all 80

All
Preferred velocity : 0-0.2 $m.s^{-1}$
Preferred depth : 20-65 cm
Preferred substrate: boulder to marginal vegetation
Preferred cover : visual cover

B.unitaeniatus most preferred quiet waters of medium depths (45-55 cm) often in close proximity to flowing waters (0.3 $m.s^{-1}$ still 0.6 suitable). They were often sampled in deep pools and farm dams that were connected by flowing channels. They preferred visual cover associated with boulder, vegetation and cobble, to velocity cover, and, like *B.annectens*, utilized and preferred certain soft bottomed pools without structural cover.

MANAGEMENT CONSIDERATIONS

B.unitaeniatus is a fish of the upper LZ confined to the Sand River and a narrow band in the Sabie River and was never very common in any particular season. Numbers caught at some stations were further influenced by their tendency to local movements in shoals.

Although they appeared largely stable in numbers except during the worst of the dry season, they did show effects of the drought, suggesting some degree of sensitivity (see volume II). *B.unitaeniatus* was reduced from 7% of the catch pre-drought to 1% in the LZ after the failed wet season by May 1992 with the worst of the drought still to follow. By May 1993, after a normal wet season, their numbers had not recovered and remained at 2% of the catch. It is unclear why *B.unitaeniatus* may have been lost from the Luvuvhu and Olifants rivers within the KNP in recent years (Russell & Rogers, 1989).

Barbus viviparus

(bowstripe barb) Figures 7.25 & 7.26

GENERAL DISTRIBUTION

A small minnow species of the east coast rivers and lakes from northern Mozambique to the Vungu River in southern Natal (Skelton, 1993). Gaigher (1969) records it from all the main tributaries of the KNP

WITHIN THE SABIE-SAND SYSTEM

- **Distribution:** *B.viviparus* is a warm water species occurring in all the LZ tributaries of the Incomati system. In the Sabie River (Table 7.2) it is found from site 6 (402 mASL) to the Mozambique border at Mlondozi (site 20, 140 mASL). In the Sand River and its main tributary, the Mutlumuvi River (Table 7.4), it is found from site 11 and Site 25 (538 mASL & 660 mASL respectively). It is not found beyond the confluence of the Sabie and Komati Rivers or in the cooler Marite River (Gaigher, 1969).

- **Abundance:** *B.viviparus* is the most numerous small fish of the lowveld in the Sabie-Sand system. In years with normal seasonal flows, it made up 21% of the catch. Its numbers were highly seasonal, with the highest relative percentages recorded following the wet season (May) when fish were concentrated in the main stream (31%). Their numbers declined by half by the end of the dry season (14% in November). At the height of the wet season their numbers had just started to recover (16% in February).

Like other minnow species *B.viviparus* was more common in the lower order Sand River and its tributary the Mutlumuvi (Fig. 7.13). Here they were on average twice as abundant compared to comparable Sabie reaches. Within the Sabie River, a CPUE of 0.5 fish/min was attained in the middle LZ reaches, which was reduced towards the Mozambique border. The species is absent in the lower Incomati.

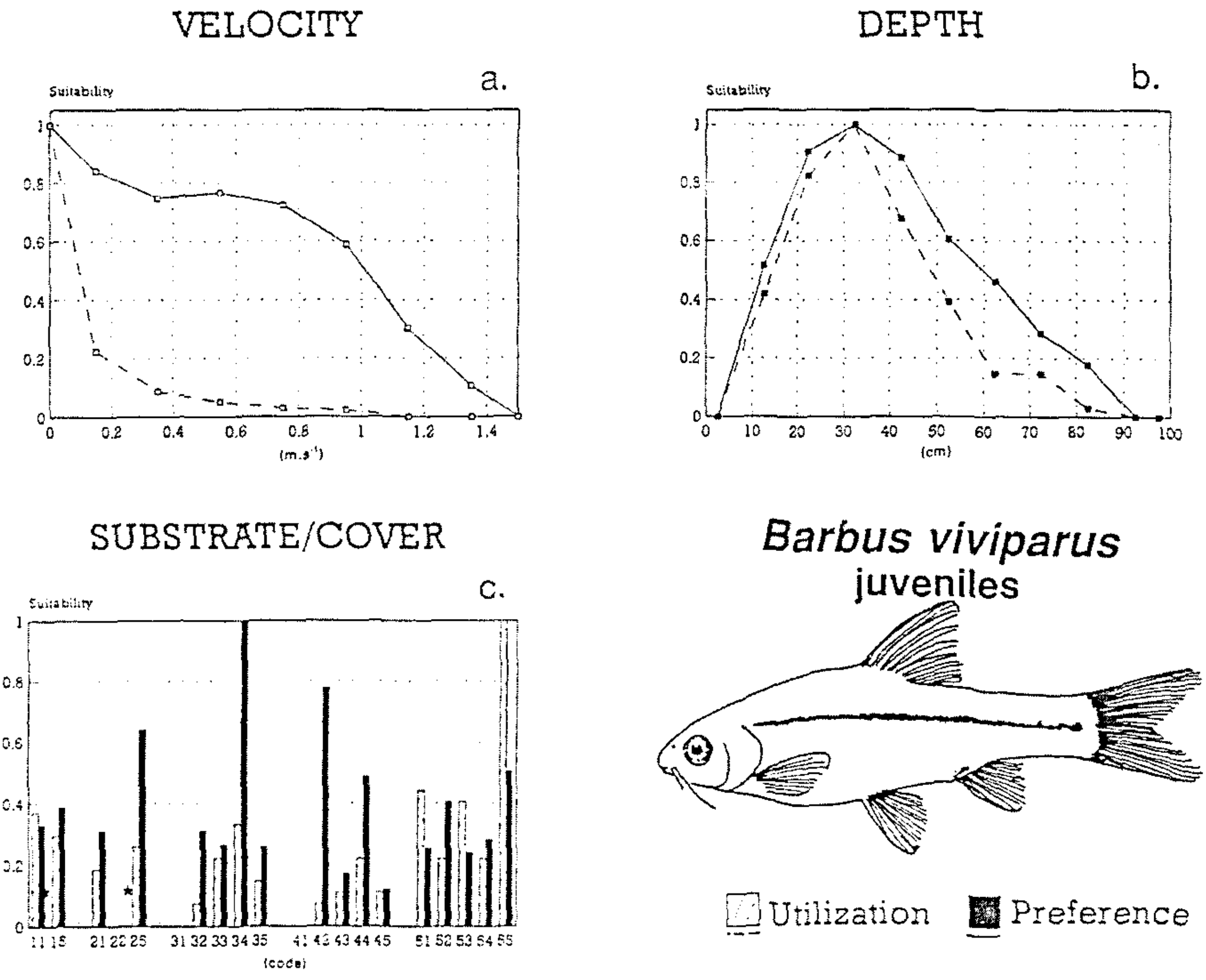

Figure 7.25: Utilization and preference curves for velocity and depth, as well as substrate/cover histograms for *Barbus viviparus* juveniles. Juveniles preferred quiet waters or cover adjacent to moderate flows mostly below 0.3 $m.s^{-1}$ with flows of 0.95 $m.s^{-1}$ still suitable) (a). Shallow waters were preferred (32 cm) (b). Although they utilized all cover and substrate types (c) particularly marginal vegetation, they preferred boulders in flow (instream velocity shelter), pebbles and shade. * = excluded substrate codes not possible within cover type.

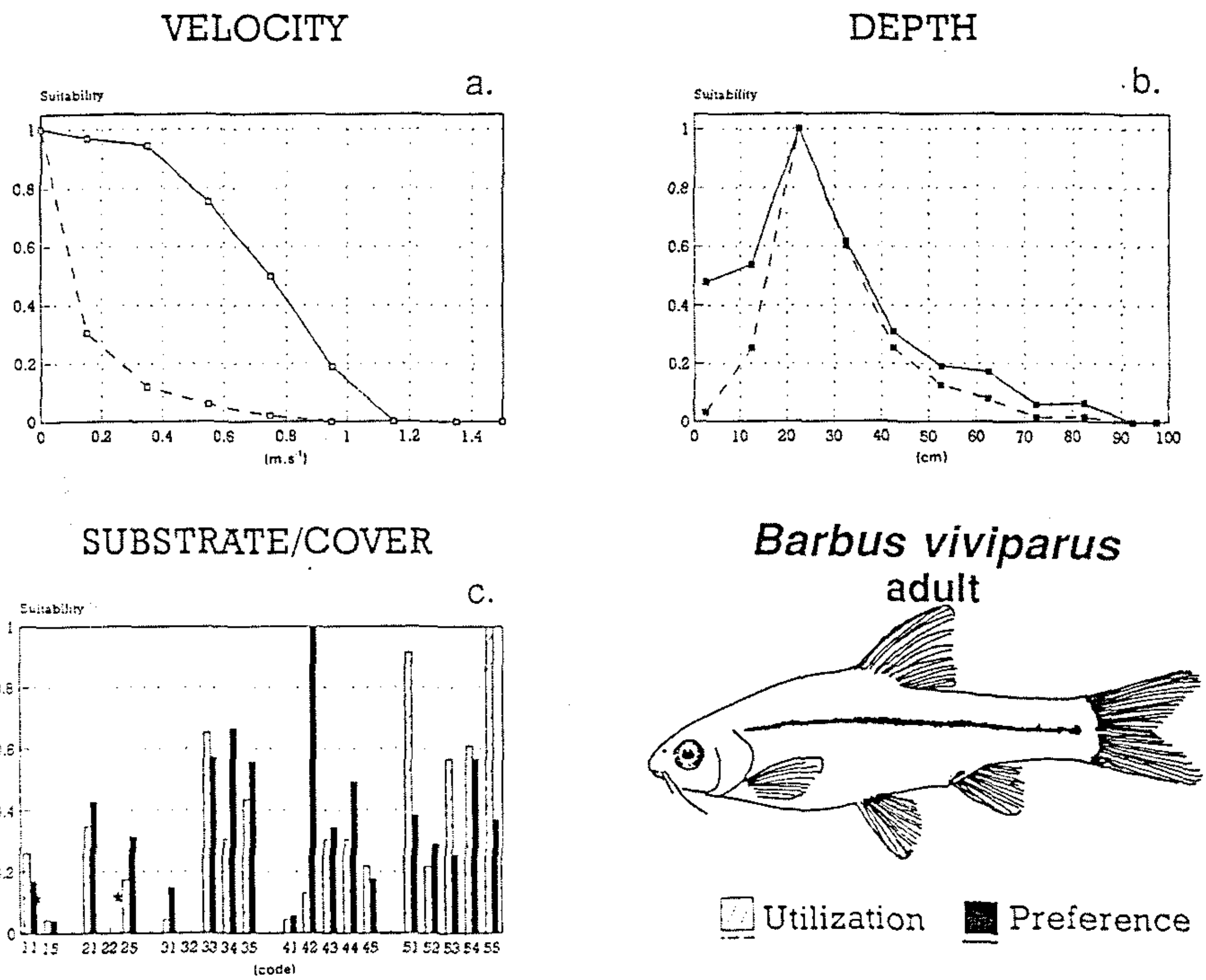

Figure 7.26: Utilization and preference curves for velocity and depth, as well as substrate/cover histograms for *Barbus viviparus* adults. Adults preferred quiet waters adjacent to flow mostly below 0.5 $m.s^{-1}$ but up to 0.7 $m.s^{-1}$ (a). They preferred shallow waters (22 cm) (b). This minnow utilizes all cover and substrate types (c), particularly marginal vegetation and cobble adjacent to flow. They showed preference for gravel and pebbles, a limited cover type. * = excluded substrate codes not possible within cover type.

MICROHABITAT NEEDS

Number of records: juveniles 127, adults 151

Number of individuals: juveniles, 194 adults 226

Juveniles
Preferred velocity : 0-0.2 $m.s^{-1}$
Preferred depth : 20-55 cm
Preferred substrate: boulder
Preferred cover : velocity shelter

Adults
Preferred velocity : 0-0.5 $m.s^{-1}$
Preferred depth : 20-30 cm
Preferred substrate: gravel/pebble
Preferred cover : visual cover

Without quantifying microhabitat variables, it is difficult to identify subtle difference in the extent of habitat use between often very similar species such as the minnows. Gaigher (1973) showed that *B.viviparus* was found as commonly in riffles as in pools. Our microhabitat data show that both juveniles and adults preferred quiet waters (zero flow) adjacent to flow (Table 7.10).

Juveniles were found in flows mostly less than 0.2 $m.s^{-1}$ while adults mostly preferred flows less than 0.5 $m.s^{-1}$. Our microhabitat curves broadly agree with those of Gore *et al.* (1992). We record marginally higher velocities and shallower depths (by 10 cm). Gore *et al.* (1992) limited their sampling to the river reaches within the KNP which did not include the preferred lower order stream habitat of *B.viviparus.*

Of the commonly occurring species of quiet waters adjacent to flow, *B.viviparus* was found in the shallowest of waters (Table 7.11), with adults preferring slightly shallower waters (22 cm deep) than juveniles (33 cm deep). Both juveniles and adults utilized a variety of substrate and cover types, particularly marginal vegetation (Fig. 7.25c & Fig. 7.26c), preferring velocity shelter amongst boulder and pebbles in quiet waters.

MANAGEMENT CONSIDERATIONS

B.viviparus is the indicator species of the LZ for the Sabie-Sand Rivers as classified by TWINSPAN (Fig. 7.2).

B.viviparus, as with other minnow summer breeding species, is sensitive to summer flow regimes, and the failure of the 1992 wet season greatly reduced their relative numbers (Table 7.7). *B.viviparus* was reduced from the most abundant small species on average in the lowveld (30% in May) to only the third most abundant (17% in May 1992) (Fig. 7.12a.b & c).

In the dry season following the 1992 drought, base flows in the Sabie River were at their lowest ever and the Sand River lowveld ceased to flow for five months. *B.viviparus* persisted in instream refuge pools (Table 9, Vol II) throughout the drought, due to their tolerance, but also through their particular preference for shallow waters, which allowed them to avoid concentrations of predators such as the catfish *Clarias gariepinus* (page 101 Vol II). By the end of the first normal wet season (May 1993), *B.viviparus* were at the lowest levels recorded (16%), showing that they must have been reduced dramatically in the lowveld (Fig. 7.12d).

Chiloglanis anoterus

(pennant-tailed rock catlet) Figures 7.27 & 7.28

GENERAL DISTRIBUTION

This small catlet is endemic to the escarpment streams of the Incomati and Phongolo system (Skelton,1993). Here it occurs almost exclusively within the Sabie system with only isolated populations found in the Komati and Phongolo headwaters (Gaigher,1969).

WITHIN THE SABIE-SAND SYSTEM

- **Distribution:** *C.anoterus* is a cold-warm tolerant species largely confined to the Sabie and Sand headwaters within the Incomati. It occurs in all but the smallest of mountain streams penetrating the perennial Sabie lowveld where suitable riffles are available (220 mASL, site 9, Table 7.2) but is absent in the Sand River LZ probably due its irregular flow.

- **Abundance:** Even though it has a limited distribution, it is numerically the most important fish in the FHZ, making up 70% of the catch. In the LZ *C.anoterus* accounts for 9% of the catch on average. They were most abundant in second and third order streams in both the Sand and Sabie sub-catchments with numbers decreasing with increasing stream order and decreasing altitude (Fig. 7.14). *C.anoterus* is a summer breeder but their relative numbers are stable through different seasons in both the FHZ and LZ.

MICROHABITAT NEEDS

Number of records: juveniles 144, adults 160

Number of records: juveniles 244, adults 295

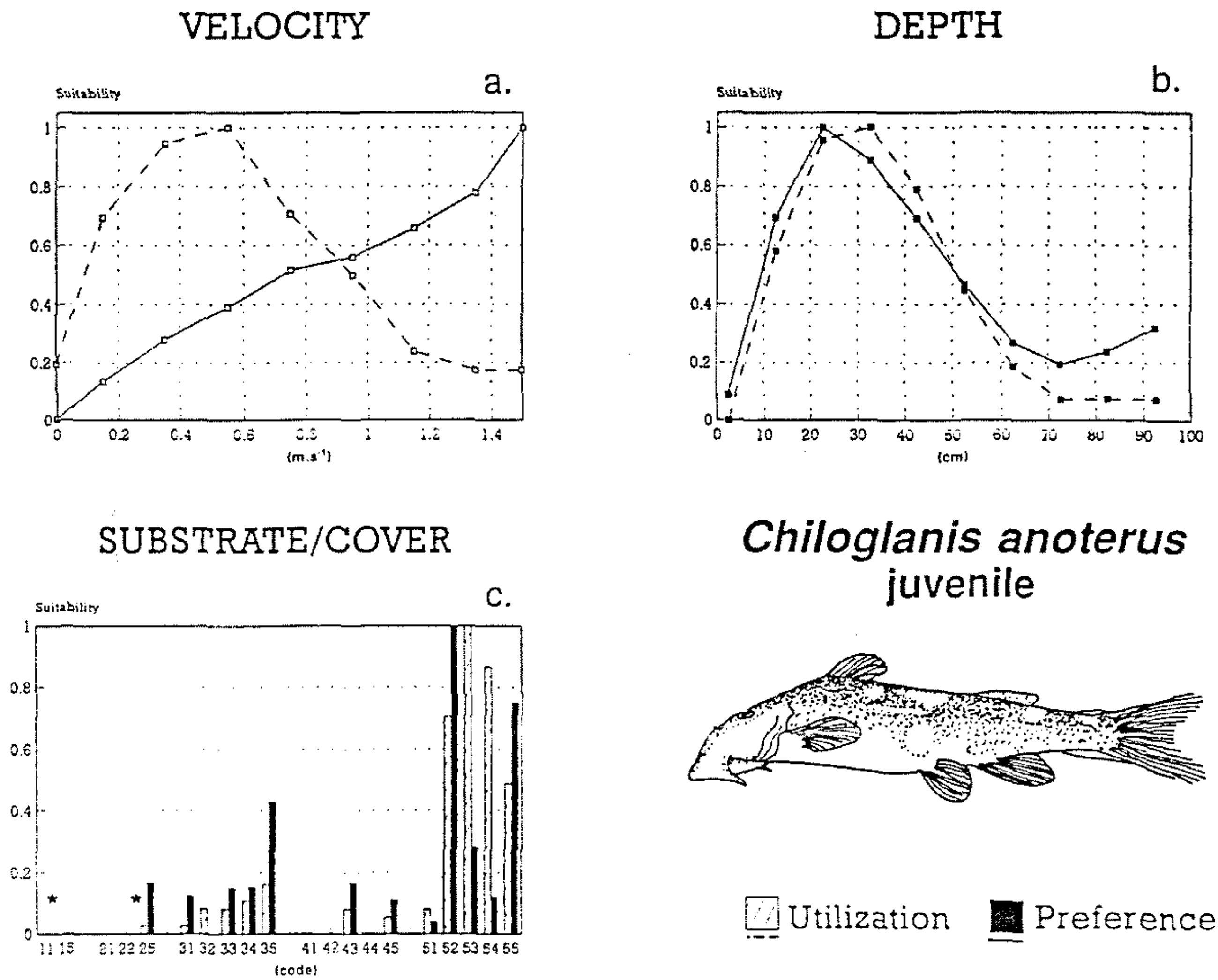

Figure 7.27: Utilization and preference curves for velocity and depth, as well as substrate/cover histograms for *Chiloglanis anoterus* juveniles. Juveniles preferred the fastest of flows (>1.4 m.s^{-1}) (a) which were limited within the system to rapid areas, and utilized shallow waters (22 cm) (b). They utilized velocity and combined velocity/visual cover exclusively (c), mostly within cobble and boulder, but showed preference for both gravels and bedrock in flow. ** = excluded substrate codes not possible within cover type.*

Juveniles
Preferred velocity : >1.4 $m.s^{-1}$
Preferred depth : 15-35 cm
Preferred substrate: gravel/pebble
Preferred cover : combined velocity and visual cover

Adults
Preferred velocity : >1.4 $m.s^{-1}$
Preferred depth : 20-50 cm
Preferred substrate: gravel/pebble
Preferred cover : combined velocity and visual cover

C.anoterus is associated with rapids and both juveniles and adults prefer the fastest of flows available (>1.4 $m.s^{-1}$) (Table 7.10). Although faster flows were more typical of the FHZ reaches (Fig. 7.15a & d), even in the FHZ, preferred flows were limiting as seen by very different utilization and preference curves. Juveniles preferred slightly shallower waters to adults but both were found in shallow waters (30 cm deep) (Table 7.11).

Juveniles and adults were mostly found using a combination of velocity and visual cover (Fig. 7.27c & 7.28c). In rapids, the flow was often turbulent enough to act as visual cover. Juveniles mostly preferred pebbles as cover or turbulent flow over bedrock while adults preferred pebble. Substrates smaller than cobble were limited so use was also made of cobble and boulders.

MANAGEMENT CONSIDERATIONS

C.anoterus is largely unique to the Sabie system being indicative of the FHZ (Fig. 7.8) where it is the most numerous species. Although it is found in the Sabie River within the lowveld, this should be seen as an extension of its preferred range, and only possible if perennial flows are maintained. The availability of its preferred microhabitat is very limited in the lowveld. *C.anoterus* is seen to be highly sensitive to low oxygen levels in captivity. This suggests that, unlike the robust *C.paratus*, they would not survive a period in isolated refuge pools. They are not found in the Sand River lowveld in areas known to have dried in resent years.

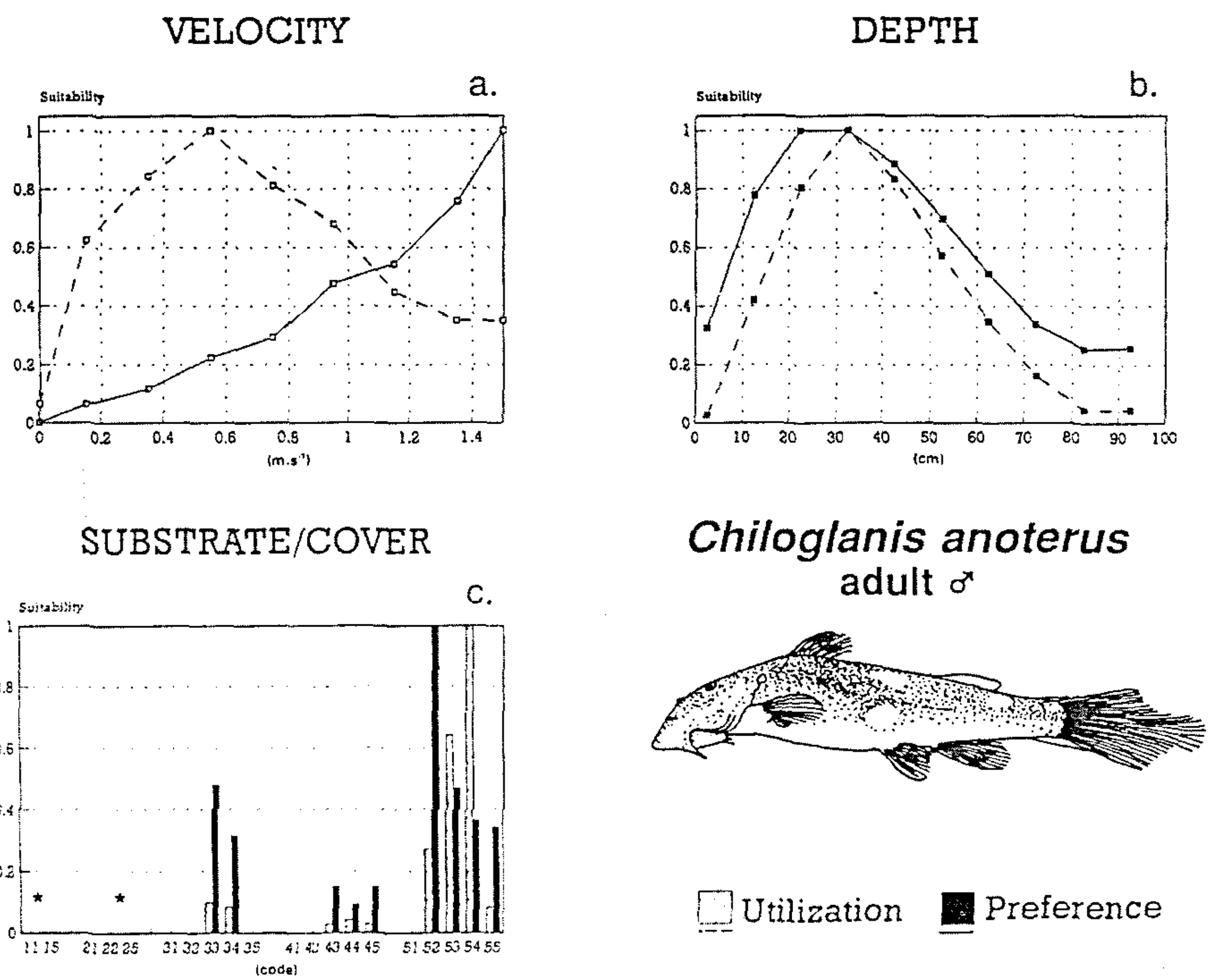

Figure 7.28: Utilization and preference curves for velocity and depth, as well as substrate/cover histograms for *Chiloglanis anoterus* adults. Like juveniles, adults preferred the most rapid of flows (>1.4 $m.s^{-1}$) (a) which were restricted to rapids. Shallow waters (22-32 cm) were preferred (b). Adults almost exclusively utilized combined velocity/visual cover (c) within cobble and boulder but showed preference for the limited gravel/pebble substrates in flow. * = excluded substrate codes not possible within cover type.

During the drought of 1992 reduced summer flow in the FHZ dramatically reduced *C.anoterus* in both the FHZ and LZ (Fig. 7.11 & 7.12, Table 7.6 & 7.7). In the FHZ *C.anoterus* was reduced to only the third most numerous species. By the end of the following wet season and after the worst of the drought, the numbers of *C.anoterus* in the FHZ had recovered fully while those of the LZ were at record lows. *C.anoterus* is a summer breeder that produces few, exceptionally large eggs so their numbers would definitely not recover rapidly. Their apparent rapid recovery in the FHZ is difficult to explain while their poor performance in the LZ is more expected. Possibly, local movement within the reach may explain this. What ever the reason, their reduction and continual low numbers following the drought in the LZ show this species to be vulnerable to low-flows.

Labeo molybdinus

(leaden labeo) Figures 7.29 & 7.30

GENERAL DISTRIBUTION

This common large cyprinid is found in rivers and lakes of the lower Zambezi to the Tugela system in Natal (Skelton,1993). Gaigher (1969) records it from all of the lowveld rivers of the KNP except the Shingwedzi where it has been recorded in the past.

WITHIN THE SABIE-SAND SYSTEM

- **Distribution:** *L.molybdinus* is warm-cold tolerant species confined to the LZ of all the Incomati system but they do not penetrate the lower reaches onto the coastal plain. *L.molybdinus* were found from 402 mASL (site 7) and 538 mASL (site 11) in the Sabie and Sand rivers respectively (Table 7.2 & 7.3), while a population of adults were found in the cool waters of the Marite River (620 mASL, site 21) (Table 7.3).

- **Abundance:** *L.molybdinus* made up 8% of the lowveld catch (Fig. 7.8a). Their numbers were surprisingly aseasonal for a fecund summer spawner, but were highest in May following the summer breeding season (Fig. 7.8b). Percentages showed a gradual decrease with the passage of the dry season, with a wet season low before new cohorts were recruited in February (Fig. 7.8e).

MICROHABITAT NEEDS

Number of records: juveniles 127, adults 34

Number of individuals: juveniles 154, adults 41

Juveniles
Preferred velocity : 0.6-1.5 $m.s^{-1}$
Preferred depth : 15-45 cm
Preferred substrate: gravel/pebble or cobble
Preferred cover : visual, velocity or combined cover

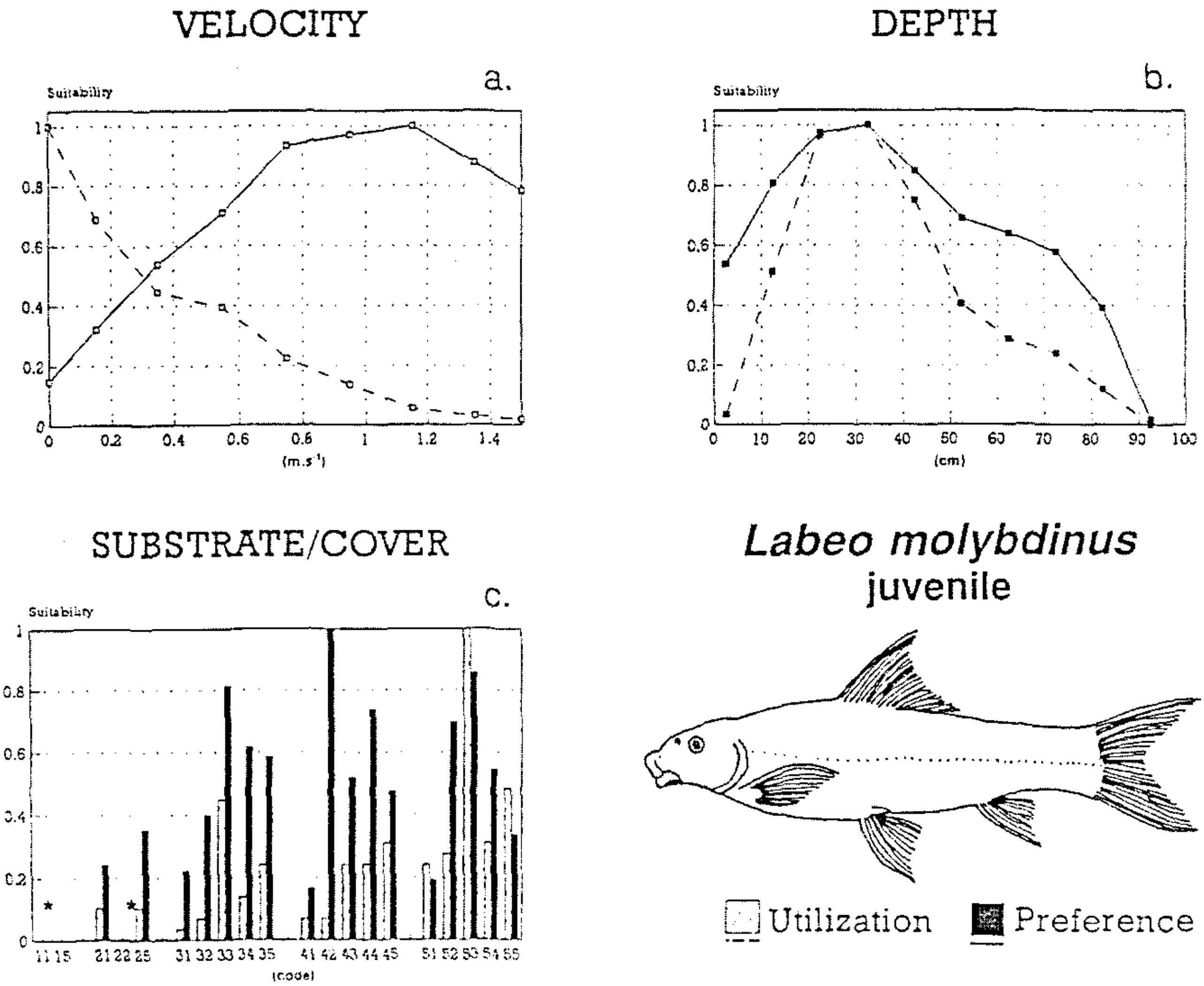

Figure 7.29: Utilization and preference curves for velocity and depth, as well as substrate/cover histograms for *Labeo molybdinus* juveniles. Juveniles most preferred moderate flows (1.15 m.s^{-1}) (a) and shallow (33 cm) to slightly deeper waters (b). They largely utilized cover (c), mostly cobble in currant (combined velocity and visual cover), preferring cobble substrates in currant and gravel/pebble & boulders in quieter waters. * = excluded substrate codes not possible within cover type.

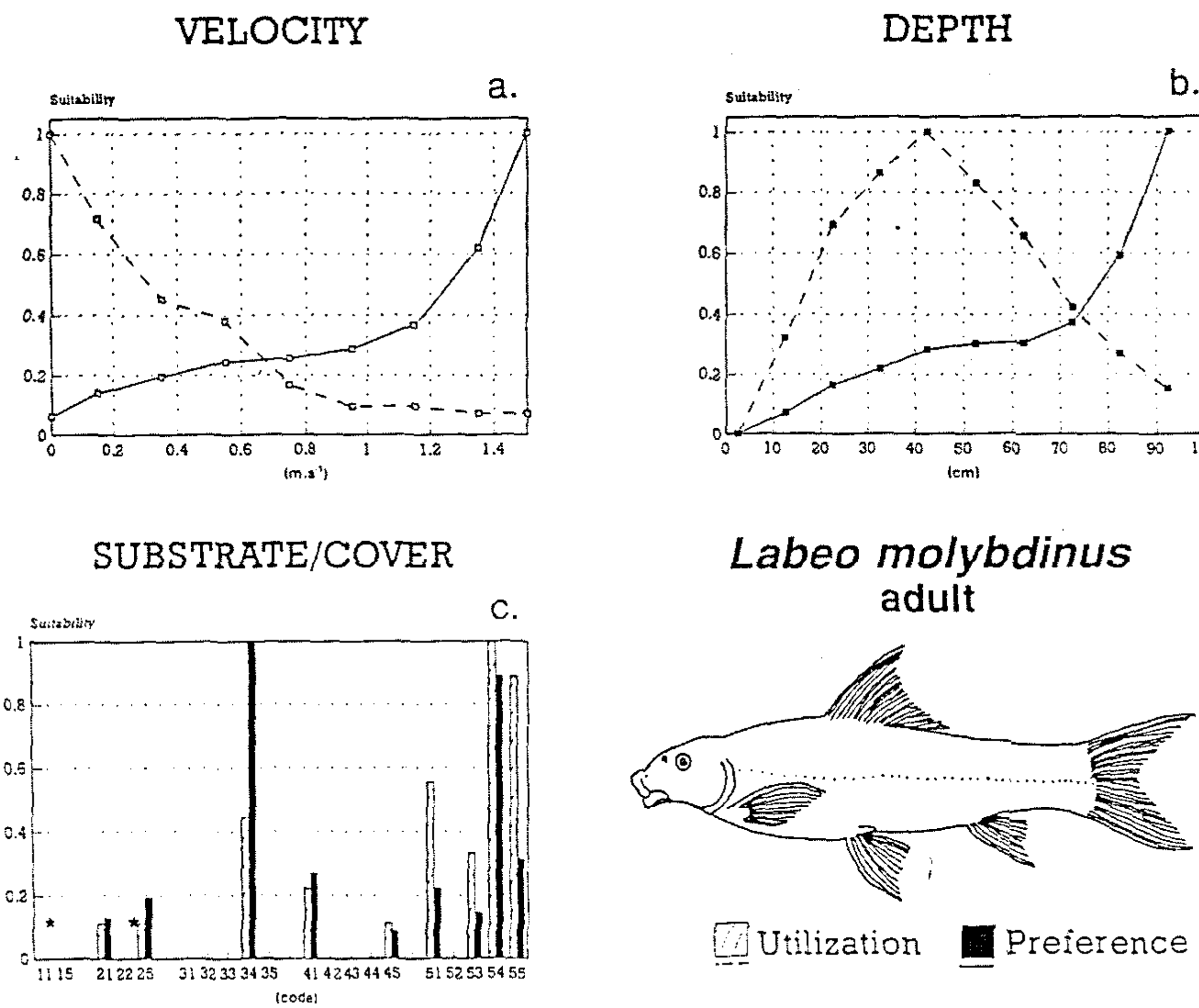

Figure 7.30: Utilization and preference curves for velocity and depth, as well as substrate/cover histograms for *Labeo molybdinus* adults. Adults preferred high velocity flows (>1.4 $m.s^{-1}$) (a) often in shallow waters (40 cm) (b). Adults largely utilized combined velocity/visual cover associated with boulders and bedrock (c). They preferred boulders in flow above all other substrate types. * = excluded substrate codes not possible within cover type.

