A Pre-impoundment study of the Sabie-Sand River System, Mpumalanga with special reference to predicted impacts on the Kruger National Park

Volume Two

Effects of the 1992 drought on the fish and macro-invertebrate fauna

SR Pollard* • DC Weeks# • A Fourie*

Report to the Water Research Commission
by the
*Freshwater Research Unit, University of Cape Town, and
#Institute for Water Research, Rhodes University

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

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The name of the region where this work was done was changed from
EASTERN TRANSVAAL
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Where the name Eastern Transvaal appears in the text, please read
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EXECUTIVE SUMMARY

In 1992, Southern Africa experienced the most severe drought in recorded history, exacerbating the already precarious water resources of the region. The flow of the Sabie River in the Eastern Transvaal decreased to previously undocumented levels. Natural episodic disturbances such as drought may have a pronounced effect on stream ecosystem dynamics. A number of authors (Chapman et al., 1991; Fausch & Bramblett, 1991) have stressed the importance of ecological research regarding the effects of disturbance in shaping the structure of communities, particularly in terms of the implications for management. This research need is even more urgent in the face of increasing anthropogenic disturbances and demands placed on aquatic systems. Conditions of drydown and cessation of flow restrict biota to deteriorating habitat quality and, monitoring of a drought period provides insight into a species ability to survive such periods.

Consequently, a comprehensive monitoring programme was initiated in May, 1992, at the start of the dry season in order to assess the effects of the drought on fish and macro-invertebrate communities in the Sabie and Sand Rivers. The Drought Monitoring Programme formed part of an ongoing, three year ecological survey of these rivers. Conditions throughout the drought period offered an opportunity to address species and community responses to shrinking habitats and vastly fluctuating chemical environments.

Three sites were chosen, one at the confluence of the Sabie and Sand Rivers, one on the Sand River (Londolozi) and one on the lower Sabie River (Mlondozi). Fish and invertebrates communities, as well as chemical and physical parameters, were monitored in pools and in the river on a monthly basis. Herein we document the results of this study.

1. Overall trends

The sub-tropical lowveld region is characterised by wet/dry cycles and furthermore, cessation of flow has been reported in the lower Sand River since 1980. Consequently, although it would be expected that the species assemblage here represents a relatively robust community, the drought in 1992 was far more protracted and severe than in other years. Flow ceased in the Sand River in June and previously unprecedented low flows persisted through the final months in the Sabie River (0.5 m^3s^{-1}).

We submit that a so-called 'normal' dry cycle would result in trends seen between June and August, with most species surviving. However, patterns emerging in September, and in October at Londolozi were likely to reflect the extreme ends of the spectrum, as temperatures and evaporation increased with the onset of warmer weather.

(a) The main channel

In September, the main channel of the Sabie River was still flowing, albeit at very low flows. In this area, the physical habitat changed as a function of progressively decreasing flows. The appearance of opportunistic invertebrate species such as *Povilla* in the riffle, emphasises the drastic deterioration of habitat. The absence of suitable habitat seems to be a more important factor than deteriorating chemical parameters (within limits).

In general, both the run and riffle areas maintained a constant species diversity of fish, although abundances of most species declined, noticeably that of the barred minnow (*Opsaridium zambezensis*), a red-data species. In addition, the abundance of flow-associated species such as *Barbus marequensis*, *Labeo molybdinus* and *Micralestes acutidens* decreased. With time, the run shifted from domination by the redbreasted tilapia (*Tilapia rendalli*) to that of the bowstripe barb (*Barbus viviparus*). The riffle area was initially dominated the catlet, *Chiloglanis paratus*. The abundance of this flow-dependent species decreased notably with the progression of the drought. In the latter months the large-scale yellowfish (*B.marequensis)* was the most abundant species in the riffle.

