SIMILARITIES AND DIFFERENCES BETWEEN RIVERS OF THE KRUGER NATIONAL PARK

WJ Muller • MH Villet

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Water Research Commission

SIMILARITIES AND DIFFERENCES BETWEEN RIVERS OF THE KRUGER NATIONAL PARK

Report to the Water Research Commission

by

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FINAL REPORT TO THE WATER RESEARCH COMMISSION

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CHAPTER 1:
INTRODUCTION

Aquatic ecosystems play an important role in the maintenance of ecological diversity and ecosystem functioning at both local and regional scales (Roux *et al.*, 1999). Effective management of riverine ecosystems requires an understanding of their ecosystem processes. In order to understand ecosystem processes, and interactions between the landscape and riverine ecosystems, it is necessary to have both spatial and temporal data at both landscape and site-pecific scales (Allan and Johnson, 1997). There are many tools available for the analysis of these data to provide insight and understanding of the data in order to understand influences on aquatic ecosystems. Increasingly complex computational tools allow analysis and modeling of data in order to explain river, and subsequent biological, processes from landscape (catchment) processes (Johnson and Gage, 1997), although the scale at which analysis and interpretation occurs is important.

Science and management need to interact in order to truly succeed in effectively applying adaptive management and incorporate monitoring and assessment programmes in management processes (Rogers and Biggs, 1999). However, water resource management is often undertaken in the context of incomplete information and knowledge of functioning ecosystem processess and responses: this inevitably leads to uncertainty and unpredictability (Roux *et al.* 1999). One of the major challenges for managing rivers is to be able to monitor rivers effectively in order to detect changes as they occur, to identify the causes of the changes and to distinguish beween natural and anthropogenic causes of change. Adaptive management is required to effectively manage rivers, but this does require that there is an understanding of, and information for, the rivers being managed. Rogers and Biggs (1999) highlighted the need to integrate monitoring programmes with indicators in order to undertake assessments of ecosystem health as part of the management plan of the rivers of the Kruger National Park in order to maintain, and restore, natural river ecosystem health and biodiversity (Rogers and Bestbier, 1997). One of the main aims of the Kruger National Park Rivers Research Programme (KNPRRP) was to contribute to the conservation of the natural environment by developing skills and methods to understand the ecological functioning of the natural environment and to predict responses of the river systems to natural and anthropogenic changes in order to effectively manage them (Breen, 1994, in van Rensburg and Dent, 1997).

Classification systems are able to provide useful management information, but many have focussed on abiotic rather than biotic factors because resultant biotic patterns are likely to be correlated with abiotic components (Solomon *et al.*, 1999). Much of the classification of the Kruger National Park has focussed on classification of land with little regard for rivers (these were incorporated into the two classification systems proposed by Venter and Gertenbach (in Solomon *et al.*, 1999)). The objective of this project is to identify similarities and differences between the five major rivers of the Kruger National Park, towards the design and testing of a classification framework in order to aid management of the KNP rivers by contributing to effective monitoring. This will be achieved through the following:

1. collate available (current and historical) information concerning physical and biological variables for the Luvuvhu, Letaba, Olifants, Sabie and Crocodile Rivers, using a common dataset to establish the degree of similarities and differences between these five major rivers of the KNP; and

2. determine how different the rivers are, in order to optimize monitoring and management programmes for these differences.

The aim of this project was not to classify the rivers of the KNP. The project rather aims to identify gaps in data availability which may result in inadequate and inappropriate management of the rivers. Results (in the form of a data matrix) emanating from this study could assist in establishing expected natural conditions and biota in the five major rivers of the KNP, and knowledge from data-rich rivers (e.g. Sabie River) could potentially be extrapolated to data-poor rivers, or sections of rivers. Invertebrates and fish are the main tools of aquatic species biodiversity monitoring, and require an understanding of the natural presence, absence and abundance patterns in aquatic ecosystems. This study contributes to this understanding by organising available information of biotic and abiotic information.

CHAPTER 2: MATERIALS AND METHODS

DATA COLLECTION

Venter (1991) grouped the major rivers of the Kruger National Park into management units. These same basic units, or river reaches, were used as the basis for this project and are reported in Table 1. Assessment and analysis of data and information for this project was restricted to the Luvuvhu, Letaba, Olifants, Sabie and Crocodile Rivers. Accordingly, only data which could unequivocally be assigned to the previously described management units of these rivers were used in the analysis. Due to budget limitations and time constraints of the project, data collection could not be exhaustive: sources of data that were not readily obtainable, or could not easily be assigned to reaches, were not used. Data were collected at three levels: catchment information (general catchment descriptions), abiotic data (flow and water quality) and biotic (macroinvertebrates and fish) data.

Catchment information

General catchment information was taken from a number of published and unpublished sources, including 1:250 000 and 1:50 000 maps. Catchment information such as catchment area (km^2), mean annual runoff (m^3 × 10^6), mean annual precipitation (mm), length of river inside the Kruger National Park (km), mean gradient (m/km) and any in-stream structures for each of the five major rivers are listed to describe general catchment characteristics.

Gertenbach (1983) classified the KNP into landscapes, where a landscape is defined as an area with a specific geormorphological, climate, soil and vegetation pattern with an associated fauna. A total of 35 landscapes were identified in the KNP, some of which were defined as part of particular rivers (e.g. Luvuvhu, Sabie and Crocodile Rivers). The landscape information could, in most cases, be extracted to the defined river reaches and provides catchment information in terms of altitude, rainfall and general soil types.

Flow data

Flow variability is considered to be important in determining biotic community structure and can be represented by the coefficient of variation (Pegg and Pierce, 2002). Daily average flow data were obtained from the Department of Water Affairs and Forestry and, following the method described by Pegg and Pierce (2002), the coefficient of variation was determined for flow data from each of the weirs. Limited flow data were available: data from tributaries were not used and there were a limited number of flow gauging weirs in the rivers. Data are best used to describe the general flow variability of the rivers in the Kruger National Park rather than characterise each of the reaches within the rivers.

Water quality data

Water quality data were obtained from the Department of Water Affairs and Forestry Water Management System database. Data records from 1998 onwards were used in the present study.

Restricting the length of the data record reduced the number of DWAF weirs for which water quality data were available in each of the reaches. However this data restriction was justified by the following reasons. Since the project aimed at providing input to management of the rivers, an assessment of the more recent water quality in each of the rivers, and their reaches, would be more useful and appropriate. In addition, an increase in pH is evident in the DWAF water quality database in the late 1980s; this increase is apparently a result of a change in analytical method for pH (DWAF-IWQS personell, pers. com.), which would confound analysis and interpretation of results.

Biotic data

There are sources of biological data that have not been used in this study: this is due to information that could not be assigned to a river reach and therefore was not considered useful for this project and omitted from the data set. Biological data are restricted to presence / absence level, i.e. data on abundance of species or families were not available, and neither was there flow data or water quality data associated with the biological data. Due to data paucity, seasonality could not be taken into account. Analysis of temporal trends of changes in biotic composition could not be undertaken for the same reason.

Fish data were available at species level of identification (Pienaar, 1978; Russell, 1997). Macroinvertebrate data were available at family level indentification (Deacon, pers. comm.; National River Health Programme database, Rivers Database Version 2.2, 2003; Uys, 1998; Moore, 1991).

DATA ANALYSES

Catchment information and physical characteristics of the rivers and reaches was captured in tabular form. These data were not analysed further and only a qualitative description of this information is provided.

Water quality data and biotic (macroinvertebrates and fish) data were analysed using Principle Component Analysis (PCA). PCA is a popular and effective method of detecting patterns in multivariate data. It allows reduction in the number of variables to be analysed, and results in a series of axes that explain the majority of variation in the data. PCA (Statistica Version 6, 2002) was used to undertake exploratory analysis of the data to assess whether there were patterns of similarity, or differences, between rivers and within rivers. Where relevant, nonparametric Analysis of Variance (ANOVA) (using Kruskal-Wallis tests using the factor scores) was used to establish whether differences or similarities between and within rivers were significant, because the data did not meet the assumptions of parametric ANOVA.

Analysis of flow data

A coefficient of variation for the monthly average flow data was obtained and used to describe the flow variability. Although flow duration curves were obtained, these were not found to be useful for the purposes of this study and are thus excluded from further discussion.

Analysis of water quality data

Water quality constituents that were used in the analysis were: pH, total alkalinity (TAL), total inorganic nitrogen (TIN; NO_3+NO_2-N + NH_4-N), orthophosphate (PO_4-P), Si, SO_4, F, Na, Mg, Cl, K and Ca. Electrical conductivity (EC) and total dissolved salts (TDS) were excluded from the PCA analysis as these are measures of the total ions in the sample and could potentially mask effects of other individual water quality constituents (i.e. they could result in autocorrelations which are not necessarily meaningful). Due to the limited number of water quality monitoring points, as well as limitations of the number of samples, no quantitative analysis of possible similarities or differences within rivers (i.e. between reaches), or seasons, could be undertaken.

Summary statistics (median, 25^{th} percentile, 75^{th} percentile, minimum and maximum values) of the water quality constituents were used to assess and describe patterns of similarity between rivers and river reaches. PCA of the data was undertaken and, where appropriate, ANOVA of the factors was undertaken to assess whether differences in water quality between rivers and river reaches were statistically significant.

Analysis of biological data

All available biological data (invertebrate and fish) were used in a PCA to assess similarities between rivers and reaches. However, due to data paucity, more detailed analysis (seasonal trends) was not possible. Tables of families (macroinvertebrates) and species (fish) were further used to describe similarities and differences between rivers and river reaches.