Adults
Preferred velocity : >1.5 $m.s^{-1}$
Preferred depth : >95 cm
Preferred substrate: boulder
Preferred cover : visual or combined visual/velocity shelter

Both juvenile and adult *L.molybdinus* preferred riffle areas in the shallow waters accessible by electrofishing, with juveniles preferring marginally slower velocities (1.15 $m.s^{-1}$) in shallow water (33 cm deep). Adults were found in the highest flows available (>1.4 $m.s^{-1}$) in the deepest of waters sampled (>95 cm deep).

In riffles, both juveniles and adults utilized the combined velocity and visual cover afforded by cobble and boulders respectively. Juveniles actually preferred some quieter waters in the visual cover of pebble and boulder substrates besides rock substrates in both runs and riffle. Adults preferred the large rocky substrates where they took cover against velocity or against visual predators.

MANAGEMENT CONSIDERATIONS

L.molybdinus was common throughout the LZ of our study area. Their absence from the lower Incomati river probably stems from the needs of the juveniles regarding flow and their preference for rocky substrates, particularly riffles.

L.molybdinus was not particularly sensitive to drought. They survived well in the drought pools isolated at Londolozi for five months (Vol II). Percentages did declined marginally from 10-7% after the failure of the 1992 wet season but they recovered rapidly in the following season. *L.molybdinus* together with the catfish *Clarias gariepinus* were able to breed very successfully with the very first rain following the drought when other species were still emaciated due to the harsh conditions within drought pools. Their percentage had risen from only 7% at the height of the drought to 26% by the first good season.

More important than *L.molybdinus*'s tolerance of drought is perhaps its ability to respond rapidly following drought. Their success is enhanced by their high fecundity and their tendency to regional movement in response to flood events, allowing recolonization of depopulated areas.

Micralestes acutidens

(silver robber) Figures 7.31 & 7.32

GENERAL DISTRIBUTION

M.acutidens is a medium size characin that shoals in flowing to open waters and has an extensive distribution from the Zaire system to the Phongolo (Skelton,1993). Gaigher (1969) reported it from all of the main rivers of the KNP while Russell and Rogers (1989) reported it as absent from the Olifants River within the KNP in the mid 1980's.

WITHIN THE SABIE-SAND SYSTEM

- **Distribution:** *M.acutidens* is a warm-cold tolerant species that is particularly widespread within the lowveld tributaries of the Incomati system (appendix III). It was found from 488 mASL (site 5) and 538 mASL (site 11) in the Sabie and Sand rivers respectively, to the Mozambique border.

- **Abundance:** *M.acutidens* was common where it occurred in both the Sabie and Sand sub-catchments particularly in the upper LZ. Although they were never sampled in sufficient numbers to be considered, by our definition, as ecologically important to the typical assemblage in either the FHZ or LZ, they probably should be included as they were often particularly apt at avoiding capture.

MICROHABITAT NEEDS

Number of record: juveniles 40, adults 31

Number of individuals: juveniles 49, adults 40

Juveniles
Preferred velocity : 0-0.1 $m.s^{-1}$
Preferred depth : 15-45 cm
Preferred substrate: gravel/pebble or boulder
Preferred cover : visual or velocity shelter

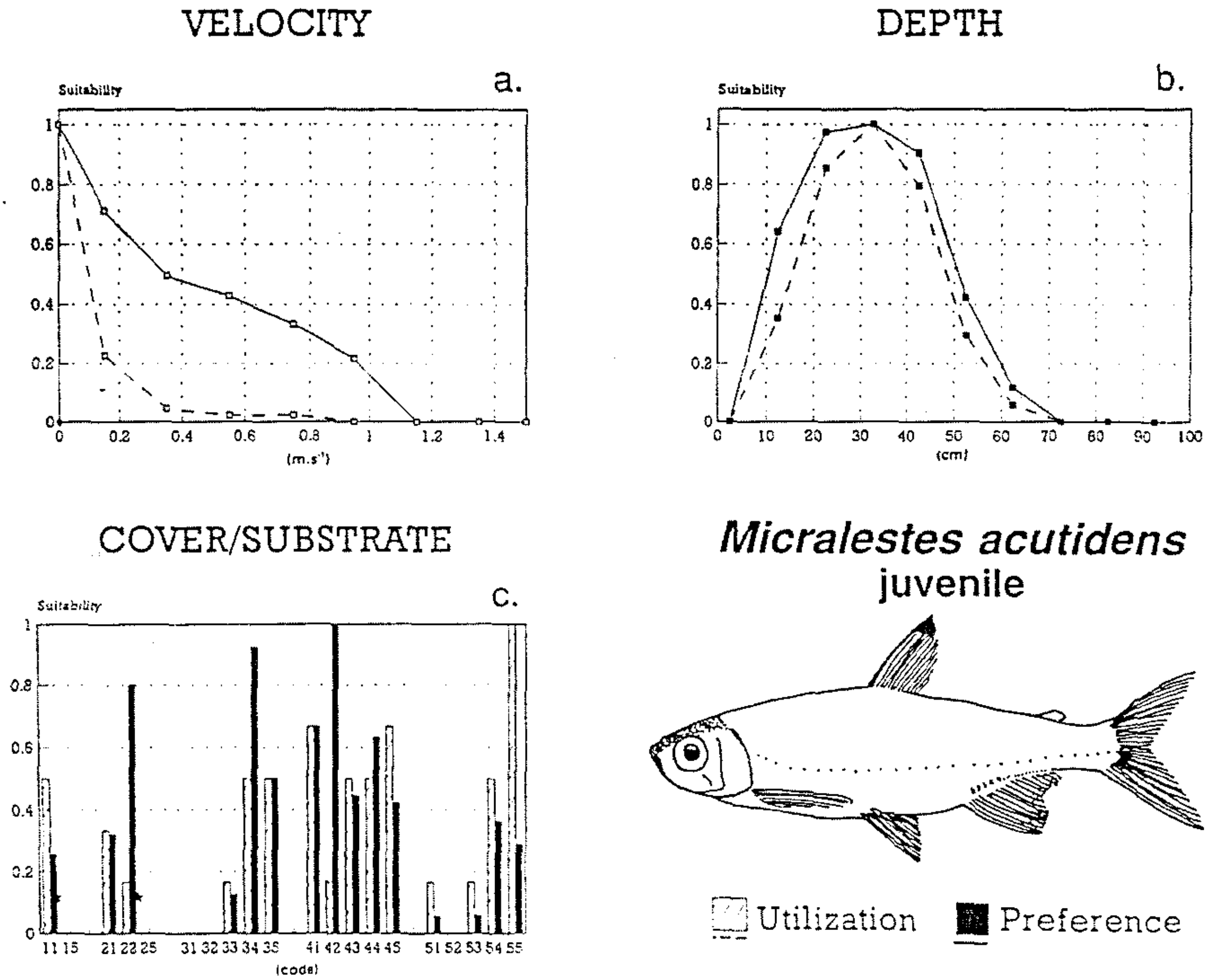

Figure 7.31: Utilization and preference curves for velocity and depth, as well as substrate/cover histograms for *Micralestes acutidens* juveniles. Juveniles most prefer quiet waters below 0.1 $m.s^{-1}$ (a) and shallow waters (33 cm) (b). Juveniles utilized visual and velocity cover over a range of substrates (c) but particularly within marginal vegetation over bedrock. They preferred gravel/pebble beds, a limited substrate type. * = excluded substrate codes not possible within cover type.

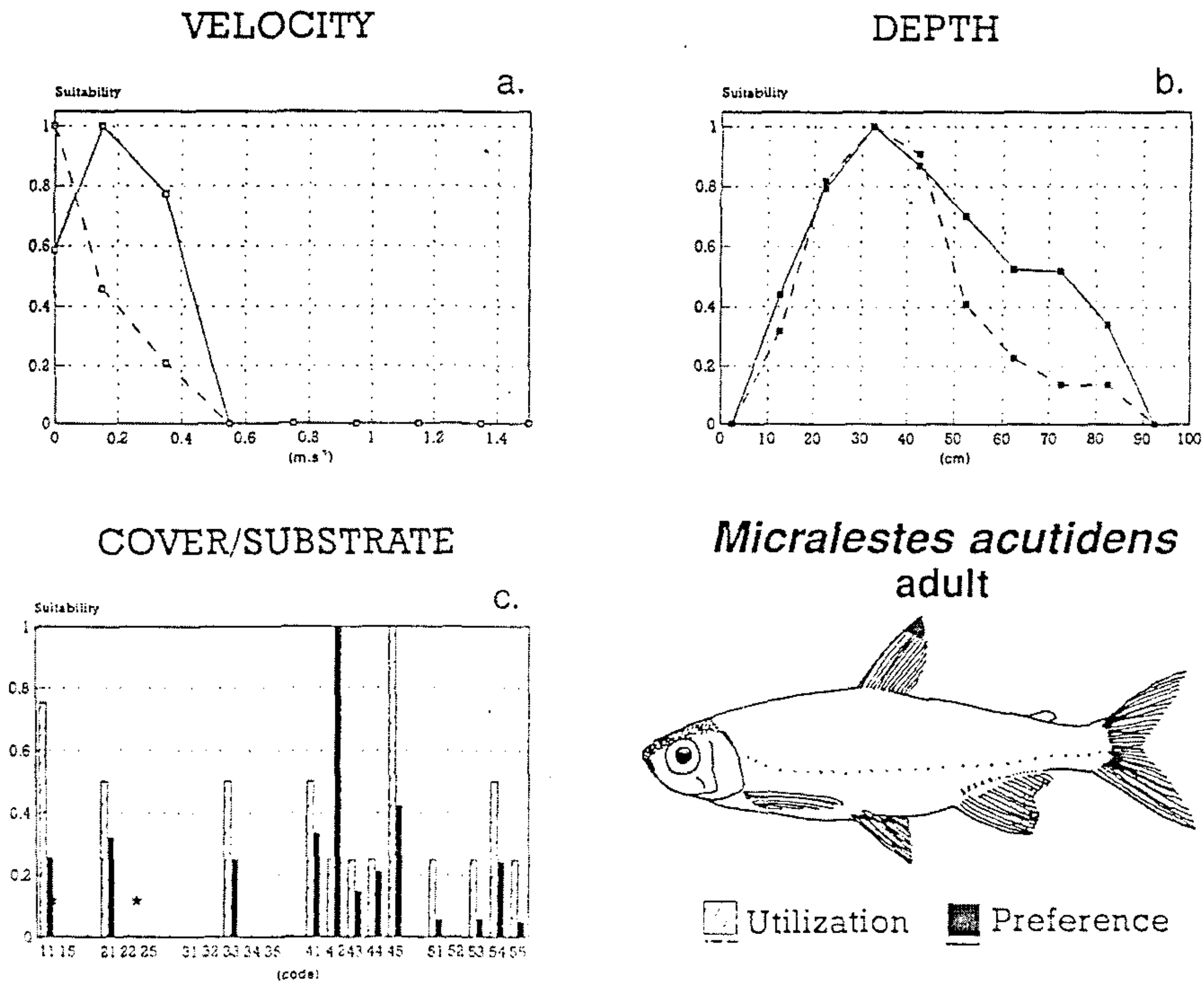

Figure 7.32: Utilization and preference curves for velocity and depth, as well as substrate/cover histograms for *Micralestes acutidens* adults. Adults most preferred marginal to slow-flows (0.15 $m.s^{-1}$) (a) with flows between 0-<0.4 $m.s^{-1}$ suitable. Shallow to slightly deeper waters (33 cm) were preferred (b). They utilized marginal vegetation (visual cover) (c) to open waters over sand (no cover) but like juveniles, preferred gravel/pebble as a substrate, which was limited in the lowveld. * = excluded substrate codes not possible within cover type.

Adults
Preferred velocity : >0-0.3 $m.s^{-1}$
Preferred depth : 20-50 cm
Preferred substrate: gravel/pebble
Preferred cover : visual cover

In shallow waters, juvenile and adult *M.acutidens* preferred different flow regimes with juveniles choosing quieter waters adjacent to flow while adults most preferred runs (0.15 $m.s^{-1}$) (Table 7.10). Both were found in shallow waters (33 cm deep) by preference (Table 7.11).

M.acutidens are highly mobile and characteristically in the water column so it is not surprising that they should be found utilizing a wide range of cover and substrate types. While both adults and juveniles utilized marginal vegetation, juveniles seemed to utilize more vegetation in flow while adults were more often captured in pools. Large populations of *M.acutidens* are generally seined in pools, particularly downstream of rapids (Russell, *pers com.*).

Like many small fish species or juveniles both adults and juveniles preferred pebble substrate in quiet or, with juveniles, flowing waters. Juveniles also preferred the shelter of boulders in current.

MANAGEMENT CONSIDERATIONS

M.acutidens is probably moderately sensitive to water quality conditions with an intolerance to low oxygen levels suggested by Gaigher (1973). We found that individuals were able to withstand five months of isolation during the Londolozi drought but only in exposed pools that retained healthy oxygen regimes. They were lost in pool L11 in the first month of isolation where low levels of oxygen were recorded (Vol II). It appears that *M.acutidens* has been lost in the Olifants River (Russell and Rogers, 1989).

Opsaridium zambezense

(barred minnow) Figure 7.33

GENERAL DISTRIBUTION

O.zambezense is widespread from the Zaire system through the Okavango and east coastal rivers, south to the Phongolo River (Skelton,1993). Gaigher (1969) reports it from all the tributaries of the Incomati and Olifants River within the LZ and the lower FHZ (appendix III).

WITHIN THE SABIE-SAND SYSTEM

- **Distribution:** *O.zambezense* is a warm-cold tolerant species which occurred in both the Sabie and Sand subcatchment. Within the Sabie *O.zambezense* ranged from the FHZ (site 5, 488 mASL & site 18, 450 mASL) to the LZ riffles (sites 9, 220 mASL) (Table 7.2-7.3). Unlike Gaigher (1969) who found it in the lowveld of the Sand River, we found it confined to the perennial headwaters of the Sand only (Site 11 & 19). It was subsequently lost from the Mutlumuvi (site 19) with the construction of the Zoeknog dam.

- **Abundance:** *O.zambezense* was more numerous within the cooler water of the LZ and the FHZ of the Sabie River (site 5) with progressively fewer individuals sampled further into the lowveld.

MICROHABITAT NEEDS

Number of records: juveniles, 19

Number of individuals: juveniles, 20

Juveniles
Preferred velocity : 0.2-0.7 $m.s^{-1}$
Preferred depth : 10-30 cm
Preferred substrate: gravel/pebble
Preferred cover : visual cover

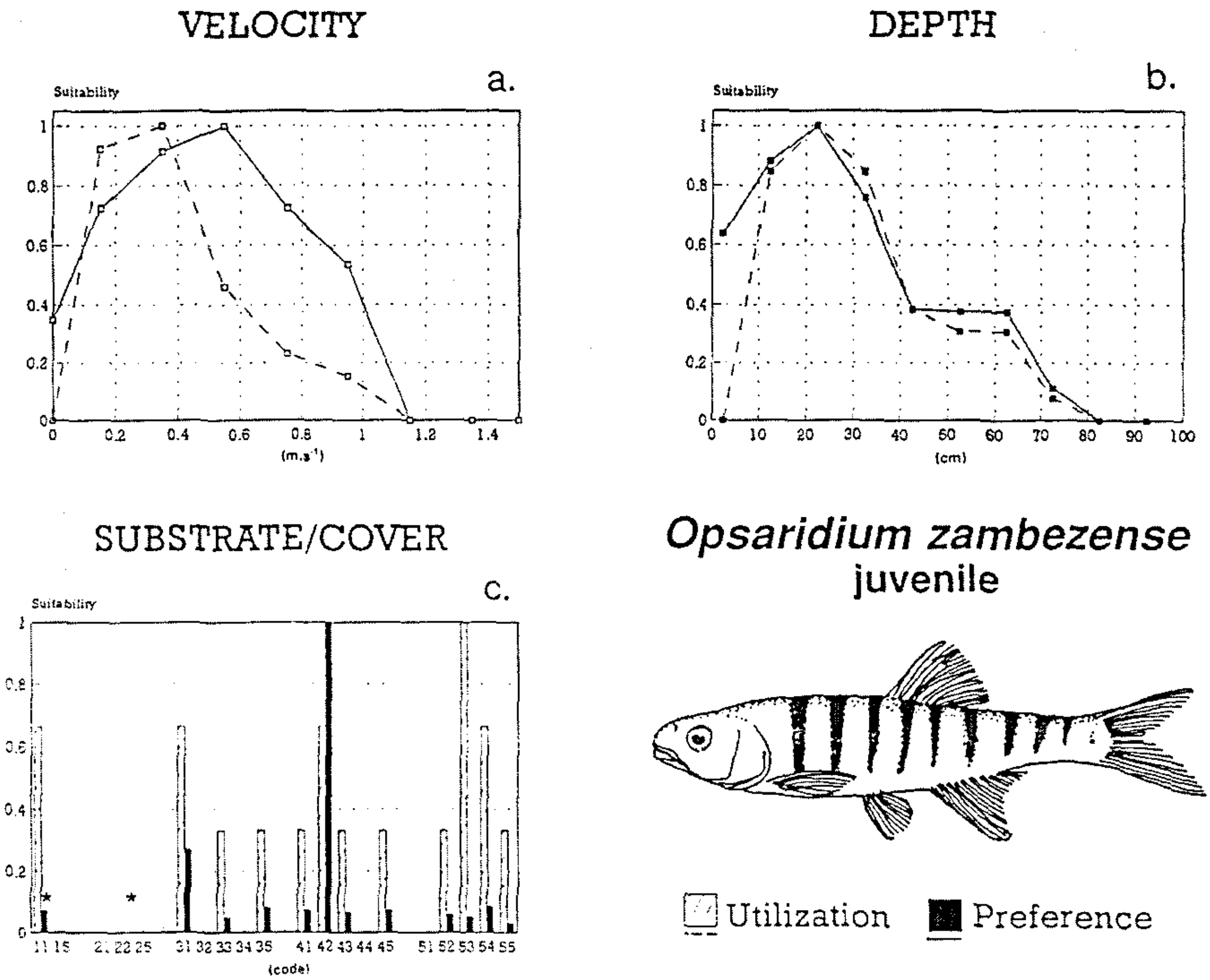

Figure 7.33: Utilization and preference curves for velocity and depth, as well as substrate/cover histograms for *Opsaridium zambezensis* juveniles. Juveniles most preferred medium flows (0.55 m.s^{-1}) (a) in shallow waters (22 cm) (b). All cover and substrate types were utilized (c) except overhead cover. Although they utilized cobble in flow they preferred gravel/pebble, a limited substrate type in the head of downstream pools in the lowveld.
* = excluded substrate codes not possible within cover type.

O.zambezense is generally associated with well-aerated reaches of flowing water in runs and the heads of pools (Skelton, 1987). Gaigher (1973) showed that at higher altitudes they utilized rapids more, while at lower altitudes they were often found in pools. This agrees with Russell (*pers com.*) who found them to be numerous in pools below runs in the lower Sabie River lowveld.

In general we would agree with the above findings and would add that, from limited records, it appears that they prefer shallow waters. In shallow waters, *O.zambezense* most preferred rapids with flows of 0.55 $m.s^{-1}$ (Table 7.10).

Like *M.acutidens*, *O.zambezense* is highly mobile and was found utilizing a wide range of cover and substrate types, with the combined cover afforded by rocky substrates in rapids the most utilized. Like many other juveniles and small species, they showed a preference for a gravel-pebble substrate.

MANAGEMENT CONSIDERATIONS

O.zambezense is clearly a very sensitive fish and is classified as "indeterminate-rare" in South Africa (Skelton, 1987). It has suffered reductions in distribution over the last twenty years both at the scale of lowveld rivers (Olifants) and within reaches of others (Sand River).

We found it sensitive to low oxygen in captivity as suggested by Skelton (1987) and others and this probably explains why it is not presently found within the lower Sand River. It was also lost from the perennial upper Mutlumuvi River with the Zoeknog construction and dam burst effects. This species may not be able to survive conditions in refuge pools during periods of no-flow. For these species to persist in the lowveld reaches, some permanent flow is essential.

Oreochromis mossambicus

(Mozambique tilapia) Figures 7.34 & 7.35

GENERAL DISTRIBUTION

O.mossambicus is widely distributed in the east coast rivers from the lower Zambezi to the Bushmans River in the eastern Cape Province (Skelton, 1993) being common in all of the lowveld rivers that cross the KNP (Gaigher, 1969), and in the Incomati and all of its tributaries from the LZ to the coastal plain (appendix III).

WITHIN THE SABIE-SAND SYSTEM

- **Distribution:** *O.mossambicus* is a warm water species found extensively in the lowveld reaches of both the Sabie and Sand sub-catchments (Table 7.2 & 7.3).

- **Abundance:** *O.mossambicus* was the second most abundant species in the LZ (12%, Fig. 7.8a). *O.mossambicus* abundance was highly seasonal. Their numbers reduced slightly from May to August (7 to 4%) but increased dramatically with the onset of summer prior to the arrival of the summer rains in November (20%). This agrees with Skelton (1993) who reports that *O.mossambicus* breeds in the summer months, but unlike most of the riverine fishes, typically cyprinids, they were able to breed early in summer *independent* of the first rains. By February, their numbers had been diluted or reduced to 17%, although this was still the second most abundant species in the system.

MICROHABITAT NEEDS

Number of records: juveniles 135, adults 29

Number of individuals: juveniles 194, adults 30

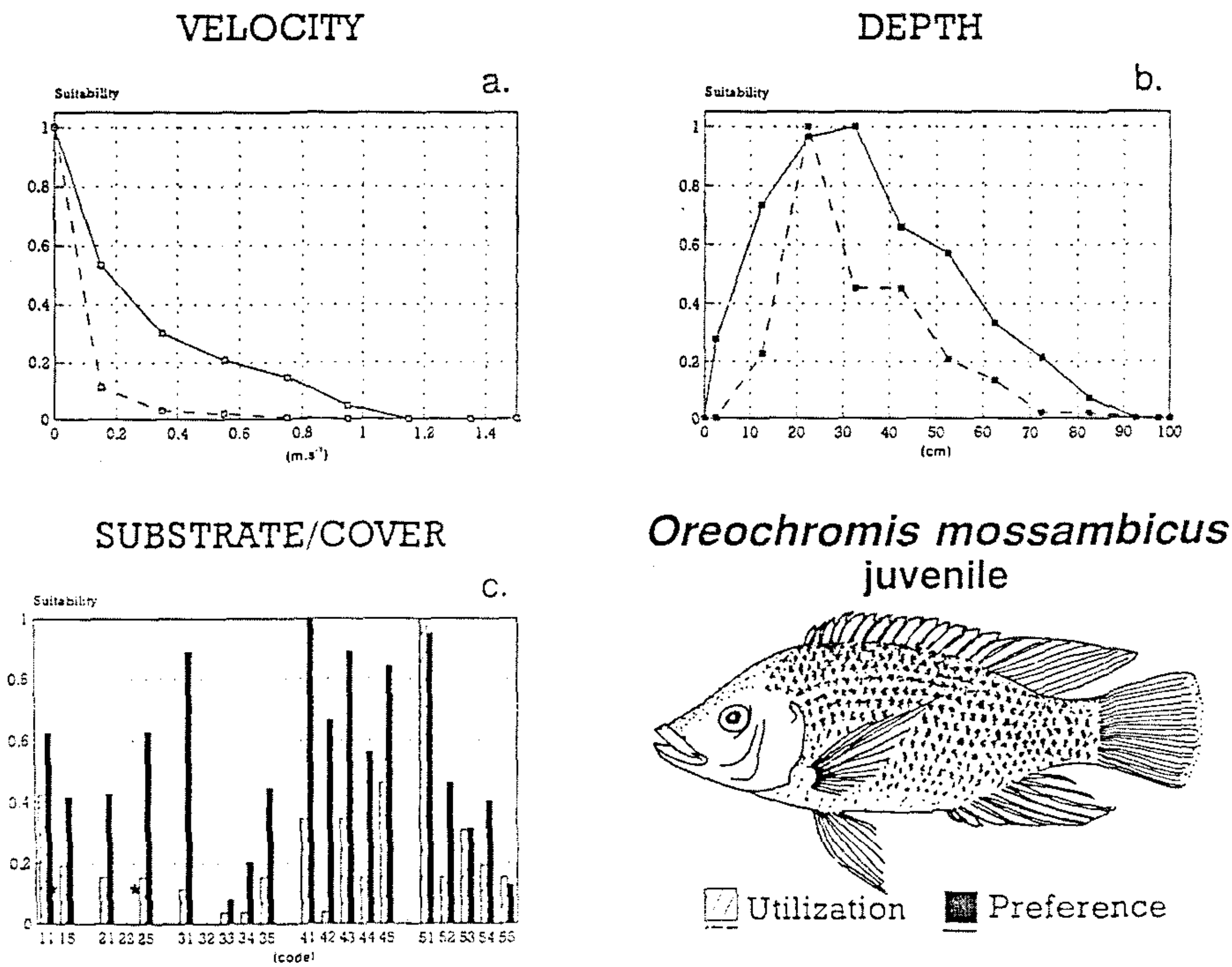

Figure 7.34: Utilization and preference curves for velocity and depth, as well as substrate/cover histograms for *Oreochromis mossambicus* juveniles. Juveniles prefer shallow waters (32 cm) (b) with zero flow (a). Cover and substrate use is ubiquitous (c). Besides vegetation bordering sandy runs with flow, preference is for visual cover in all substrates excluding boulders. * = excluded substrate codes not possible within cover type.

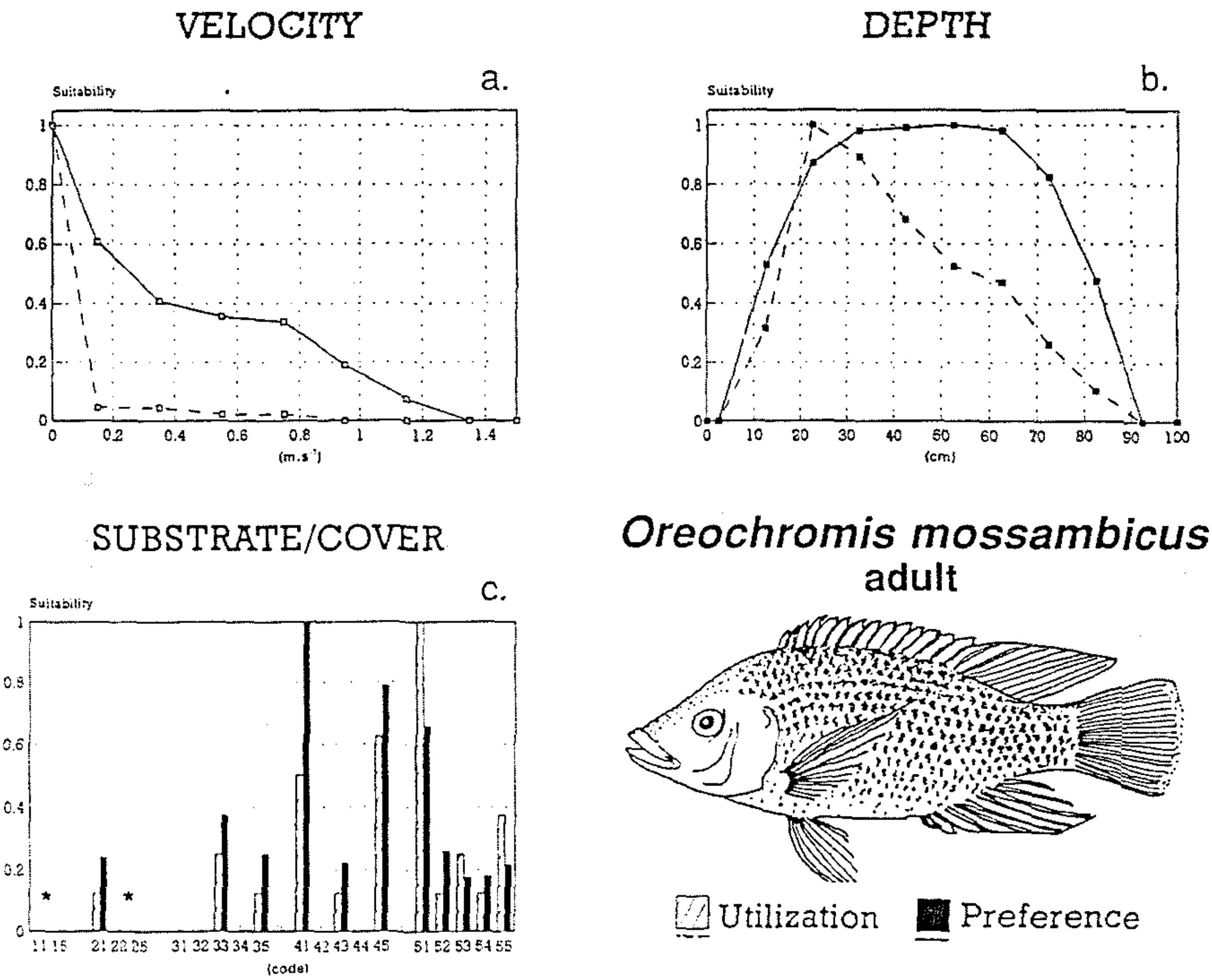

Figure 7.35: Utilization and preference curves for velocity and depth, as well as substrate/cover histograms for *Oreochromis mossambicus* adults. Adults prefer zero flow (a) with some tolerance of higher flows at lower suitability and shallow to deeper waters (33-63 cm) (b). Like juveniles, they mostly utilized marginal vegetation over sand (c) with combined cover. Adults preferred marginal cover over sand without flow or adjacent to flow, over bedrock. * = excluded substrate codes not possible within cover type.

Juveniles
Preferred velocity : 0 $m.s^{-1}$
Preferred depth : 20-40 cm
Preferred substrate: fines/marginal vegetation or cobble
Preferred cover : visual, velocity or combined cover

Adults
Preferred velocity : 0 $m.s^{-1}$
Preferred depth : 30-80 cm
Preferred substrate: fines/marginal vegetation
Preferred cover : visual cover

O.mossambicus is known from most kinds of waters except in very fast flow (Skelton,1993). Our results confirm that both juveniles and adults prefer quiet waters (zero flow) with flows above 0.15 $m.s^{-1}$ being unsuitable.

Of the fish captured, juveniles preferred slightly shallower waters (33 cm deep) to adults which were most numerous in waters 33-63 cm deep. Many adults evaded capture by their tendency to flee from shallower waters when approached to take refuge in the deepest portions of pools.

Juveniles in particular were ubiquitous in their use of cover and substrate. Besides vegetation bordering sandy runs, their preference was for visual cover in all but the largest of boulders. Adults used mostly marginal vegetation bordering flow, with fewer in open water away from cover. They preferred visual cover in quiet waters in marginal vegetation bordering runs in sandy channels.

MANAGEMENT CONSIDERATIONS

O.mossambicus is one of the most successful fishes of the lowveld rivers. Besides being tolerant of high salinities, and temperatures (Skelton,1993), it is able to breed independent of the rainy season, even in the smallest of pools where it matures at a stunted size. This allows

O.mossambicus to thrive in drought conditions in the region and makes it a good indicator of drought or system mismanagement in the lowveld rivers.

While most species were reduced in numbers during the drought, *O.mossambicus* together with other cichlids in the catchment benefitted by the resultant lower flows. *O.mossambicus* increased from 5% in May 1991 to 27% by May 1992 (Table 7.7).

With the progression of the drought over the following dry season, *O.mossambicus* proved highly resilient in the refuge pools formed when the Sand River stopped flowing for five months. While other cichlids finally decreased in abundance under extreme conditions, *O.mossambicus* bred as stunted adults. After the first normal wet season (May 1993), their numbers had reduced to 24% but were still high.

The tendency of the cichlid *O.mossambicus* to dominate the catch in drought affected systems in south eastern lowlands has been identified before (Merron *et al.*, 1993 and Jackson, 1989). These characteristics makes this a good indicator of the present and near past condition of the lowveld rivers of the Sabie system.

Pseudocrenilabrus philander

(southern mouthbroader) Figures 7.36 & 7.37

GENERAL DISTRIBUTION

This small cichlid extends from the southern Zaire basin through the Limpopo to southern Natal. It is also found in the Orange River (Skelton, 1993). Gaigher (1969) reported it from the Incomati and its tributaries where populations extended from the foothills to the coastal plain (appendix III).

WITHIN THE SABIE-SAND SYSTEM

- **Distribution:** *P.philander* is eurythermal in the Sabie system and is found from the foothills (site 28, 867 mASL) to the lowveld (site 20, 140 mASL) (Table 7.2). Their distribution was never uniform and absence from reaches was often difficult to explain. In the Sand River they were only found below 458 mASL at site 12 (Table 7.4).

- **Abundance:** *P.philander* was one of the three cichlid species that was important within the LZ, and made up 6% of the catch. Like other cichlid species, they were able to breed early in summer before the start of the rainy season. Their relative numbers increased from 1% in August to 9% by November at the start of the rainy season (Fig. 7.8b-c). They remained numerous (9%) throughout the wet season unlike other cichlids.