Table 1: Description of the boundaries of the river reaches (segments) of each of the five major rivers of the Kruger National Park (from Venter, 1991)

REACH	LUVUVHU	LETABA	OLIFANTS	SABIE	CROCODILE
Reach-1	Dongadzivha to Mukangalani Stream	Mahlangeni to Matrabowa Mouth	Mamba Weir to 1km west of Nwamanzi	Western border of KNP to 1.5km west of confluence with Sand River	Western border to 1km east of Malelane high water bridge
Reach-2	Mukangalani Stream to Makahane	Matrabowa Mouth to Hatlanidi Creek	West of Nwamanzi to Olifants Camp	1.5km west of confluence with Sand River to 1km east of confluence with Nwatindlopfu River	1km east of Malelane high water bridge to 5km east of Lwakahle
Reach-3	Makahane to where KNP border turns north (upstream of Mutale Mouth) and Lanner Gorge	Hatlanidi Creek to Engelhardt Dam	Olifants Camp to confluence with Letaba River	1km east of confluence with Nwatindlopfu River to 3km west of confluence with Lubyelubye River	5km east of Lwakahle to 0.5km west of Pombo
Reach-4	Upstream of Mutale Mouth to the start of Lanner Gorge	Engelhardt Dam to rapids	Letaba River confluence to eastern border of KNP	3km west of confluence with Lubyelubye River to 1.5km west of Mlondozi River	0.5km west of Pombo to Nkongoma
Reach-5	End of Lanner Gorge to high water bridge	Rapids to confluence with Olifants River		1.5km west of Mlondozi River to eastern border of KNP	Nkongoma to eastern border of KNP
Reach-6	High water bridge to confluence with Limpopo River				

CHAPTER 3:
RESULTS

Landscape descriptions

The Luvuvhu, Letaba, Sabie and Crocodile Rivers originate in the Drakensberg along the Great Escarpment, while the Olifants River has cut through the Great Escarpment and originates in the Highveld (Venter and Bristow, 1986). These authors also described the geomorphology and drainage of the Kruger National Park (KNP). For the major part, the landscape of the KNP is classified as plains with a gentle eastward slope. The erosion surfaces in the KNP are mainly from the late Tertiary period (Luvuvhu River) with some erosion surfaces from the Quartenary period in the Letaba, Olifants, lower Sabie and lower Crocodile Rivers. In general, the landscape is typically undulating, gently undulating or flat and lithological differences result in changes in relief. The drainage of the area is typically from west to east. Venter and Bristow (1986) suggest that river valley morphology of the KNP rivers indicates geomorphological upliftment has not subsided and is rhythmic and gentle. Details of general catchment features of the rivers, both inside and outside the KNP, are found in Table 2. Flow variability between the rivers is described as the coefficient of variation (%CV) and this is shown to be highest for the Sabie and Letaba Rivers. The %CV for the Luvuvhu, Olifants and Crocodile Rivers are similar.

The KNP falls within the savanna biome of South Africa. Landscapes which form this savanna biome were described in detail by Gertenbach (1983). Each landscape comprises a number of different features, such as altitude, annual rainfall, soil types and vegetation types. The defined river reaches were associated with these landscapes and brief descriptions of the landscapes (*e.g.* altitude (m), annual rainfall (mm), soils and dominant vegetation) are listed in Table 3. Not all reaches could be associated with specific landscapes (*e.g.* Reach 2 in the Luvuvhu River and Reaches 4 and 5 in the Letaba River) but a general pattern is evident: there are differences in landscapes between the rivers, as well as within the rivers, with some exceptions. The Sabie River is comprised entirely of a single landscape, and this is similar to Reaches 2-5 of the Crocodile River. The Letaba River is also comprised of a single landscape as far as could be ascertained: the most downstream reaches could not be assigned landscapes. The Luvuvhu, Olifants and Crocodile Rivers each comprise 2 different landscape types.

Table 4 lists the dominant geological, soil and river features in the five major rivers of the KNP (from Venter, 1991). From the table it is obvious that the rivers encompass a diverse range of geology, soils and morphology, and these no doubt have influence on the ecological processes within the rivers. Between rivers there is some overlap in each of the general features (geology, soils, river valley, bank morphology and channel morphology), but there are also differences in these features within rivers, i.e. between reaches. These data were not used in statistical analysis in this study, but rather serve as a qualitative description of the rivers and their reaches. However, a detailed river-landscape study undertaken by Carter and Rogers (1995) supports the generalised tabulated descriptions in Tables 2, 3 and 4: variation in landscape between rivers is complex and while there may be some similarities between rivers, there are also many differences. In general terms, these features suggest the presence of a diverse range of biotopes which could support a diverse range of organisms (*e.g.* invertebrates and fish).

Van Niekerk and Heritage (1993) divided the Sabie River into nine macro-reaches: this was based on river plan form, geomorphology, major tributaries, geology and gradient. Some of these reaches overlap with the management reaches identified by Venter (1991). Unfortunately this level of information is not available for the remainder of the rivers considered for this study and so the information is not considered in more detail.

Results of analysis of water quality data

The paucity in water quality data collection is shown in Table 5. There are differences in the number of water quality monitoring points in each of the rivers, but the number of samples taken from these monitoring points varies. As a result of this, the water quality analysis could only be undertaken at the crude level of rivers. Analysis of within-river similarities was limited due to insufficient data: for three of the rivers (Letaba, Olifants and Sabie Rivers) there was only one water quality monitoring point, while in the Luvuvhu and Crocodile Rivers there were only two water quality monitoring points (Table 5).

Figure 1 shows a scree plot of the Eigenvalues of the PCA of the selected water quality variables for the five major rivers in the Kruger National Park for data from 1998 to 2003. The graph shows that 78% of the variability of the data can be accounted for by the first three factors. After this, increasing the number of factors accounts for only marginal increases in accounting for data variability and therefore only the first three factors are considered further in the analysis. The remaining Eigenvalues are less than 1, indicating that they have less information content than the average of the original chemical variables. This indicates that the rivers vary in three major ways or themes. These themes can be interpreted by examining the Eigenvectors. Water quality constituents associated with the three identified factors can be seen in Figures 2A and 2B. Factor 1 is strongly associated with ions (F, Mg, Ca, Cl, K, SO_4 and Na), Factor 2 is strongly associated with Si, SO_4 and K, while Factor 3 is associated most strongly with nutrients (TIN and PO_4). It is because Factor 3 is strongly associated with nutrients that it was decided to include Factor 3 in the assessment. These can be interpreted as variation in salinity (or salinization) (Factors 1 and 2) and nutrients (Factor 3).

ANOVA of the rivers' factor scores for Factors 1-3 allowed the statistical differentiation of the rivers. With regard to Factors 1 and 2 (salinity), the Sabie and Luvuvhu Rivers were the most similar with the lowest concentrations of ions (e.g. Cl, K, Ca, F, SO_4 and also represented as EC and TDS) (Tables 5 and 6). The Letaba, Olifants and Crocodile Rivers were distinct and increasingly saline. In terms of nutrients (Factor 3), the Sabie, Luvuvhu and Olifants Rivers formed a distinct group. The Letaba River was different from the group, while the Olifants River showed some similarity to the Crocodile River, which was otherwise distinctive (Tables 5 and 6). Overall, the water quality seemed to suggest 3 groups: the Sabie and Luvuvhu River, the Letaba River and the Olifants and Crocodile Rivers.

Although it was beyond the scope of the project to investigate exactly which of the water quality constituents were resulting in significant differences found between rivers, Table 5 depicts the summary statistics of the water quality constituents considered in the analysis and the following qualitative assessments can be drawn.

Median pH did not vary significantly between rivers and was a contributing constituent in all the Factors. The Crocodile River had higher TIN concentrations that any of the other four rivers, although this trend was not evident for PO_4-P. The Olifants and Letaba Rivers had the highest concentrations of SO4, Cl, K, Ca, F, EC and TDS, with the Luvuvhu and Sabie Rivers showing the lowest concentrations of these constituents. The Crocodile River had intermediate concentrations for the water quality constituents considered.

Although there were insufficient water quality monitoring points to undertake statistical analysis, results in Table 5 suggest that there may be downstream improvement in water quality, when comparing Reaches 1 in the Luvuvhu, Olifants and Crocodile Rivers with reaches further downstream. This changes in water quality was most notable for TIN.

Due to project constraints (data and time), it was not possible to examine seasonality of the water quality data. However, this may warrant further investigation as some of the water quality patterns detected in the current assessment may be linked to season.

Results of analysis of invertebrate data

Data for in-stream macroinvertebrates is in the form of presence / absence as data on species abundance were not available for this study. Similarly, analysis is restricted to the family taxon level, and more detailed analysis using species data may yield different results. Comprehensive analysis of within-in river similarity (reaches) could not be undertaken due to data paucity, and neither could a comprehensive assessment be undertaken of seasonality of presence / absence of taxa.

Out of a total possible 65 families found in all rivers, the most diverse rivers are the Sabie and Crocodile Rivers with 58 and 51 families of macroinvertebrates represented in these rivers respectively. The Luvuvhu River is the least diverse with 24 families represented, while the Letaba and Olifants Rivers have intermediate diversity in macroinvertebrates (43 and 46 families respectively). A total of 16 macroinvertebrate families was common to all rivers (although not necessarily to all of the reaches within a river).

A summary of invertebrate families found in each of the five major rivers of the KNP is listed in Table 7. Although insufficient data are available to allow for a seasonal assessment, there is indication of a possible seasonal pattern in Figure 5; however, sufficient data are not yet available to explore this further. It is apparent from Table 7 that some rivers have been undersampled (e.g. Luvuvhu and Olifants) as no data were available for some of the reaches within those rivers. Although some families are represented in a single reach within a river (e.g. Prosopistomatidae in Reach 4 of the Sabie River) or only within one of the rivers (e.g. Perlidae and Athericidae in the Sabie River) this may reflect a difference in sampling intensity within a river and between rivers. Presence or absence of families is a reflection of habitat availability, sampling intensity, season and flow condition at the time of sampling: none of these factors have been taken in to account in this assessment as this information was not readily available.

The scree plot for the Eigenvalues of the PCA of the invertebrate data is shown in Figure 3. The graph shows that 43% of the variability in the five major rivers of the KNP can be accounted for by the first four factors, where each factor is a unique combination of macroinvertebrates sampled in the KNP rivers. A qualitative assessment of the scree plot shows that there is an inflection in the graph after Factor 4 and, to prevent over-fitting of the model, only these first 4 factors were considered in the remainder of the analysis (Jackson, 1993). This graph suggests that there is considerable variation in the invertebrate presence/absence in the rivers of the KNP.

This is further confirmed by Figure 4 and Table 8. Figure 4 shows that each of the factors is comprised of many of the invertebrates which were sampled; the same pattern is discernible when Factor 1 is plotted against Factors 3 or 4 and these graphs are therefore not depicted. A case plot (Figure 5) suggests that there may be a grouping in the factor planes Factor 1 x Factor 2. However, no further groupings could be found for the other factor planes (Factor 1 x Factor 3, Factor 1 x Factor 4) and this grouping should be interpreted with caution. Analysis of Factors 1 to 4 did not reveal any consistent patterns with regard to significant differences between rivers for each of the Factors (Table 8). Results suggest that paucity of data would not yield accurate analysis and interpretation of within river patterns.

Results of analysis of fish data

Data for fish is in the form of presence / absence of species and details of their abundance were not available for this study. Comprehensive analysis of within-in river similarity (reaches) could not be undertaken due to data paucity, and neither could a comprehensive assessment be undertaken of seasonality of presence / absence of taxa. Temporal patterns of change could not be assessed due to data paucity.

A total of 46 fish species have been recorded in the five major rivers of the KNP (Table 9). Of these, 31 species have been recorded in all 5 rivers, although not necessarily in all reaches (there were fish recordes for each of the identified management reaches). The lowest species diversity was recorded in the Letaba River with only 32 out of the total 46 fish species having been recorded from there, while the Sabie and Crocodile Rivers each yielded 38 species. There were 8 fish species which were recorded only once (i.e. in one reach in one of the rivers), 4 of which were only recorded in the Crocodile River, while 2 were found in the Luvuvhu River and one each in the Sabie and Olifants Rivers.

The scree plot for the Eigenvalues of the fish data is shown in Figure 6. Similar to the invertebrate data, a low percentage of the variability in the rivers of the KNP can be accounted for by the first four factors. The low Eigenvalue for Principle Component Factor 1 (Figure 6) indicates high community structure variability and heterogeneity. Although the scree plot indicates that four axes are information rich, an examination of the Eigenvectors for Principle Component Factor 2 shows that this information is about very rare (or undersampled) species, e.g. *Acanthopagrus berda*, *Tilapia sparmanii*, *Aplocheilichthys johnstoni* and *Barbus argenteus*. Due to the lack of generality of the subsequent axes / factors, only Factor 1 was analysed further (Figure 7 is an example, depicting a Factor 1 x Factor 2 plot). Results in Table 10 show that there are no significant differences in fish species composition between rivers of the KNP. This suggests that there is considerable variation in the fish community composition of the rivers in the KNP.

Within-river comparisons could not be undertaken due to insufficient data.

Table 2: General catchment features of the five major rivers of the Kruger National Park: these features refer to characteristics both in and outside the Kruger National Park.

CATCHMENT FEATURE	LUVUVHU	LETABA	OLIFANTS	SABIE	CROCODILE
Catchment area (km^2)	5956 (includes Mutale catchment)	13824	54434	6252	10455
Mean Annual Runoff (m^3×10^6)	529	819	2284	849	1238
Mean Annual Precipitation (mm)	731	671	698	833	879
Forming boundary of KNP	partly	no	no	partly	yes
Length of river inside KNP	81	98	100	111	116
Topography and gradient (inside the KNP)	1150-200 (450-200)	1850-150 (300-150)	2750-150 (300-150)	2300-200 (450-200)	2150-150 (400-150)
Mean gradient (m/km)	3.5	1.6	1.5	2.5	1.8
In-stream structures (indicates features in the KNP)	Albassini Dam	Fanie Botha Dam	Loskop Dam Blyderivierspoort Dam Doornpoort Dam Rhenosterkop Dam Rust der Winter Dam Middleburg Dam Witbank Dam		Braam Raubenheimer Dam
Flow: % coefficient of variation	88	106	82	94	87

Table 3: Description of the landscapes associated with the Luvuvhu, Letaba, Olifants, Sabie and Crocodile Rivers, and their management reaches, of the Kruger National Park (based on Gertenbach, 1983).

<table>
<tr><th></th><th>LUVUVHU</th><th>LETABA</th><th>OLIFANTS</th><th>SABIE</th><th>CROCODILE</th></tr>
<tr><td>Reach-1</td>
<td>LANDSCAPE 15:
Colophospernum mopane forest:
Alt. 360-420m
Ann. rainfall: 500-550mm
Deep soils, rich in sodium
High tree savannah</td>
<td rowspan="3">LANDSCAPE 10:
Letaba River Rugged Veld:
Alt. 250-400m
Ann. rainfall: 450-500mm
Shallow stony soils
Sparse field layer
Dominant woody species: C. mopane, Combretum apiculatum, etc.
Stream banks dominated by similar species to Landscape-7, although more open</td>
<td>LANDSCAPE 7:
Olifants River Rugged Veld:
Alt. 250-300m
Ann. rainfall: 450-500mm
Shallow stony soils
Dry landscape
Sparse field layer
Dense woody component, dominated by more than 25 species</td>
<td rowspan="5">LANDSCAPE 4:
Thickets of Sabie and Crocodile Rivers:
Alt. 200-350m
Ann. rainfall: 500-550
Shallow soils saturated with sodium
River banks are dominated by woody species and best described as densely overgrown: vegetation dominated by Acacia nigrescens and C. apiculatum</td>
<td>LANDSCAPE 2:
Malelane Mountain Bushveld:
Alt. 350-800m
Ann. rainfall: 600-1000mm
Shallow rocky soils with limited clay content in bottomlands
Moderate to dense forest vegetation, dominated by C. apiculatum</td></tr>
<tr><td>Reach-2</td><td>#</td>
<td rowspan="3">LANDSCAPE 21:
Combretum spp./Acacia spp. Rugged Veld:
Alt. 180-300m
Ann. rainfall: 450-500mm
Shallow soils
Sparse to absent field layer
Dominated by a number of woody species</td>
<td rowspan="4">LANDSCAPE 4
Thickets of Sabie and Crocodile Rivers:
Alt. 200-350m
Ann. rainfall: 500-550
Shallow soils saturated with sodium
River banks are dominated by woody species and best described as densely overgrown: vegetation dominated by Acacia nigrescens and C. apiculatum</td></tr>
<tr><td>Reach-3</td>
<td rowspan="4">LANDSCAPE 28:
Limpopo/Levubu Floodplains:
Alt. 200-250m
Ann. avg. rainfall: 438mm
Alluvial soils
Sparse field layer
Closed river forest, dominated by Acacia albida, Ficus sycamorus, etc.</td></tr>
<tr><td>Reach-4</td><td>#</td></tr>
<tr><td>Reach-5</td><td>#</td><td></td></tr>
<tr><td>Reach-6</td><td></td><td></td><td></td><td></td></tr>
</table>

#: Descriptions of landscapes in Gertenbach (1983) could not be associated with these reaches

Table 4: Dominant geological, soil and river features of the Luvuvhu, Letaba, Olifants, Sabie and Crocodile Rivers