MICROHABITAT NEEDS

Number of records: juveniles 53, adults 36

Number of individuals: juveniles 63, adults 41

Juveniles
Preferred velocity : 0 $m.s^{-1}$
Preferred depth : 10 cm
Preferred substrate: gravel/pebble
Preferred cover : visual cover

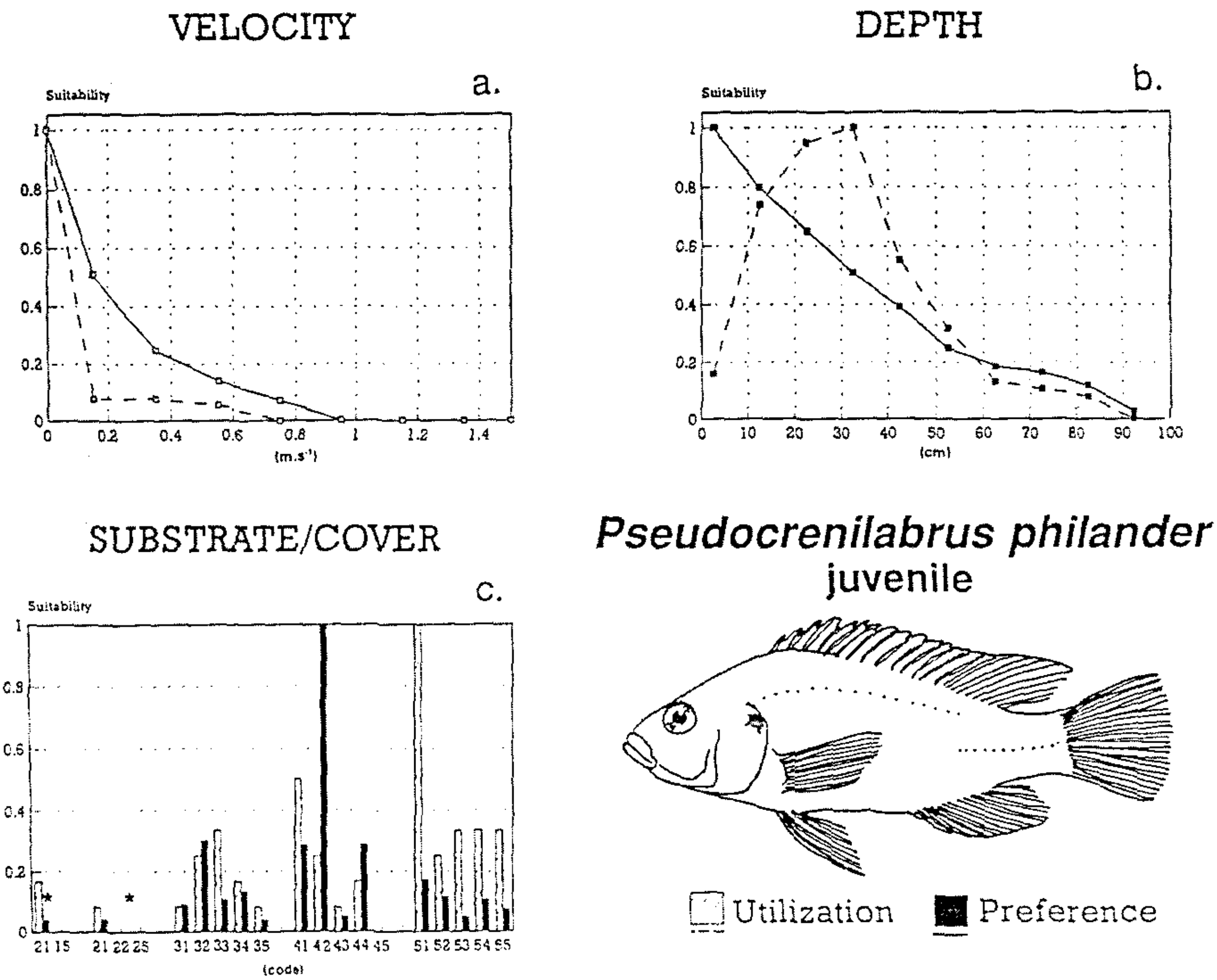

Figure 7.36: Utilization and preference curves for velocity and depth, as well as substrate/cover histograms for *Pseudocrenilabrus philander* juveniles. Most preferred quiet backwaters in zero flow (a) and very shallow waters (<12 cm) (b). Juveniles utilized cover both instream velocity and visual (c). All substrates, but particularly marginal vegetation over fines/sand was used. Juveniles preferred a gravel/pebble substrate in backwaters to all others. * = excluded substrate codes not possible within cover type.

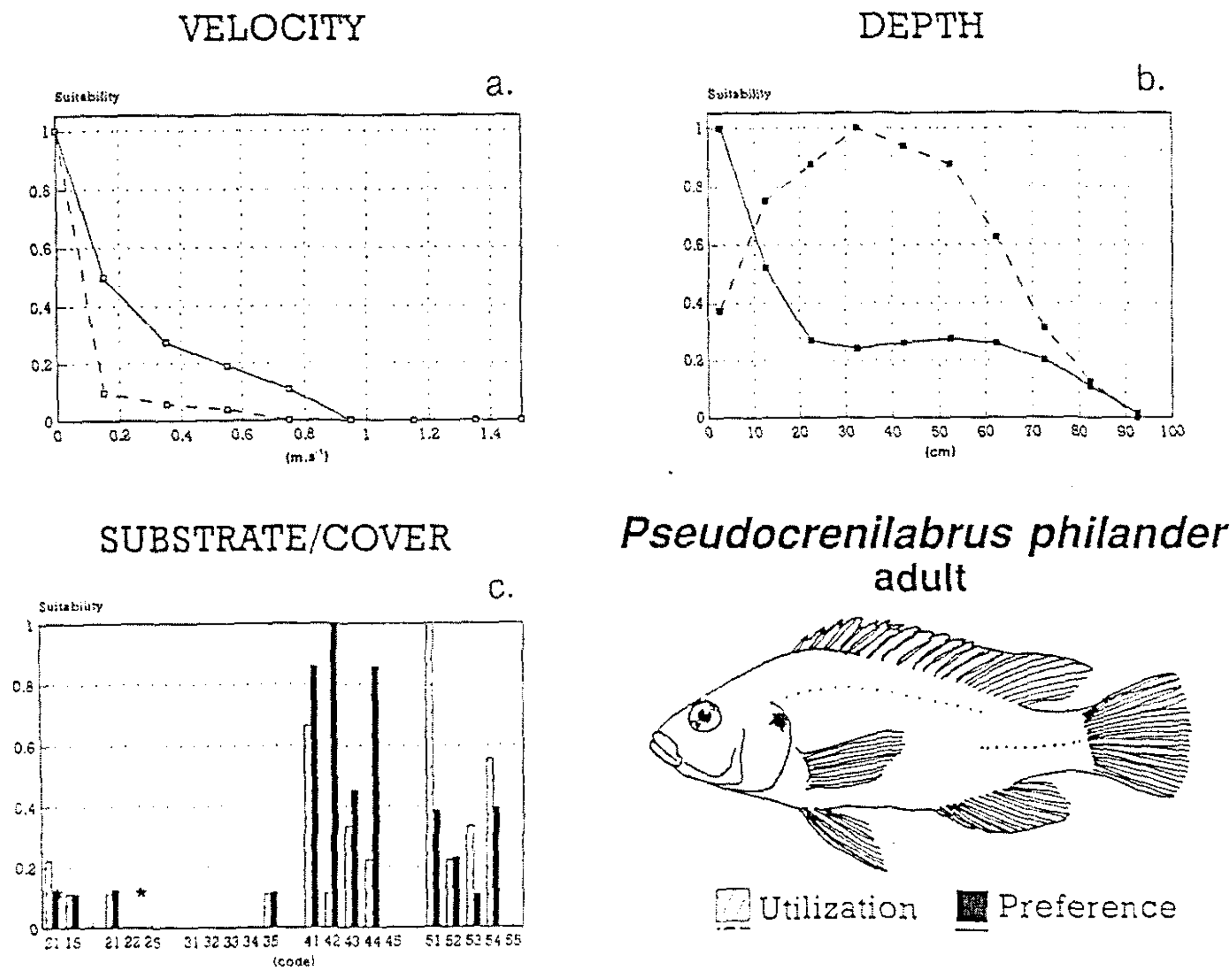

Figure 7.37: Utilization and preference curves for velocity and depth, as well as substrate/cover histograms for *Pseudocrenilabrus philander* adults. Like juveniles, adults preferred quiet backwaters with zero flow in shallow waters (mostly below 8 cm depth). They utilized visual cover both in and out of flow and particularly marginal vegetation over sand. They preferred visual cover in backwaters over most substrate types. * = excluded substrate codes not possible within cover type.

Adults
Preferred velocity : 0 $m.s^{-1}$
Preferred depth : 10 cm
Preferred substrate: marginal vegetation/fines or gravel or boulder
Preferred cover : visual cover

Both Skelton (1993) and Gaigher (1969) describe habitat use as ranging from quiet pool to flowing waters and rapids. In the Sabie system both juvenile and adult *P.philander* utilized and preferred very quiet waters in backwaters and pools (Table 7.10) with flows above 0.15 $m.s^{-1}$ unsuitable. Both adults and juveniles further preferred the shallowest of waters sampled around the edges of pools and runs (Table 7.11).

Adult and juvenile fish were most commonly found in vegetation surrounding runs and pools with some flow, but both preferred quiet waters with visual cover. Both, but especially juveniles, chose the limited gravel-pebble substrate type, while adults also liked boulder or vegetation cover in quiet waters.

MANAGEMENT CONSIDERATIONS

P.philander was important in the lowveld rivers but its patchy distribution and wide temperature tolerance limits its usefulness as an indicator of system condition. Its numbers were neither responsive to season or drought. *P.philander* was the only ecologically important species that did not respond favourably or negatively to the changing flow regime of the 1992 drought (Table 7.7).

Serranochromis meridianus

(lowveld largemouth) Figure 7.38

GENERAL DISTRIBUTION

S.meridianus is endemic to the coastal lakes of southern Mozambique and Maputoland as well as the Sabie and Sand tributaries of the Incomati system (Gaigher, 1969; Skelton,1993).

WITHIN THE SABIE-SAND SYSTEM

- **Distribution:** *S.meridianus* is found in the Sand and Sabie rivers in warm waters from 538 mASL (site 11) 406 mASL (site 6) respectively.

- **Abundance:** Although never numerous, they were more common in the upper Sand River at site 11 although larger specimens were collected in the Sabie right up to the Mozambique border at Mlondozi (site 20).

MICROHABITAT NEEDS

Number of records: juveniles 53

Number of individuals: juveniles 64

Juveniles
Preferred velocity : 0 $m.s^{-1}$
Preferred depth : 25-50 cm
Preferred substrate: marginal vegetation or boulder
Preferred cover : visual cover

Skelton (1993) describes its habitat as in standing or slow flowing waters in marginal vegetation. Our results show that juveniles do prefer pools and backwaters (Table 7.10), preferring zero flow, avoiding flows above 0.15 $m.s^{-1}$. This agrees closely with the velocity curve produced by Gore *et al.* (1992) for *S.meridianus* in the KNP lowveld waters even though life stage and habitat availability were not taken into account. Juveniles are found in, and prefer, shallow waters (33-43 cm deep) (Table 7.11). Gore *et al's.* (1992) suggestion that

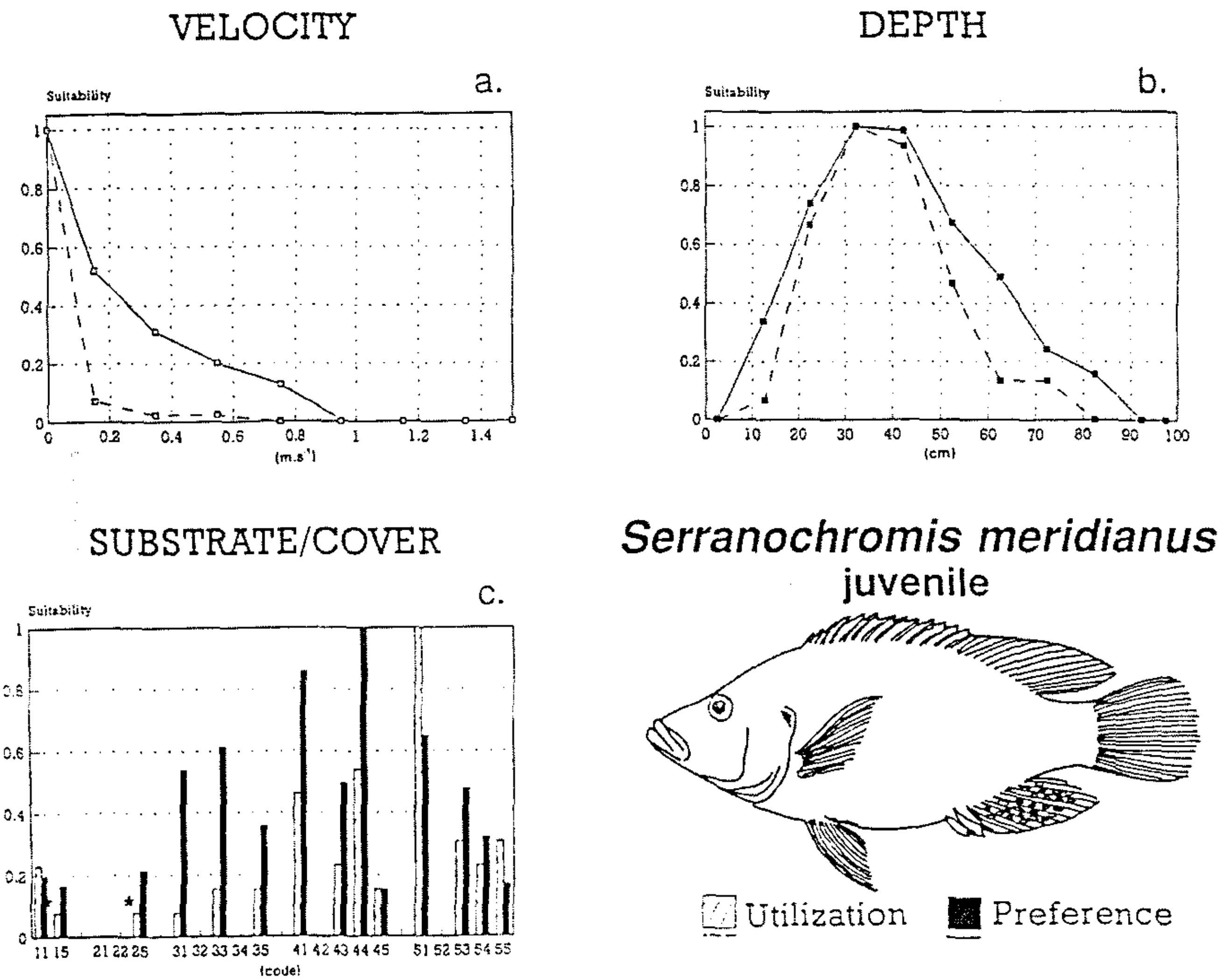

Figure 7.38: Utilization and preference curves for velocity and depth, as well as substrate/cover histograms for *Serranochromis meridianus* juveniles. Juveniles fish preferred shallow (32-42 cm) (b) backwaters with zero flow (a). They utilized mostly marginal vegetation adjacent to flow (combined cover) but they preferred backwaters in both vegetation over sand and within boulders (instream visual cover) (c). * = excluded substrate codes not possible within cover type.

deeper waters are preferred, may be a reflection of adult use. *S.meridianus* were found utilizing marginal vegetation adjacent to flow in pools and runs but they preferred the cover of boulders or vegetation in quiet waters. Adults would be expected to have similar needs but are probably found in deeper pools unsuitable for electrofishing.

MANAGEMENT CONSIDERATIONS

S.meridianus is classified as rare in the red data book (Skelton, 1987) because of its limited distribution.

It seems that *S.meridianus* is limited by its habitat preference for quiet waters with cover in vegetation and rock substrates. In a system without a well developed floodplain and little lose substrate (Fig.7.15f) *S.meridianus* populations are split between the upper Sand River with its warm low order rocky reaches, and the coastal floodplains.

Like *T.rendalli* it responded favourably to the failure of the rainy season, increasing in numbers in the upper Sand River in the sluggish but still flowing reaches. Unlike *O.mossambicus* they were unable to breed in the lower reaches of the Sand River within crowded drought pools, although individuals did survive the full five months of isolation. An interesting correlation existed between it and instream refuge pools (Vol II). Like *B.viviparus*, *S.meridianus* individuals were isolated in pools associated to flow proximity. This may relate to its preference for the numerous small minnows as food which we have show prefer quiet water but mostly marginal to flow (Table 7.10).

Tilapia rendalli

(red-breasted tilapia) Figure 7.39

GENERAL DISTRIBUTION

Widespread from the eastern and southern Zaire basin southward in warm waters to southern Natal (Skelton,1993). Gaigher recorded this species in all the lowveld tributaries of the Limpopo and Incomati. It also occurs on the coastal plains and in estuaries.

WITHIN THE SABIE-SAND SYSTEM

- **Distribution:** In the Sabie system *T.rendalli* is confined to the warm waters of the lowveld. It was recorded at every station between site 6 (402 mASL), 11 (538 mASL) and site 20 (140 mASL) on the Mozambique border.

- **Abundance:** *T.rendalli* makes up 8% of the LZ species assemblage (Table 7.2a), but like almost all species in the lowveld, their numbers are seasonally influenced. Their relative abundance was lowest in May (2%, Fig. 7.8b), at the start of the dry season when flood spawning cyprinids were most numerous. Their relative numbers remained low until the start of the summer months before the rains when their density increased dramatically (24%, Fig. 7.8d) in the warm slow-flowing runs which are used for breeding. By February, *T.rendalli*'s numbers had waned again, with flood spawner numbers increasing.

MICROHABITAT NEEDS

Number of records: juveniles 117

Number of individuals: juveniles 206

Juveniles
Preferred velocity : 0 $m.s^{-1}$
Preferred depth : 10-35 cm
Preferred substrate: gravel/pebble to boulder
Preferred cover : visual cover

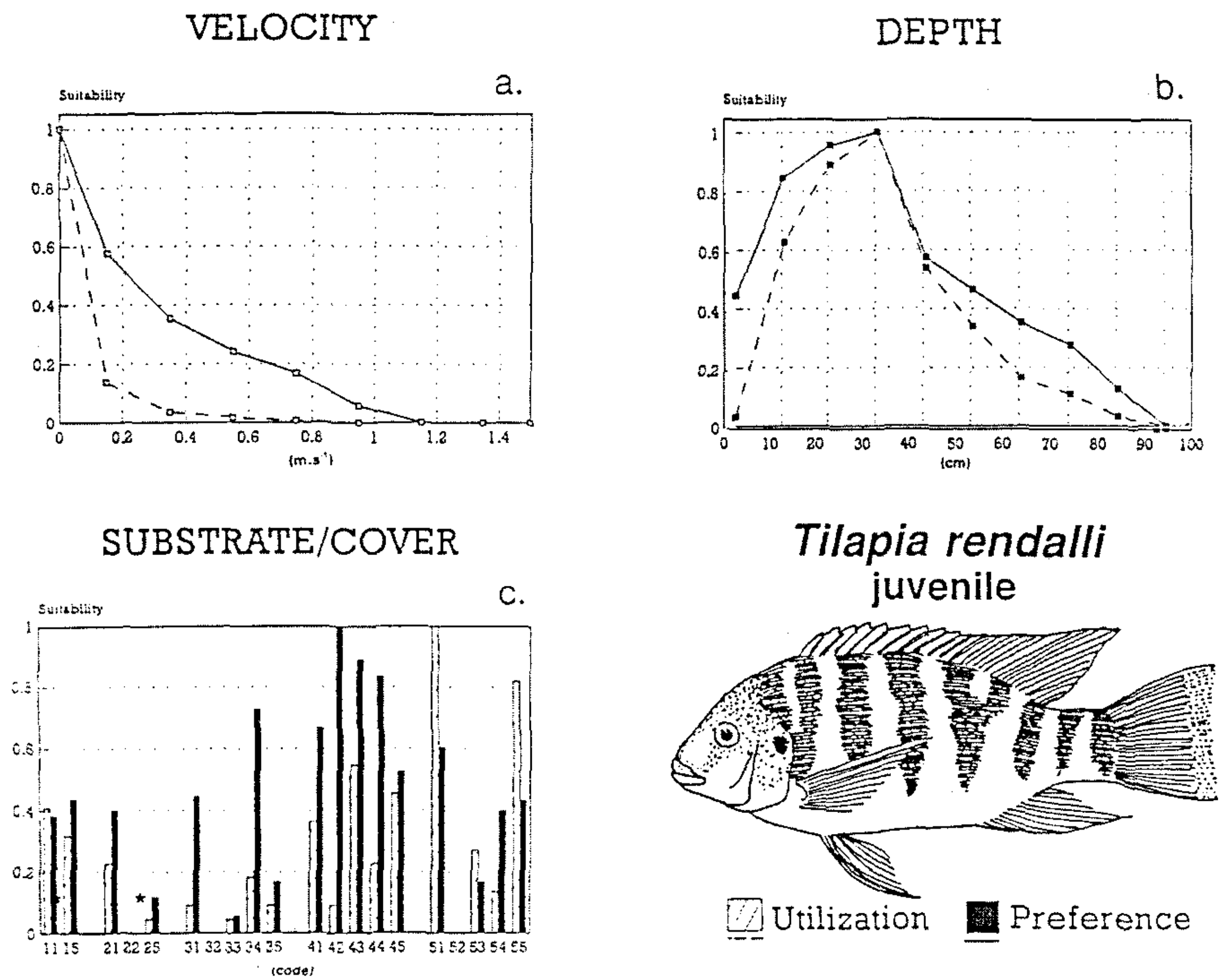

Figure 7.39: Utilization and preference curves for velocity and depth, as well as substrate/cover histograms for *Tilapia rendalli* juveniles. Juveniles preferred shallow (32 cm) backwaters (b) in zero flow (a). They were mostly collected in marginal vegetation over both fines and bedrock (c) adjacent to flow (combined cover) but they preferred quiet backwaters with no flow within gravels, cobbles, boulders or vegetation. Some preference for boulders in current (instream velocity shelter) was shown. * = excluded substrate codes not possible within cover type.

T.rendalli juveniles were found in backwaters and pools (Table 7.10) where they utilized shallow waters (32 cm deep) (Table 7.11), as suggested by (Skelton,1993). *T.rendalli* juveniles were most often found in the cover of vegetation bordering pools with flow or in runs. Their preference however was for quiet waters in cover which ranged from vegetation to boulder. In marginal flows they showed some preference for boulder cover. Adults were found in deeper pools and so were not sampled often enough for microhabitat curve analysis.

MANAGEMENT CONSIDERATIONS

T.rendalli is consistently dispersed within the lowveld waters, at times numerous, and sensitive to seasonal changes, suggesting that it is a useful indicator species.

T.rendalli responded to the failed wet season, as it would to a typical dry season, by increasing its relative numbers at the expense of flushing flow-dependent species. Percentages increased from 1% throughout the LZ in May 1991 to 20% by May 1992. However *T.rendalli* was unable to breed in the extreme conditions of the drought in refuge pools (Vol II) where their numbers were reduced more substantially than some other tolerant species. This suggest that they may be sensitive to harsh drought conditions. Their numbers were reduced by May 1993, unlike those of *O.mossambicus*.

If the lowveld rivers are deprived of seasonal flushing flows, but a base-flow is maintained, the numerical importance of this cichlid would increase greatly.

Varicorhinus nelspruitensis

(Incomati chiselmouth) Figure 7.40

GENERAL DISTRIBUTION

Endemic to the escarpment streams of Incomati and Phongolo system (Skelton, 1993 & Gaigher, 1969).

WITHIN THE SABIE-SAND SYSTEM

- **Distribution:** *V.nelspruitensis* is found within the cooler FHZ waters of the Sabie and Marite Rivers above 488 mASL (site 5).

- **Abundance:** *V.nelspruitensis* makes up 10% of the species assemblage in the FHZ (Fig. 7.7a). They are known to be summer spawners but their numbers were not particularly seasonal, although they were recorded at their lowest following the wet season (May, 5%). This may partly be explained by the large increase of the relative number of *B.polylepis*.

MICROHABITAT NEEDS

Number of records: juvenile 64

Number of individuals: juvenile 87

Juveniles
Preferred velocity : 0-0.6 $m.s^{-1}$
Preferred depth : 20-80 cm
Preferred substrate: boulder to bedrock
Preferred cover : visual or combined visual/velocity shelter

Juveniles had little preference for a any particular flows, except for avoiding the highest of flows (>1.2 $m.s^{-1}$). They were found in almost all flow velocities available in the high gradient FHZ (Fig. 7.15a), from quiet waters adjacent to flow, to rapid runs in shallow waters

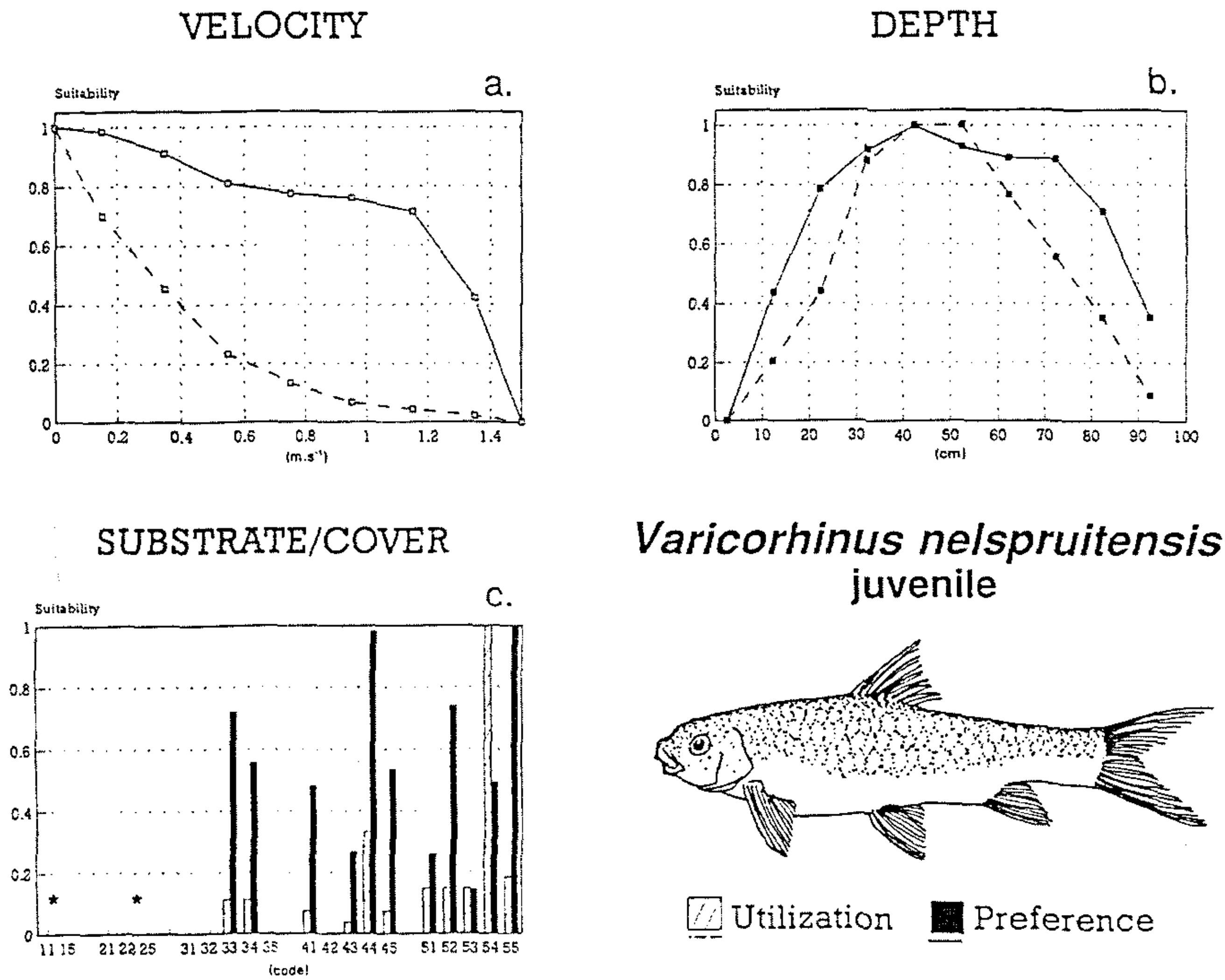

Figure 7.40: Utilization and preference curves for velocity and depth, as well as substrate/cover histograms for *Varicorhinus nelspruitensis* juveniles. Juveniles mostly preferred moderate flows (a) of less than 0.6 $m.s^{-1}$ in shallow waters (43 cm) (b). They took shelter in a variety of substrate and cover types (c), predominately boulders in flow (combined instream cover) but preferred root mats adjacent to cobble in flow and boulder in quiet waters. * = excluded substrate codes not possible within cover type.

(43 cm deep). Juveniles did utilize mostly rock and boulder runs, but they preferred visual boulder cover in quieter waters and marginal vegetation or cobble in flow. Adults were difficult to sample, possibly because of their deeper water requirements. They were gill-netted in cool deep pools where flow was sluggish.

MANAGEMENT CONSIDERATIONS

V.nelspruitensis is very restricted in its distribution within the Sabie system and may be limited by substrate needs. *V.nelspruitensis* needs hard substrates for effective feeding, as its lips are modified to scrape periphyton from rock. Adults would also find the scarcity of suitable deep water pools limiting. Juveniles relatively abundant during the drought when flows remained perennial but waters were warmer.

During the 1992 drought, summer flows were consistently low and this resulted in the substantial increase of *V.nelspruitensis*, (5% in May 1991 to 19% in May 1992) (Fig. 7.11a-b). They were further able to survive the passage of the extreme dry season.

Numbers of *V.nelspruitensis* and other common cyprinid species are probably limited in the FHZ by the high current speeds of normal summer flows.

7.5.4 SYNTHESIS OF MICROHABITAT REQUIREMENTS

Flow was arguably the strongest of factors structuring the use of habitat by organisms. Flow preference was used to divide the baseline shallow-water fish assemblage into groups of species that were typical of different macrohabitats:

a) Backwaters and pools
b) Quiet waters marginal to flow
c) Runs
d) Riffles and rapids

a) Fishes of Backwaters and Pools

Eight lifestages of six species of the baseline assemblage preferred zero flow to all other flow velocities (Table 7.10). This included all the target cichlids and two deep pool minnows (*B.annectens* & *B.radiatus*). They all belong to the LZ baseline assemblage where quiet waters are more common (Fig. 7.15d). Cichlids were further able to breed in early summer, independent of the seasonal summer flows. All these species were widespread in the low-order warmwater streams of the lowveld and extended onto the coastal plain. Lifestages of the remaining species that were important in both FHZ and LZ streams, preferred some degree of flow. They were more numerous in the foothills or low-order lowveld streams with none resident in the lower Incomati system within the coastal plain.

Most backwater cichlids preferred waters of shallow to medium depths (>20-80 cm deep; Table 7.11) except *P.philander* which preferred very shallow waters (10 cm deep). The two pool minnows preferred the deepest of pools sampled (>90 cm deep).

Almost lifestages of all species studied preferred some type of direct instream cover. Fishes of backwaters and pools preferred visual instream cover in zero-flow (Table 7.13) of all types (Table 7.12). They particulary preferred marginal vegetation (substrate code 1) and pebble (substrate code 2). The preference for marginal vegetation is masked but can be inferred

Table 7.10: Summary of velocity microhabitat requirements for target fish lifestages of the Sabie-Sand system (Figures 7.16-7.40). Four macrohabitat types are discussed based on flow microhabitat requirements. Often juvenile and adult lifestages show different preference. Six species and eight lifestages preferred predominately still waters (backwaters & pools). Here preference peaked at zero flow and was <0.2 $m.s^{-1}$ at a suitability of 0.6. This included all the cichlids and the two minnows. Some lifestages preferred quiet waters adjacent to flow (preference peaks at zero flow with flows >0.2 $m.s^{-1}$ at a suitability of 0.6). They were predominantly minnows and juveniles of run species. Five lifestages preferred runs (flows between >0-0.6 $m.s^{-1}$) while six preferred riffles to runs (flows >0.2-1.4 $m.s^{-1}$).

SPECIES	FLOW PREFERENCE			
	BACKWATERS & POOLS	MARGINAL FLOWS	RUNS	RIFFLES & RAPIDS
Barbus annectens (juveniles)	Zero			
Barbus radiatus (all)	Zero			
Oreochromis mossambicus (juveniles)	Zero			
Oreochromis mossambicus (adults)	Zero			
Pseudocrenilabrus philander (juveniles)	Zero			
Pseudocrenilabrus philander (adult)	Zero			
Serranochromis meridianus (juveniles)	Zero			
Tilapia rendalli (juveniles)	Zero			
Micralestes acutidens (juveniles)		Zero to 0.1		
Barbus unitaeniatus (all)		Zero to 0.2		
Barbus viviparus (juveniles)		Zero to 0.2		
Barbus trimaculatus (juveniles)		Zero to 0.3		
Barbus viviparus (adults)		Zero to 0.5		
Varicorhinus nelspruitensis (juveniles)		Zero to 0.6		
Barbus polylepis (juveniles)			>0 - 0.2	
Barbus trimaculatus (adults)			>0 - 0.2	
Micralestes acutidens (adults)			>0.1 - 0.2	
Barbus eutaenia (juveniles)			>0.4 - 0.5	
Barbus eutaenia (adult)			>0.0 - 0.6	
Opsaridium zambezense (juveniles)				0.2 - 0.7
Barbus marequensis (juveniles)				0.5 - 0.8
Labeo molybdinus (juveniles)				0.6 - 1.5
Chiloglanis anoterus (juveniles)				>1.3
Chiloglanis anoterus (adults)				>1.4
Labeo molybdinus (adults)				>1.4

Table 7.11: Summary of depth microhabitat preference for target fish lifestages of the Sabie-Sand system ordered within identified macrohabitats types (Figures 7.16-7.40). Larger asterisk marks the peak of preference while the regular asterisk denotes a preference above 0.8 suitability. Eight lifestages of seven species prefer depths from shallow backwaters to deep pools. Six lifestages of five species prefer habitats marginal to flow from shallow waters (25-45 cm: *Barbus viviparus*) to medium depths (55-85 cm). Five lifestages of four species similarly prefer a range of shallow to medium depths. Six lifestages of four species of riffle to rapid areas prefer shallow waters (25-45 cm) with large adult *Labeo molybdinus* preferring deep waters (>90 cm).

MACROHABITAT	SPECIES	DEPTH PREFERENCE (cm)									
		10	20	30	40	50	60	70	80	90	>90
BACKWATERS & POOLS	*Pseudocrenilabrus philander* (adults)	*									
	Pseudocrenilabrus philander (juveniles)	*									
	Serranochromis meridianus (juveniles)		•	*	•	•					
	Oreochromis mossambicus (juveniles)		•	*	•						
	Tilapia rendalli (juveniles)	•	•	*	•						
	Oreochromis mossambicus (adults)		•	•	•	*	*	•			
	Barbus annectens (juveniles)								•	•	*
	Barbus radiatus (all)									•	*
MARGINAL TO FLOW	*Barbus viviparus* (adults)		*	•							
	Micralestes acutidens (juveniles)		•	*	•	•					
	Barbus viviparus (juveniles)		•	*	•						
	Barbus unitaeniatus (all)		•	•	*	*	•				
	Varicorhinus nelspruitensis (juveniles)		•	•	*	•	•	•	•		
	Barbus trimaculatus (juveniles)						•	*	•	•	
RUNS	*Barbus eutaenia* (adults)	*	•	•							
	Barbus eutaenia (juveniles)		*	•							
	Micralestes acutidens (adults)		•	*	•	•					
	Barbus trimaculatus (adults)					•	•	*	*	•	
	Barbus polylepis (juveniles)							*	•		
RIFFLES & RAPIDS	*Barbus marequensis* (juveniles)		*								
	Opsaridium zambezense (juveniles)	•	*	•							
	Chiloglanis anoterus (juveniles)		*	•							
	Chiloglanis anoterus (adults)	•	*	*	•	•					
	Labeo molybdinus (juveniles)		•	*	•	•					
	Labeo molybdinus (adults)									•	*

Table 7.12: Summary of substrate microhabitat preference, independent of cover, for target fish lifestages of the Sabie-Sand system ordered within identified macrohabitats types (Figures 7.16-7.40). Substrate codes (units); Table 7.9. Fish found in backwaters and pools utilized all substrate types (1), including both marginal vegetation and fines, which were less preferred by more flow dependent species, and gravel (2). Quiet water species when found in marginal flows preferred boulder (4) while fishes in runs were often found in marginal vegetation (5). Riffle and run species preferred gravel. Gravel was a limited substrate type in both the FHZ and LZ.