	LUVUVHU	LETABA	OLIFANTS	SABIE	CROCODILE
Dominant geology					
Reach-1	Quarzite, coarse sandstone and basalt/andesite (Soutspansberg Group)	Gneiss and migmatite (Makhutswi Gneiss) and amphibolite (Gravelotte Group)	Pegmatite, gneiss and migmatite (Makhutswi Gneiss), and schist and amphobolite (Gravelotte Group)	Granite, gneiss and migmatite (Nelspruit Granite)	Amphibolite and schist (Onverwacht Group) and Granite, gneiss and migmatite (Nelspruit Granite)
Reach-2	Shale, mudstone, sandstone and coal (Ecca Group)	Gneiss (Makhutswi Gneiss)	Olivine-poor basalt (Sabie River Basalt formation)	Granite and gneiss (Nelspruit Granite)	Granite, gneiss (Nelspruit Granite)
Reach-3	Fine-grained, massive sandstone (Clarens formation)	Fine-grained sandstone (Clarens formation), shale (Ecca Group) and olivine-rich basalt (Letaba Basalt formation)	Olivine-poor basalt (Sabie River Basalt formation)	Granite, gneiss and migmatite (Nelspruit Granite)	Granite, gneiss (Nelspruit Granite)
Reach-4	Olivine-rich basalt (Letaba Basalt formation)	Olivine-poor basalt (Sabie River Basalt formation)	Rhyolite (Jozine formation)	Sandstone (Clarens formation) and olivine-poor basalt (Sabie River Basalt formation)	Shale (Ecca Group) and sandstone (Clarens formation) and olivine-poor basalt (Sabie River Basalt formation)
Reach-5	Olivine-rich basalt (Letaba Basalt formation) with sandstone outcrops (Clarens formation)	Olivine-poor basalt (Sabie River Basalt formation)		Rhyolite (Jozini formation)	Olivine-poor basalt (Sabie River Basalt formation) and rhyolite (Jozini formation)
Reach-6	Olivine-rich basalt (Letaba Basalt formation)				
Dominant soils					
Reach-1	Lithosols, Mispah, Hutton, Clovelly	Glenrosa, Mispah	Lithosols, Mispah, Glenrosa	Glenrosa, Clovelly, Hutton, Sterkspruit, Estcourt, Swartland	Glenrosa, Shortlands, Swartland, Sterkspruit
Reach-2	Swartland, Glenrosa, Lithosols	Glenrosa, Mispah	Mispah, Glenrosa, Lithosols, Milkwood, mayo	Glenrosa, Clovelly, Hutton, Sterkspruit, Estcourt, Swartland	Glenrosa, Bonheim, Sterkspruit

	LUVUVHU	LETABA	OLIFANTS	SABIE	CROCODILE
Reach-3	Lithosols, Mispah, Hutton, Clovelly	Lithosols, Mispah, Glenrosa, Swartland, Mayo, Milkwood	Lithosols, Mispah, Glenrosa	Glenrosa, Clovelly, mayo, Swartland, Bonheim	Glenrosa, Bonheim, Sterkspruit
Reach-4	Milkwood, Mayo, Lithosols	Glenrosa, Lithosols	Lithosols, Mispah	Sterkspruit, Pinedene, Shortlands, Swartland, Glenrosa	Sterkspruit, Pinedene, Shortlands, Swartland, Glenrosa
Reach-5	Milkwood, Mayo, Lithosols	Lithosols		Lithosols, Mispah	Glenrosa, Shortlands, Swartland, Lithosols, Mispah
Reach-6	Milkwood, Mayo, Lithosols				
Dominant river valley formation					
Reach-1	Deep and V to U-shaped	Wide and flat	Wide	Wide	Wide
Reach-2	Shallower and wider than Reach-1	Wide and flat	Wide	Wide	Wide
Reach-3	Deep and U-shaped	Wide and flat	Moderately wide	Wide	Wide
Reach-4	Moderately wide and shallow	Wide and flat	V- to U-shaped	Wide	Wide
Reach-5	Wide and flat	Narrow, deep		Moderately wide	Moderately wide
Reach-6	Wide and flat				
Dominant river bank morphology					
Reach-1	Irregular, but often steep with vertical cliffs	Steep and moderately high	Steep and high	Moderately steep and high	Moderately steep and high
Reach-2	High and steep	Moderately steep and low	Gradual inclination and low	Gradual slope and low	Gradual slope and low
Reach-3	Vertical cliffs	Steep and high	Steep and high	Moderately steep and high	Moderately steep and high
Reach-4	Steep and high	Moderately steep and low	Steep/vertical and high	Moderately steep and high	Moderately steep and high
Reach-5	Steep/vertical and high	Steep and high		Steep/vertical and high	Steep and high
Reach-6	Steep/vertical and high				

	LUVUVHU	LETABA	OLIFANTS	SABIE	CROCODILE
Dominant river channel morphology					
Reach-1	Single channel: deep pools alternating with 5-30m rapids	Flat riverbed with secondary channel	Single channel: flat riverbed with shallow stream, deep pools and short rapids over solid rock	Single or slighly divided channel, irregular riverbed with deep pools and shallow streams and rapids over solid rock	Single channel with irregular riverbed, with deep pools and shallow stream with few rapids
Reach-2	Single channel: deep pools alternating with 5-15m rapids	Highly divided irregular riverbed	Irregular and highly divided channel with deep channels separated by islands	Highly divided with narrow channels, irregular riverbed with a shallow stream and rapids over solid rock	Highly divided with narrow channels, and deep pools irregular riverbed, rapids over solid rock
Reach-3	Single channel: deep pools alternating with 5-15m rapids	Flat riverbed with secondary channel	Single channel: deep pools and rapids, at times highly incised forming waterfalls and deep narrow ravines	Single/moderately divided channel, irregular riverbed, deep pools and shallow stream and rapids over solid rock	Single/moderately divided channel, flat riverbed, shallow stream and rapids over solid rock
Reach-4	Single channel: deep pools with few, short, rapids	Highly divided irregular riverbed	Single channel: many deep pools and little rapids	Single/moderately divided channel, irregular riverbed, deep pools and shallow stream and rapids over solid rock	Single/moderately divided channel, flat riverbed, shallow stream and rapids over solid rock
Reach-5	Single channel: deep pools, shallow stream on sand with few stoney rapids	Single channel: deep pools with frequent rapids		Highly divided with narrow channels, irregular riverbed, shallow stream and rapids over solid rock	Single/slightly divided channel, with deep pools between banks of rock
Reach-6	Single channel: deep pools and shallow stream on sand				

Table 5: **Summary of water quality in five major rivers of the Kruger National Park. Shaded blocks indicate reaches where there are no current water quality monitoring points (i.e. no data since 1998, although there may be older data records which were not considered useful for this study).**

		LUVUVHU						LETABA					OLIFANTS				SABIE					CROCODILE				
		1	2	3	4	5	6	1	2	3	4	5	1	2	3	4	1	2	3	4	5	1	2	3	4	5
Sample size		73				75		116					46	42			63					201	143		246	225
pH	Med	8				7.9		8.3					8.4	8.3			7.9					7.9	8.1		8.2	8.3
	25%	7.8				7.8		8.1					8.3	8			7.7					7.8	8		8.1	8.1
	75%	8.1				8.1		8.5					8.5	8.4			8					8	8.3		8.4	8.4
	Min	7.3				7.1		7.5					7.3	5.3			7.3					6.7	7		7.3	7
	Max	8.2				8.7		8.8					8.7	8.8			8.8					8.6	8.6		9.2	9.4
TIN	Med	0.21				0.1		0					0.27	0			0.23					0.56	0.57		0.5	0.49
	25%	0.1				0		0					0.13	0			0.12					0.41	0.41		0.28	0.31
	75%	0.43				0.31		0.1					0.45	0.23			0.28					0.69	0.75		0.7	0.65
	Min	0				0		0					0	0			0					0.04	0.04		0.04	0
	Max	2.5				0.88		2.76					0.72	1.5			0.42					2.4	1.4		1.8	2.4
PO_4-P	Med	0				0		0					0	0			0					0.05	0.04		0.03	0
	25%	0				0		0					0	0			0					0.03	0.02		0.02	0
	75%	0				0		0					0.1	0			0					0.06	0.04		0.04	0
	Min	0				0		0					0	0			0					0	0		0	0
	Max	0.51				0.14		0.11					0.12	0.15			0.1					0.18	0.33		0.23	0.35

		LUVUVHU						LETABA					OLIFANTS				SABIE					CROCODILE				
		1	2	3	4	5	6	1	2	3	4	5	1	2	3	4	1	2	3	4	5	1	2	3	4	5
SO_4	Med	5				5.9		14.1					53.1	51.9			5.7					14.9	21.2		23.3	19.6
	25%	2				4.4		8.6					32.4	26.2			4.3					11.4	15		17.3	13.1
	75%	7.3				7.9		19.7					90.5	73.3			7					16.6	26.6		28.9	26.1
	Min	2				2		2					19.2	18			2					2	5.1		2	4.5
	Max	18.8				21.3		203					551	198			16.5					48	38.8		45.3	51.7
Na	Med	7.5				11		38.3					29.5	27.9			5.6					9.4	19.1		31.6	34.3
	25%	6.8				8.9		25.2					21.8	19.9			4.9					7.3	12.2		20.9	23.6
	75%	8.1				13.4		63.9					42	43			6.7					10.3	24.4		41.2	43.9
	Min	3.9				5.2		10.2					13	11.4			2.9					3.3	4.7		3	3.4
	Max	13.2				102		336					142	70.9			67.2					34.9	71.6		91.7	86.5
Mg	Med	5.5				6		16.7					22.2	24.7			4.3					8.5	15.7		18.9	18.7
	25%	4.6				5.1		10.1					16.2	17.8			3.7					6.4	10.1		13	12.3
	75%	5.9				7.2		24.9					33.4	35.5			5.1					9.6	20.5		24.4	25.3
	Min	2.1				3		4.7					8.6	8.7			1.5					4	4.8		4.4	5.7
	Max	9				40.4		71.9					124	58.2			22.2					25.8	40		50.7	42.2
Cl	Med	9.2				14.9		55					30.5	32.3			6.2					12.9	19.1		29.5	37.1
	25%	6.8				11.3		33.8					21.1	22.9			4.5					10.3	14.5		18.1	25.3
	75%	11.3				18.1		85.7					50	51.3			9.1					16.1	22.5		35.8	44.8
	Min	0.5				0.5		13.8					11.3	0.5			0.5					0.5	0.5		0.5	0.5
	Max	25.9				148		300					164	92.4			76.7					152	106		126	128

		LUVUVHU						LETABA					OLIFANTS				SABIE					CROCODILE				
		1	2	3	4	5	6	1	2	3	4	5	1	2	3	4	1	2	3	4	5	1	2	3	4	5
K	Med	0.8				0.77		2.7					4.4	4.8			0.71					1.2	1.2		1.4	1.4
	25%	0.65				0.64		2.1					2.9	3.1			0.58					0.95	1		1.2	1.1
	75%	0.95				1		3.2					7.8	7.8			0.91					1.2	1.3		1.5	1.5
	Min	0.38				0.41		0.7					2.2	2.1			0.15					0.62	0.55		0.41	0.15
	Max	2.23				1.9		8.2					49.5	19			7.4					4.6	2.4		6.8	3.4
Ca	Med	8.4				8		23					28.8	28.9			7.5					13.6	17.8		21.8	21.7
	25%	7.5				6.8		16.4					22.8	24.8			6.1					10.9	14		16.5	15.7
	75%	9.03				9.5		29.4					36.8	33.9			8.5					15.7	20.9		25.9	26.6
	Min	2.9				5.5		10.4					17.3	17.9			3.8					7.5	8.2		6	7.7
	Max	13.5				31		93.1					70.2	44.9			25.8					29.7	50.8		47.7	49.3
F	Med	0.12				0.13		0.21					0.34	0.33			0.13					0.17	0.2		0.25	0.25
	25%	0.11				0.11		0.18					0.3	0.29			0.12					0.14	0.17		0.21	0.2
	75%	0.14				0.16		0.25					0.46	0.45			0.15					0.17	0.22		0.29	0.29
	Min	0.1				0.1		0.12					0.2	0.19			0.1					0.11	0.12		0.1	0.11
	Max	0.25				0.66		2.7					2.5	0.89			0.31					0.62	0.45		0.42	0.41
Si	Med	7.7				6.6		8.2					7.2	6.8			6.2					7.4	9.5		11.1	10.9
	25%	7				5.1		6.6					6.7	5.9			5.8					6.8	8.6		10.1	9.8
	75%	8.5				7.5		9.3					8.1	8.4			7.3					7.8	10.3		11.9	11.8
	Min	5.1				4		0.41					4.7	4.3			1.6					0.2	5.8		3.4	5.8
	Max	10.3				18		16.4					10.9	10.3			13.5					24.4	19.2		35.2	17.7

		LUVUVHU						LETABA					OLIFANTS				SABIE					CROCODILE				
		1	2	3	4	5	6	1	2	3	4	5	1	2	3	4	1	2	3	4	5	1	2	3	4	5
TAL	Med	48.6				52.4		126					131	155			39.7					60.6	106		138	137
	25%	41.7				42		89.1					108	123			32.2					50.1	66.9		99.4	95.7
	75%	53.1				61.1		171					176	187			45.7					65.4	137		177	179
	Min	17.1				24.2		48.2					73.9	48.1			26.1					34	35.6		21.9	45.2
	Max	69.6				257		438					246	207			195					178	288		298	278
EC	Med	13.6				15.3		45.4					47.4	49.4			10.5					20.4	32.2		41.4	41.1
	25%	10.9				13.4		30.4					38.4	39			9.4					16.4	23.2		30.1	31.3
	75%	14.7				19.6		63.6					64	65.2			12.1					22.9	40.5		51.4	53.7
	Min	5.7				8.8		16.5					25	27.3			7					11.9	12.9		10.5	13.8
	Max	23.4				97.5		249					196	99.9			63					51.6	89.4		84.4	98.5
TDS	Med	95.4				108		307					336	361			78					136	231		295	290
	25%	87				95		206					261	289			71					111	154		214	215
	75%	105				127		447					455	458			90					150	289		377	392
	Min	49				63		115					173	171			56					77.4	88.8		79	98.3
	Max	149				657		1412					1404	725			438					379	640		647	659

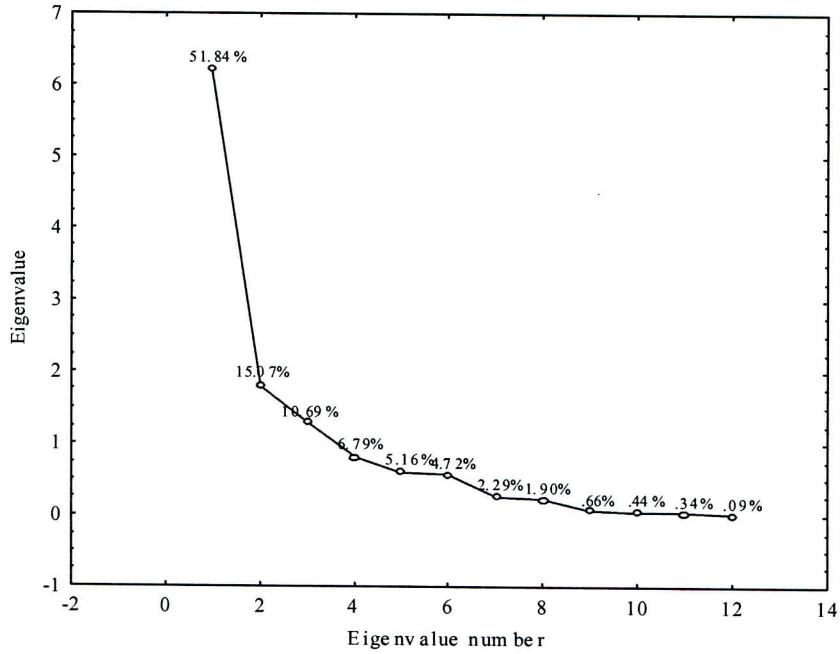

Figure 1 **Scree plot of the Eigenvalues of the correlation matrix of the selected water quality constituents for data from 1998 to 2003 for the Luvuvhu, Letaba, Olifants, Sabie and Crocodile Rivers in the Kruger National Park.**

Table 6:	**Similarities in water quality between the Luvuvhu, Letaba, Olifants, Sabie and Crocodile Rivers. Similarities, as defined by no statistically significant difference, are denoted by the same letters (significant difference $p<0.05$).**				
Between Rivers					
	Luvuvhu	**Letaba**	**Olifants**	**Sabie**	**Crocodile**
Factor 1	A	B	C	A	E
Factor 2	A	B	C	A	E
Factor 3	A	B	A, C	A	C

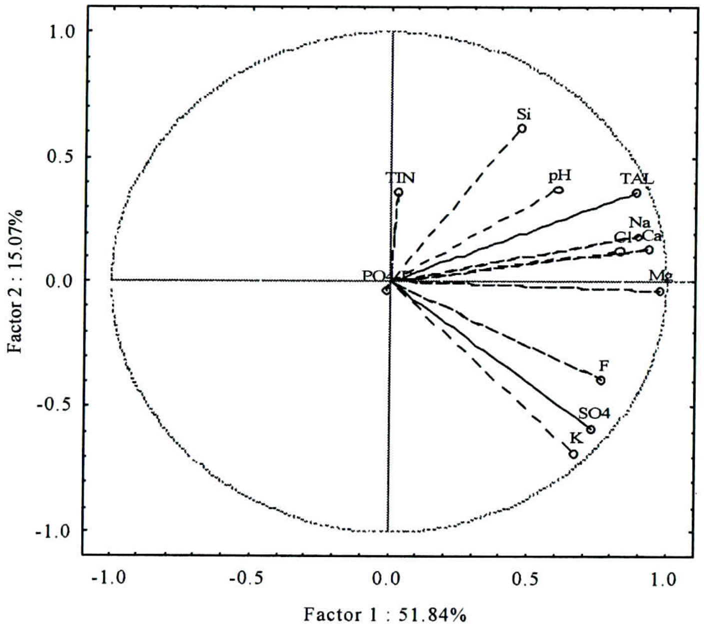

Figure 2A **Plot of the water quality constituents Factor coefficients on the Factor 1 x Factor 2 plane.**

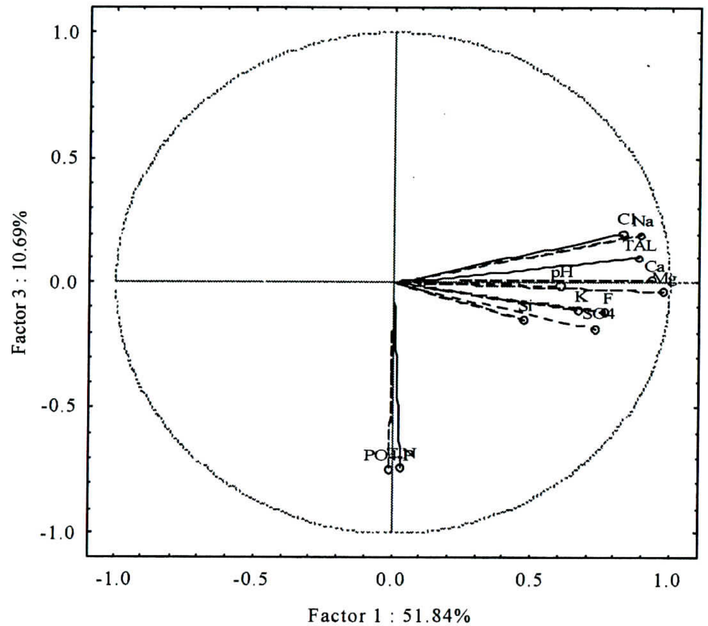

Figure 2B **Plot of the water quality constituents Factor coefficients on the Factor 1 x Factor 3 plane**