MACROHABITAT	SPECIES	SUBSTRATE CODES				
		1	2	3	4	5
BACKWATERS & POOLS	*Oreochromis mossambicus* (adults)	0				•
	Pseudocrenilabrus philander (juveniles)		0			
	Barbus annectens (juveniles)	0	0	0		
	Pseudocrenilabrus philander (adults)	0	0		0	
	Tilapia rendalli (juveniles)	•	0	0	0	
	Serranochromis meridianus (juveniles)	0		•	0	
	Oreochromis mossambicus (juveniles)	0	•	0		0
	Barbus radiatus (all)					0
MARGINAL TO FLOW	*Barbus viviparus* (adults)		0		•	
	Micralestes acutidens (juveniles)	•	0		0	
	Barbus trimaculatus (juveniles)			0	0	•
	Barbus viviparus (juveniles)		•		0	•
	Barbus unitaeniatus (all)	•		•	0	0
	Varicorhinus nelspruitensis (juveniles)		•	•	0	0
RUNS	*Micralestes acutidens* (adults)		0			
	Barbus eutaenia (adults)	0	•	0		•
	Barbus eutaenia (juveniles)		0	•		0
	Barbus polylepis (juveniles)	•	•		•	0
	Barbus trimaculatus (adults)				0	0
RIFFLES & RAPIDS	*Chiloglanis anoterus* (juveniles)		0			
	Opsaridium zambezense (juveniles)		0			
	Chiloglanis anoterus (adults)		0			•
	Labeo molybdinus (juveniles)		0	0	•	
	Labeo molybdinus (adults)				0	
	Barbus marequensis (juveniles)					0

when visual cover is coded for over substrates where no cover is expected (ie over sand or bedrock quadrats).

Table 7.13: Summary of cover microhabitat preference, independent of substrate, for target fish lifestages (Figures 7.16-7.40) of the Sabie-Sand system ordered within identified macrohabitats types. Cover codes (tens); Table 7.9. Zero records preference above 0.8 suitability while an asterisk records suitability above 0.6. Most fish examined preferred direct cover, both visual and/or velocity, to no cover. Backwater species (mostly cichlids) preferred instream-visual cover (40). When fish that preferred quiet waters utilized marginal flows (typically cyprinids) they preferred velocity shelter. Fish in runs preferred both velocity and visual cover except *Barbus eutaenia* (juveniles) which preferred shade (20) and roots (50). In the turbid waters of riffles and rapids, combined cover was often preferred (50).

MACROHABITAT	SPECIES	COVER CODES				
		10	20	30	40	50
	Barbus annectens (juveniles)	0		0	0	
	Oreochromis mossambicus (juveniles)	•	•	0	0	0
	Tilapia rendalli (juveniles)			•	0	•
BACKWATERS	*Serranochromis meridianus* (juveniles)			•	0	•
& POOLS	*Pseudocrenilabrus philander* (adults)				0	
	Pseudocrenilabrus philander (juveniles)				0	
	Barbus radiatus (all)				0	
	Oreochromis mossambicus (adults)				0	•
	Barbus viviparus (juveniles)		•	0	•	
	Micralestes acutidens (juveniles)		•	0	0	
MARGINAL TO	*Barbus trimaculatus* (juveniles)		•	0	0	
FLOW	*Barbus unitaeniatus* (all)	•			0	
	Barbus viviparus (adults)			•	0	
	Varicorhinus nelspruitensis (juveniles)			•	0	0
	Barbus eutaenia (juveniles)		0	•		0
	Barbus eutaenia (adults)			0		•
RUNS	*Barbus trimaculatus* (adults)			0	0	
	Barbus polylepis (juveniles)			•	0	•
	Micralestes acutidens (adults)				0	
	Barbus marequensis (juveniles)	0				
	Labeo molybdinus (adults)			0		0
RIFFLES &	*Labeo molybdinus* (juveniles)			0	0	0
RAPIDS	*Opsaridium zambezense* (juveniles)				0	
	Chiloglanis anoterus (juveniles)					0
	Chiloglanis anoterus (adults)					0

b) Fishes Marginal to Flowing Waters

Six life stages of five fish species (Table 7.10) preferred quiet waters (zero velocity), but mostly in close proximity to flow (velocities of >0.2 $m.s^{-1}$ 0.6 suitable). They were all small minnows or juveniles of the larger cyprinid *V.nelspruitensis* with the exception of juveniles of the characin *M.acutidens*.

Shallow water fishes of marginal flows preferred all but the shallowest and deepest of waters sampled (>20-90 cm deep). They too preferred direct instream cover (Table 7.13) especially visual cover in quiet waters or velocity cover in moderate velocities. These minnows share a substrate preference (Table 7.12) for boulder except for adult *B.viviparus* which preferred gravel/pebble.

c) Fishes of Runs

Five lifestages of four species (Table 7.10) preferred slow to moderate velocities in runs (>0-0.4 $m.s^{-1}$). They were all medium sized minnows or juveniles of large cyprinids (*B.polylepis*) excepting the adults of the characin *M.acutidens*. They showed little preference (Table 7.11) for depth within the shallower waters of runs.

The target fishes typical of runs all preferred some cover (Table 7.13), mostly instream velocity or visual, particularly marginal vegetation/roots (substrate codes 1 & 5) (Table 7.12).

d) Fishes of Riffles and Rapids

Six lifestages of four species preferred the high velocities and turbid flows of riffles and rapids (>0.4->1.5 $m.s^{-1}$) (Table 7.10). They included riffle specialists including the two species known to be sensitive to low-flow conditions (*C.anoterus* & *O.zambezense*).

Depth preference for these fishes (Table 7.11) probably reflects the shallow nature of riffle habitat (>20-50 cm deep) with only adults of the large cyprinid *L.molybdinus* preferring the deepest waters sampled (>90 cm deep).

The cover preferred by riffle species (Table 7.13) is influenced by the combined velocity and visual cover offered by turbid flows. Both *C.anoterus* and *L.molybdinus* juveniles and adults preferred the combined cover of riffles with a gravel/pebble substrate (except the large adult labeos which preferred boulder) (Table 7.12). *O.zambezense* preferred visual cover afforded in the upstream end of pools over a gravel/pebble substrate, while *B.marequensis* juveniles preferred exposed bedrock in fast flows.

8. COMPARISONS OF CONDITIONS IN THE SABIE-SAND WITH THE LETABA RIVER

8.1 INTRODUCTION

A report of a two year study of the relationship between low-flows and the river fauna of the Letaba River (Chutter and Heath, 1993) has recently been produced. One of the joint aims of that project and the project to investigate the pre-impoundment conditions of the Sabie-Sand River system was to make comparisons of the findings of the two, in order to improve our understanding of the similarities and differences between the rivers of the Kruger National Park.

The purpose of this chapter is to present some preliminary comparisons of the conditions and fauna of the two rivers. Such comparisons have to be treated with caution, since the two rivers have many differences, and it is therefore difficult to disentangle the precise reasons for any differences between the faunas. Efforts were made to standardise the sampling procedures used by the two project teams, but there were inevitable differences in the intensity of sampling and in the details of the methods used. For example, results from fish sampling are crucially dependent on the fishing methods used, and the types of method that are most suitable in any part of the river depend on the habitats, water depth, current speed, and size of the river. For both projects, electro-shockers were used in shallow water, and gill-nets in deeper water. In addition, seine nets were used to sample off-stream pools in the Letaba River and fish traps were used to sample small species in the Sabie-Sand. Apart from these differences, it is impossible to equate the relative sampling effort in the two rivers, so no attempt is made in this paper to compare the relative abundances of the species.

Sites sampled in the Letaba River were all downstream of the Fanie Botha Dam, and were therefore confined to the middle- and lowveld. The Sabie-Sand system was sampled from the upper reaches on the escarpment to the Mozambique border, but, for the purposes of this paper, only the fauna from sites in the middle and lower reaches of the river, downstream of Hazeyview, are compared with the Letaba fauna. The middle- and lowveld reaches of both the Letaba and Sabie-Sand Rivers are within the Lowveld Zone (LZ) as seen by the presence of the indicator species *Barbus viviparus*.

8.2 PHYSICAL CHARACTERISTICS OF THE RIVERS

The Sabie is a perennial river, while the Letaba is now a temporary system, although it was a perennial system in its natural state. The Sand River, the major tributary of the Sabie system, was probably perennial along most of its length in its natural state, but is now often reduced to pools during the dry season, and the sandier reaches may dry up completely during severe droughts, as in 1992.

Table 8.1: Summary of the physical characteristics of the Sabie and Letaba rivers.

CHARACTERISTIC	SABIE RIVER	LETABA RIVER
Source Altitude (m)	2 130	1 830
Distance to Mozambique border (km)	175	280
Catchment area (km^2)	6252	13824
Stream order in KNP	5	5
MAR (m^3x10^6)	849	819
MAP (mm)	833	671
Sediment yield ($tonnes/km^2/yr$)	400-600	400-600

The Letaba is a larger system than the Sabie, having a channel length 105 km longer than the Sabie to the Mozambique border, and a catchment area more than twice as big, although both are fifth order rivers. Table 8.1 summarises the main physical characteristics of the two rivers. The Sabie rises at a higher altitude than the Letaba, and being shorter, has a far steeper gradient to the Mozambique border. This steepness gives the Sabie its characteristic bedrock and boulder channel in much of the middle reaches upstream of the Sabie-Sand confluence. Downstream of the confluence the river acquires many of the typical features of the Sand River, becoming braided and sandy along much of its length. The Letaba River is also a mixture of bedrock and sandy substrates, but is heavily modified by weirs, causeways and dams. The middle and lower reaches of the river sampled by Chutter and Heath are regulated by the Fanie Botha Dam near Tzaneen, and 8 of the 14 sampling sites were situated in or immediately downstream of dams, weirs or causeways. The Sabie River is unregulated and contains only small gauging weirs along the mainstream.

The Sabie River is considered to be the least impacted of the rivers of the KNP, and to contain the most diverse fauna of any river in South Africa (O'Keeffe *et al.*, 1989a). The Letaba is considered the most degraded, mainly because of the modifications to the flow regime and the regulation by the Fanie Botha Dam.

8.3 WATER CHEMISTRY

The water quality of both the Sabie and Letaba systems is good to excellent. Table 8.2 summarises some of the main water quality variables available from sites on the western and eastern boundaries of the KNP. Total dissolved salts in the Sabie are at exceptionally low concentrations, the mean concentrations being not far removed from distilled water! Total phosphate and nitrogen concentrations are similarly low. In the Letaba River dissolved salts are 4 to 6 times as high as in the Sabie, but are still very much lower than the concentrations in drinking water throughout much of South Africa. Nutrient concentrations are also higher,

Table 8.2: Water quality at the western and eastern boundaries in the Sabie and Letaba rivers. Means and ninetieth percentiles (in brackets) are shown. Data in brackets are the maximum measured concentrations. Data from van Veelen (1990) and Moore *et al.* (1991).

RIVER	TDS	EC	pH	NO_3+NO_2	TOT P
Sabie (Phabene)	74 (88)	11 (13)	7.0 (6.4 - 7.4)	0.22 (0.32)	0.014 (0.029)
Letaba (Mahlangene)	283 (527)	42 (76)	7.6 (7.1 - 8.1)	0.26 (0.58)	0.034 (0.053)
Lower Sabie	89 (103)	13 (15)	7.1 (6.5 - 7.8)	0.13 (0.26)	0.017 (0.033)
Letaba (Klipkoppiesdrift)	236 (350)	-	7.9 (7.2 - 8.5)	-	0.037 (0.15)

but are still well within acceptable limits. From preliminary experiments into the tolerances of invertebrates from the Sabie River, which have been run by the Institute for Water Research, it does not appear that the concentrations of dissolved salts in the Letaba River would have any adverse effects on the fauna. In these experiments, invertebrates were kept in experimental streams at concentrations of between 70 and 1100 mg/l TDS without showing any additional signs of stress at the higher concentrations.

8.4 THE FISH FAUNA

Thirty-nine fish species have been recorded from the Letaba River according to the records of the Transvaal Provincial Administration, and 33 of these were sampled during the recent study by Chutter and Heath (1993) (see Table 8.3a). The 6 species not recorded in this study included three which are restricted to the upper reaches of the river, one rarity (*Platygobius aenofuscus*) only recorded from the confluence of the Letaba and Olifants Rivers, the Tiger fish (*Hydrocynus vittatus*) which has recently been recorded from the lower reaches of the river in a separate study, and an eel (*Anguilla marmorata*) which is described as being "not

Table 8.3a: Fish species found during this project in the middle Sabie and Sand rivers, and by Chutter & Heath (1993) in the Letaba River. The fourth column indicates those species common to all three rivers.

FISH SPECIES	SABIE RIVER	SAND RIVER	LETABA RIVER	SABIE, SAND + LETABA
Anguilla bengalensis	•	+		
Anguilla mossambicus	+	+	+	+
Barbus afrohamiltoni	+	•	+	+
Barbus annectens	+	+	+	+
Barbus brevipinnis		•		
Barbus eutaenia	+	+	+	+
Barbus lineomaculatus			+	
Barbus marequensis	+	+	+	+
Barbus paludinosus	+	+	+	+
Barbus radiatus	+	+	+	+
Barbus toppini	+	+	+	+
Barbus trimaculatus	+	+	+	+
Barbus unitaeniatus	+	+	+	+
Barbus viviparus	+	+	+	+
Brycinus imberi	+		+	
Chiloglanis anoterus	+	+		
Chiloglanis paratus	+	+	+	+
Chiloglanis pretoriae			+	
Chiloglanis swierstrai	+	+	+	+
Clarias gariepinus	+	+	+	+
Glossogobius callidus	+	+	?	?
Glossogobius giuris	+		+?	
Hydrocynus vittatus	+			
Labeo congoro	+		+	
Labeo cylindricus	+	•	+	+
Labeo molybdinus	+	+	+	+
Labeo rosae	+	+	+	+
Labeo ruddi	+	+	+	+
Marcusenius macrolepidotus	+	+	+	+
Mesobola brevianalis	+	+	+	+
Microlestes acutidens	+	+	+	+
Opsaridium zambezense	+	+		
Oreochromis mossambicus	+	+	+	+
Petrocephalus catostoma	+	+	+	+
Pseudocrenilabrus philander	+	+	+	+
Serranochromis meridianus	+	+		
Shilbei intermedius	+	+	+	+
Synodontis zambezensis	+	•	+	+
Tilapia rendalli	+	+	+	+
Tilapia sparrmanii			+	

• : marginal records

easy to catch even when abundant" (Chutter and Heath, 1993). In comparison, 49 fish species have been recorded from the Sabie-Sand system, and during the current study 37 of these were sampled in the middle and lower reaches of the Sabie-Sand. Of the species not recorded in Table 8.3, all were either restricted to the upper reaches, or are rarities which have only been recorded occasionally. It therefore appears that the whole suite of lowveld species typical to each river is still present, but whether at reduced densities compared to historical conditions cannot be inferred.

Table 8.3b: Fish species found only in one of the three rivers.

FISH SPECIES	SABIE RIVER ONLY	SAND RIVER ONLY	LETABA RIVER ONLY
Barbus brevipinnis		+	
Barbus lineomaculatus			+
Chiloglanis pretoriae			+
Hydrocynus vittatus	+		
Tilapia sparrmanii			+

Thirty species from the present studies were common to the Letaba and Sabie Rivers, and 27 species were common to the Letaba and Sand Rivers (Table 8.3). Unsurprisingly, all the species found in the Sand River were common to the Sabie. Five species commonly found in the Sabie River were not found in the Letaba. In addition, *Barbus brevipinnis* was recorded rarely from the middle reaches of the Sand River, but is generally restricted to the upper reaches of the Sabie and Sand, and was not recorded from the Letaba. *Labeo congora* was present in the Sabie, but was only found once in the Letaba River. It requires good summer flows and favours deep pools, and may well have been excluded from most of the Letaba by changes in the hydrological regime and consequent loss of favourable habitat. *Anguilla bengalensis* was found once from the lower Sabie and within the middle Sand, but not in the Letaba. *Hydrocynus vittatus* was sampled from the Sabie and is known to be in the lower reaches of the Letaba (see above), but its distribution in both rivers may have been restricted by flow reductions, diminishing deep-water habitat, and barriers to migration.

Table 8.3c: Fish species common to the rivers indicated.

FISH SPECIES	SABIE + SAND ONLY	SABIE + LETABA ONLY
Anguilla bengalensis	+	
Brycinus imberi		+
Chiloglanis anoterus	+	
Glossogobius callidus	+	
Labeo congoro		+
Opsaridium zambezense	+	
Serranochromis meridianus	+	

Chiloglanis anoterus, a small catlet with a wide sucker mouth for attaching itself to rocks in clear fast-flowing reaches in rapids, was relatively common in the Sabie River, but has never been recorded from the Letaba. It was also recorded from two sites in the upper-middle Sand River, downstream of healthy populations in the cooler foothill zone. *Opsaridium zambezense*, which was not uncommon in the Sabie but has never been recorded from the Letaba, is a species which requires perennial flow and clear water, and may well be a suitable indicator species for these conditions. *Glossogobius callidus*, a goby, was commonly recorded from the lower Sabie, but not from the Letaba. There is a strong possibility that this species was mis-identified as *G.giuris* in the Letaba. The only other species which is exclusive to the Sabie River is *Serranochromis meridianus*, confined to the Sabie-Sand system within the eastern Transvaal, which has therefore never been present in the Letaba.

Three species of fish were sampled in the Letaba but not found in the middle Sabie or the Sand. *Tilapia sparrmanii* is a widespread and hardy species throughout the country, but was only found in very low numbers in the Letaba, and only in the upper reaches of the Sabie and Marite. *Barbus lineomaculatus*, classified as being of intermediate sensitivity by Kleynhans (1991), was also found in very low numbers in the Letaba, but not in the Sabie-Sand. The third species apparently exclusive to the Letaba was *Chiloglanis pretoriae* which was the most numerous species sampled by Chutter and Heath (1993). This species is closely related to, but distinct from, *C.anoterus*, and may be comparable ecologically. It seems to occur in greater concentrations within the warmer mid-reaches of the Letaba, than does its sister species in the mid-Sabie.

8.5 INVERTEBRATES

Even more caution must be applied in the comparison of the invertebrate fauna of the two rivers. Compounding the errors introduced by the variability in the sampling effort, and the extreme heterogeneity of distribution typical of stream invertebrates, is the inadequate taxonomy of these groups. Many groups such as the *Oligochaeta* can rarely be identified further than to class, and even those which can often be taken to species, such as the *Ephemeroptera*, are often in dire need of revision. This comparison has had to work at taxonomic levels common to the studies on both the rivers (i.e. at the lowest common taxonomic level for each group). If, for example, a mayfly has been identified to species level in the Letaba, but only to genus level in the Sabie, the comparison can only be made at the genus level. In consequence, the comparisons are often at a relatively coarse level, and these preliminary results can only serve as an indication of the broad differences between the two systems.

The comparison used taxon lists from the present studies, and from that of Moore and Chutter (1988), who surveyed all the main rivers within the Park. Data from all habitats have been used, even though Chutter and Heath (1993) concentrated mainly on the stones-in-current fauna. The sampling intensity in the Sabie River during the present study was also more intensive and longer-term than that in the Letaba, so that at least some of the groups found only in the Sabie may be present in low densities in the Letaba. Nevertheless, we can be confident that all the common and abundant groups in both rivers are represented in the collections.

Table 8.4 Comparison of invertebrate taxa from the Letaba and Sabie-Sand systems. Data from Fourie (unpublished), Chutter and Heath (1993) and Moore and Chutter (1988). Taxonomic levels are variable because of identification difficulties, but have been equated for the two river systems. "Total" refers to the total number of taxa recorded fo. each system. The taxa listed in subsequent rows are those which are exclusive to each system.

		SABIE/SAND	LETABA
TOTAL		135	110
Ephemeroptera	Adenophlebiodes sp.	+	
	Compsoneuriella sp.	+	
	Demoulina sp	+	
	Dicercomyzon sp.	+	
	Machadorythus sp.	+	
	Neurocaenis sp.	+	
	Notonurus sp.		+
	Oligoneuriopsis elizabethae	+	
	Prosopistoma sp.	+	
	Pseudopannota vinosum		+
Trichoptera	Athripsodes sp	+	
	Barbarochthon sp.	+	
	Diplectroninae	+	
	Psychomyiellodes sp.	+	
Odonata	Allocnemis sp.	+	
	Chlorocypha sp	+	
	Ellatoneura sp	+	
	Enallagma sp.	+	
	Metacnemis sp.	+	
	Syncordulia sp		+
	Zygonyx sp	+	
Diptera	Atherix sp	+	
	Ceratopogonidae	+	
	Dolichopodidae		+
	Limnophora sp		+
	Procladius sp	+	
	Psychodidae sp	+	
	Stratiomyidae		+
Coleoptera	*Dryopidae*	+	
	Methles sp	+	
	Noteridae	+	
	Peschetius sp	+	
	Staphylinidae	+	
Hemiptera	Mesoveliidae	+	
	Microdinodes sp		+
	Micronecta sp	+	
	Pleidae	+	
Plecoptera	Neoperla spio	+	
Lepidoptera	Pyralidae	+	
Mollusca	Bulinus sp	+	
	Lymnaea sp		+
Oligochaeta	Dero sp.	+	
Tardigrada		+	

At common taxonomic levels 135 taxa have been recorded from the Sabie-Sand system compared to 110 from the Letaba (Table 8.4). Of these, 35 groups were exclusive to the Sabie-Sand, and 8 were exclusive to the Letaba. The animals found only in the Sabie-Sand were mainly insects (Table 8.4), and covered a wide range of orders: 8 mayflies; 4 caddisflies; 6 dragonflies; 4 dipteran flies; 3 hemipteran bugs; a stonefly; and a moth. Non-insects exclusive to the Sabie-Sand include a snail, a worm and a tardigrade water bear. The groups exclusive to the Letaba were also diverse, and included 2 mayflies; a dragonfly; 3 dipteran flies; a hemipteran bug; and a snail.

Once again this comparison highlights the greater diversity of the Sabie-Sand system, but also confirms that the fauna of the Letaba is far from impoverished. It would be rash to ascribe the differences in invertebrate communities in the two rivers simply to differences in the flow regimes, since the Sand River has a seasonal flow regime similar to the Letaba, and yet appears not to be inhabited by the 8 groups exclusive to the Letaba (Table 8.4).

8.6 CONCLUSION

The results presented here confirm the generally-held opinion that the Sabie River contains a more diverse fauna than the Letaba. However, the fauna of the Letaba is still diverse, and appears to have improved since the surveys reported by Russell and Rogers (1989) on fish, and by Moore and Chutter (1988) on invertebrates. These two earlier surveys were done in the wake of severe droughts in the early 1980's, and, at least in the case of Moore and Chutter's surveys, at a time when the Letaba was flowing much less frequently than during Chutter and Heath's recent study.

Moore and Chutter (1988) concluded that there had been little long-term change in the fauna of the Sabie River since the survey of 1959, and that it remained the most diverse of the rivers in the Park, while the Letaba was the least diverse. However, Chutter and Heath

(1993) considered that the Letaba contained a healthy diversity at the time of their study (1990 and 1991), but there has subsequently been the worst drought on record during 1992. The effects of this drought have been monitored (volume II) in the Sabie-Sand. They found that, although species have not disappeared from the rivers, the fish community suffered major changes in relative abundance, changing from a cyprinid-dominated community to one dominated by the hardy cichlid species *Oreochromis mossambicus* as the drought progressed. The invertebrate communities also suffered major changes, especially in the Sand River when it was reduced to standing water. These changes may not be irreversible, and the first stages of recovery were monitored in volume II, following good rains in late 1992, but the ability of the communities to recover from repeated drought conditions is very much in doubt. The constant reduction in flow with increasing upstream water demands is likely to cause these conditions.

Chutter and Heath (1993) consider that too much emphasis may have been placed on flow as the determining factor for fish and invertebrate communities, citing the similar diversities recorded during their study in flow-stressed reaches as in constantly-flowing reaches of the Letaba. They consider that reductions in diversity are more likely to be a consequence of multiple changes in the hydrology, water quality, use of agricultural biocides, etc. It is probable that the differences in diversity between the Sabie and the Letaba are also the consequence of a number of factors, including habitat diversity, the lack of instream barriers in the Sabie, lower turbidity in the Sabie, as well as the constant flow of water. To disentangle the effects of these factors would be very difficult, and therefore efforts need to be made to address all possible causes of river degradation.

This comparison has not pointed to the reasons for the differences in diversity between the two rivers, but has identified a number of species/groups which would repay closer study, since they are the ones which survive in one system but not the other. Among the fish, *Chiloglanis anoterus*, *Opsaridium zambezense*, and *Labeo congoro* might be the best indicator species to concentrate on, while the reasons for the continued survival in the Letaba of *Barbus* *eutenia*, a sensitive species requiring clear flowing-water habitat, could provide clues for the maintenance of habitat in other rivers. Of the invertebrates, the habitat requirements of the mayflies and caddisflies which are confined to the Sabie-Sand system should be identified, as should those of *Neoperla spio*, a stone fly which is wide-spread in low numbers in the Sabie and upper Sand rivers, but absent from the Letaba. A major priority will be to link these comparative findings about the biota to information on the geomorphology and riparian vegetation of the two rivers, information on which is being gathered by current projects in the programme. An understanding of the differences in the physical and vegetation structure of the rivers should improve our understanding of the reasons for the differences in the riverine fauna.

9. CONCLUSIONS: THE CONDITION AND COMMUNITIES OF THE SABIE-SAND SYSTEM

9.1 PHYSICO-CHEMISTRY

Water quality in the Sabie-Sand River is generally good to excellent, with the exception of elevated turbidity in the Sand River. In the upper reaches the pH is relatively low, and the system is therefore poorly buffered and sensitive to changes in the catchment. Concentrations of dissolved salts generally increased downstream, but were never high, and are well within even the most stringent user guidelines. The turbidity of water in the catchment is low during low-flows, and sediment yields in the catchment pose no serious threat to large reservoirs (Chunnett *et al.*, 1990). The Sand River experiences higher average turbidities than the Sabie, as might be expected of a more temporary system. The construction of the Zoeknog Dam resulted in the highest turbidities ever recorded (1400 NTU and 0.888 g/l). Very high turbidities were also measured in the Sand River following the collapse of the central section of the Zoeknog Dam. DO concentrations were on average at or around 100%, although some very low DO concentrations were measured in isolated pools during the 1991-92 drought, shortly before the pools dried out. Temperatures between 5.6 and 34.8°C were measured in the rivers, and it appears that the absolute temperature is less important than the rate of temperature change.

Nutrient concentrations for PO_4, NO_3, NO_2 and NH_4, in the Sabie and Sand rivers were generally very low, but phosphate concentrations up to 1.16 mg/l were measured at site 6 in the Sabie in April 1993; and 1.41 mg/l at site 9 in the Sabie in May 1993. Concentrations in excess of 1 mg/l are not only high for the Sabie, but for freshwaters in general, and would be likely to give rise to eutrophic conditions, especially in downstream impoundments.

The results of this project generally confirm the prevalent view that the water quality in the Sabie-Sand is adequate for all uses, but they do raise some disturbing concerns in relation to turbidity and nutrient concentrations. Water quality effects due to past gold-mining can still be seen today, in the form of an impoverished fish fauna in the middle reaches. The Sabie has been subjected to major water quality problems in the past, and the fauna has recovered due to the presence of unimpacted tributaries. The deterioration of flows and water quality in these tributaries would seriously impair the resilience of the river system to cope with further stress.

9.2 INVERTEBRATE COMMUNITY STRUCTURE

Invertebrate groups are closely related to the changing flow conditions throughout the three and a half years of the study, rather than to seasonal changes, or to different river zones. The drought had a very severe impact on invertebrate abundance, with a decrease of almost an order of magnitude between 1990 and the height of the drought in 1992. The pre-drought 1990 samples were by far the most diverse in terms of numbers of taxa per sample, averaging 29.4, compared to 14.8 for the drought upper samples, and 15.8 for the drought lower. The "recovery" samples were also depauperate, with an average of 14.3 taxa per sample. It seems clear that the drought halved the diversity of the riffle fauna, while recovery seems to take longer than the seven months of good flows which were sampled at the end of the project.

Eleven of the 36 taxa common in the 1990 pre-drought samples disappeared from the riffle habitat during the drought, and there were 6 taxa which occurred in the drought samples but did not occur in the wetter 1990 conditions. The marginal vegetation contained the most taxa (189), and the sediments the least (120). Abundances were high for all three habitats, and were particularly high for the sediments (2638 individuals per grab sample of 0.00225 m^3). The marginal vegetation contained the highest number of taxa which were restricted to one habitat (24), compared to 13 in riffles and only one unique taxa in soft sediments.

Sediments in pools and slow-flowing areas form the largest area of benthic habitat, especially in the lowveld, followed by bedrock, which harbours lower densities and diversities of invertebrates than riffle. Marginal vegetation is probably the next most common habitat, since it is present all the way along the river, at least during medium and high flows. Riffle, which forms the habitat for the most consistent and best indicator community, is by far the least common habitat, especially in the middle and lower reaches of the river.

An analysis of the microhabitat preferences of two of the major insect groups, in terms of substrate type, depth and current speed, indicates that the Ephemeroptera have less specific requirements than the Trichoptera. The Trichoptera showed a distinct preference for the riffle habitat, and avoided both emergent reeds and overhanging vegetation. Both groups occurred in highest densities of individuals and in numbers of taxa at depths between 0-30cm. The Trichoptera showed very clear preferences for stronger current speeds, but the Ephemeroptera were distributed throughout a wide range of flows from 0.25 to >1 $m.s^{-1}$.

From our analysis, it appears that 30 cm of medium to fast flowing water - between 0.63 to 1 $m.s^{-1}$, but not below the former - through the riffle, would provide ideal conditions, conducive to the maintenance of the maximum diversity and abundance of invertebrates.

9.3 FISH ASSEMBLAGES

Forty-nine species of fish were recorded in the Sabie-Sand catchment, including 4 alien species, making it the most species-rich river system in South Africa. The cooler montane-escarpment fauna is less diverse, but more species are regionally endemic. The more diverse lowveld fauna belongs to the tropical east-coast eco-region which includes much of Mozambique, from the lower Zambezi and Limpopo valleys and extends to Mkuzi, northern Zululand (Skelton, 1993). Both *Barbus brevipinnis* and *Serranochromis meridianus* are endemic to the Incomati system.

Fishes of very small adult size (< 10 cm) make up a high proportion of the Sabie-Sand rivers diversity, both within the low order feeder streams and potamon reaches. Cyprinids are the most abundant taxonomic group (48.9%) including 12 minnows and 8 large cyprinids, 5 of which are mudfishes (Appendix III). Catfish account for 20% of the total diversity, which includes 7 specialised small species within the genera *Amphilius* and *Chiloglanis*. Cichlids make up 11.1% (5 spp) of the species diversity, with *Oreochromis mossambicus* in particular dominating assemblages in many studies during times of drought.

Three patterns in the distribution and abundance of fishes within the Sabie-Sand rivers can be discerned:

1) Two broad ichthyological river zones, where one group of species replaces another within a narrow temperature range in the Sabie and Sand rivers.
2) Within each zone, additional species appear with distance downstream, due to increased habitat diversity and depth as the river gets bigger.
3) Within zones, each tributary sampled in the Sabie-Sand system has a characteristic fish fauna, with variations from a baseline species assemblage. This reflects local habitat availability, and stream profile.

Temperature is the best correlate for these patterns, and fish species were allocated to five categories of temperature tolerance:

1) Cold Stenothermal Species (species always restricted in the catchment to cool waters).
2) Warm Stenothermal Species (species only ever found in warm waters).
3) Cold Species (cold water species marginally tolerant of warmer waters).

4) Warm Species (warm water species marginally tolerant of cool waters).

5) Eurythermal (species that show wide tolerance to both warm and cold temperatures within the system).

Two fish assemblages could be identified: those of the foothill (FHZ), and lowveld zones (LZ). These ichthyological zones correspond to the Montane-Escarpment and Tropical East-Coast eco-regions respectively (Skelton, 1993).

Fourty-two species were collected in the Sabie River. The FHZ within the Sabie River is particularly expansive, with a cold finger of water penetrating the lowveld. Fish diversity in the FHZ is highest at the interface with the LZ partly due to the overlap of some warm cold-tolerant species, including many minnows. At least 6 fish species are missing from the middle reaches of the Sabie River, probably as a result of historic pollution from gold mining activities, and continued isolation of the upper reaches of the Sabie River by waterfalls. The Marite River is a major tributary of the Sabie River and important as a cold water refuge for FHZ species. The Sabie LZ stretches downstream of site 6, and supports more than 20 species. The Sand River has a very limited FHZ with a very sudden transition to the LZ. The full complement of Sand River LZ species occurs from Site 11, which was close enough to the headwaters to be perennial, resulting in the presence of two flow sensitive species, the warm cold-tolerant *Opsaridium zambezense* and the cold warm-tolerant *Chiloglanis anoterus*. *C.anoterus* was selected as the indicator species for the FHZ since it provided 60 to 81% of the catch at FHZ sites (see Fig. 7.7), compared with 1 to 16% of the catch at LZ sites (Fig. 7.8). *Barbus viviparus* was identified as the indicator species of the LZ zone since it was present at all the LZ sites, but was never captured at any of the FHZ sites. While temperature-altitude is the strongest axis determining the presence or absence of species, spatial changes at smaller scales (within zones) are probably a consequence of habitat changes down the rivers.