Table 7: **Summary table of invertebrate families sampled in each of the management reaches of the five major rivers of the Kruger National Park (data were obtained from Moore, 1991; Uys, 1998; the National River Health Programme database). All seasonal data were combined. Cells marked with shading indicate that no data were available for those reaches.**

	Luvuvhu						Letaba					Olifants				Sabie					Crocodile				
Reach	**1**	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
Coelenterata	✓		✓							✓		✓			✓	✓			✓						✓
Turbellaria	✓		✓									✓				✓			✓	✓	✓	✓			✓
Oligochaeta			✓				✓			✓		✓	✓		✓	✓			✓	✓	✓	✓		✓	
Leeches							✓			✓		✓	✓						✓					✓	
Potamonautidae										✓															
Atyidae							✓			✓															
Hydracarina	✓		✓				✓	✓				✓				✓				✓	✓				✓
Plecoptera																✓			✓	✓					
Perlidae																✓			✓	✓		✓			
Baetidae	✓		✓				✓		✓	✓	✓	✓	✓		✓	✓		✓	✓	✓	✓	✓	✓	✓	✓
Caenidae	✓		✓				✓		✓	✓	✓	✓	✓			✓		✓	✓	✓	✓	✓	✓	✓	✓
Heptageniidae	✓		✓				✓		✓	✓		✓				✓		✓	✓	✓	✓	✓		✓	✓
Leptophlebiidae							✓		✓	✓	✓	✓	✓			✓			✓	✓	✓	✓	✓	✓	
Oligoneuridae							✓		✓	✓		✓				✓		✓						✓	

	Luvuvhu						Letaba					Olifants				Sabie					Crocodile				
Reach	**1**	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
Polymitarcidae																✓									
Prosopistomatidae																			✓						
Tricorythidae	✓		✓				✓		✓	✓	✓	✓			✓	✓		✓	✓	✓	✓	✓		✓	✓
Odonata	✓		✓									✓				✓				✓					
Calopterygidae										✓						✓									
Chlorocyphidae																✓			✓	✓		✓			
Coenagrionidae							✓		✓	✓		✓	✓			✓		✓	✓	✓		✓		✓	
Aeshnidae										✓														✓	
Corduliidae							✓		✓			✓				✓			✓	✓				✓	
Gomphidae							✓		✓	✓	✓	✓	✓			✓		✓	✓	✓		✓	✓	✓	✓
Libellulidae							✓		✓	✓		✓	✓			✓			✓	✓	✓	✓	✓	✓	✓
Pyralidae	✓		✓									✓								✓	✓				✓
Belostomatidae							✓		✓	✓		✓				✓		✓	✓	✓				✓	
Corixidae							✓		✓	✓	✓	✓	✓			✓		✓	✓	✓		✓	✓	✓	
Gerridae	✓						✓		✓	✓		✓			✓				✓			✓		✓	
Naucoridae			✓							✓		✓	✓		✓	✓			✓	✓	✓	✓	✓	✓	
Nepidae							✓			✓		✓							✓					✓	

	Luvuvhu						Letaba					Olifants				Sabie					Crocodile				
Reach	**1**	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
Notonectidae							✓		✓	✓		✓							✓	✓		✓		✓	
Pleidae							✓		✓	✓						✓			✓					✓	
Veliidae							✓		✓	✓		✓	✓			✓			✓	✓		✓	✓	✓	
Hydropsychidae	✓		✓				✓		✓	✓	✓	✓	✓		✓	✓		✓	✓	✓	✓	✓	✓		✓
Philopotamidae							✓			✓	✓					✓			✓	✓		✓			
Psychomyiidae																			✓						
cased caddis							✓		✓	✓		✓	✓			✓		✓	✓	✓		✓	✓	✓	
Hydroptilidae	✓		✓									✓			✓	✓				✓		✓	✓		✓
Leptoceridae	✓		✓												✓	✓				✓	✓				✓
Dytiscidae							✓		✓	✓	✓	✓			✓	✓			✓	✓	✓	✓	✓	✓	✓
Elmidae/Dryopdiae	✓		✓				✓			✓		✓			✓	✓			✓	✓	✓	✓	✓	✓	✓
Gyrinidae	✓		✓				✓			✓		✓				✓		✓	✓	✓	✓	✓		✓	✓
Helodidae																			✓					✓	
Hydraenidae										✓			✓			✓			✓	✓			✓	✓	
Hydrophilidae										✓		✓				✓			✓	✓		✓		✓	✓
Anthomyidae																					✓				
Athericidae																✓			✓	✓					

	Luvuvhu						Letaba					Olifants				Sabie					Crocodile				
Reach	**1**	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
Ceratopogonidae												✓	✓			✓			✓				✓	✓	
Chironomidae	✓		✓				✓		✓	✓	✓	✓	✓		✓	✓		✓	✓	✓	✓	✓	✓	✓	✓
Culicidae							✓			✓		✓			✓				✓			✓		✓	
Dixidae																✓									
Ephydridae																✓									
Muscidae												✓				✓			✓	✓	✓				✓
Rhagionidae			✓													✓				✓					✓
Simuliidae	✓		✓				✓		✓	✓	✓	✓	✓		✓	✓		✓	✓	✓	✓	✓	✓	✓	✓
Tabanidae	✓		✓				✓		✓	✓	✓	✓	✓		✓	✓			✓	✓	✓	✓	✓	✓	✓
Tipulidae	✓		✓				✓		✓	✓	✓	✓	✓			✓			✓	✓	✓			✓	✓
Ancylidae	✓		✓									✓			✓	✓				✓	✓				✓
Bulininae																				✓					
Lymnaeidae										✓		✓													
Physidae										✓		✓												✓	
Corbiculidae			✓									✓			✓	✓				✓					✓
Sphaeriidae							✓		✓	✓		✓	✓			✓			✓	✓		✓	✓	✓	
Unionidae							✓			✓															

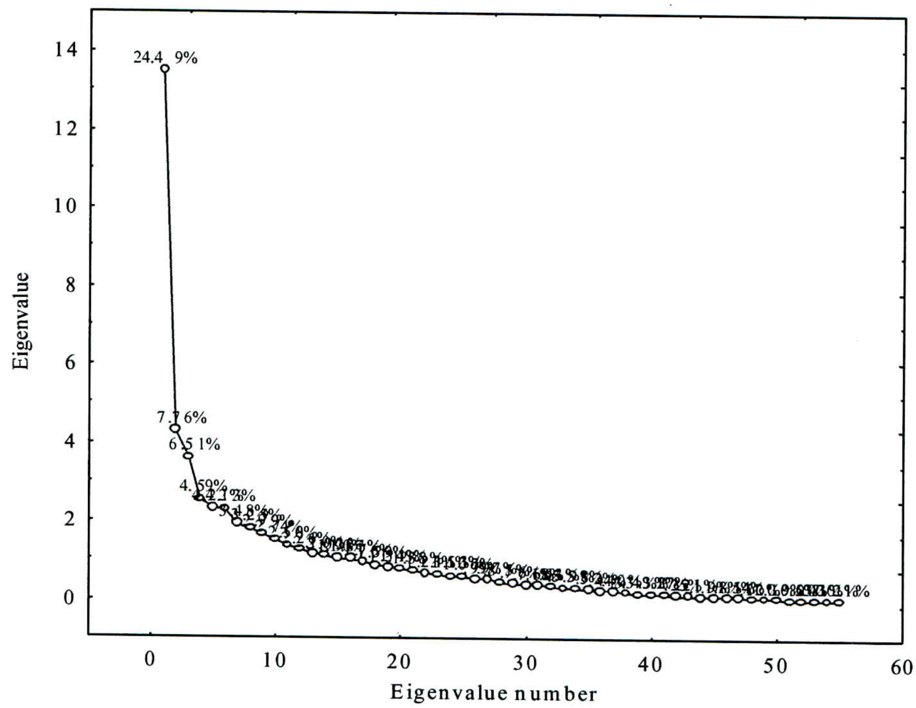

Figure 3 **Scree plot of the Eigenvalues of the correlation matrix of the invertebrates of the Luvuvhu, Letaba, Olifants, Sabie and Crocodile Rivers in the Kruger National Park.**

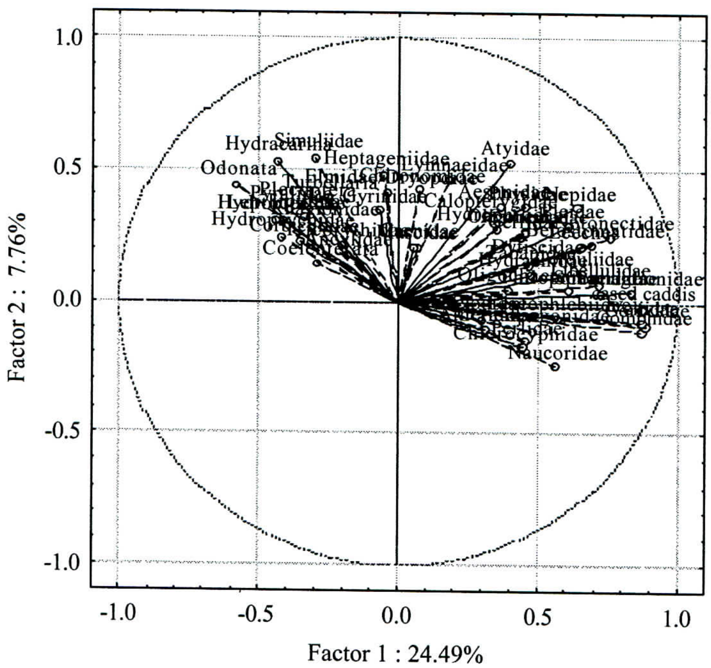

Figure 4 **Plot of the invertebrate Factor coefficients on the Factor 1 x Factor 2 plane.**