A core group of fish species, comprising 6% or more of the May catch, were selected to test for, and define, pre-drought and drought samples. Samples taken between May 1990 and August 1991 were identified as pre-drought, and used to describe baseline assemblages that best represented the ichthyofaunas for both the Foothill and Lowveld Zones. Sixteen species were identified, (Three are common to both zones):

a) **FHZ:** *Barbus eutaenia*
Barbus marequensis
Barbus polylepis
Chiloglanis anoterus
Pseudocrenilabrus philander
Tilapia sparrmanii
Varicorhinus nelspruitensis

b) **LZ:** *Barbus annectens*
Barbus marequensis
Barbus radiatus
Barbus trimaculatus
Barbus unitaeniatus
Barbus viviparus
Chiloglanis anoterus
Labeo molybdinus
Micralestes acutidens
Oreochromis mossambicus
Pseudocrenilabrus philander
Tilapia rendalli

Seasonal changes within the FHZ baseline assemblage were not marked, although cyprinids tended to increase in percent proportion of the catch by the end of the wet season, while seasonal changes within the LZ were very marked. At the start of the dry season, 75% of the core species catch was typically cyprinid. At the end of the dry cycle (November), and with the onset of the wet season, cichlids had increased to over 50% of the fish sampled. Patterns in species abundance and composition were not confined to seasonal changes and zonation, but included the effects of disturbance, both natural (the drought) and anthropogenic (the failure of Zoeknog Dam).

After temperature, drought was one of the major determinants of species pattern, particularly within the LZ, affecting the relative proportions of the LZ fish assemblage rather than causing local extinctions. However, prolonged or repeated drought would result in species loss. Most species showed reductions with the failure of the 1992 wet season, while the proportions of cichlids increased. Cyprinids were reduced from 78% to less than 50% of the catch, while cichlids increased to over half the CPUE.

Fish assemblages during the recovery phase were quite different from both pre-drought and drought LZ assemblages with *O.mossambicus* persisting in greater numbers in post-drought baseline assemblages. Others species remained at low numbers, notably *C.anoterus* and *B.marequensis*, and *B.unitaeniatus*. *B.viviparus* remained at roughly half its pre-drought density. Although the drought was severe, a few species made an early comeback. Young *L.molybdinus* were very numerous (as were *L.rosae* and *B.afrohamiltoni* in some sites, for the first time during the project) and some minnows also recovered early (*B.trimaculatus*) or survived well in refuge pools (*B.annectens* & *B.radiatus*).

Eighteen target species were selected for detailed microhabitat requirement description. Species were selected as representative of the fish fauna as a whole on the basis of diversity of requirements, importance, and abundance. These included the sixteen identified baseline species which cover the full range of life-history styles and habitats, and two species which were listed red data species (Skelton, 1987), namely *Opsaridium zambezense* and *Serranochromis meridianus*.

The microhabitat variables flow, depth, substrate and cover were used to characterise those aspects of habitat which would be most affected by changes in the flow regime. Flow was arguably the strongest factor structuring the use of habitat by organisms. Flow preference was used to divide the baseline shallow-water fish assemblage into habitat groups which included:

a) **Fishes of Backwaters and Pools;** 8 lifestages of 6 species preferred zero flow to all other flow velocities.

b) **Fishes Marginal to Flowing Waters;** 6 life stages of 5 fish species preferred quiet waters (zero velocity), but mostly in close proximity to flow (velocities of >0.2-0.6 $m.s^{-1}$).

c) **Fishes of Runs;** 5 lifestages of four species (Table 7.10) preferred slow to moderate velocities in runs (>0-0.6 $m.s^{-1}$).

d) **Fishes of Riffles and Rapids;** 6 lifestages of four species preferred the high velocities and turbid flows of riffles and rapids (>0.2->1.4 ms^{-1}).

9.4 THE SABIE RIVER

The results of this three year survey have shown that all the species that were recorded in the river during Pienaar's (1978) survey are still present in the river, and that the riverine fauna of the Sabie still appears to be as diverse as ever. Some of the larger species, such as the tiger fish and *Labeo congoro*, may be present in only low numbers, and this is a result of the lack of extensive deep habitat in the river. This survey was conducted mainly during times of very low-flow, and may therefore have given a biased picture in this regard. For similar reasons, the floodplain spawners, such as *Labeo rosae*, are also scarce in the system, since they rely on over-bankfull flows to provide breeding habitat. The communities had yet to recover from the drought when sampling stopped in May 1993, so it is difficult to say how long full recovery may take. It is certain that, if low-flow conditions become the norm, the communities in the Sabie will change considerably.

Water quality in the Sabie is still excellent, and in some aspects is considerably better than the drinking water supplied in much of South Africa. It is important to remember that we are not dealing with an original state of the river, since mine dump pollution virtually wiped out the natural fauna in the middle reaches earlier in the century. The recovery of the fauna has been remarkable, and has only been possible because of the presence of refuge tributaries in the system. The Marite River remains the most important cool-water refuge in the system. One cannot help wondering if the same level of recolonisation would be possible if similar pollution were to reach the Sabie now.

9.5 THE SAND RIVER

The middle reaches of the Sand River have been reduced to seasonal flow during most years, with the result that the communities are significantly different from those of the perennial reaches. This makes the maintenance of the perennial upper warm tributaries of vital importance as refuges for recolonisation. The drought, the construction and subsequent collapse of the Zoeknog Dam on the Mutlumuvi, and the diversion of the upper Sand by the Champagne Castle Citrus Estates during 1991, all combined to degrade conditions in these upper reaches. If such multiple events and conditions were to become more frequent, the survival of natural communities in the upper and middle portions of the Sand River would be put at risk.

REFERENCES

Acocks, J.P.H. 1975. Veld types of South Africa. *Memoirs of Botanical Survey of South Africa* 40: 128pp. Department of Agriculture, Technical Services, South Africa.

Acocks, J.P.H. 1976. Riverine vegetation of the semi-arid and arid regions of South Africa. *Journal of the South African Biological Society*, 17: 21-35.

Alexander, W.J.R. 1985. Hydrology of low latitude southern hemisphere land masses. *Hydrobiologia* 125: 75-83.

Alexander, W.J.R. 1985. Hydrology of low-latitude Southern Hemisphere land masses. *In*: B.R. Davies and R.D. Walmsley (Eds.), *Perspectives in Southern Hemisphere Limnology. Developments in Hydrobiology*, 78, Dr W. Junk, Dordrecht, pp. 75—83.

Armitage, P.D. 1984. Environmental changes induced by stream regulation and their effect on lotic macroinvertebrate communities. *In*: A. Lillehammer and S.J. Saltveit. *Regulated Rivers* Univeritetsfarleglet, Oslo.

Balinsky, B.I. 1965. A preliminary list of ther dragonflies (Odonata) of the Kruger National Park. *Koedoe* 8: 95-96.

Barmuta, L.A. and P.S. Lake. 1982. On the value of the River Continuum Concept. *N.Z. J. Mar. Freshwat. Res.* 16: 227-231.

Belaud, A., P. Chaveroche, P. Lim and C.Sabaton. 1989. Probability-of-use curves applied to brown trout (*Salmo trutta fario* L.) in rivers of southern France. *Regulated Rivers: Research and Management*: 3: 321-336.

Bonetto, A.A. 1975. Hydrologic régime of the Parana River and its influence on ecosystems. *In*: *Landscapes of river basins* (South America) Springer-Verlag, New York.

Boulton, A.J. and P.S. Lake. 1988. Australian temporary streams - some ecological characteristics. *Verh. Internat. Verein. Limnol.* 23: 1380-1383.

Bovee, K.D. 1982. *A guide to stream habitat analysis, using instream flow incremental methodology*. Instream Flow Information Paper 12, U.S.D.I., Fisheries and Wildlife Service, Office of Biological Surveillance. FWS/OBS-82/26, 248 pp.

Bovee, K.D. 1986. Development and evaluation of habitat suitability criterior for use in the Instream Flow Incremental Methology. *Instream Flow Incremental Paper* 21: U.S.D.I. Fish. Wildl. Serv. Office of Biol. Serv. FWS/OBS - 86/7: 205pp.

Bovee, K.D. and T. Cochnauer. 1977. Development and evaluation of weighted area criteria, probability-of-use curves for instream flow assessments: fisheries. *Increase Flow*

Information Paper 3. U.S.D.I. Fish. Wildl. Serv., Officer of Biol. Serv. FWS/OBS-77/63: 89pp.

Bovee, K.D. and R.T. Milhous. 1978. Hydraulic simulation in instream flow studies: theory and techniques. *Instream flow Information Paper No. 5 FWS/OBS-78/33*. Cooperative Instream service Group, Fort Collins, USA. 130pp.

Braack, H.H., I.H. Davidson, J.A. Ledger and D.J. Lewis. 1981. Records of sand-flies (Diptera: Psychodidae: Phlebotominae) feeding on Amphibia, with a new record from the Kruger National Park. *Koedoe* 24: 187-188.

Bray, J.R. and J.T. Curtis. 1957. An ordination of the upland Forest communities of southern Wisconsin. *Ecol. Monogr.* 27: 325-349.

Bruton, M.N. 1985. The effects of suspensoids on fish. *Hydrobiologia* 125: 221-241.

Bruton, M.N. and K.H. Cooper (Eds.). 1980. Studies on the ecology of Maputaland. Rhodes University and the Natal Branch of the Wildlife Society of Southern Africa. 560pp.

Bruton, M.N. and R.H. Taylor. 1979. Cichlid fish mortality in a freshwater lake in Natal. *The Lammergeyer* 27: 1-4.

Bruwer, C. (Ed.) 1991. *Flow Requirements of Kruger National Park Rivers. Proceedings of a Workshop held from 14-19 March, 1987, at Skukuza in the Kruger National Park.* Department of Water Affairs and Forestry, Pretoria, Technical Report, TR149, 141 pp.

Bruwer, C.A. (Ed.). 1993. *Flow Requirements of the Kruger National Rivers and impact of proposed water resources development* Part I: Water requirements at the critical level. Department of Water Affairs Technical Report, Pretoria.

Bruwer, C.A. In Press. Determination of flow requirements and impact of proposed water resources development on the Crocodile River within the Kruger National Park. In: C.A. Bruwer (Ed.). *Flow requirements of the Kruger National Park Rivers and impact of proposed water resources development. Part I: Water requirements at the critical level,* Department of Water Affairs Technical Report.

Butorin, N.V. and A.V. Monakow. 1984. The effect of the Volga flow regulation on biological processes. *In:* A. Lillehammer and S.J. Saltveit, *Regulated Rivers.* Universitetsforleget, Oslo.

Byren, B.A. and B.R. Davies. 1989. The effect of stream regulation on the physico-chemical properties of the Palmiet River, South Africa. *Regulated Rivers: Research and Management* 3: 107-121.

Canton, S.P., L.D. Cline, R.A. Short and R.V. Ward. 1984. The macroinvertebrates and fish of a Colorado stream during a period of fluctuating discharge. *Freshwater Biology* 14: 311-316.

Carter, A.J. and A.H. Rogers. 1989. *Phragmites* reedbeds in the Kruger National Park: The complexity of change in riverbed state. pp. 339-346. *In*: Kienzle, S. and Maaren, H., (Eds.), *Proceedings of the Fourth South African National Hydrological Symposium, University of Pretoria.*

Cilliers, C., P. Reid and J. Roderigues. 1987. Kewerwyfies oorwin in Krugerwildtuin. *Custos.* 15(11): 20-21.

Chunnett, Fourie & Partners. 1987. The Sabie River water resources development study: Briefing paper for assessing the in-stream water requirements of the natural environment and to assess the impact of the water resources development - Pretoria.

Chunnet, Fourie & Partners. 1990. *Water resources: Planning of the Sabie River catchment.* Report to the South African Department of Water Affairs and Forestry.

Chutter, F.M. 1969. The distribution of some stream invertebrates in relation to current speed. *Int. Rev. ges. Hydrobiol.* 54(3): 413-422.

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

Chutter, F.M., P.J. Ashton., D. Walmsley and A. Van Schalkwyk. In press. An interim assessment of the water requirements of the Letaba and Shingwedzi Rivers, Kruger National Park. In: C.A. Bruwer (Ed.). *Flow requirements of Kruger National Park Rivers and impact of proposed water resources development Part I: Water Requirements at the critical level.* Department of Water Affairs, Technical Report.

Chutter, F.M. and F.C. De Moor. 1983. Preliminary report on a survey of the conservation status of the major rivers in the Kruger National Park C.S.I.R., N.I.W.R. Project No. 620/2151/4. File No. W6/151/3 W11/12/3.

Chutter, F.M. and R.G.M. Heath. 1993. *Relationships between low flows and the river fauna in the Letaba River.* Water Research Commission Report 293/1/93, Pretoria, 79 pp.

Connell, J.H. 1978. Diversity in tropical rain forests and coral reefs. *Science* 199: 1802-1310.

Courot, A. 1989. Determination of hydraulic parameters for instream flow assessments. *Regulated Rivers : Research and Management* 3: 337-344.

Craig, J.F. and J.B. Kemper. 1987. *Regulated Streams : Advances in Ecology.* Plenum Press. New York and London. 431pp.

Cummins, K.W. 1979. The natural stream ecosystem. In: J.V. Ward and J.A. Stanford (eds). *The Ecology of Regulated Streams*. Plenum Press, New York and London.

Cummins, K.W. 1992. Catchment characteristics and river ecosystems. *In:* P.J. Boon, P. Calow and G.E. Petts (Eds.). River conservation and management. John Wiley & Sons Ltd.

Davies, B.R. 1979. Stream Regulation in Africa: A Review. *In*: J.V. Ward and J.A. Stanford (Eds.). *The Ecology of regulated streams*. Plenum Press, New York and London.

Davies, B.R. 1989. Where rivers once flowed. *Conserva*, March,: 12-15.

Davies, B.R., B. Bonthuys, W. Fourie, A. Marcus, S. Rossouw, C. Sellick, L. Theron, W. Uys, L. van Rooyen, M. van Zyl and A. Viljoen. 1991. The Sabie-Sand System. Chapter 7. *In:* C.A. Bruwer (Ed.). Proceedings of a workshop on the flow requirements of Kruger National Park Rivers, Skukuza, Department of Water Affairs, Pretoria.

Davies, B.R. and J.A. Day. 1986. *The Biology and Conservation of South Africa's Vanishing Waters*, Department of Extra-Mural Studies, University of Cape Town, and the Wildlife Society of Southern Africa, Western Cape Branch, Cape Town, 186 pp.

Davies, B.R. and J.A. Day. 1989. Physical and chemical attributes important in the biological functioning of river ecosystems. *S.A. Nat. Sci. Prog. Report No. 162:* 17-39.

Davies, B.R., R.W. Palmer, J.H O'Keeffe and B.A. Byren. 1989. The effects of impoundments on the flow and water quality of two contrasting southern African river systems. In: S. Kiensle and H. Maaren (eds.). *Proceedings of the Fourth South African National Hydrological Symposium. Pretoria.* 447pp.

Davies, B.R., J.H. O'Keeffe and C.D. Snaddon. 1993a. *A review of the ecological functioning, management and conservation of southern African river and stream ecosystems.* Water Research Commission, Pretoria. In press.

Davies, B.R. and J.H. O'Keeffe. Unpublished. A pre-impoundment study of the Sabie-Sand River system, Eastern Transvaal, with special reference to predicted impacts on the Kruger National Park. A project proposal.

Davies, B.R., M. Thoms and M. Meador. 1992. Viewpoint: An assessment of the ecological impacts of inter-basin water transfers, and their threats to river basin integrity and conservation. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 2: 325-349.

Davies, B.R., M.C. Thoms, K.F. Walker, J.H. O'Keeffe and J.A. Gore. 1993b. Dryland Rivers: Their Ecology, Conservation and Management. *In*: P. Calow and G.E. Petts (Eds.). *The Rivers Handbook* Volume 2. Blackwell Scientific, Oxford. In press.

Engelbrecht, J.S. 1986. Bewaringstatus van riviere en lotiese vleilande in die Transvaal *Inkomatisisteem Sabierivier. Asook die moontlike invloed van beplande damme op bedeigde* en endemiese plant- en vissoorte. Projek Nr. TN 6/4/2/3/6. Provinsiale visserye. Lydenburg.

Fausch, K.D. and R.G. Bramblett. 1991. Disturbance and fish communities in intermittent tributaries of a great western plains river. *Copeia*, 1991(3), 659-674.

Ferrar, A.A. (Ed.) 1989. *Ecological Flow Requirements for South African Rivers.* South African National Scientific Programmes Report, 162, Council for Scientific and Industrial Research, Pretoria, 116 pp.

Ferrar, A.A., J.H. O'Keeffe and B.R. Davies. 1988. *The River Research Programme, South African National Scientific Programmes, Report no. 146.*

Field, J.G., K.R. Clarke and R.M. Warwick. 1982. A practical strategy for analysing multispecies distribution patterns. *Marine Ecology Progress Series* 8: 37-52.

Gaigher, I.G. 1969. Aspekte met betrokking tot die ekologie, geografie en taksonomie van varswatervisse in die Limpopo- en Incomatirivier sisteem. Unpublished DSc. thesis, Rand Afrikaans University, Johannesburg.

Gaigher, I.G. 1970. Ecology of the tiger-fish (*Hydrocynus vittatus*) in the Incomati River system, South Africa. *Zoologia Africana* 5(2): 211-227.

Gaigher, I.G. 1973. The habitat preferences of fishes from the Limpopo River system, Transvaal and Mocambique. *Koedoe* 16: 103-116.

Gaschignard, O. and A. Berly. 1987. Impact of large discharge fluctuations in the macroinvertebrate populations downstream of a dam. In: J.F. Craig and J.B. Kemper. *Regulated Streams: Advances in Ecology.* Plenum Press, New York and London.

Geer, W.H. 1987. A method for treatment of data from the Instream Flow Incremental Methodology for instream flow determination. *In*: J.F. Craig and J.B. Kemper *Regulated Streams : Advances in Ecology.* Plenum Press. New York and London.

Gertenbach, W.P.D. 1980. Rainfall patterns in the Kruger National Park. *Koedoe, 26: 9-*121.

Gertenbach, W.P.D. 1983. Landscapes in the Kruger National Park. *Koedoe* 26: 9-121.

Gore, J.A. 1987. Development and application of macroinvertebrate instream flow models for regulated flow management. *In*: J.F. Craig and J.B. Kemper (Eds.). *Regulated Streams: Advances in Ecology.* Plenum Press, New York and London.

Gore, J.A. and J.M. King. 1989. Application of the revised physical habitat simulation (PHABSIM II) *to minimum flow evaluations of South African rivers.* pp. 289-296. *In:* Kienzle, S. and Maaren, H., (Eds.), *Proceedings of the Fourth South African National Hydrological Symposium*, University of Pretoria.

Gore, J.A. and J.M. King. Unpublished a. Application of the revised physical habitat simulation (PHABSIM II) to minimum flow evaluations of the South African Rivers.

Gore, J.A. and J.M. King. Unpublished b. An introduction to the Instream Flow Incremental Methodology: A technique for predicting optimum and minimum flows for biota in a river.

Gore, J.A., J.B. Layzer and J.M. King. 1987. *Instream Flow Incremental Methodologies: Kruger National Park.* Technology Transfer Workshop.

Gore, J.A., J.B. Layzer and I.A. Russell. 1992. Non-traditonal applications of instream flow techniques for conserving habitat biota in the Sabie River of southern Africa. *In:* Boon, P. J., P. Calow & G.E. Petts. (Eds.). River conservation and management. John Wiley & Sons Ltd.

Gore, J.A. and J.M. Nestler. 1988. Instream Flow studies in perspective. *Regulated Rivers: Research and Management* 2: 93-101.

Gore, J.A., J.M. Nestler and J.B. Layzer. 1989. Instream Flow predictions and management options for biota affected by peaking - power hydroelectric operations. *Regulated Rivers: Research and Management* 3: 35-48.

Gustard, A. 1984. The characterisation of flow régimes for assessing the impact of water resource management on river ecology. *In:* A. Lilliehammer and S.J. Saltveit. *Regulated Rivers.* Universitetsforleget, Oslo.

Gustard, A. 1989. Compensation flows in the U.K.: a hydrological review. *Regulated Rivers: Research and Management* 3: 49-59.

Gustard, A. and G.A. Cole. 1987. Towards a rational assessment of residual flows below reservoirs. *In:* J.F. Craig and J.M. Kemper (Eds.). *Regulated Streams : Advances in Ecology.* Plenum Press, New York and London.

Greenwood, P. H. 1995. Gobiid fishes of the genus *Glossogobius* in the Limpopo system: a first record and a range extension of *G. callidus* (Smith, 1937). *South African Journal of Aquatic Sciences* 20 (1/2): 88-92.

Hall, C.A.S., J.H. Jourdonnais and J.A. Stanford. 1989. Assessing the impacts of stream regulation in the Flathead River Basin, Montana, U.S.A. I. Simulation modelling of system water balance. *Regulated Rivers: Research and Management* 3: 61-77.

Harrison, A.D. 1966. Recolonisation of a Rhodesian stream after drought. *Arch. Hydrobiol.* 62(3): 405-421.

Higgs, G. and G. Petts. 1988. Hydrological changes and river regulation in the U.K. *Regulated Rivers: Research and Management* 2: 349-368.

Hill, M.O. 1979. TWINSPAN -- A FORTRAN program for arranging multivariate data in an ordered two-way table by classification of the individuals and attributes. *Ecology and Systematics*. Cornell University. Ithaca, New York.

Hooper, F.F. and D.R. Ottey. 1988. Responses of macroinvertebrates of two headwater streams to discharge fluctuations. *Verh. Internat. Verein. Limnol.* 23: 1159-1166.

Horwitz, R.J. 1978. Temporal variability patterns and the distributional patterns of stream fishes. *Ecological Monographs* 48: 307-321.

Hughes, D.A. 1966a. Mountain streams of the Barbeton Area, Eastern Transvaal. Part I, A Survey of the Fauna. *Hydrobiologia* 27: 401-438.

Hughes, D.A. 1966b. Mountain streams of the Barbeton Area, Eastern Transvaal Part II, the effect of vetational shading and direct illumination on the distribution of Stream Fauna. *Hydrobiologia* 27: 439-459.

Hynes, H.B.N. 1960. *The Biology of Polluted Waters*, Liverpool University Press, Liverpool.

Hynes, H.B.N. 1964. The use of biology in the study of water pollution. *Chem. Ind.* 435-436.

Irving, J.R. 1987. The effects of varying flows in man-made streams on Rainbow trout. (*Salmo gairdneri* (Richardson) fry. *In*: J.F. Craig & J.B. Kemper (Eds.). *Regulated Streams: Advances in Ecology*. Plenum Press, New York and London.

Jackson, P.B.N. 1989. Prediction of regulation effects on natural biological rhythmns in south-central African freshwater fish. *Regulated Rivers: Research and Management* 3: 205-220.

Joubert, S.C.J. 1986. Pollution of the Kruger National Park rivers. *Afr. Wildlife* 40: 29-30.

Joubert, S.C.J. 1986. *Masterplan for the management of the Kruger National Park.* Unpublished report of the Kruger National Park. 6 Volumes, 981pp.

Jubb, R.A. 1962. The significance of air temperature extremes in some ecological studies. *Suid-afrikaanse Joernaal vir Wetenskap* 58(11): 344-345.

Jubb, R.A. 1968. The *Barbus* and *Varicorhinus* species (Pisces: Cyprinidae) of Transvaal. *Annals of the Transvaal Museum* 26: 79-97.

King, J.M. and J.H. O'Keeffe, J.H. 1989. Looking to the future - South Africa's requirements. *S.A. Nat. Sci. Prog.* Report No. 162: 110-116.

King, J.M., F.C. de Moor, A.J. Botha and A.H. Coetzer. 1989. Water quality requirements of invertebrates, macrophytes and other mesobiota. *S.A. Nat. Sci. Prog. Report* No. 162: 57-70.

King, J.M. and R.E. Tharme. 1993. *Assessment of the Instream Flow incremental methodology, and initial developemt of alternative instream flow methodologies for South Africa.* Final Contract Report to the South African Water Research Commission, Pretoria. In press.

Kleynhans, C.J. 1991. Voorlopige riglyne vir die klassifisering van Transvaalse inheemse vissorte in sensitiwiteitsklasse. Sensitiewe viswerkswinkel: Skukuza, NKW, 23-25 September.

Kok, H.M. 1980. *Ecological studies of some important fish species of the Pongolo Floodplain, Kwazulu, South Africa.* Unpublished DSc thesis, University of Port Elizabeth.

Lake, P.S., L.A. Barmuta, A.J. Boulton, S. Campbell and R.M. St Claire. 1985 Australian streams and northern hemisphere stream ecology: comparisons and problems. *Proc. Ecol. Soc. Aust.* 14: 61-82.

Lalancette, L-M. 1981. Ellipsoidal trap for freshwater minnows and suckers. *Prog. Fish-Cult.* 43(4): 193-194.

Lillehammer, A. and S.J. Salveit. 1984. *Regulated Rivers.* Universitetsforlaget A.S., Oslo, 540pp.

Lowe-McConnell, R.H. 1979. Ecological aspects of seasonality in fishes of tropical waters. *Symp. zool. Soc. Lond.* 44: 219-241.

Meffe, G.K. and A.L. Sheldon. 1990. Post-defaunation recovery of fish assemblages in southerastern blackwater streams. *Ecology* 7(2): 657-667.

Merron, G.S. and M.N. Bruton. 1993. Implications of water release from the Pongolapoort Dam for the fish and fishery of the Phongolo floodplain, Zululand. *Sth. Afr. J. aquat. Sci.* 19: 34-40.

Merron, G.S. and P. La Hausse de Lalouviere. 1987. The response and recovery of fish stocks of the Pongolo floodplain during and after a period of prolonged drought. pp. 89-110. *In*: Proceedings of a Symposium on the Ecology and Conservation of Wetlands in South Africa. Ecosystems Programme Occasional Report, 28, Council for Scientific and Industrial Research Pretoria.

Millhous, R.T., D.L. Wegner and T. Waddle. 1984. User's guide to the physical habitat simulation system. *Instream Flow Information Paper II.* U.S.D.I. Fish. Wildl. Serv. Office of Biol. Serv. FWS/OBS - 81/43 (revised).

Minshall, G.W. 1988. Stream Ecosystem Theory: a global perspective. *J. N. Am. Benthol. Soc.* 7(4): 236-288.

Minshall, G.W., K.W. Cummins, R.C. Petersen, C.E. Cushing, D.A. Bruno, J.R. Sedell and R.G. Vannote. 1985. Developments in stream ecosystem theory. *Can J. aquat. Sci.* 42: 1045-1055.

Moore, C.A. 1991. *A Survey of the Conservation Status and Benthic Biota of the Six Major Rivers of the Kruger National Park.* Unpublished M.Sc. thesis, Zoology Department, University of Pretoria, 131 pp.

Moore, C.A. and F.M. Chutter. 1988. *A Survey of the Conservation Status and Benthic Biota of the Six Major Rivers of the Kruger National Park.* Unpublished Contract Report, National Institute for Water Research, Council for Scientific and Industrial Research, Pretoria, 55 pp.

Naiman, R.J., J.M. Melillo, M.A. Lock and T.E. Ford. 1987. Longitudinal Patterns of ecosystem processing and community structure in a subarctic River Continuum. *Ecology* 68(5): 1139-1156.

Newbold, J.D. 1987. Phosphorous spiralling in rivers and river reservoir systems: implications of a model. *In*: J.F. Craig and J.B. Kemper (Eds.). *Regulated Streams: Advances in Ecology.* Plenum Press, New York and London.

Newbold, J.D., R.V. O'Neill, J.W. Elwood and W. van Winkle. 1982. *Nutrient spiralling* in streams. Implication for nutrient limitation and invertebrate activity. *Am. Nat.* 120: 628-652.

Niemie, G.J., P. DeVore, N. Detenbeck, D. Taylor, A. Lima, J. Pastor, J.D. Yount and R.J. Naiman. 1990. Overview of case studies on recovery of aquatic systems from disturbance. *Environmental Management* 14(5): 571-587.

Oberdorff, T., E. Guilbert and J-C. Lucchetta. 1993. Patterns of fish species richness in the Seine River basin, France. *Hydrobiologia* 259: 157-167.

Oberholzer, G and J.A. van Eeden. 1967. The freshwater molluscs of the Kruger National Park. *Koedoe* 10: 1-42.

O'Keeffe, J.H. 1985. The conservation status of the Sabie and Groot Letaba Rivers within the Kruger National Park. IFWS Special Report No. 85/2. Rhodes University, Grahamstown.

O'Keeffe, J.H. 1986. *Ecological Research on South African Rivers - A Preliminary Synthesis.* South African National Scientific Programmes Report, 121, Council for Scientific and Industrial Research, Pretoria, 121 pp.

O'Keeffe, J.H. (1991). The Luvuvhu River. *In:* A preliminary assessment. in: C.A. Bruwer (ed.). Proceedings of a workshop on the flow requirements of the Kruger National Park Rivers. Dept. of Water Affairs Technical Report TR 149.

O'Keeffe, J.H., D.B. Danilewitz and J.A. Bradshaw. 1987. An expert system approach to the assessment of the conservation status of rivers. *Biological Conservation,* 40, 69-84.

O'Keeffe, J.H., B.R. Davies, J.M. King and P.H. Skelton. 1989a. The conservation status of southern African rivers. pp. 276-299. *In:* Huntley, B.J. (Ed.). *Biotic Diversity in Southern Africa,* Oxford University Press, Cape Town.

O'Keeffe, J.H., J.M. King, J.A. Day, D. Roussouw, D.W. Van Der Zel and R. Skorozewski. 1989b. *General Concepts and Approaches to In-stream Flow Assessment.* South African National Scientific Programmes Report, 162, Council for Scientific and Industrial Research, Pretoria, 41-55.

Oosthuizen, J.H. 1979. Redescription of *Placobdella multistriata* (Johansson, 1909) (Hirudinea:Glossiphoniidae). *Koedoe* 22: 61-79

Orth, D.J. 1987. Ecological considerations in the development and application of instream flow-habitat models. *Regulated Rivers: Research and Management.* 1: 171-181.

Palmer, R. and J.H. O'Keeffe. 1989. Temperature characteristics of an impounded river. *Arch. Hydrobiol.* 116(4): 471-485.

Petts, G.E. 1984. *Impounded Rivers.* John Wiley & Sons. 326pp.

Pienaar, U.de V. 1961. A supplementary checklist of Decapoda, fresh-water fish, Amphibia, reptiles and small mammals recorded in the Kruger National Park. *Koedoe* 4: 167-177.

Pienaar, U.de V. 1966. An experimental cropping scheme of Hippopotami in the Letaba River of the Kruger National Park. *Koedoe* 9: 1-33.

Pienaar, U.de V. 1978. The freshwater fishes of the Kruger National Park, National Parks Board, South Africa.

Pienaar, U. De V. 1985. Indications of progressive desiccation of the Transvaal lowveld over the past 100 years, and implications for the water stabilisation programme in the Kruger National Park. *Koedoe,* 28, 93-165.

Pienaar, U.de V., W.D. Haacke and N.H.G. Jacobsen. 1978. The reptiles of the Kruger National Park. National Parks Board, South Africa.

Plymouth Marine Laboratory. 1992. *User Guide to PRIMER; Version 3.1a prepared for training workshop on Multi-variate Analysis of Benthic Community Data*, Kristineberg Marine Research Stattion, February 1993, 53 pp.

Power, M.E., R.J. Stout, G.E. Cushing, P.P. Harper, F.R. Hauer, W.J. Matthews, P.B. Moyle, B. Statzner and I.R. Wais de Bagden. 1988. Biotic and abiotic controls in river and stream communities. *J.N. Am. Benthol. Soc.* 7(4): 456-479.

Ranta, E. and P. Sevola. 1984. Effects of short term regulation on fish stocks in the rivers Kyrönjoki and Lapnanjoki, Finland. *In:* A. Lillehammer and S.J. Saltveit. (Eds.). *Regulated Rivers.* Universitetsforleget, Oslo.

Reiser, D.W., M.P. Ramey and T.R. Lamert. 1987. Considerations in assessing flushing flow needs in regulated stream systems. *In:* J.F. Craig and J.B. Kemper (Eds.). *Regulated Streams: Advances in Ecology* Plenum Press, New York and London.

Roberts, C.P.R. 1983. Environmental constraints on water resources development. *Proceedings of the South African Institute of Civil Engineers*, 1: 16-23.

Russell, I. A. and K.H. Rogers. 1989. The distribution and composition of fish communities in the major rivers of the Kruger National Park. Proceedings of the South African Aquatic Sciences Symposium, Pretoria. Pages 281-288.

Ryder, G.U. and D. Scott. 1988. The applicability of the River Continuum Concept to New Zealand streams. *Verh. Internat. Verein Limnol.* 23: 1441-1445.

Schultz, K.H., J.J.Steyn and R. Rose-Innes. 1958. A culicine mosquito survey of the Kruger National Park. *Koedoe* 1: 189-200.

Sciacchitano, I. 1961. Su alcune sanguisughe del Parco Nazionale Kruger (Sud Africa). *Monitore Zoologico Italiano* 69: 144-148.

Scott, K.M.F. 1975. The value of larval stages in systematic studies of the Trichoptera, with particular reference to the Hydropsychidae from Africa south of the Sahara. *Proc. I. Congr. ent. Soc. sth. Afr.* 41-52.

Scott, D. and C.S. Shirvell. 1987. A critique of the Instream Flow Incremental Methodology and observation on flow determination in New Zealand. *In*: J.F. Craig and J.B. Kemper (Eds.). *Regulated Streams: Advances in Ecology*. Plenum Press, New York and London.

Shepard, R.N. 1962. The analysis of proximities: multidimensional scaling with an unknown distance function. *Psychometrika* 27: 125-140.

Shirvell, C.S. 1986. Pitfalls of habitat simulation in the Instream Flow Incremental Methodology. *Can. Tech. Rep. Fish. Aquat. Sci.* 1460: 68pp.

Simons, D.B. 1979. Effects of stream regulation on channel morphology. In: J.V. Ward & J.A. Stanford. *The Ecology of Regulated Streams.* Plenum Press, New York and London.

Skelton, P.H. 1987. South African Red Data Book - fishes. South African National Scientific Programmes Report No. 137.

Skelton, P.H. 1993. A complete guide to the freshwater fishes of southern Africa. Southern Book Publishers. Halfway House.

Slauson, W.L. 1988. Constructing suitability curves from data. *In:* K. Bovee and J.R. Zuboy (Eds.). Proceedings of a workshop on the development and evaluation of habitat suitability criteria. U.S. Department of the Insterior Fish and Wildlife Service Research and Development. Washington, D.C. Biological Report 88(11).

Smith, C.D., D.M. Harper and P.J. Barham. 1990. Engineering operations and invertebrates: linking hydrology with ecology. *Regulated Rivers: Research and Management.* 5: 89-96.

South African Department of Water Affairs. 1986. *Management of the Water Resources of the Republic of South Africa.* Department of Water Affairs, Pretoria. Pagination various.

South African Department of Water Affairs and Forestry. 1993. South African water quality guidelines. Vol.4. Agricultural use. First Edition. Published by DWAF, Pretoria. ISBN 0-621-1543-6.

Southwood, T.R.E. 1977. Habitat, the templet for ecological strategies? *J. Anim. Ecol.* 46: 337-365.

Stanford, B., and J.V. Ward. 1979. *The Ecology of Regulated Streams.* Plenum Press, New York and London.

Stanford, B., F.R. Hauer and J.V. Ward. 1988a. Serial discontinuity in a large river system. *Verh. Internat. Verein. Limnol.* 23: 1114-1118.

Statzner, B., J.A. Gore and V.H. Resh. 1988b. Hydraulic stream ecology: observed patterns and potential applications. *J.N. Am. Benthol. Soc.* 7(4): 307-360.

Statzner, B. and B. Higler. 1985. Questions and comments on the River Continuum Concept. *Can. J. Fish Aquat. Sci.* 42: 1048-1044.

Statzner, B. and B. Higler. 1986. Stream hydraulics as a major determinant of benthic invertebrate zonation patterns. *Freshwat. Biol.* 16: 127-139.

Stephenson, W.T., D. Burgess. 1980. Skewness of data in the analysis of species-in-sites-in-times. *Proc. R. Soc. Queensland* 91: 37-52.

Strahler, A.N. 1957. Quantitative analysis of watershed geomorphology. *Transactions, American Geophysical Union* 38(6): 913-920.

Stuckenberg, B.R. 1969. Effective temperature as an ecological factor in southern Africa. *Zoologica Africana* 4(2): 145-197.

Van Dyke, L.P. 1978. Plaagdoders in rivierwater van die Nasionale Krugerwildtuin. *Koedoe* 21: 77-80.

Van Jaarsveld, J. 1985. Kan visarend dié aanslag oorleef? *Custos* 14(9): 8-11.

Van Niekerk, H. 1986. Krugerwildtuin in die spons. *Custos* 14(11) 23-26.

Vannote, R.L., C.W. Minshall, K.W. Cummins, J.R. Sedell and C.E. Cushing. 1980. The River Continuum Concept. *Can. J. Fish. Aquat. Sci.* 37: 130-170.

Van Veelen, M. 1990. Kruger National Park - Assesment of current water quality status. *Report presented at the Workshop on the Preliminary Water Quality Guidelines for the Kruger National Park Rivers.* Held in Pretoria form 23 to 24 October 1990. ii + 138pp.

Vasquez, E. 1989. The Orinoco River: A review of hydrological research. *Regulated Rivers: Research and Management* 3: 381-392.

Venter, F.J. 1990. *Fisiese kenmerke van bereike van die standhoudende riviere in die Nationale Kruger Wildtuin.* Internal Report of the National Parks Board, Skukuza, 20 pp.

Venter, F.J. and J.W. Bristow. 1986. An account of the geomorphology and drainage of the Kruger National Park. *Koedoe* 29: 117-124.

Vogt, I. 1991. Short-term geomorphological changes in Kruger National Park Rivers. *Final report to the Foundation for Research Development.* 34 pp.

Ward, J.V. 1982. Ecological aspects of stream regulation: responses in downstream lotic reaches. *Water Pollution and Management Reviews (New Delhi)* 2: 1-26.

Ward, J.V. 1984. Ecological perspectives in the management of aquatic insect habitat. In: V.H. Resh and D.M. Rosenberg (eds.). *The Ecology of Aquatic Insects*, Praeger, New York.

Ward, J.V. 1985. Thermal characteristics of running waters. *Hydrobiologia* 125: 31-46.

Ward, J.V., B.R. Davies, C.M. Breen, J.A. Cambray, F.M. Chutter, J.A. Day, F.C. de Moor, J. Heeg, J.H. O'Keeffe and K.P. Walker. 1984. Stream regulation. In: R.C. Hart and B.R. Allanson (Eds.). *Limnological criteria for management of water quality in the southern hemisphere. S.A. Nat. Sci. Prog. Report.* No. 93.

Ward, J.V. and J.A. Stanford. (Eds.). 1979. *The Ecology of Regulated Streams*. Plenum Press, New York and London.

Ward, J.V. and J.A. Stanford. 1980. Effects of reduced and perturbated flow below dams on fish food organisms in Rocky Mountain trout streams. *In:* Allocation of Fishery Resources. Proceedings of the Technical Consultation on Allocation of Fishery Resources held in Vichy, France 20-23 April.

Ward, J.V. and J.A. Stanford. 1982. Thermal responses in the evolutionary ecology of aquatic insets. *A. Rev. Entomol.* 27: 97-117.

Ward, J.V. and J.A. Stanford. 1983. The Serial Discontinuity Concept of lotic ecosystems. *In:* T.D. Fontaine III and S.M. Bartell (Eds.). *Dynamics of Lotic Ecosystems*. Ann Arbor Science, Michigan.

Ward, J.V. and J.A. Stanford. 1987. The ecology of regulated streams: Past accomplishments and directions for future research. *In:* J.F. Craig and J.B. Kemper (Eds.). *Regulated Streams: Advances in Ecology*. Plenum Press, New York and London.

Webster, J.R. 1975. Analysis of potassium and calcium dynamics in stream ecosystems on the souther Appalachian watersheds of contrasting vegetation. *Ph.D. thesis*, University of Georgia, Athens, Georgia, U.S.A.

Welcomme, R.L. 1985. River fisheries. FAO Fisheries Technical Paper 262. Food and Agriculture Orginization of the united Nations. Rome. ix + 133pp.

Wells, J.J. 1992. *A Pre-impoundment Study of the Biological Diversity of the Benthic Macro-invertebrate Fauna of the Sabie-Sand River system.* Unpublished M.Sc. thesis, Freshwater Research Unit, University Cape Town. 206 pp.

Wesche, T.A., V.R. Hasfurther, W.A. Hubbert and Q.D. Skinner. 1987. Assessment of flushing flow recommendations in a steep, rough regulated tributary. *In:* J.F. Craig and J.B. Kemper (Eds.). *Regulated Streams: Advances in Ecology*. Plenum Press, New York and London.

Williams, W.D. 1988. Limnological imbalances: an antipodean viewpoint. *Freshwater Biology* 20: 407-420.

Williams, R.D. and R.N. Winger. 1987. Macroinvertebrate response to flow manipulation in the Strawberry River. Utah (U.S.A.) *In:* J.V. Ward and J.A. Winterbourn, M.J., J.S. Rounick and B. Cowie. 1981. Are New Zealand Stream ecosystems really different? *N.Z.J. Mar. Freshwat. Res.* 15: 321-328.

Wolff, S.W., T.A. Wesche and W.A. Aubert. 1989. Stream channel and habitat changes due to flow augmentation. *Regulated Rivers: Research and Management* 4: 225-233.

Wright, J.F., P.D. Armitage, M.T. Furse and D. Moss. 1988. A new approach to the biological surveillance of river quality using macroinvertebrates. *Verh. Internat. Verein. Limnol.* 23: 1548-1552.

Wright, J.F., P.D. Armitage and M.J. Furse. 1989. Prediction of invertebrate communities using stream measurements. *Regulated Rivers: Research and Management* 4: 147-155.

APPENDIX I

A PRE-IMPOUNDMENT STUDY OF THE SABIE-SAND RIVER SYSTEM, EASTERN TRANSVAAL

LITERATURE REVIEW

by

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INTRODUCTION

An increasing awareness of the ecological value of aquatic ecosystems and their role in maintaining supplies of usable water is apparent in South Africa today. This is due to South Africa being brought to the realisation of the limitations of its water supplies, caused by a rapidly growing population and relatively well-developed economy (Ferrar *et al.*, 1988; King and O'Keeffe, 1989; O'Keeffe *et al.*, 1989a). Over 40% of South Africa's total river runoff has been impounded (Davies, 1979; Alexander, 1985), river systems having become the primary source of water for agricultural, industrial and domestic consumption. The established trend of seasonal shortages and increasing costs of water is escalating and is already placing constraints on future development (Ferrar *et al.*, 1988). Thus there is a need for detailed examinations of river systems in South Africa. However, an extensive knowledge of limnological advances on a global scale and an understanding of concepts which have been developed in stream ecology are necessary as a basis for research in South Africa.

CONCEPTS IN STREAM ECOLOGY

During the last decade a number of important hypotheses have been developed in river ecology. Presently there are four "cornerstone concepts" (Ward *et al.*, 1984) which form a basis for stream studies.

One of the most controversial is the River Continuum Concept (RCC) by Vannote *et al.*, (1980). The RCC considers the whole fluvial system as a continuous drainage basin gradient (eg. Cummins, 1979; Naiman *et al.*, 1987; O'Keeffe *et al.*, 1989a,b). The RCC states that from the headwaters to the mouth of any river there is a gradient of physical conditions which elicits a series of responses within the constituent populations, resulting in a continuum of biotic adjustments and consistent patterns of loading, transport, utilization and storage of organic matter along the length of the river (Vannote *et al.*, 1980). The headwaters tend to be heterotrophic, detrital-based systems, relying on allochthonous inputs of organic material for their energy. The system becomes more autotrophic further downstream, with an increased production of autochthonous organic material (eg. Ward & Stanford, 1987; Davies & Day, 1989). Thus, the processes in the downstream reaches are directly linked to those in the upstream reaches (eg. Naiman *et al.*,1987; Byren & Davies, 1989).

The validity of the concept has come in for considerable debate (eg. Winterbourn *et al.*, 1981; Barmuta & Lake, 1982; Ward *et al.*,, 1984; Minshall *et al.*, 1985; Statzner & Higler, 1985; Naiman *et al.*, 1987; Ryder & Scott, 1988, Williams, 1988, O'Keeffe *et al.*,1988a, Lake *et al.*, 1985). The major criticism of the concept is that the RCC may not be globally applicable (Williams, 1988), and remembering that the individual of a species is the unit of evolution, *not* the community.

The concept was originally hypothesised for North American rivers (Ferrar *et al.*, 1987) and gives an holistic view of stream ecosystem structure and functioning (Minshall *et al.*, 1985; Naiman *et al.*, 1987). However, Winterbourn *et al.*, (1981) suggest that Southern Hemisphere rivers differ from those in the Northern Hemisphere, and that rivers are stochastic systems prone to natural disasters (droughts and floods) with an unstructured biota of hardy opportunists (O'Keeffe, 1986; O'Keeffe *et al.*, 1989a). This view point is supported by other studies relating to Southern Hemisphere stream ecosystems (eg. Barmuta & Lake, 1982; Lake *et al.*, 1985). Statzner & Higler (1985) challenged the RCC, correctly questioning the five basic tenets: namely, energy equilibrium of the physical system and its biological analogue; trophic patterns; temporal sequencing of species replacement and utilisation of energy inputs; time invariance and absence of succession, and patterns of biological diversity. They argued that the tenets are open to interpretation, some need extension, others are unanticipated by the current state of knowledge. However, the utility of the RCC lies in the identification of a set of general conditions and relationships that can be used to study and compare stream systems (Statzner & Higler, 1985; Naiman *et al.*, 1987; Ryder & Scott, 1988) - it is not intended as a description of biological components of all rivers in an individualistic context (Minshall *et al.*, 1985).

Two concepts linked closely to the RCC are the Nutrient Spiralling Hypothesis (NSH) of Webster, 1975 (see also, Newbold *et al.*, 1982; Newbold, 1987) and the Serial Discontinuity Concept (SDC) of Ward & Stanford (1983a). The NSH highlights the difference between lake and river ecosystems (Ward *et al.*, 1984), Ferrar *et al.*, 1988). In a river, the nutrients are envisaged as moving downstream in a helical fashion (eg. Newbold *et al.*, 1982), as they alternate between organic and inorganic phases (being fixed by the benthos and then later released) rather than remaining in a closed cycle (eg. Cummins, 1979; Ward *et al.*, 1985, Byren & Davies, 1989; Davies & Day, 1989). Spiralling length is an index of the efficiency of utilisation of nutrients supplied from the watershed, since it reflects the number of times the nutrient molecule is recycled within a stream reach (Ward & Stanford, 1987). This concept also has applications in situations where nutrient transfer in streams is interrupted by an impoundment (Ward *et al.*, 1984).

The SDC (Ward & Stanford, 1983a) which assumes that the RCC and NSH are conceptually sound, states that few stream ecosystems are uninterrupted continua but are more often regulated by dams, which are interruptions to the longitudinal gradients predicted by the RCC. These discontinuities disrupt a wide variety of biotic and abiotic processes, requiring a "recovery distance" (*sensu* O'Keeffe *et al.*, 1989a) to "reset" the river to the original state before perturbation (Ward & Stanford, 1983a; Stanford *et al.*, 1988, Byren & Davies, 1989; Davies & Day, 1989; O'Keeffe *et al.*, 1989a). Within this concept, two parameters are used to evaluate the relative impact of impoundments on riverine structure and functioning, and the discontinuity distance: namely, longitudinal shift of a given variable in a stream, and the intensity of the perturbation (Ward & Stanford, 1987; Stanford *et al.*, 1988).

The fourth "cornerstone concept" is the Intermediate Disturbance Hypothesis (Connell, 1978; Ward & Stanford, 1986: Ward *et al.*, 1984; Ferrar *et al.*, 1988). This predicts that biotic diversity will be greatest in communities subjected to moderate levels of disturbance. Disturbance, here, refers to the extent of change and does not necessarily imply human disturbance, although the imposition of a controlled flow régime on the environment may affect the community diversity by changing the level of disturbance.

EFFECTS OF IMPOUNDMENTS ON RIVERS

One of the greatest disturbances to river systems is impoundment. This has become a cause for concern for river biologists, and the literature on stream regulation is expanding rapidly (see for example Ward & Stanford, 1979; Lillehammer & Saltveit, 1984; Petts, 1984; Craig & Kemper, 1987). Until recently, the ecological consequences of impoundments have played a negligible role in the decision making of the siting, design, construction and management of dams; economic, political and social considerations being of prime importance (Palmer & O'Keeffe, 1990).

The regulation of running waters by impoundment has diverse manifestations (eg. Ward *et al.*, 1984), many of which are linked to, and profoundly influence lotic ecosystem functioning. There are four types of modifications which take place due to impoundments (Palmer and O'Keeffe, 1990). they are:

1. Biotic modifications
2. Chemical modifications
3. Thermal modifications
4. Hydrological modifications

1. Biotic Modifications

The most pronounced biological modification which occurs after dam closure is an *increase in the density of the fauna downstream from the dam* (Butorin and Monakow, 1984; Palmer & O'Keeffe, 1990). The reasons for this vary from dam to dam. Deep release dams let out organically-enriched water which increases productivity (eg. Palmer & O'Keeffe, 1990), while surface-release water introduces large quantities of zooplankton (Palmer & O'Keeffe, 1990; see Ward & Stanford, 1979, amongst many others). *Although biomass may increase, the macroinvertebrate diversity* below dams decreases, often favouring pest species (eg. Ward *et al.*, 1984). Butorin & Monakow (1984) also noted that there is a considerable increase in the number of phytoplankton species and their biomass below impoundments.

Fish are also adversely affected by impoundments. Their population density, growth, biomass, fecundity, production, species composition and movements all change after dam closure (eg. Ward *et al.*, 1984). The fish that are affected the most are diadromous and semi-diadromous species, as they can no longer get to their spawning grounds (Butorin & Monakow, 1984). The reduction in flow after impoundment also leads to the closure of estuary mouths, leading to a loss of nursery areas for marine fish species (Ward *et al.*, 1984).

All these biological effects are the result of the inter-relationships between the thermal, chemical and hydrological modifications which occur on impoundment and subsequent regulation of the river system.

2. **Chemical modifications**

Chemical modifications due to impoundment are many and varied. The most important are discussed below.

Oxygen: Deoxygenation is expected in hypolimnetic-release dams and is only restored in turbulent conditions (Armitage, 1984). It is often linked with an increase in hydrogen sulphide concentrations, which may be lethal to fish. This is often a localised effect, with rapid recovery downstream (Armitage, 1984).

Salinity: Impoundments act as sinks for dissolved solids (Armitage, 1984). This, compounded with increased evaporation, leads to an increase in salinity in man-made lakes (Armitage, 1984). The salinity dissolved solids cycle may also undergo a complete reversal or a delay in seasonal maxima and minima (Palmer & O'Keeffe, 1990).

Ionic concentrations: With an increase in salinity one would expect the ionic concentrations above and below the dam to differ. However, Ward (1982) observed that the influent and effluent of dams were often similar in this respect.

Nutrients: Reservoirs may act as nutrient sinks (O'Keeffe *et al.*, 1989), and the quality of reservoir releases depend on their timing and depth characteristics (Ward, 1982; Armitage, 1984; Davies *et al.*, 1989). Byren & Davies (1989) found on the Palmiet River, Western Cape, that the nutrient loads increase downstream of the dam, but that recovery was rapid.

3. **Thermal modifications**

Water temperature influences distribution, growth, maturity and emergence of stream invertebrates (Ward & Stanford, 1982; Armitage, 1984). The temperature régime in regulated streams may be altered in five ways: increased diel constancy (Palmer &

O'Keeffe, 1990; Armitage, 1984; Byren & Davies, 1989); increased seasonal constancy (Palmer & O'Keeffe, 1989; Byren & Davies , 1989); summer cooling (Palmer & O'Keeffe, 1989; Armitage, 1984; Byren & Davies, 1989); winter warming (Palmer & O'Keeffe, 1989, Armitage, 1984; Byren & Davies, 1989); and thermal pattern changes (Armitage, 1984). Large modifications such as these may have significant impacts on seasonal timing of major biotic processes (eg. Ward, 1982).

4. Hydrological modifications

Hydrologically, impoundments affect rivers both upstream and downstream of the wall (eg. Simons, 1979). Upstream, an impoundment reduces the velocity of flow, increases the depth of flow and causes deposition of sediment and aggradation, which increases river-bed elevation, increasing the propensity for flooding (Simons, 1979; Armitage, 1984). Downstream the water is clear, due to sediment trapping within the impoundment, and degradation of the channel occurs (Simons, 1979; Armitage, 1984). This may lead to an increased gradient and a lowering of the water table (Simons, 1979) as well as to lowering of river-bed elevation, and to substratum hardening (Wolff *et al.*, 1989).

An important effect of impoundments is the dampening of seasonal flow fluctuations. In particular the flood régime is affected (Palmer & O'Keeffe, 1990, Ward *et al.*, 1984; Higgs & Petts, 1988). Flooding clears rivers of sediment and opens the mouth to the sea. The flooding cycle of a river also coincides with many biological processes (eg. fish migration and spawning) (Ward *et al.*, 1984) and, if mismanaged, dam releases in the wrong period may cause an imbalance in the life cycles of the biota. Unfortunately, sudden fluctuations of discharge are characteristic of many regulated rivers throughout the world (Petts, 1984; Higgs & Petts, 1988).

The effect of flow regulation by reservoirs has usually been to increase low flows (Higgs & Petts, 1988). The preferred approach when dealing with compensation flows is that where releases are varied to maintain flow at a particular threshold to a downstream point (Gustard & Cole, 1987; Gustard, 1989). Recently the Instream Flow Incremental Methodology (IFIM) (Bovee, 1982) has been used to determine minimum flow requirements for a variety of species.

FLOW REQUIREMENTS OF RIVERS AND THE INSTREAM FLOW INCREMENTAL METHODOLOGY (IFIM)

Stream flow plays a large role in determining habitat diversity (eg. Ward & Stanford, 1983b), and therefore, the nature and diversity of organisms in the system. A reduction in flow, relative to the natural flow régime, can result in reduction in habitat diversity, the appearance of pest species, desynchronisation of life cycles and, ultimately, elimination of part of the natural biota of the system (eg. Ward & Stanford, 1983; O'Keeffe *et al.*, 1989b). In recent years, some freshwater research has headed in the direction of the flow requirements of rivers (eg. Gore & King, unpublished a,b; Gustard, 1984; Geer, 1987; Gore, 1987; Orth, 1987; Scott & Shirvell, 1987; Wesche *et al.*, 1987; Gore & Nestler, 1988; Reiser *et al.*, 1987; Courot, 1989; Gore & King, 1989; Gustard, 1989; O'Keeffe *et al.*, 1989b; Wolff *et al.*, 1989; Wright, *et al*, 1989), and hydraulic and hydrological parameters associated with riverine biota (Chutter, 1969; Bonetto, 1975; Canton *et al.*, 1984; Ranta & Servola, 1984; Statzner & Higler, 1986; Gaschignard & Berley, 1987; Irvine, 1987; Williams & Winger, 1987; Boulton & Lake, 1988; Hooper & Ottey, 1988; Power, *et al.*, 1988; Statzner *et al.*, 1988b; Gore *et al.*, 1989; Hall *et al.*, 1989; Vásquez, 1989; Smith *et al.*, 1990).

In the United States, the U.S. Fish and Wildlife Service has developed a documentation and computer programme system known as the Instream Flow Incremental Methodology (IFIM) (Bovee, 1982). This is considered to be one of the most advanced and sophisticated of all available methodologies for instream flow assessments (Shirvell, 1986; O'Keeffe *et al.*, 1989b) and is used as a basis for legislated flow reservations in the United States (Gore &

King, unpublished a). IFIM combines hydraulic and hydrological information of the flow in a river reach with the physical-habitat requirements of riverine organisms, as indicators of ecosystem integrity (Gore & King, 1989). Physical Habitat Simulation (PHABSIM II) (Milhous *et al.*, 1984) is the computer model, implementing IFIM, which quantifies changes in physical habitat, with increments of flow change (Gore & Nestler, 1988).

The underlying principles of PHABSIM II are that each species exhibits habitat preferences, and the range of habitat conditions it is able to tolerate can be defined for each species as suitability-of-use curves (Bovee & Cochnauer, 1977; Gore & Nestler, 1988; Belaud *et al.*, 1989). Originally, IFIM was used to quantify the water requirements of fish (Gore & King, unpublished b) but the methodology has since been modified for invertebrate studies (Gore, 1987).

For the application of IFIM both macrohabitat variables such as channel structure, water quality, temperature and sediment yield, and microhabitat variables, water velocity and discharge, depth and substratum composition, need to be measured (Bovee, 1982). This leads to the development of "species-suitability-criteria" for both macro- and microhabitats. Overlaying usable macro- and microhabitat then provides a Weighted Usable Area (WUA) estimate for the species concerned, as a function of the series of discharges under assessment.

Crucial to the successful assessment of minimum flow requirements of rivers is the *prior identification of the purpose for which the assessment will be made and the identification of target species.*

Biological Indicators and Target Species

IFIM rests on the use of physical habitat requirements of riverine organisms as an indicator of ecosystem integrity (Gore & King, 1989). Organisms are adapted to live within certain environmental limits (some have wide tolerances, others have narrower tolerances). These limits indicate a community's resilience, and if environmental changes exceed those limits at any point along a river, the community structure will collapse and there will be an establishment of a new, altered structure (King *et al*, 1989). Thus, it is import~nt to identify those species, or communities most sensitive to a change in flow when working with IFIM.

IFIM in the South African context

Only in recent years has research in South Africa headed in the direction of the flow requirements of rivers (King & O'Keeffe, 1989). The application of IFIM is escalating (Gore & King, 1989; Gore & King, unpublished a) and, if used effectively, may give valuable information on the minimum flow requirements for a number of South African rivers. Preliminary studies in this area have been done on the Eerste and Olifants rivers (Western Cape) (Gore & King, 1989), and on the rivers of the KNP (Bruwer, 1987; Chutter and Heath, 1993; Gore *et al.*, 1987; Gore *et al.*, 1992).

King and Tharme (1994) have recently published the results of a major trial of IFIM on the fish and invertebrates of the Olifants River (western Cape). Their conclusions were as follows:

- The method is complex and difficult to grasp conceptually, requiring the input of many different disciplines.
- It is an outstanding training tool, but is confusing, user-unfriendly and incomplete. because the PHABSIM II model is the only part which is regularly used. The macrohabitat sections, which provide the vital context for the PHABSIM output, have not been developed.
- The model has considerable potential, but can also be misused in the hands of inexperienced users. It requires the input of a hydraulics engineer.
- IFIM is a very resource-intensive methodology, requiring large amounts of time, expertise, and manpower for results which only provide part of an answer to the instream flow requirements of a river.
- The methodology was generally designed to provide single figure water requirements for single, economically important species in generally homogeneous rivers, such as

for trout in upland cobble-bed rivers. The requirements for South African rivers are more for flows that will maintain the full suite of ecological and physical processes, including water quality, in our rivers.

- The authors felt that the collection of hydraulic data and information on the habitat requirements of the biota were the most valuable contributions of the use of PHABSIM, but that, because of its costs and limited output, its application to South African rivers will remain limited to those for which detailed databases are already available.

Invertebrate Communities and Target Species

Despite major ecological roles played by insects in aquatic habitats, they have only been given cursory consideration in terms of their requirements; only rarely are they considered as an integral part of habitat management (Ward, 1984). Initially IFIM (Bovee, 1982) was designed to improve the habitat of certain fish species only (King *et al.*, 1989). However, more recent research has indicated that some riverine invertebrates may have narrower tolerances, particularly different life stages, to flow changes than do many fish species (Gore & Judy, 1981), and a small loss in fish habitat may indicate a large loss for benthic macroinvertebrates (King *et al*., 1989). Also, any imbalances in benthic community structure could lead to further decreases in invertebrate numbers, with resultant effects throughout the complex assemblage of biota associated with the river (Gore, 1987). Ward (1984) listed possible modifications to insect communities which may occur due to a change in the flow régime.

The identification of target or indicator species, and the use of biotic indices, have long been tools used in the assessment of water quality (eg. Hynes, 1960, 1964; Chutter, 1972; Wright *et al.*, 1988). The same methods may be used for the identification of target species, or communities, for application in PHABSIM II. Chutter (1972) discussed the different indices and systems that have been used to determine water quality. Two types of biological indicator exist; those that rely on a single indicator species which is sensitive to change, as used in the SAPROCHIENSYSTEM (Kolkwitz & Marsson, 1908, 1909 as cited by Chutter, 1972), and diversity indices (Chutter, 1972), which assess a whole community. Even Beak's index (Beak, 1965, as cited by Chutter, 1972), which looks at a whole macroinvertebrate fauna, like the SAPROHIENSYSTEM, relies on a subjective decision as to the sensitivity of the animal to water quality (Chutter, 1972). Biological indices based on diversity, however, are less subjective and, because they do not require that the organisms to be taxonomically identified, may be used by investigators with limited taxonomic background (Chutter, 1972).

A single sensitive species may be used to identify the threshold at which a river becomes degraded (in terms of flow and water quality). A biotic index based on diversity, however, shows the extent of change, as more species are lost. Chutter (1972) stated that a Diversity Index is based on three hypotheses: that faunal communities of pristine streams and rivers are definable; that they change in a predictable manner with a change in water quality (in this case flow), and that the greater the disturbance, the greater the change in the fauna.

Fish Target Species

Fish, both interesting and highly visable, are often the focus of ecological research in aquatic systems and have been used extensively in the development of microhabitat needs including the instream flow incremental metholodgy (IFIM) (Bovee, 1982).

As with macro-invertebrates, the choice of fish as target species depends on the aims of the research. Although it would be desirable to have data on hand for all species this is often impractical and species need to be selected to be representative of the questions set. In the project on hand, this revolved around changes in discharge and seasonal response. Target species were therefore drawn from assemblages adapted to various flow environments.

Bovee (1986) has pointed out three useful behavioral categories; obligate riverine, facultative riverine and facultative lacustrine. Here, fish range from species dependent on the lotic river environment for one or more of their life-history stages, to species utilizing low- to zero-flow microhabitats. The relevance here is the usefulness of lotic fish species for flow-related aims. This would rule out a lacustrine species as ideal target species, all considerations being equal. Other factors, such as conservation status, hydrological tolerance, and even distribution, may be important in reaching a decision.

The Sabie-Sand River System

Through upland afforestation, water abstraction and river regulation, lowveld rivers are being changed from perennial to seasonal in character. All six major rivers that run through the Kruger National Park (KNP) originate in catchments west of, and outside the jurisdiction of the Park. Of these, only the Sabie River remains unregulated and perennial (Davies, 1979). The Sabie River has been identified as perhaps the most important natural river for nature conservation in South Africa. (Chutter & De Moor, 1983; Moore & Chutter, 1988; O'Keeffe *et al.*, 1989a). Its biota is relatively undisturbed and at the moment its waters are relatively unpolluted (Chunnett, *et al.*, 1987).

In spite of the apparent value of the Sabie-Sand system, eight dam sites have been identified for future development (Chunnett, *et al.*, 1987) and, therefore, there is a real need for more information about possible effects. The present ecological database for the river system within the KNP (Moore & Chutter, 1988) is extensive but does not allow for the use of instream-flow models (eg. IFIM: Bovee, 1982). Outside the KNP, the database is very sparse, comprising a survey of the invertebrate fauna (Hughes 1966a; 1966b), some surveys of the fish fauna by the Transvaal Provincial Administration, Department of Nature and Environmental Conservation (Davies & O'Keeffe, 1991).

REFERENCES

Acocks J.P.H. 1975. Veld types of South Africa. *Memoirs of Botanical Survey of South Africa* 40: 128pp. Department of Agriculture, Technical Services, South Africa.

Alexander W.J.R. 1985. Hydrology of low latitude southern hemisphere land masses. *Hydrobilogia* 125: 75-83.

Armitage P.D. 1984. Environmental changes induced by stream regulation and their effect on lotic macroinvertebrate communities, in: A. Lillehammer and S.J. Saltveit. *Regulated Rivers* Univeritetsfarleglet, Oslo.

Barmuta L.A. & P.S. Lake. 1982. On the value of the River Continuum Concept. *N.Z. J. Mar. Freshwat. Res. 16:* 227-231.

Belaud A., P. Chaveroche, P. Lim & Sabaton. Probability-of-use curves applied to brown trout *(Salmo trutta fario* L.) in rivers of southern France. *Regulated Rivers: Research and Management*: 3 321-336.

Bonetto A.A. 1975. Hydrologic régime of the Parana River and its influence on ecosystems. In: *Landscapes of river basins* (South America) Springer-Verlag, New York.

Boulton A.J. & P.S. Lake. 1988. Australian temporary streams - some ecological characteristics. *Verh. Internat. Verein. Limnol.* 23: 1380-1383.

Bovee K.D. 1982. A guide to stream habitat analysis, using instream flow incremental methodology. *Instream Flow Information Paper* 12: U.S.D.I. Fish. Wildl. Serv. Office of Biol. Serv. FWS/OBS - 82/26: 248pp.

Bovee K.D. 1986. Development and evaluation of habitat suitability criterior for use in the Instream Flow Incremental Methology. *Instream Flow Incremental Paper* 21: U.S.D.I. Fish. Wildl. Serv. Office of Biol. Serv. FWS/OBS - 86/7: 205pp.

Bovee K.D. & T. Cochnauer. 1977. Development and evaluation of weighted area criteria, probability-of-use curves for instream flow assessments: fisheries. *Increase Flow Information Paper 3*. U.S.D.I. Fish. Wildl. Serv., Officer of Biol. Serv. FWS/OBS-77/63: 89pp.

Bruwer C.A. (Ed.). 1993a. *Flow Requirements of the Kruger National Rivers and impact of proposed water resources development* Part I: Water requirements at the critical level. Department of Water Affairs Technical Report, Pretoria.

Butorin N.V. & A.V. Monakon. 1984. The effect of the Volga flow regulation on biological processes. In: A. Lillehammer and S.J. Saltveit, *Regulated Rivers*. Universitetsforleget, Oslo.

Byren B.A. & B.R. Davies. 1989. The effect of stream regulation on the physico-chemical properties of the Palmiet River, South Africa. *Regulated Rivers: Research and Management 3*: 107-121.

Canton S.P., L.D. Cline, R.A. Short & J.V. Ward. 1984. The macroinvertebrates and fish of a Colorado stream during a period of fluctuating discharge. *Freshwater Biology 14:* 311-316.

Chunnett, Fourie & Partners. 1987. The Sabie River water resources development study: Briefing paper for assessing the in-stream water requirements of the natural environment and to assess the impact of the water resources development - Pretoria.

Chutter F.M. 1969. The distribution of some stream invertebrates in relation to current speed. *Int. Rev. ges. Hydrobiol.* 54(3): 413-422.

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

Chutter F.M. & F. C. de Moor. 1983. Preliminary report on a survey of the conservation status of the major rivers in the Kruger National Park C.S.I.R., N.I.W.R. Project No. 620/2151/4. File No. W6/151/3 W11/12/3.

Chutter F.M., P.J. Ashton, B. Walmsley & A. van Schalkwyk. In press. An interim assessment of the water requirements of the Letaba and Shingwedzi Rivers, Kruger National Park. In: C.A. Bruwer (Ed.). *Flow requirements of Kruger National Park Rivers and impact of proposed water resources development Part I: Water Requirements at the critical level.* Department of Water Affairs, Technical Report.

Connell J.H. 1978. Diversity in tropical rain forests and coral reefs. *Science 199:* 1802-1310.

Courot A. 1989. Determination of hydraulic parameters for instream flow assessments. *Regulated Rivers : Research and Management 3:* 337-344.

Craig J.F. & J.B. Kemper. 1987. *Regulated Streams : Advances in Ecology*. Plenum Press, New York and London. 431pp.

Cummins K.W. 1979. The natural stream ecosystem. In: J.V. Ward and J.A. Stanford (eds). *The Ecology of Regulated Streams*. Plenum Press, New York and London.

Davies B.R. 1979. Stream Regulation in Africa: A Review. In: J.V. Ward and J.A. Stanford (eds.). *The Ecology of regulated streams.* Plenum Press, New York and London.

Davies B.R. & J.A. Day. 1989. Physical and chemical attributes important in the biological functioning of river ecosystems. *S.A. Nat. Sci. Prog. Report No. 162:* 17-39.

Davies B.R., R.W. Palmer, J.H. O'Keeffe & B.A. Byren. 1989. The effects of impoundments on the flow and water quality of two contrasting southern African river systems. In: S. Kiensle and H. Maaren (eds.). *Proceedings of the Fourth South African National Hydrological Symposium, Pretoria.* 447pp.

Davies B.R. & J.H. O'Keeffe. Unpublished. A pre-impoundment study of the Sabie-Sand River system, Eastern Transvaal, with special reference to predicted impacts on the Kruger National Park. A project proposal.

Davies B.R., B. Bonthuys, W. Fourie, A. Marcus, S. Rossouw, C. Sellick, L. Theron, W. Uys W., L. van Rooyen, M. van Zyl & A. Viljoen. In Press. The Sabie-Sand System. *Chapter 7. In: C. Bruwer (ed.). Flow Requirements of the Kruger National Park Rivers and the Impact of Proposed Water Resource Developments,* Department of Water Affairs.

Ferrar A.A., J.H. O'Keeffe. & B.R. Davies. 1988. *The River Research Programme, South African National Scientific Programmes, Report no. 146.*

Gaschignard O. & A. Berly. 1987. Impact of large discharge fluctuations in the macroinvertebrate populations downstream of a dam. In: J.F. Craig and J.B. Kemper. *Regulated Streams: Advances in Ecology.* Plenum Press, New York and London.

Geer W.H. 1987. A method for treatment of data from the Instream Flow Incremental Methodology for instream flow determination. In: J.F. Craig and J.B. Kemper *Regulated Streams : Advances in Ecology.* Plenum Press, New York and London.

Gertenbach W.P.D. 1983. Landscapes in the Kruger National Park. *Koedoe 26*: 9-121.

Gore J.A. 1987. Development and application of macroinvertebrate instream flow models for regulated flow management. In: J.F. Craig and J.B. Kemper (eds.). *Regulated Streams: Advances in Ecology.* Plenum Press, New York and London.