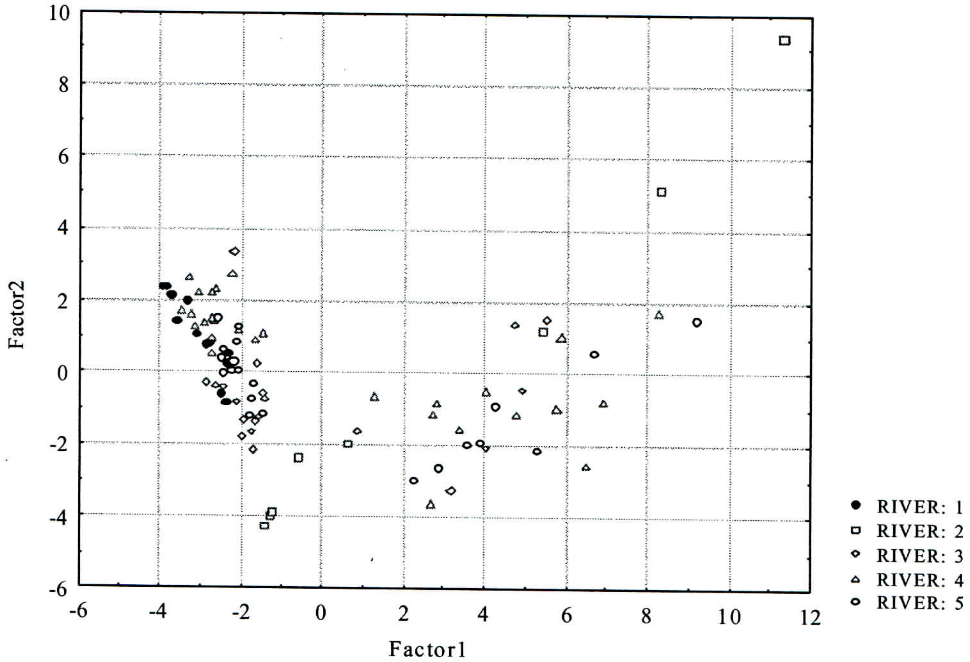

Figure 5 **Invertebrate community Principle Component Analysis Plot showing Factor 1 x Factor 2 cases per river (label numbers refer to rivers as follows: 1=Luvuvhu River; 2=Letaba River; 3=Olifants River; 4=Sabie River; 5=Crocodile River).**

Table 8: **Similarities in invertebrate family composition between the Luvuvhu, Letaba, Olifants, Sabie and Crocodile Rivers for each of the Factors. Similarities, defined as no statistically significant differences, are denoted by the same letters (significant difference s<0.05). Due to insufficient data, patterns for within-river differences could not be determined.**

Between Rivers

	Luvuvhu	Letaba	Olifants	Sabie	Crocodile
Factor 1	A	B,C	B	B,C	B
Factor 2	A	B,C	A,B,C	B	A,D
Factor 3	A	A	B	A	A,B
Factor 4	A	A	B,C	A,C	A,C

Table 9: **Summary table of fish species sampled in each of the management reaches of the five major rivers of the Kruger National Park (data were obtained from Pienaar, 1978 and Russel, 1997) All seasonal data, were available, were combined.**

	Luvuvhu						Letaba					Olifants				Sabie					Crocodile				
Reach	**1**	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
Acanthopagrus berda																									✓
Amphilius uranoscopus	✓			✓												✓									
Anguilla bengalensis																									✓
Anguilla marmorata			✓				✓				✓				✓	✓	✓		✓	✓				✓	✓
Anguilla mossambica	✓					✓	✓						✓			✓	✓	✓	✓					✓	✓
Aplocheilichthys johnstonii						✓																			
Awaous aeneofuscus						✓																			
Barbus afrohamiltoni		✓		✓	✓	✓	✓		✓	✓	✓		✓					✓	✓	✓				✓	
Barbus annectens	✓			✓					✓	✓		✓				✓	✓	✓	✓	✓	✓				
Barbus argenteus																✓									
Barbus eutaenia																✓	✓	✓	✓		✓		✓	✓	
Barbus marequensis	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Barbus mattozi													✓												
Barbus paludinosus				✓		✓			✓	✓			✓	✓		✓		✓			✓	✓			
Barbus radiatus	✓			✓	✓	✓	✓		✓	✓		✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	
Barbus toppini	✓			✓	✓	✓	✓		✓	✓	✓	✓	✓	✓		✓	✓	✓	✓		✓	✓			

	Luvuvhu						Letaba					Olifants				Sabie					Crocodile				
Reach	1	2	3	4	5	6	1	2	3	4	5	1	2	3	4	1	2	3	4	5	1	2	3	4	5
Barbus trimaculatus	✓			✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Barbus unitaeniatus		✓		✓			✓		✓	✓		✓	✓			✓		✓	✓		✓	✓		✓	
Barbus viviparous	✓	✓		✓	✓		✓		✓	✓		✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Brycinus imberi	✓			✓	✓	✓	✓		✓	✓			✓	✓	✓	✓	✓	✓	✓	✓		✓		✓	✓
Carcharinus leucas						✓																			
Chetia brevis																					✓				
Chiloglanis anoterus																✓			✓		✓			✓	
Chiloglanis paratus	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓		✓		✓	✓	✓
Chiloglanis pretoriae	✓					✓			✓	✓		✓	✓	✓	✓	✓	✓							✓	
Chiloglanis swierstrai						✓			✓	✓	✓		✓	✓		✓	✓		✓		✓		✓	✓	✓
Clarias gariepinus	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Glossogobius giuris	✓	✓		✓	✓	✓	✓		✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓				✓	✓
Hydrocynus vittatus	✓			✓	✓	✓			✓	✓	✓				✓	✓	✓	✓	✓	✓				✓	✓
Labeo congoro	✓				✓	✓				✓		✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
Labeo cylindricus	✓			✓	✓	✓	✓		✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Labeo molybdinus	✓			✓	✓		✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Labeo rosae	✓			✓	✓	✓	✓		✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	

	Luvuvhu						Letaba					Olifants				Sabie					Crocodile				
Reach	**1**	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
Labeo ruddi	✓					✓	✓		✓	✓		✓	✓			✓									
Marcusenius macrolepidotus	✓			✓	✓		✓		✓	✓		✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Mesobola brevianalis	✓			✓		✓	✓		✓	✓		✓	✓			✓	✓	✓	✓	✓		✓	✓	✓	
Micralestes acutidens	✓			✓	✓	✓	✓		✓	✓		✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Opsaridium zambezensense												✓	✓	✓		✓	✓	✓	✓		✓		✓	✓	
Oreochromis mossambicus	✓			✓	✓	✓	✓		✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Petrocephalus catostoma	✓					✓				✓	✓		✓			✓	✓	✓	✓	✓			✓	✓	
Pseudocrenilabrus philander				✓						✓		✓	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	
Schilbe intermedius	✓				✓	✓	✓		✓	✓			✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Serranochromis meridianus																✓	✓	✓	✓	✓					✓
Synodontis zambezensis					✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓				
Tilapia rendalli	✓			✓	✓	✓	✓		✓	✓		✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Tilapia sparrmanii																					✓				

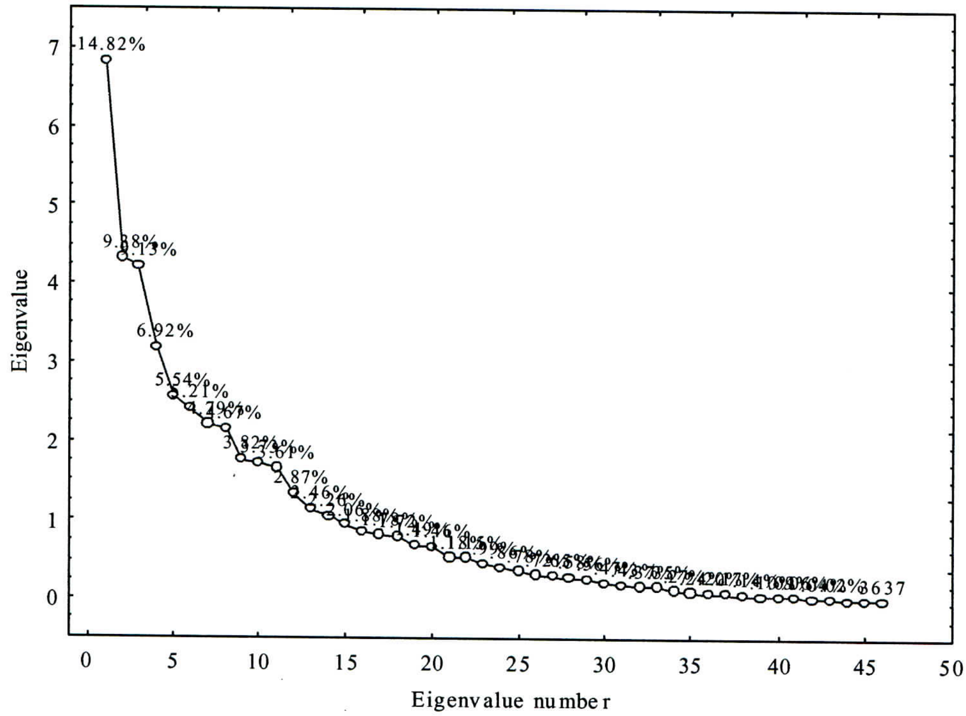

Figure 6 **Scree plot of the Eigenvalues of the correlation matrix of the fish data from the Luvuvhu, Letaba, Olifants, Sabie and Crocodile Rivers in the Kruger National Park.**