Gore J.A. & J.M. King. Unpublished a. Application of the revised physical habitat simulation (PHABSIM II) to minimum flow evaluations of the South African Rivers.

Gore J.A. & J.M. King. Unpublished b. An introduction to the Instream Flow Incremental Methodology: A technique for predicting optimum and minimum flows for biota in a river.

Gore J.A. & J.M. King. 1989. Application of the revised physical habitat simulation (PHABSIM II) to minimum flow evaluations of South African rivers. In: S. Kiensle and H. Maaren (eds.). *Proceedings of the Fourth South African National Hydrological Symposium*, Pretoria. 447pp.

Gore J.A., J.B. Layser & J.M. King. 1987. *Instream Flow Incremental Methodologies: Kruger National Park.* Technology Transfer Workshop.

Gore J.A. & J.M. Nestler. 1988. Instream Flow studies in perspective. *Regulated Rivers: Research and Management 2:* 93-101.

Gore J.A., J.M. Nestler & J.B. Layser. 1989. Instream Flow predictions and management options for biota affected by peaking - power hydroelectric operations. *Regulated Rivers: Research and Management 3* 35-48.

Gustard A. 1984. The characterisation of flow régimes for assessing the impact of water resource management on river ecology. In: A. Lilliehammer and S.J. Saltveit. *Regulated Rivers.* Universitetsforleget, Oslo.

Gustard A. 1989. Compensation flows in the U.K.: a hydrological review. *Regulated Rivers: Research and Management 3:* 49-59.

Gustard A. & G.A. Cole. 1987. Towards a rational assessment of residual flows below reservoirs. In: J.F. Craig and J.M. Kemper (eds.). *Regulated Streams : Advances in Ecology.* Plenum Press, New York and London.

Hall C.A.S., J.H. Jourdonnais & J.A. Stanford. 1989. Assessing the impacts of stream regulation in the Flathead River Basin, Montana, U.S.A. I. Simulation modelling of system water balance. *Regulated Rivers: Research and Management 3:* 61-77.

Higgs G. & G. Petts. 1988. Hydrological changes and river regulation in the U.K. *Regulated Rivers: Research and Management 2:* 349-368.

Hooper F.F. & D.R. Ottey. 1988. Responses of macroinvertebrates of two headwater streams to discharge fluctuations. *Verh. Internat. Verein. Limnol. 23:* 1159-1166.

Hughes D.A. 1966a. Mountain streams of the Barbeton Area, Eastern Transvaal. Part I, A Survey of the Fauna. *Hydrobiologia 27:* 401-438.

Hughes D.A. 1966b. Mountain streams of the Barbeton Area, Eastern Transvaal Part II, the effect of vetational shading and direct illumination on the distribution of Stream Fauna. *Hydrobiologia 27:* 439-459.

Hynes H.B.N. 1960. *The Biology of Polluted Waters*, Liverpool University Press, Liverpool.

Hynes H.B.N. 1964. The use of biology in the study of water pollution. *Chem. Ind.* 435-436.

Irving J.R. 1987. The effects of varying flows in man-made streams on Rainbow trout. *(Salmo gairdneri* (Richardson) fry. In: J.F. Craig & J.B. Kemper (eds.). *Regulated Streams: Advances in Ecology*. Plenum Press, New York and London.

King J.M. & J.H. O'Keeffe. 1989. Looking to the future - South Africa's requirements. *S.A. Nat. Sci. Prog.* Report No. 162: 110-116.

King J.M., F.C. de Moor, A.J. Botha & A.H. Coetzer. 1989. Water quality requirements of invertebrates, macrophytes and other mesobiota. *S.A. Nat. Sci. Prog. Report* No. 162: 57-70.

Lake P.S., L.A. Barmuta, A.J. Boulton, S. Campbell & R.M. st Claire. 1985 Australian streams and northern hemisphere stream ecology: comparisons and problems. *Proc. Ecol. Soc. Aust. 14*: 61-82.

Lillemammer A. & S.J Saltveit. 1984. *Regulated Rivers*. Universitetsforlaget A.S., Oslo, 540pp.

Millhous R.T., D.L. Wegner & T. Waddle. 1984. User's guide to the physical habitat simulation system. *Instream Flow Information Paper II. U.S.D.I.* Fish. Wildl. Serv. Office of Biol. Serv. FWS/OBS - 81/43 (revised).

Minshall G.W. & K.W. Cummins, R.C. Petersen. C.E. Cushing, D.A. Bruno, J.R. Sedell & R.G. Vannote. 1985. Developments in stream ecosystem theory. *Can J. aquat. Sci. 42*: 1045-1055.

Moore C.A. & F.M. Chutter. 1988. A survey of the conservation status and benthic biota of the major rivers of the Kruger National Park. *Contract Report*. National Institute of Water Research 55pp.

Naiman R.J., J.M. Melillo, M.A. Lock. & T.E. Ford. 1987. Longitudinal Patterns of ecosystem processing and community structure in a subarctic River Continuum. *Ecology* 68(5): 1139-1156.

Newbold J.D. 1987. Phosphorous spiralling in rivers and river reservoir systems: implications of a model. In: J.F. Craig and J.B. Kemper (eds.). *Regulated Streams: Advances in Ecology*. Plenum Press, New York and London.

Newbold J.D., R.V. O'Neill, J.W. Elwood & W. van Winkle. 1982. Nutrient spiralling in streams. Implication for nutrient limitation and invertebrate activity. *Am. Nat. 120*: 628-652.

O'Keeffe J.H. 1985. The conservation status of the Sabie and Groot Letaba Rivers within the Kruger National Park. IFWS Special Report No. 85/2. Rhodes University, Grahamstown.

O'Keeffe J.H. 1986. Ecological research of South African rivers - a preliminary synthesis. *S.A. Nat. Sci. Prog.* Report NO. 121. C.S.I.R. Pretoria.

O'Keeffe J.H. (1991). The Luvuvhu River. In: A preliminary assessment. in: C.A. Bruwer (ed.). Proceedings of a workshop on the flow requirements of the Kruger National Park Rivers. Dept. of Water Affairs Technical Report TR 149.

O'Keeffe J.H., B.R. Davies, J.M. King & P.H. Skelton. 1989a. The conservation status of South African rivers. In: B.J. Huntley (ed.). *Biotic Diversity in Southern Africa: Concept and Conservation.* Oxford University Press, Oxford 380pp.

O'Keeffe J.H., J.M. King, J.A. Day, D. Rossoun, D.W. van der Zel. & R. Skorozewski. 1989b. General concepts and approaches to instream flow assessment. *S.A. Nat. Sci. Prog. Report No. 162*: 41-55.

Orth D.J. 1987. Ecological considerations in the development and application of instream flow-habitat models. *Regulated Rivers: Research and Management 1*: 171-181.

Palmer R. & J.H. O'Keeffe. 1990. Downstream effects of impoundments on the water chemistry of the Buffalo River (Eastern Cape). South Africa. *Hydrobiologia, 202:* 71-83.

Pienaar U. de V. 1985. Indications of progressive desiccation of the Transvaal lowveld over the past 100 years, and implications for the water stabilisation programme in the Kruger National Park. *Koedoe 28*: 93-165.

Petts G.E. 1984. *Impounded Rivers.* John Wiley & Sons. 326pp.

Power M.E., R.J Stout, G.E. Cushing, P.P. Harper, F.R. Hauer, W.J. Matthews, P.B. Moyle, B. Statzner & I.R. Wais de Bagden. 1988. Biotic and abiotic controls in river and stream communities. *J.N. Am. Benthol. Soc.* 7(4): 456-479.

Ranta E. & P. Sevola. 1984. Effects of short term regulation on fish stocks in the rivers Kyrönjoki and Lapnanjoki, Finland. In: A. Lillehammer and S.J. Saltveit. *Regulated Rivers.* Universitetsforleget, Oslo.

Reiser D.W., M.P. Ramey & T.R. Lamert. 1987. Considerations in assessing flushing flow needs in regulated stream systems. In: J.F. Craig and J.B. Kemper (eds.). *Regulated Streams: Advances in Ecology* Plenum Press, New York and London.

Ryder G.U. & D. Scott. 1988. The applicability of the River Continuum Concept to New Zealand streams. *Verh. Internat. Verein Limnol.* 23: 1441-1445.

Scott D. & C.S. Shirvell. 1987. A critique of the Instream Flow Incremental Methodology and observation on flow determination in New Zealand. In: J.F. Craig and J.B. Kemper (eds.). *Regulated Streams: Advances in Ecology.* Plenum Press, New York and London.

Shirvell C.S. 1986. Pitfalls of habitat simulation in the Instream Flow Incremental Methodology. *Can. Tech. Rep. Fish. Aquat. Sci.* 1460: 68pp.

Simons D.B. 1979. Effects of stream regulation on channel morphology. In: J.V. Ward & J.A. Stanford. *The Ecology of Regulated Streams.* Plenum Press, New York and London.

Smith C.D., D.M. Harper & P.J. Barham. 1990. Engineering operations and invertebrates: linking hydrology with ecology. *Regulated Rivers: Research and Management.* 5: 89-96.

Stanford B., F.R. Hauer & J.V. Ward. 1988a. Serial discontinuity in a large river system. *Verh. Internat. Verein. Limnol.* 23: 1114-1118.

Statzner B., J.A. Gore & V.H. Resh. 1988b. Hydraulic stream ecology: observed patterns and potential applications. *J.N. Am. Benthol. Soc.* 7(4): 307-360.

Statzner B. & B. Higler. 1985. Questions and comments on the River Continuum Concept. *Can. J. Fish Aquat. Sci.* 42: 1048-1044.

Statzner B. & B. Higler. 1986. Stream hydraulics as a major determinant of benthic invertebrate zonation patterns. *Freshwat. Biol.* 16: 127-139.

Vannote R.L., C.W. Minshall, K.W. Cummins, J.R. Sedell & C.E. Cushing. 1980. The River Continuum Concept. *Can. J. Fish. Aquat. Sci.* 37: 130-170.

Vasquez E. 1989. The Orinoco River: A review of hydrological research. *Regulated Rivers: Research and Management* 3: 381-392.

Ward J.V. 1982. Ecological aspects of stream regulation: responses in downstream lotic reaches. *Water Pollution and Management Reviews (New Delhi)* 2: 1-26.

Ward J.V. 1984. Ecological perspectives in the management of aquatic insect habitat. In: V.H. Resh and D.M. Rosenberg (eds.). *The Ecology of Aquatic Insects*, Praeger, New York.

Ward J.V., Davies B.R., Breen C.M., Cambray J.A., Chutter F.M., Day J.A., de Moor F.C., Heeg J., O'Keeffe J.H. & Walker K.P. 1984. Stream regulation. In: R.C. Hart and B.R. Allanson (eds.). *Limnological criteria for management of water quality in the southern hemisphere. S.A. Nat. Sci. Prog. Report.* No. 93.

Ward J.V. & J.A. Stanford (eds.). 1979. *The Ecology of Regulated Streams.* Plenum Press, New York and London.

Ward J.V. & J.A. Stanford. 1982. Thermal responses in the evolutionary ecology of aquatic insets. *A. Rev. Entomol.* 27: 97-117.

Ward J.V. & J.A. Stanford. 1983a. The Serial Discontinuity Concept of lotic ecosystems. In: T.D. Fontaine III and S.M. Bartell (eds.). *Dynamics of Lotic Ecosystems.* Ann Arbor Science, Michigan.

Ward J.V. & J.A. Stanford 1987. The ecology of regulated streams: Past accomplishments and directions for future research. In: J.F. Craig and J.B. Kemper (eds.). *Regulated Streams: Advances in Ecology.* Plenum Press, New York and London.

Webster J.R. 1975. Analysis of potassium and calcium dynamics in stream ecosystems on the souther Appalachian watersheds of contrasting vegetation. *Ph.D. thesis*, University of Georgia, Athens, Georgia, U.S.A.

Wesche T.A., V.R. Hasfurther, W.A. Hubbert, Q.D. Skinner. 1987. Assessment of flushing flow recommendations in a steep, rough regulated tributary. In: J.F. Craig and J.B. Kemper (eds.). *Regulated Streams: Advances in Ecology.* Plenum Press, New York and London.

Willaims W.D. 1988. Limnological imbalances: an antipodean viewpoint. *Freshwater Biology* 20: 407-420.

Williams R.D. & R.N. Winger. 1987. Macroinvertebrate response to flow manipulation in the Strawberry River, Utah (U.S.A.) In: J.V. Ward and J.A. Stanford. *The Ecology of Regulated Streams.* Plenum Press, New York and London.

Winterbourn M.J., J.S. Rounick & B. Cowie. 1981. Are New Zealand Stream ecosystems really different? *N.Z.J. Mar. Freshwat. Res.* 15: 321-328.

Wolff S.W., T.A. Wesche & W.A. Aubert. 1989. Stream channel and habitat changes due to flow augmentation. *Regulated Rivers: Research and Management* 4: 225-233.

Wright J.F., P.D. Armitage, M.T. Furse & D. Moss. 1988. A new approach to the biological surveillance of river quality using macroinvertebrates. *Verh. Internat. Verein. Limno.* 23: 1548-1552.

Wright J.F., P.D. Armitage & M.J. Furse. 1989. Prediction of invertebrate communities using stream measurements. *Regulated Rivers: Research and Management* 4: 147-155.

APPENDIX II

Appendix II: Full species list and total number of all invertebrates collected during all field trips and all years of the Sabie-Sand catchment study for the three major biotopes: riffle, soft sediments and vegetation. The "species numbers" in the left hand margin corresponds to the designation of each taxon, as used in the PRIMER analysis.

Species Number	Species				
	Total number of Samples	292	86	177	555
	Sample Type	Box	Grab	Sweep & quadrat	
	Biotope	Riffle	Soft-sediment	Vegetation	All Biotopes
227	CNIDARIA indet.	0	0	24	24
	Hydrozoa				
229	*Hydra* sp.	23	0	291	314
	PLATYHELMINTHES	0	0	16	16
198	Turbellaria	2728	258	1494	4480
214	NEMERTEA	11	0	12	23
215	RHYNCHOCOELA	223	0	0	223
200	NEMATODA	392	240	4	636
221	ANNELIDA indet.	3713	2864	6409	12986
218	Oligochaeta	6136	6432	15036	27604
222	Tubificidae	0	584	100	684
223	Lumbriculidae	2134	336	0	2470
224	Hirudinea	1737	512	5479	7728
	ARTHROPODA				
225	Arachnida	317	8	621	946
226	Hydracarina	21083	2688	12430	36201
205	Crustacea	8	8	12	28
	Macrura				
207	*Caridina nilotica*	480	0	2168	2648

	Brachyura	44	0	0	44
209	Potamonautes boyonianus	812	0	448	1260
210	Ostracoda	5690	2764	47602	56056
211	Copepoda	22544	6040	6340	34924
212	Conchostraca	44	64	0	108
213	Cladocera	3422	128	34168	37718
	Insecta				
202	Collembola	125	0	100	225
203	Smynthuridae	331	0	36	367
204	Isotomidae	68	0	28	96
153	Megaloptera	352	0	12	364
154	Plecoptera	4448	680	1458	6586
155	Odonata indet.	1071	16	156	1243
156	Zygoptera	218	264	1328	1810
157	Lestidae	175	0	428	603
158	Chlorolestidae	23	8	79	110
159	Protoneuridae	365	368	1180	1913
160	Chlorocyphidae	78	0	314	392
161	Coenagrionidae	50	16	1348	1414
162	Calopterigidae	0	0	7	7
163	Platycnemididae	12	0	0	12
164	Anisoptera	188	32	244	464
165	Gomphidae	493	792	232	1517
166	Aeshnidae	2763	96	332	3191
168	Corduliidae	0	32	8	40
169	Libellulidae	561	0	527	1088
1	Ephemeroptera indet.	4299	632	2548	7479
2	Baetidae indet.	9248	816	7956	18020
3	Baetidae small nymphs	41486	584	9934	52004

4	Demoulina complex	2756	168	4056	6980
5	Acentrella sp.	3850	72	545	4467
6	Afroptilum complex	4009	8	132	4149
7	Acanthiops complex	667	0	100	767
8	Cloeon complex	4390	80	1633	6103
9	Centroptiloides sp.	753	0	151	904
10	Rithrocloeon sp.	267	40	52	359
11	Afrobaetoides sp.	0	0	8	8
12	Pseudopannota complex	836	0	148	984
13	Baetis sp.	39377	1760	20755	61892
14	Potomacloeon complex	132	0	164	296
15	Centroptilum sp.	1489	0	520	2009
16	Leptophlebiidae	88	32	140	260
17	Adenophlebia complex	12	16	16	44
18	Castanophlebia sp.	538	216	27	781
19	Choroterpes complex	9679	592	1824	12095
20	Aprionyx complex	112	192	172	476
21	Thraulus sp.	22	0	20	42
22	Heptageniidae	22	8	100	130
23	Afronurus sp.	853	16	788	1657
24	Composoneuriella sp.	1207	0	1423	2630
25	Tricorythidae	0	0	196	196
26	Neurocaenis sp.	15238	88	4112	19438
27	Dicercomyzon sp.	0	0	56	56
28	Trichorythus sp.	24352	216	5076	29644
29	Ephemerythus sp.	266	0	43	309
30	Machadorythus sp.	142	19	4	165
31	Caenidae indet.	11896	21664	7822	41382
31	Caenidae small nymphs	154	128	0	282

33	*Caenospella* sp.	77	0	0	77
34	*Caenis* sp.	2422	672	2932	6026
35	*Caenodes* sp.	1001	24	1692	2717
36	*Afrocaenis* sp.	2092	488	1604	4184
37	Oligoneuridae	0	0	4	4
38	*Elassoneuria* sp.	23	0	12	35
40	Ephemerellidae	8	8	0	16
43	Prosopisthomatidae				
44	*Prosopistoma* sp.	134	0	0	134
45	*Binoculus* sp.	176	0	20	196
46	Polymitarcidae				
48	*Povilla* sp.	22	0	436	458
49	Trichoptera	5368	248	444	6060
50	Hydropsychidae indet.	77	0	0	77
50	Hydropsychidae small larvae	6037	0	608	6645
53	*Hydropsyche longifurca*	4966	104	240	5310
52	*Hydropsyche* sp.	2115	0	38	2153
54	*Amphisyche* sp.	198	0	0	198
56	*Cheumatopsyche thomasetti*	18103	72	488	18663
57	*Cheumatopsyche afra*	5807	0	208	6015
55	*Cheumatopsyche* sp.	6770	0	6654	13424
58	*Macrostemum capense*	772	0	56	828
59	*Aethaloptera maxima*	374	280	64	718
60	*Leptonema* sp.	0	0	14	14
61	*Sciadorus* sp.	1189	104	236	1529
62	Ecnomidae	143	0	8	151
63	*Ecnomus* sp.	1014	360	2275	3649
64	Leptoceridae indet.	206	32	329	567
64	Leptoceridae small larvae	22	0	100	122

65	Oecetis sp.	640	144	289	1073
66	Leptocerus sp.	0	0	44	44
67	Leptocerina sp.	0	0	24	24
68	Adicella sp.	11	0	356	367
69	Setodes sp.	23	16	83	122
70	Trichosetodes sp.	44	0	348	392
71	Paracetodes sp.	11	0	60	71
72	Ceraclea sp.	1554	96	123	1773
73	Trianodes sp.	0	0	308	308
75	Athripsodes bergensis	33	0	136	169
74	Athripsodes sp.	2364	16	320	2700
77	Calamoceratidae	0	0	92	92
78	Anisocentropus sp.	22	112	40	174
79	Helicopsychidae	11	0	180	191
82	Polycentropodidae	1980	0	0	1980
83	Nictiophylax sp.	391	24	221	636
84	Hydroptilidae indet.	1397	0	192	1589
84	Hydroptilidae small larvae	4828	8	479	5315
85	Hydroptila sp.	3281	120	167	3568
86	Catoxyella sp.	1353	8	0	1361
88	Orthotrichia sp.	1882	8	1377	3267
89	Oxyethira sp.	40	0	20	60
90	Catoxyethira sp.	207	0	24	231
91	Stactobia sp.	56	0	0	56
92	Glossosomatidae	11	0	0	11
93	Agapetus sp.	0	0	28	28
94	Psychomydae				
95	Tinodes sp.	123	0	0	123
96	Philopotamidae	2572	16	88	2676

97	Chimarra sp.	2837	0	940	3777
98	Dolophilodes sp.	720	0	21	741
99	Dipseudopsidae	11	16	4	31
100	Dipseudopsis sp.	40	240	8	288
101	Diptera	8786	1496	752	11034
102	Simuliidae indet.	168795	2568	37554	208917
102	Simuliidae small larvae	10778	0	20	10798
104	Chironomidae indet.	988675	143224	216680	1348579.1
105	Chironomidae small instars	24263	1344	1460	27067
106	Orthocladiinae	42619	672	5284	48575
107	Tanypodinae	1025	40	432	1497
108	Chironominae	6988	4008	2684	13680
110	Rhagionidae	10347	240	1104	11691
111	Tipulidae	6288	448	520	7256
112	Tabanidae	197	48	66	311
113	Empididae	1666	96	208	1970
114	Ephydridae	0	0	12	12
115	Ceratopogonidae	5678	5176	4226	15080
116	Dixidae	130	120	271	521
117	Stratiomyidae	55	120	68	243
118	Limnebidae	0	0	112	112
119	Psychodidae	131	8	155	294
120	Culicidae	1736	272	2004	4012
121	Athericidae	1188	24	60	1272
123	Dolichopodidae	23	0	0	23
124	Anthomyidae	12	0	6	18
125	Deuterophlebiidae	23	0	0	23
126	Coleoptera	5569	32	724	6325
128	Psephenidae	276	0	27	303

129	Elmidae	29462	8768	5203	43433
130	Gyrinidae	394	16	302	712
131	Heleidae	12	0	4	16
132	Heliodidae	116	0	1228	1344
133	Dryopidae	829	136	216	1181
134	Noteridae	0	0	11	11
135	Hydraenidae	28	0	52	80
136	Hydrophilidae	23	8	88	119
137	Haliplidae	0	0	8	8
138	Dytiscidae	121	304	2345	2770
139	Georyssidae	0	0	6	6
219	Lepidoptera	416	80	44	540
220	Pyralidae	1162	0	148	1310
140	Hemiptera	190	16	392	598
141	Naucoridae	165	40	497	702
142	Belostomatidae	70	0	444	514
143	Gerridae	22	0	436	458
144	Veliidae	365	24	1224	1613
145	Mesoveliidae	0	0	8	8
146	Hebridae	23	0	28	51
147	Notonectidae	730	56	1456	2242
148	Pleidae	3186	8	2012	5206
149	Corixidae	228	48	1188	1464
150	Nepidae	8	0	64	72
151	Saldidae	12	0	0	12
152	Cicadellidae	11	8	0	19
171	MOLLUSCA	804	24	2080	2908
170	Gastropoda indet.	12	8	148	168
172	_Burnupia_ sp.	1741	0	388	2129

173	Melanoides sp.	22	80	570	672
174	Lymnaea sp.	121	16	152	289
175	Physa sp.	0	0	504	504
176	Tomichia sp.	0	424	8	432
177	Helisoma sp.	11	32	572	615
178	Ferissia sp.	1923	272	1550	3745
179	Lanistes sp.	0	0	16	16
180	Gyraulus sp.	23	48	1686	1757
181	Hydrocena sp.	0	8	0	8
183	Succinea sp.	0	0	4	4
184	Planorbis sp	22	24	44	90
185	Bivalvia				
186	Ancylidae	0	0	368	368
189	Sphaeridae				
190	Sphaerium sp.	66	288	7	361
191	Pisidium sp.	89	200	1016	1305
192	Unionidae				
193	Caelatura kunenensis	0	24	387	411
194	Corbiculidae	0	24	24	48
196	Corbicula africana	0	0	11	11
195	Corbicula sp.	49	168	440	657

APPENDIX III

Table 1: Complete species list for fish found in the Incomati system tributaries and river zones. Distribution for the Sabie River is ' ased on this survey, other distribution data are taken from Gaigher (1969) and Skelton (1993). FHZ = Foothill Zone, LZ = Lowveld Zone, CP = Coastal Plain & E = Estuary.

SPECIES	DISTRIBUTION				ZONES			
	Sabie	Croc	Komati	Incomati	FHZ	LZ	CP	E
Protopteridae (lungfish)								
Protopterus annectens Poll, 1961				X			X	
Mormyridae (snoutfishes)								
Marcusenius macrolepidotus (Peters, 1852)	X	X	X	X		X	X	
Petrocephalus catostoma (Günther, 1866)	X	X	X	X		X	X	
Megalopidae (tarpon)								
Megalops cyprinoides (Broussonet, 1782)				X			?	X
Anguillidae (freshwater eels)								
Anguilla mossambica Peters, 1852	X	X	X	X	X	X	X	
Anguilla bicolor McClelland, 1844				X			X	
Anguilla bengalensis Peters, 1852	X	X	X	X			X	
Anguilla marmorata Quoy & Gaimard, 1824	X	X	X	X	X	X	X	
Kneriidae (knerias)								
Kneria auriculata (Pellegrin, 1905)		X*			X			
Cyprinidae (barbs & labeos)								
Mesobola brevianalis (Boulenger, 1908)	X	X				X		
Opsaridium zambezense (Peters, 1852)	X	X	X			X		
Barbus anoplus Weber, 1897	X	X	X		X			
Barbus motebensis Steindachner, 1894		X			X			
Barbus treurensis[1] Groenewald, 1958	extinct							
Barbus annectens Gilchrist & Thompson, 1917	X	X	X	X		X	X	
Barbus brevipinnis[2] Jubb, 1966	X				X			
Barbus unitaeniatus Günther, 1866	X	X	X			X		
Barbus viviparus Weber, 1897	X	X	X			X		
Barbus toppini Boulenger, 1916	X	X		X		X	X	
Barbus radiatus Peters, 1853	X	X	X	X		X	X	
Barbus trimaculatus Peters, 1952	X	X	X			X		

cont...

SPECIES	DISTRIBUTION				HABITATS			
	Sabie	Croc	Komati	Incomati	FHZ	LZ	CP	E
Chiloglanis swierstrai Van der Horst, 1931	X	X	X			X		
Synodontis zambezensis Peters, 1852	X	X	X	X		X	X	
Aplocheilidae (killifishes)								
Nothobranchius orthonotus (Peters, 1844)				X			X	
Cyprinodontidae (topminnows)								
Aplocheilichthys johnstoni Günther, 1893				X			X	
Aplocheilichthys katangae (Boulenger, 1912)				X			X	
Cichlidae (cichlids) (Weber, 1897)								
Pseudocrenilabrus philander	X	X	X	X	X	X	X	
Chetia brevis Jubb, 1968			X	X		X	X	
Serranochromis meridianus[5] Jubb, 1967	X			X		X	X	
Tilapia sparmanii A. Smith, 1840	X	X	X	X	X		X	
Tilapia rendalli (Boulenger, 1896)	X	X	X	X		X	X	
Oreochromis mossambicus (Peters, 1852)	X	X	X	X		X	X	
Oreochromis placidus (Trewavas, 1941)				X			X	
Carcharhinidae (requiem sharks)								
Carcharhinus leucas (Valenciennes, 1839)				X			?	X
Pristidae (saw sharks)								
Pristis microdon Latham, 1794)				X			?	X
Ambassidae (glassies)								
Ambassis gymnocephalus (Lacepède, 1801)				X			?	X
Ambassis productus Guichenot, 1866				X			?	X
Mugilidae (mullets)								
Mugil cephalus Linnaeus, 1758				X			?	X
Liza macrolepis (Smith, 1846)				X			?	X
Syngnathidae (pipefishes)								
Microphis fluviatilis (Peters, 1852)				X			?	X
Microphis brachyurus (Bleeker, 1853)				X			?	X

cont...

SPECIES	DISTRIBUTION				ZONES			
	Sabie	Croc	Komati	Incomati	FHZ	LZ	CP	E
Barbus eutaenia Boulenger, 1904	X	X				X		
Barbus argenteus Günther, 1868	X	X	X		X			
Barbus paludinosus Peters, 1852	X	X	X	X		X	X	
Barbus afrohamiltoni Crass, 1960	X	X		X		X	X	
Barbus polylepis Boulenger, 1907	X	X	X		X			
Barbus marequensis A. Smith, 1841	X	X	X		X	X		
Varicorhinus nelspruitensis [3] Gilchrist & Thompson, 1911	X	X	X			X		
Labeo rosae Steindachner, 1894	X	X	X	X		X	X	
Labeo ruddi Boulenger, 1907	X	X				X		
Labeo congoro Peters, 1852	X	X	X			X	X	
Labeo cylindricus Peters, 1852	X	X	X			X		
Labeo molybdinus Du Plessis, 1963	X	X	X			X		
Characidae (characins)								
Brycinus imberi (Peters, 1852)	X	X	X	X		X	X	
Micralestes acutidens (Peters, 1852)	X	X	X			X		
Hydrocynus vittatus Castelnau, 1861	X	X		X		X	X	
Amphiliidae (mountain catfishes)								
Amphilius natalensis Boulenger, 1917	X	X			X			
Amphilius uranoscopus (Pfeffer, 1889)	X	X	X		X			
Schilbeidae (butter catfishes)								
Schilbe intermedius Rüppell, 1832	X	X	X	X		X	X	
Clariidae (air-breathing catfishes)								
Clarias gariepinus (Burchell, 1822)	X	X	X			X	X	X
Clarias ngamensis Castelnau, 1861							X	X
Mochokidae (squeakers & suckermouth catlets)								
Chiloglanis anoterus[4] Crass, 1960	X		X*		X			
Chiloglanis bifurcus Jubb & Le Roux, 1969		X	X		X			
Chiloglanis emarginatus Jubb & Le Roux, 1969			X		X			
Chiloglanis paratus Crass, 1960	X	X	X			X		
Chiloglanis pretoriae Van der Horst, 1931	X*	X	X		X	X		

cont...

SPECIES	DISTRIBUTION				ZONES			
	Sabie	Croc	Komati	Incomati	FHZ	LZ	CP	E
Sparidae (seabreams)								
Acanthopagrus berda (Forsskål, 1775)				X			X	X
Monodactylidae (moonies)								
Monodactylus argenteus (Linnaeus, 1758)				X				X
Monodactylus falciformis Lacepède, 1801				X				X
Eleotridae (sleepers)								
Eleotris fusca (Schneider, 1801)				X			?	X
Eleotris melanosoma Bleeker, 1852				X			?	X
Gobiidae (gobies)								
Awaous aeneofuscus (Peters, 1852)				X			X	X
Glossogobius callidus (Smith, 1937)	X	X	X	X		X	X	?
Glossogobius giuris (Hamilton - Buchanan, 1822)	X	X		X		X	X	X
Redigobius dewaali (Weber, 1897)				X			X	X
River Species Totals	47	46	*39	52	17	38	35(46)	19(20)

* = Isolated population/record.

1 = *Barbus treurensis*: endemic to the upper Blyde River, possibly extinct in the upper Sabie River.

2 = *Barbus brevipinnis*: endemic to the Sand & Sabie rivers, centered in the Marite presently.

3 = *Varicorhinus nelspruitensis*: endemic to the escarpment streams of the Incomati and Phongolo Systems.

4 = *Chiloglanis anoterus*: endemic to the escarpment tributaries of the Sabie-Sand System, few isolated populations in the Phongolo River.

5 = *Serranochromis meridianus*: endemic to the Mozambique coastal lakes & Sabie-Sand tributaries of Incomati.

APPENDIX IV

Table 1: Electrofished species and abundance data for annual survey sites in the Sabie-Sand catchment. May 1990.

	Sample Sites																total	% of total
Species	1	3	4	5	6	7	8	10	11	12	13	14	15	16	18	20		
BVIV	0	0	0	0	0	37	0	0	71	191	3	4	56	0	0	4	366	24.8
BRAD	0	0	0	0	0	30	0	0	0	0	2	0	63	0	0	0	95	6.4
BTRI	0	0	0	1	0	4	0	0	14	0	0	1	70	0	0	0	90	6.1
BMAR	0	0	0	13	0	6	4	1	55	0	7	0	1	0	2	0	89	6.0
OMOS	0	0	0	0	19	21	0	0	1	5	0	6	7	0	0	30	89	6.0
CANO	0	8	8	1	0	0	3	3	14	0	0	0	0	24	17	0	78	5.3
PCAT	0	0	0	0	0	3	1	0	0	0	13	59	2	0	0	0	78	5.3
BANN	0	0	0	0	0	11	0	0	0	1	0	0	63	0	0	0	75	5.1
MACU	0	0	0	17	0	22	0	0	11	0	2	13	0	0	0	1	66	4.5
LMOL	0	0	0	1	3	3	2	0	10	3	25	0	18	0	0	0	65	4.4
MBRE	0	0	0	0	0	3	0	0	8	0	0	18	11	0	0	0	40	2.7
TREN	0	0	0	0	3	10	0	0	0	1	0	0	7	0	0	11	32	2.2
BLUT	0	0	0	1	0	1	1	2	3	3	0	0	0	0	6	0	31	2.1
PPHI	0	0	0	2	16	2	2	6	0	4	0	0	0	0	0	0	31	2.1
VNEL	0	5	8	2	0	0	0	0	0	0	0	0	0	16	0	0	31	2.1
ANAT	0	0	0	0	0	0	0	18	0	0	0	0	0	12	0	0	30	2.0
BPOL	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	30	2.0
BUNI	0	0	0	0	4	2	0	0	14	0	0	0	4	0	0	0	24	1.6
CPAR	0	0	0	0	1	2	0	0	2	0	9	0	8	0	0	0	22	1.5
MMAC	0	0	0	6	0	0	0	0	1	1	5	6	0	0	0	2	21	1.4
SMLR	0	0	0	0	2	3	0	0	1	0	0	1	14	0	0	0	21	1.4
CSWI	0	0	0	0	3	0	0	0	0	15	0	0	0	0	0	0	18	1.2
STRU	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0.8
GCAL	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	4	9	0.6
BARG	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	6	0.4
OZAM	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	6	0.4
AMOS	0	0	0	0	0	0	1	1	1	0	0	0	0	0	1	0	4	0.3
BBRE	0	0	0	0	0	0	0	3	1	0	0	0	0	0	0	0	4	0.3
CGAR	0	0	0	1	0	2	0	0	0	0	1	0	0	0	0	0	4	0.3
AURA	0	0	0	2	0	0	0	0	0	0	0	0	0	0	1	0	3	0.2
AREN	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	2	0.1
LROS	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0.1
Total																	1473	100

Table 2: Electrofished species and abundance data for annual survey sites in the Sabie-Sand catchment. May 1991.