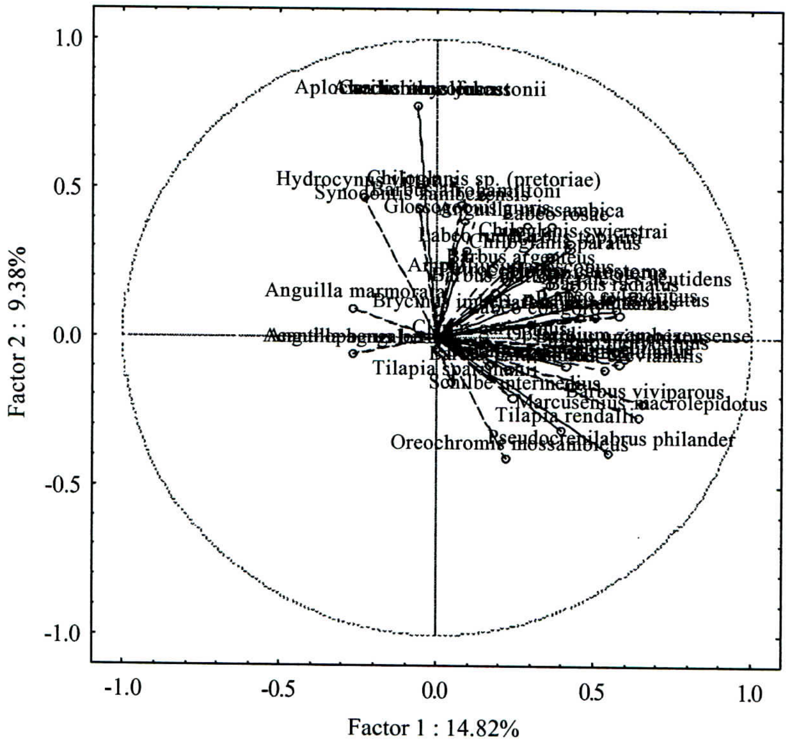

Figure 7 **Plot of the fish species Factor coefficients on the Factor 1 x Factor 2 plane.**

Table 10: Similarities in fish species composition between the Luvuvhu, Letaba, Olifants, Sabie and Crocodile Rivers. Similarities, or no detectable significant differences, are are denoted by the same letters (significant difference p<0.05). Due to insufficient data, patterns for within river differences could not be determined.

Between Rivers

	Luvuvhu	**Letaba**	**Olifants**	**Sabie**	**Crocodile**
Factor 1	A	A	A	A	A
Factor 2	A	A	A	A	A
Factor 3	A	A	A	A	A
Factor 4	A	A	A	A	A

CHAPTER 4:
DISCUSSION AND CONCLUSION

Effective management of aquatic ecosystems requires a sound understanding of the structure and function of these aquatic resources, but should also include interactions between surface water and groundwater, the floodplain, effects of gradients and the role of disturbance regimes on the ecological processes within the resources (Ward, 1998). Interactions between catchment landscape and river ecology have been known to exist for a long time, although predicting biotic community structure and in-stream processes is not yet well understood (Johnson and Gage, 1997). Catchment management requires scientific input (data), and particularly an understanding of ecosystem processes in order to understand changes in physical habitat and water quality, so that management interventions can be monitored effectively (Pollard *et al.*, 2001). Effective management is best achieved in a data-rich environment, although this is not always possible.

The development of advanced analytical tools has allowed great strides in examining complex ecological relationships (Johnson and Gage, 1997) and these have been begun to be incorporated into resource management. The limitation of any of the advanced methods of analysis may now be the data that are collected, and it becomes important to capture as much detail and information as possible. As more advanced techniques become available for data analysis and predictions, the data gaps are becoming more obvious (Johnson and Gage, 1997). This is becoming increasingly obvious where funding constraints are such that continued collection of data are not always possible. Judicious use of available methods is important in preventing misinterpretation of data and patterns observed (Johnson and Gage, 1997).

There is no single correct scale at which to describe ecosystems. A good starting point appears to be the description of patterns which will allow the formulation of mechanisms to explain the patterns, and these can then be tested and refined (Levin, 1992). By looking at the problem at different levels of scale, unpredictable and unrepeatable measures may become more stable and allow the formation of generalizations (Levin, 1992). At a reach scale, the patterns may not be discernable, but they become more obvious at a river scale. The heterogeneity of an environment allows different species to coexist, and this pattern of diversity in species is reflected in the spatial and temporal distribution of species (Levin, 1992). The units (reaches) defined by Venter (1991) are not set out to quantify ecological relationships (e.g. between landscape and abiotic and biotic components), but are clearly defined as management units. As such, they may not be appropriate to describe patterns of abiotic or biotic similarities or differences.

There are differences between, and within rivers, in the landscapes associated with the five major rivers of the Kruger National Park. The Sabie and Crocodile Rivers showed the most similarity in their landscapes, while the Luvuvhu, Olifants and Crocodile Rivers each have within-river differences in their landscapes.

There were insufficient data or taxonomic resolution of available data (particular to macroinvertebrates) to undertake a comprehensive assessment and classification of the rivers, and their reaches. There appear to be differences between the rivers at abiotic level (catchment, geology, soils etc.) but these do not appear to have impact on biological diversity, although biological data presented should be interpreted with caution. The invertebrate data analysed was at a coarse taxonomic resolution (family level only), and species-level identification may yield different results. In assessing the macroinvertebrate and fish data, no consideration was given to temporal changes (either seasonal or long term changes) in the presence / absence of fish species or macroinvertebrate families.

Assessment ofbiological diversity is affected by collection effort: spatial scale, habitats sampled and temporal scale (seasons) affect the diversity of organisms collected. Organisms are able to respond to disturbances at a local scale and their absence from a particular site during a single collecting trip does not signify their absence from the reach but merely that they have not been collected. Invertebrates show great species diversity within a family taxonomic level: the assessment undertaken for this study was at a family level taxonomic resolution and differences within family (*i.e.* at genus and species taxonomic resolution) would not be reflected.

Difference in sampling effort between different studies, as well as sampling effort for specific species, may significantly affect the data analysis undertaken in this study. This was found to be especially true for macroinvertebrates in a study undertaken by de Moor (2002) where it was impossible to distinguish between two rivers (the Mooi and Mkomazi Rivers) on the basis of family level identification. A rapid sampling technique, such as that used in the South African Scoring System (SASS; a commonly used method to assess river health and on which most of the data used in this study is based), versus a more detailed and comprehensive biodiversity survey will obviously be dependent on the question being addressed. However, even a single group (family) done to species level identification may provide greater insight into characterizing rivers (particularly due to availability of species-specific habitat).

Macroinvertebrate assessment undertaken here confirms results of a study undertaken by O'Keeffe and Uys (1998), which suggested that different sampling intensity may bias results and interpretation. There are limitations on data interpretation as a result of the state of taxonomy of many of the organisms being considered and final analysis can only be undertaken at the crude level of family rather than at the more sophisticated level of species. In addition, the assessment undertaken here considers only the presence / absence of families and no cognisance is taken of abundance.

Both the Luvuvhu and Letaba Rivers have had significant alterations in their flow patterns (both are now temporary rivers) and although the Sabie River remains a perennial river, flows as low as $<0.5m^3.s^{-1}$ have been recorded during drought periods (O'Keeffe and Uys, 1998). These changes in flow pattern may result in changes in biodiversity, although levels of similarity between the Luvuvhu, Letaba and Sabie Rivers suggest that changes in biodiversity are not only linked to changes in flow pattern but may be linked to e.g. changes in water quality and habitat availability.

Russell and Rogers (1989) undertook a comparison of fish distributions in the major rivers of the Kruger National Park between surveys undertaken in the 1960s and 1980s. Several species had either disappeared from the rivers or else showed decreased distribution: these distribution decreases were most prevalent in the Luvuvhu, Letaba and Olifants Rivers, with fewer notable changes in the Sabie and Crocodile Rivers. New fish distributions were recorded in all the rivers except the Luvuvhu River, with inceased distributions of selected species in the Sabie, Crocodile and Letaba Rivers. These changes in fish distribution patterns were attributed to changes within the rivers, most notably changes associated with alteration in flow patterns (decreased flow), changes in water quality (particularly increased silt levels in the rivers) and resultant changes (reduction) in suitable habitat available for the fish species.

Studying the rivers inside the KNP independently of their course outside the KNP may not prove useful because the upstream conditions will have significant effects on the processes taking place inside the KNP. While this project does not attempt to describe these upstream processes, it is important to take cognisance of this for managing rivers inside the KNP. This is particularly significant as upstream demands on flow (regulation of quantity and pattern) and water quality will have significant impacts on biota in the rivers.

A river-signature approach for conservation planning was developed by Roux *et al.* (2002) for ecosystems where few data were available. Although this approach has not been tested, and uses somewhat different data to that incorporated in this study, it may be possible to incorporate data from this study into such a river-signature approach for use in biodiversity and conservation management.

CHAPTER 5:
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