	Sample Sites																		total	% of total
Species	1	3	4	5	6	7	8	10	11	12	13	14	15	16	19	20	21	25		
BVIV	0	0	0	0	37	20	6	0	19	156	31	71	52	0	105	5	0	0	502	25.1
CANO	0	34	4	1	15	3	0	0	43	4	0	0	0	15	34	0	29	101	283	14.2
BMAR	0	0	0	0	39	20	15	2	21	0	18	0	1	2	20	0	7	5	150	7.5
BTRI	0	0	0	0	16	13	2	0	11	3	20	5	36	0	2	1	0	1	110	5.5
LMOL	0	0	0	0	7	18	8	0	11	10	25	14	6	0	8	3	0	0	110	5.5
BRAD	0	0	0	0	0	1	0	0	0	3	9	10	79	0	3	0	0	0	105	5.3
BEUT	0	0	0	2	5	0	0	6	8	5	0	1	0	0	18	0	1	19	65	3.3
MACU	0	0	0	0	5	2	29	0	2	3	3	1	5	0	15	0	0	0	65	3.3
BUNI	0	0	0	0	5	40	2	0	2	1	0	6	1	0	2	0	0	4	63	3.2
OMOS	0	0	0	0	0	4	1	0	13	2	11	2	16	0	6	3	0	0	58	2.9
ANAT	0	0	0	0	0	0	0	43	0	0	0	0	0	9	0	0	0	3	55	2.8
BHRE	0	0	1	0	0	0	0	22	1	0	0	0	0	8	0	0	3	13	48	2.4
PCAT	0	0	0	0	0	1	0	0	0	0	0	39	6	0	2	0	0	0	48	2.4
CPAR	0	0	0	0	0	0	10	0	0	16	8	8	2	0	0	0	0	0	44	2.2
BANN	0	0	0	0	0	4	2	0	0	2	5	9	15	0	5	0	0	0	42	2.1
MBRE	0	0	0	0	0	2	5	0	6	0	0	0	2	0	18	0	0	0	33	1.7
SMLR	0	0	0	0	0	0	0	0	15	0	5	2	11	0	0	0	0	0	33	1.7
PPHI	0	0	0	0	6	1	0	0	0	3	8	0	0	0	9	0	0	0	27	1.4
VNEL	0	3	2	0	0	0	0	0	0	0	0	0	0	20	0	0	2	0	27	1.4
TREN	0	0	0	0	0	5	0	0	0	1	1	0	9	0	1	1	0	0	18	0.9
BPOL	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	10	0	17	0.9
CSWI	0	0	0	0	0	6	1	0	0	0	7	0	3	0	0	0	0	0	17	0.9
BARG	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	16	0.8
MMAC	0	0	0	2	0	1	0	0	0	0	1	1	0	0	5	1	1	1	13	0.7
BPAL	0	0	0	0	0	0	0	0	2	0	0	0	0	0	9	0	0	0	11	0.6
CGAR	0	0	0	0	0	2	0	0	0	0	2	1	0	0	3	0	0	1	9	0.5
STRU	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0.4
AMOS	1	0	0	0	0	1	0	0	0	0	0	0	0	1	1	0	0	3	7	0.4
AURA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	4	0.2
OZAM	0	0	0	1	0	0	1	0	2	0	0	0	0	0	0	0	0	0	4	0.2
BIMB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	3	0.2
TSPA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	3	0.2
GCAL	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	2	0.1
total																			1991	100

Table 3: Electrofished species and abundance data for annual survey sites in the *Sabie-Sand* catchment. *May 1992.*

	Sample Sites																			total	% of total
Species	1	3	5	6	7	8	9	10	11	12	13	14	15	16	17	19	20	21	25		
OMOS	0	0	0	2	24	17	13	0	30	28	140	60	78	0	0	14	39	0	16	460	21.7
BVIV	0	0	0	2	0	0	7	0	3	7	124	34	12	0	0	37	7	0	0	233	11
TREN	0	0	0	13	9	18	5	0	42	0	33	34	15	0	0	7	49	0	0	225	10.6
BMAR	0	0	27	18	4	20	7	3	0	0	1	9	2	0	38	2	0	42	1	174	8.2
CANO	0	24	11	16	3	0	3	6	0	0	0	0	0	17	9	2	0	7	41	139	6.6
PPHI	0	0	11	17	21	1	2	0	0	29	28	0	0	0	0	11	1	0	0	119	5.6
VSEL	0	9	7	0	0	0	0	0	0	0	0	0	0	25	46	0	0	22	0	109	5.1
BBRE	0	0	0	0	0	0	0	39	0	0	0	0	0	21	8	0	0	2	10	80	3.8
GCAL	0	0	0	0	0	2	1	0	0	0	0	12	23	0	0	0	32	0	0	70	3.3
LMOL	0	0	0	3	5	2	13	0	2	0	0	10	17	0	0	2	0	0	0	54	2.5
BTRI	0	0	0	0	0	0	4	0	6	0	8	12	0	0	0	0	0	0	13	43	2.0
ANAT	0	0	0	0	0	0	0	28	0	0	0	0	0	10	2	1	0	0	0	41	1.9
MACU	0	0	1	0	3	5	1	0	0	0	2	8	15	0	0	5	0	0	0	40	1.9
BARG	0	0	0	0	0	0	0	0	0	0	0	0	0	32	4	0	0	0	0	36	1.7
BEUT	0	0	17	0	0	0	0	9	1	0	0	2	0	0	0	4	0	0	3	36	1.7
BPOL	0	0	30	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	36	1.7
SMER	0	0	0	6	3	4	0	0	14	0	0	1	3	0	0	0	0	0	0	31	1.5
BANN	0	0	0	0	0	0	0	0	1	0	0	27	0	0	0	2	0	0	0	30	1.4
CPAR	0	0	0	2	4	2	15	0	0	0	0	1	0	0	0	0	2	0	0	26	1.2
STRU	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	21	1.0
BRAD	0	0	0	0	0	0	0	0	4	0	1	12	0	0	0	2	0	0	0	19	0.9
MBRE	0	0	0	0	0	0	0	0	1	0	0	6	1	0	0	8	0	0	0	16	0.8
OZAM	0	0	1	1	0	1	6	0	0	0	0	0	0	0	0	3	0	0	0	12	0.6
CGAR	0	0	0	0	0	0	0	0	0	3	2	2	0	0	0	1	2	0	1	11	0.5
MMAC	0	0	0	0	0	0	0	0	0	0	0	3	0	1	0	0	5	2	0	11	0.5
CSWI	0	0	3	2	0	4	10	0	0	0	0	0	0	0	0	0	0	0	0	10	0.5
BUNI	0	0	0	0	0	0	0	0	6	0	1	0	0	0	0	0	0	0	1	8	0.4
TSPA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	8	0.4
BPAL	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	1	0	2	0	6	0.3
AURA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	5	0.2
AMOS	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	3	0.1
GGUI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	3	0.1
PCAT	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	3	0.1
LCYL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0.0
ABEN	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0.0
total																				2134	100

Table 4: Electrofished species and abundance data for annual survey sites in the Sabie-Sand catchment. May 1993.

Species	Sample Site 1	3	4	5	6	7	10	11	12	13	14	15	16	19	20	21	25	27	total	% of total
CANO	0	87	31	4	5	2	2	1	0	0	0	0	1	0	0	23	1	10	167	14.7
LMOL	0	0	0	27	19	0	0	20	29	9	12	1	0	8	30	1	1	0	157	13.9
OMOS	0	0	0	0	9	4	0	0	1	4	50	5	0	36	19	0	0	0	128	11.3
BMAR	0	0	0	5	2	32	0	15	18	6	17	0	0	0	4	3	0	0	102	9.0
BVIV	0	0	0	0	11	11	0	9	11	2	8	0	0	13	23	0	0	0	88	7.8
BTRI	0	0	0	8	7	0	0	8	2	9	10	1	0	4	2	0	6	16	73	6.4
BBRE	0	0	4	0	0	0	22	0	0	0	0	0	17	0	0	0	7	7	57	5.0
LROS	0	0	0	0	0	2	0	0	0	0	15	2	0	0	31	0	0	0	50	4.4
BAFR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	46	0	0	0	46	4.1
VNEL	0	19	2	0	0	0	0	0	0	0	0	0	7	0	0	6	0	0	34	3.0
BEUT	0	0	3	11	0	0	4	4	0	0	0	0	0	0	0	4	0	5	31	2.7
BRAD	0	0	0	0	0	0	0	0	0	0	6	0	0	0	22	0	0	0	28	2.5
CGAR	0	0	0	0	1	0	0	2	1	2	5	0	0	3	4	0	1	2	21	1.9
MACU	0	0	0	0	7	5	0	6	0	0	0	0	0	0	2	0	0	0	20	1.8
ANAT	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	3	19	1.7
BANN	0	0	0	0	2	2	0	1	0	0	1	0	0	1	12	0	0	0	19	1.7
PPHI	0	0	1	12	5	1	0	0	0	0	0	0	0	0	0	0	0	0	19	1.7
BUNI	0	0	0	1	6	4	0	1	0	0	1	1	0	0	5	0	0	0	14	1.2
IREN	0	0	0	0	6	0	0	0	0	2	0	0	0	2	0	0	0	0	10	0.9
CPAR	0	0	0	0	1	0	0	0	2	4	1	0	0	0	0	0	0	0	8	0.7
CSWI	0	0	0	2	0	2	0	0	2	0	0	0	0	0	1	0	0	0	7	0.6
MBRE	0	0	0	0	0	1	0	4	0	0	0	0	0	1	0	0	0	0	6	0.5
STRU	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0.5
MMAC	0	0	0	2	0	0	0	1	0	0	0	1	0	1	0	0	0	0	5	0.4
AMOS	0	0	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0.4
TSPA	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	3	0	0	4	0.4
AURA	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	3	0.3
BARG	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	2	0.2
BPOL	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0.2
OZAM	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0.2
BIMB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0.1
total																			1133	100

Table 5: Electrofished FHZ species and abundance data for quarterly monitoring sites. August 1990 - May 1991.

	Sample Sites												total	% of total
	3				5				21					
Species	AUG	NOV	FEB	MAY	AUG	NOV	FEB	MAY	AUG	NOV	FEB	MAY		
CANO	30	57	26	34	6	15	0	1	19	14	4	29	235	59.8
VNEL	3	3	2	3	5	1	0	0	7	19	3	2	48	12.2
BMAR	0	0	0	0	0	1	0	0	1	19	1	7	29	7.4
BPOL	0	0	0	0	3	0	1	7	0	0	0	10	21	5.3
TSPA	0	0	0	0	0	0	0	0	4	6	3	3	16	4.1
BEUT	0	0	0	0	7	1	1	2	0	0	0	1	12	3.1
MMAC	0	0	0	0	4	0	0	2	1	0	0	1	8	2.0
AURA	0	0	0	0	0	3	0	0	0	2	2	0	7	1.8
BBRE	0	0	0	0	0	0	0	0	4	0	0	3	7	1.8
ANAT	0	0	0	0	0	0	0	0	1	4	0	0	5	1.3
BUNI	0	0	0	0	3	0	0	0	0	0	0	0	3	0.8
AMOS	0	1	0	0	0	0	0	0	0	0	0	0	1	0.3
OZAM	0	0	0	0	0	0	0	1	0	0	0	0	1	0.3
total													393	100

Table 6: Electrofished FHZ species and abundance data for quarterly monitoring sites. August 1991 - May 1992.

	Sample Sites												total	% of total
	3				5				21					
Species	AUG	NOV	FEB	MAY	AUG	NOV	FEB	MAY	AUG	NOV	FEB	MAY		
CANO	20	24	51	24	12	9	13	11	18	35	17	7	241	36.4
BMAR	0	0	0	0	8	3	12	27	3	16	16	42	127	19.2
VNEL	2	14	12	9	1	1	0	7	6	16	4	22	94	14.2
BPOL	0	0	0	0	9	4	1	30	0	1	0	3	48	7.2
BEUT	0	0	0	0	15	5	1	17	0	0	0	0	38	5.7
TSPA	0	0	0	0	0	0	0	0	3	11	7	8	29	4.4
CSWI	0	0	0	0	5	6	6	3	0	1	0	0	21	3.2
AURA	0	0	0	0	2	4	2	0	4	1	2	5	20	3.0
PPHI	0	0	0	0	1	0	1	11	0	0	0	0	13	2.0
BBRE	0	0	0	0	1	0	0	0	2	2	2	2	9	1.4
AMOS	0	0	0	1	0	0	0	0	1	2	0	1	5	0.8
MMAC	0	0	0	0	2	0	0	0	1	0	0	2	5	0.8
ANAT	0	0	0	0	0	0	0	0	0	3	0	0	3	0.5
OZAM	0	0	0	0	0	0	2	1	0	0	0	0	3	0.5
BUNI	0	0	0	0	1	0	1	0	0	0	0	0	2	0.3
LMOL	0	0	0	0	0	0	2	0	0	0	0	0	2	0.3
CTAR	0	0	0	0	1	0	0	0	0	0	0	0	1	0.2
MACU	0	0	0	0	0	0	0	1	0	0	0	0	1	0.2
total													662	100

Table 7: Electrofished FHZ species and abundance data for quarterly monitoring sites. August 1992 - May 1993.

	Sample Sites												total	% of total
	3				5				21					
Species	AUG	NOV	FEB	MAY	AUG	NOV	FEB	MAY	AUG	NOV	FEB	MAY		
CANO	84	47	31	87	12	14	0	4	23	21	3	23	349	44.1
BMAR	0	0	0	0	21	5	2	5	46	24	5	3	111	14.0
VNEL	12	22	[illegible]	19	0	4	1	9	20	18	0	6	109	13.8
TSPA	0	0	0	0	0	0	2	0	15	26	1	3	49	6.2
BEUT	0	0	0	0	18	2	8	11	0	1	1	4	45	5.7
BPOL	0	0	0	0	30	1	1	2	1	3	0	0	38	4.8
PPHI	0	0	0	0	3	6	10	12	0	0	0	0	31	3.9
CSWI	0	0	0	0	7	7	0	2	0	0	0	0	16	2.0
BBRE	0	0	0	0	0	0	0	0	4	2	4	0	10	1.3
MACU	0	0	0	0	4	0	6	0	0	0	0	0	10	1.3
AURA	0	0	0	0	0	1	0	0	6	0	0	2	9	1.1
AMOS	0	0	0	0	0	1	1	3	1	0	0	0	6	0.8
MMAC	0	0	0	0	0	0	0	2	0	1	0	0	3	0.4
OZAM	0	0	0	0	1	0	1	0	0	0	0	0	2	0.3
ANAT	0	0	0	0	0	0	0	0	1	0	0	0	1	0.1
BUNI	0	0	0	0	0	0	0	1	0	0	0	0	1	0.1
LMOL	0	0	0	0	0	0	0	0	0	0	0	1	1	0.1
													791	100

Table 8: Electrofished LZ species and abundance data for quarterly monitoring sites on the Sabie River. August 1990 - May 1991.

	Sample Sites												total	% of total
	6				7				20					
Species	AUG	NOV	FEB	MAY	AUG	NOV	FEB	MAY	AUG	NOV	FEB	MAY		
RVIV	-	0	-	37	60	0	1	20	19	5	0	5	147	21.2
BUNI	-	0	-	5	73	0	0	40	0	0	0	0	118	17.0
BRAD	-	0	-	0	89	0	0	1	0	0	0	0	90	13.0
BMAR	-	5	-	39	1	1	1	20	0	0	0	0	67	9.7
BTRI	-	0	-	16	9	0	2	13	0	1	0	0	41	5.9
TREN	-	0	-	0	2	4	0	5	3	24	2	1	41	5.9
LMOL	-	0	-	7	5	0	0	18	1	1	1	3	36	5.2
CANO	-	15	-	15	0	0	1	3	0	0	0	0	34	4.9
BANN	-	0	-	0	27	0	0	4	0	0	0	0	31	4.5
OMOS	-	0	-	0	1	0	0	4	3	1	9	3	21	3.0
PPHI	-	3	-	6	1	1	0	1	0	0	0	0	12	1.7
PCAT		0	-	0	10	0	0	1	0	0	0	0	11	1.6
MACU	-	0	-	5	1	0	1	2	0	0	0	0	9	1.3
CSWI	-	0	-	0	2	0	0	6	0	0	0	0	8	1.2
MMAC	-	0		0	3	2	0	1	0	0	0	1	6	0.9
BEUT	-	0	-	5	0	0	0	0	0	0	0	0	5	0.7
CGAR		0		0	0	0	1	2	0	0	0	1	4	0.6
BIMB		0	-	0	0	0	0	0	0	0	0	3	3	0.4
GCAL	-	0	-	0	0	0	0	0	0	2	1	0	3	0.4
MBRE	-	0	-	0	0	0	1	2	0	0	0	0	3	0.4
AMOS	-	0	-	0	0	0	0	1	0	0	0	0	1	0.1
CPAR		0		0	1	0	0	0	0	0	0	0	1	0.1
OZAM	-	0	-	0	0	0	1	0	0	0	0	0	1	0.1
total													693	100

Table 9: Electrofished LZ species and abundance data for quarterly monitoring sites on the Sabie River. August 1991 - May 1992.

	Sample Sites												total	% of total
	6				9				20					
Species	AUG	NOV	FEB	MAY	AUG	NOV	FEB	MAY	AUG	NOV	FEB	MAY		
TREN	0	4	18	13			5	5	1	20	4	49	119	15.3
OMOS	0	0	16	2			8	12	6	9	9	39	101	13.0
RVIV	0	0	0	2			12	2	13	16	20	7	97	12.5
CANO	19	18	21	16			2	3	0	0	0	0	81	10.4
LMOL	5	4	11	1			6	10	4	7	15	0	65	8.4
BMAR	3	0	17	14			2	7	0	10	1	0	58	7.5
CPAR	2	3	6	2			9	15	2	3	7	2	51	6.6
GCAL	0	0	0	0			0	1	2	0	10	32	45	5.8
PPHI	1	2	13	17			2	0	0	1	0	1	37	4.8
MACU	0	0	1	0			15	1	0	14	3	0	34	4.4
CSWI	1	0	27	2			1	1	0	0	0	0	32	4.1
MMAC	0	0	0	0			0	0	0	0	3	5	8	1.0
OZAM	0	0	1	1			0	6	0	0	0	0	8	1.0
BTRI	0	0	0	0			1	4	0	0	0	0	7	0.9
SMER	1	0	0	6			0	0	0	0	0	0	7	0.9
BRAD	0	0	0	0			0	0	1	5	0	0	6	0.8
LCYL	0	0	0	0			0	0	3	1	2	0	6	0.8
BEUT	3	0	0	0			0	0	0	0	0	0	3	0.4
BIMB	0	0	0	0			0	0	0	0	3	0	3	0.4
GGUI	0	0	0	0			0	0	0	0	0	3	3	0.4
CGAR	0	0	0	0			0	0	0	0	0	2	2	0.3
PCAT	1	0	0	0			0	0	1	0	0	0	2	0.3
AMOS	0	0	0	0			0	1	0	0	0	0	1	0.1
BUNI	0	0	1	0			0	0	0	0	0	0	1	0.1
total													777	100

Table 10: Electrofished LZ species and abundance data for quarterly monitoring sites on the Sabie River. August 1992 - May 1993.

	Sample Sites												total	% of total
	6				9				20					
Species	AUG	NOV	FEB	MAY	AUG	NOV	FEB	MAY	AUG	NOV	FEB	MAY		
LMOL	8	7	6	27	17	0	-	-	0	6	58	36	165	22.9
TREN	20	8	2	6	4	6	-	-	18	1	0	0	65	9.0
BVIV	0	0	1	11	11	8	-	-	2	0	6	23	62	8.6
BMAR	3	15	3	2	23	2	-	-	0	0	2	4	54	7.5
PPHI	28	9	0	5	7	0	-	-	1	0	0	0	50	7.0
BAFR	0	0	0	0	0	0	-	-	0	0	1	46	47	6.5
OMOS	0	0	1	9	2	3	-	-	8	4	1	19	47	6.5
CANO	17	4	3	5	10	0	-	-	0	0	0	0	39	5.4
MACU	8	1	2	7	10	8	-	-	0	0	0	2	38	5.3
LROS	0	0	0	0	0	0	-	-	0	0	1	31	32	4.5
BRAD	0	0	0	0	1	1	-	-	0	0	0	22	24	3.3
BTRI	0	0	2	8	1	7		-	0	1	0	2	21	2.9
CPAR	0	3	1	1	13	1	-	-	0	0	0	0	19	2.6
BANN	0	0	0	2	0	2	-	-	0	0	0	12	16	2.2
BUNI	0	0	1	6	0	1	-	-	0	0	0	0	8	1.1
CGAR	0	0	0	0	0	0		-	1	0	3	4	8	1.1
CSWI	1	0	0	0	4	0		-	0	0	0	1	6	0.8
SMER	2	0	0	0	2	1	-		0	0	0	0	5	0.7
MMAC	0	0	0	0	0	1		-	3	0	0	0	4	0.6
OZAM	0	0	0	2	1	1		-	0	0	0	0	4	0.6
OCAL	0	0	0	0	0	0		-	1	1	1	0	3	
AMOS	1	0	0	0	0	0			0	0	0	0	1	0.1
BIMB	0	0	0	0	0	0	-	-	0	0	0	1	1	0.1
total													719	100

Table 11: Electrofished LZ species and abundance data for quarterly monitoring sites on the Sand River. August 1990 - May 1991.

	Sample Sites												total	% of total
	[illegible]				[illegible]				[illegible]					
Species	AUG	NOV	FEB	MAY	AUG	NOV	FEB	MAY	AUG	NOV	FEB	MAY		
[illegible]	22	6	6	19	6	6	15	31	89	14	19	105	322	21.9
BMAR	40	4	1	2	14	0	[illegible]	18	15	0	1	20	161	11.0
LMOL	11	10	4	11	[illegible]	1	4	25	18	7	4	8	120	8.2
OMOS	0	2	[illegible]	11	[illegible]	1	8	41	13	36	24	6	120	8.2
CANO	2	0	0	41	0	0	0	0	7	1	0	56	87	5.9
BTRI	13	3	0	11	2	0	1	20	1	2	29	2	84	5.7
MACU	0	2	2	2	8	1	0	1	2	6	45	15	81	5.5
BANN	0	0	0	0	0	0	4	5	0	1	60	5	75	5.1
MBRE	8	4	5	6	[illegible]	0	0	0	24	0	4	18	70	4.8
BEUT	11	1	4	4	[illegible]	0	[illegible]	[illegible]	22	4	0	18	67	4.6
PPHI	0	0	0	1	[illegible]	0	0	8	0	12	33	9	62	4.2
BRAD	0	0	0	[illegible]	[illegible]	0	13	9	0	0	14	3	37	2.5
TREN	6	16	4	1	[illegible]	0	2	0	0	5	2	1	37	2.5
CGAR	0	0	1		0	0	0	2	0	0	28	3	34	2.3
SMER	5	0	2	15	0	0	2	5	0	0	0	0	27	1.8
CPAR	0	0	0	0	0	2	0	8	0	3	2	0	24	1.6
MMAC	1	0	0	0	2	0	0	1	9	0	0	5	18	1.2
BPAL	0	0	0	2	0	0	0	0	0	0	3	9	14	1.0
BUNI	6	0	0	2	[illegible]	0	5	0	1	0	1	2	14	1.0
CSWI	0	0	0	0	2	0	0	[illegible]	0	0	0	0	2	0.1
OZAM	1	0	0	2	0	0	0	0	1	0	0	0	4	0.3
AMOS	0	0	0	0	1	0	0	0	0	0	0	1	2	0.1
PCAT	0	0	0	0	0	0	0	0	0	0	0	2	2	0.1
BBRE	0	0	0	1	0	0	0	0	0	0	0	0	1	0.1
total													1470	[illegible]

Table 12: Electrofished LZ species and abundance data for quarterly monitoring sites on the Sand River. August 1991 - May 1992.

	Sample Sites												total	% of total
	11				14				19					
Species	AUG	NOV	FEB	MAY	AUG	NOV	FEB	MAY	AUG	NOV	FEB	MAY		
BVIV	4	3	0	3	18	19	25	34	40	22	23	37	228	14.2
TREN	0	27	44	42	1	23	44	31	0	1	8	7	228	14.2
OMOS	0	24	18	30	2	9	26	60	10	5	14	14	212	13.2
BANN	8	0	0	1	51	6	13	27	29	3	2	2	142	8.8
BEUT	11	2	0	1	0	0	0	2	60	25	9	4	114	7.1
CANO	37	0	0	0	0	0	0	0	24	8	6	2	77	4.8
LMOL	13	4	3	2	6	4	8	10	6	6	12	2	76	4.7
BMAR	21	11	0	0	1	2	0	9	21	0	4	2	71	4.4
BTRI	26	5	2	6	5	6	5	12	4	0	0	0	71	4.4
MACU	3	0	3	0	4	9	21	8	4	1	1	5	59	3.7
BRAD	0	0	0	4	9	6	15	12	6	0	1	2	55	3.4
SMER	2	6	10	14	2	4	9	1	0	0	0	0	48	3.0
MBRE	0	0	2	1	3	0	15	6	5	5	2	8	47	2.9
PPHI	0	0	0	0	0	0	2	0	12	9	3	11	37	2.3
BUNI	16	0	0	6	2	5	0	0	2	3	0	0	34	2.1
GCAL	0	0	0	0	2	2	18	12	0	0	0	0	34	2.1
MMAC	0	2	2	0	0	0	0	3	15	2	0	0	24	1.5
BPAL	0	0	0	0	0	1	1	0	12	4	1	1	20	1.2
CGAR	0	0	0	0	2	0	0	2	5	1	0	1	11	0.7
PCAT	0	0	0	0	1	0	0	3	3	0	0	0	7	0.4
OZAM	0	0	0	0	0	0	0	0	3	0	0	3	6	0.4
CPAR	1	0	0	0	0	2	0	1	0	0	0	0	4	0.2
AMOS	0	0	0	0	0	0	0	0	0	0	1	0	1	0.1
ANAT	0	0	0	0	0	0	0	0	0	0	0	1	1	0.1
LCYL	0	0	0	0	0	0	0	1	0	0	0	0	1	0.1
SINT	0	0	0	0	0	0	1	0	0	0	0	0	1	0.1
total													1609	100

Table 13: Electrofished LZ species and abundance data for quarterly monitoring sites on the Sand River. August 1992 - May 1993.

	Sample Sites												total	% of total
	11				14				19					
Species	AUG	NOV	FEB	MAY	AUG	NOV	FEB	MAY	AUG	NOV	FEB	MAY		
OMOS	27	11		0	45	93	14	50	36	346	1	36	659	45.1
BVIV	0	3		9	46	17	8	8	89	19	2	13	214	14.6
LMOL	1	5		20	14	11	16	12	1	6	3	8	97	6.6
PPHI	0	0		0	0	0	0	0	23	71	0	0	94	6.4
TREN	23	3		0	8	0	0	0	18	7	0	2	61	4.2
BMAR	0	0		15	1	6	7	17	4	0	0	0	50	3.4
BTRI	0	8		6	5	1	5	10	1	1	1	4	44	3.0
MACU	0	2		6	0	6	4	0	13	1	0	0	32	2.2
CGAR	0	0		2	0	16	2	5	1	2	0	3	31	2.1
BRAD	0	0		0	15	3	2	6	0	4	0	0	30	2.1
BANN	0	0		1	13	6	4	1	2	1	0	1	29	2.0
MBRE	0	13		4	0	0	0	0	8	0	0	1	26	1.8
GCAL	0	0		0	18	1	0	0	1	1	0	0	21	1.4
[illegible]	0	0		0	1	0	2	15	0	0	0	0	18	1.2
BEUT	0	0		4	0	0	0	0	9	1	2	0	16	1.1
SMER	10	0		0	3	0	0	0	0	0	0	0	13	0.9
BUNI	0	1		1	0	2	0	1	1	1	0	0	7	0.5
PCAT	0	0		0	4	1	0	0	0	0	0	0	5	0.3
CANO	0	0		2	0	0	0	0	2	0	0	0	4	0.3
MMAC	0	0		1	0	0	1	0	0	0	0	1	3	0.2
OZAM	0	0		0	0	0	0	0	3	0	0	0	3	0.2
ABEN	0	0		0	1	0	1	0	0	0	0	0	2	0.1
BPAL	0	0		0	0	0	0	0	0	2	0	0	2	0.1
CPAR	0	0		0	0	0	0	1	0	0	0	0	1	0.1
total													1462	100

Table 14: Wire-trap species and abundance data for quarterly monitoring sites, catchment wide. August 1990 - May 1991.

Species	Sample Sites													total	% of total
	3	5	6	7	11	13	14	19	20	21	22	23	24		
BVIV	0	0	16	76	8	2	9	295	62	0	0	72	49	589	21.4
BIRI	0	2	13	60	69	38	0	185	0	0	0	95	98	560	20.3
BPAL	0	0	0	45	0	0	0	4	0	0	0	432	0	481	17.4
OMOS	0	0	0	0	1	6	0	8	48	0	0	107	4	174	6.3
BUNI	0	0	0	0	21	0	0	50	0	4	14	53	26	168	6.1
MACU	0	2	0	2	5	1	0	84	0	0	0	0	52	146	5.3
BANN	0	0	0	0	2	0	0	132	0	0	0	0	0	134	4.9
BBRE	0	0	0	0	0	0	0	0	0	41	64	0	0	105	3.8
TREN	0	0	0	0	0	2	0	3	5	1	0	92	0	103	3.7
BEUT	0	26	0	26	0	0	0	1	0	0	0	0	4	57	2.1
BMAR	0	0	5	5	0	0	0	0	0	18	13	0	10	51	1.8
PPBI	0	0	0	0	0	0	0	39	1	0	0	0	0	40	1.5
TSPA	0	0	0	0	0	0	0	0	0	31	4	0	0	35	1.3
BARG	0	0	0	0	0	0	0	0	0	0	30	0	0	30	1.1
BPOL	0	12	0	12	0	0	0	0	0	4	0	0	0	28	1.0
BRAD	0	0	0	0	0	1	0	23	0	0	0	0	1	25	0.9
LMOL	0	0	0	0	5	0	0	1	0	0	0	2	2	10	0.4
MBRE	0	0	0	0	4	0	0	0	0	0	0	0	0	4	0.1
SMER	0	0	0	0	2	0	0	2	0	0	0	0	0	4	0.1
BIMB	0	0	0	0	0	0	0	0	3	0	0	0	0	3	0.1
MMAC	0	0	0	0	0	0	0	0	0	0	3	0	0	3	0.1
VNEL	0	1	0	1	0	0	0	0	0	0	1	0	0	3	0.1
BAFR	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0.0
CGAR	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0.0
LCYL	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0.0
SINT	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0.0
total														2757	100

Table 15: Wire-trap species and abundance data for quarterly monitoring sites, catchment wide. August 1991 - May 1992.

	Sample Sites													*total*	*% of total*
Species	3	5	6	9	11	13	14	19	20	21	22	23	24		
BVIV	0	0	0	0	24	193	424	18	0	0	0	138	66	863	23.8
BPAL	0	0	0	0	99	15	0	36	0	0	0	348	0	498	13.7
BBRE	0	1	0	0	0	0	0	0	0	55	317	4	0	377	10.4
BTRI	0	2	1	0	128	3	93	9	0	0	0	17	67	320	8.8
BUNI	0	61	0	0	29	1	6	4	0	0	59	33	80	273	7.5
MACU	0	0	0	0	13	18	198	3	0	0	0	0	4	236	6.5
BANN	0	0	0	0	13	16	111	67	0	0	0	0	10	217	6.0
TSPA	0	3	0	0	0	0	0	0	0	46	124	0	0	173	4.8
BEUT	0	119	0	0	1	0	0	0	0	7	0	0	4	131	3.6
OMOS	0	0	0	4	1	5	6	20	1	0	0	77	5	119	3.3
TREN	0	0	0	1	19	4	24	4	1	0	0	41	9	103	2.8
BPOL	0	61	0	0	0	0	0	0	0	5	1	0	0	67	1.8
BMAR	0	20	0	0	0	0	1	0	0	10	34	0	1	66	1.8
BARG	0	0	0	0	0	0	0	0	0	18	40	0	0	58	1.6
LMOL	0	0	5	0	5	0	9	3	0	0	0	7	11	40	1.1
SMER	0	0	1	0	9	0	4	0	1	0	0	0	10	25	0.7
PPHI	0	15	0	0	0	1	0	4	0	0	0	0	0	20	0.6
BRAD	0	0	0	0	1	0	3	0	1	0	0	0	7	12	0.3
BTOP	0	0	0	0	0	10	0	0	0	0	0	0	0	10	0.3
GCAL	0	0	0	0	0	0	0	0	6	0	0	0	0	6	0.2
CSWI	0	0	0	0	0	0	0	0	0	0	0	0	4	4	0.1
VNEL	0	4	0	0	0	0	0	0	0	0	0	0	0	4	0.1
MMAC	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0.1
total														3624	100

Table 16: Wire-trap species and abundance data for quarterly monitoring sites, catchment wide. August 1992 - May 1993.

	Sample Sites												total	% of total
Species	3	5	6	9	11	14	19	20	21	22	23	24		
BVIV	-	0	10	0	2	240	9	23	0	0	-	0	284	14.7
PCAT	-	0	0	0	0	0	0	0	0	0	-	275	275	14.3
TSPA	-	5	0	0	0	0	0	0	241	24	-	0	270	14.0
BEUT	-	222	0	0	0	0	0	0	11	0	-	0	233	12.1
BBHE	-	9	0	0	0	0	0	0	93	120	-	0	222	11.5
BTRI	-	7	30	0	24	121	0	0	0	0	-	0	182	9.4
BMAR	-	0	0	0	0	0	0	0	35	93	-	17	145	7.5
PPHI	-	65	3	2	0	0	0	0	0	0	-	0	70	3.6
BANN		0	0	0	0	58	0	0	0	0	-	0	58	3.0
BUNI		12	0	0	2	0	0	0	5	15	-	0	34	1.8
BAFR	-	0	0	0	0	0	0	22	0	0	-	0	22	1.1
SZAM	-	0	0	0	0	0	0	0	0	0	-	22	22	1.1
OMOS	-	0	0	8	0	1	1	1	0	0	-	6	17	0.9
BPAL	-	0	0	0	15	0	1	0	0	0	-	0	16	0.8
LMOL	-	0	0	0	1	3	0	2	0	0	-	8	14	0.7
BRAD	-	0	0	0	0	12	0	0	0	0	-	0	12	0.6
TREN	-	0	4	0	2	4	0	0	0	0	-	2	12	0.6
VNEL	-	0	0	0	0	0	0	0	1	9	-	0	10	0.5
MACU	-	4	2	0	0	2	1	0	0	0	-	0	9	0.5
BPOL	-	2	0	0	0	0	0	0	1	2	-	0	5	0.3
BIMB	-	0	0	0	0	0	0	4	0	0	-	0	4	0.2
BARG	-	0	0	0	0	0	0	0	0	3	-	0	3	0.2
MBRE	-	0	0	0	0	0	0	0	0	0	-	3	3	0.2
BTOP	-	0	0	0	0	2	0	0	0	0	-	0	2	0.1
SMER	-	0	0	1	1	0	0	0	0	0	-	0	2	0.1
CGAR	-	0	0	0	0	0	0	0	0	0	-	1	1	0.1
GCAL	-	0	0	0	0	0	0	1	0	0	-	0	1	0.1
total													1928	100