(b) Isolated pools

With respect to isolated pools, a pronounced change in invertebrate community structure, accompanied by a loss of numbers of taxa and thus species diversity could be seen as the drought conditions intensified. A complete change from a lentic to a lotic community was obvious from the high numbers of Copepods and Cladocerans and the marked absence of more flow-sensitive species.

Regarding fish, the overall trends from this study are consistent with those of Merron & Lalouviere (1987) from the Pongola in which the Mozambique tilapia, *Oreochromis mossambicus* substantially dominated almost all habitats during drought. This species possesses a wide physiological tolerance and'reproductive strategy facilitating its survival in adverse conditions. At Mlondozi, catches were alternatively dominated by the Mozambique tilapia or the redbreasted tilapia (*T.rendalli*). At Mlondozi, the freshwater goby (*Glossogobius callidus*) was the second most abundant species in June (31% of total CPUE), but decreased substantially thereafter. The second most abundant species at Londolozi was *B.viviparus*, comprising between 10 and 25% of the catch.

However, although *O.mossambicus* dominated overall catches, closer examination revealed this species was rare in, and never dominated shaded pools. These pools were alternatively dominated by the silver robber (*M.acutidens)*, the broadstriped barb (*Barbus annectens*) or the bowstripe barb (*B.viviparus)*.

2. Habitat selection

These results suggested that certain species favour particular habitats and, given sufficient time during drydown, "select" preferred habitats, and move accordingly prior to cessation of flow. This has important implications for management.

From this study a number of variables emerged as important in explaining the distribution of certain species in isolated pools.

■ Our data indicate that **depth** and **volume** were the most frequently implicated criteria in explaining the initial distribution of the certain species, namely the broadstripe barb (*B.annectens*), the yellowfish (*B.marequensis*), the Beira barb (*Barbus radiatus*), the river sardine (*Mesobola brevianalis*) and the river goby (*G.callidus*). Depth alone appeared to be important in the case of the silver robber, *M.acutidens*. Generally, these variables underscored the distribution of highly motile species such as the minnows and cyprinids, particularly the open water species.

■ In contrast, neither depth nor volume appeared to account for the distribution of the larger labeos which were widespread. In the case of these more sedentary species which were consistently found in association with in-pool boulders, **cover** appeared to be important determinant. This may in part reflect the feeding requirements of these species.

■ At isolation, certain species were widespread such as the abundant and **generalist** bowstripe barb (*B.viviparus*), whilst others, such as the **specialist** catlet *C.paratus*, was restricted to pools that lay directly below riffles.

■ Additionally, some species appeared to be restricted to **instream** or **offstream** pools, most notably Toppins barb *Barbus toppini* and the straightfin barb, *Barbus paludinosus* which were never recorded in instream pools. These two species are characteristic of standing water bodies. Other species more common in offstream or "marginally" offstream pools were *M.brevianalis* and *O.mossambicus*, while both *B.viviparus* and the lowveld largemouth, *Serranochromis meridianus* were typically found in instream pools.

■ In this study, the distribution of *B.marequensis*, *Barbus trimaculatus*, *Marcusenius macrolepidotus* and *S.meridianus* was positively correlated with **offstream cover**, whilst *O.mossambicus* appeared to avoid shaded pools.

3. "Sensitive" and "robust" species

The barred minnow *Opsaridium zambezensis* and the pennat-tailed rock catlet *Chiloglanis anoterus* represent two species that are unable to survive present conditions within the lower Sand River sub-catchment, although present above and below this zone.

Some species were capable of surviving the extreme conditions of the drought either by behavioural or physiological adaptations, although abundances decreased in almost all species. A number of species were numerous at the start of the dry season and had disappeared from pools in the latter months. These were the straightfin barb *(B.paludinosus)* and the bulldog *(M.macrolepidotus)*. However, the straightfin barb, characteristic of offstream pools, is generally considered to be a tolerant species and only disappeared at the final stages of the drought. Toppins barb, found in close association with the straightfin barb in offstream pools, survived the final stages by shoaling at the edge of the pool in the top few centremeters of free water. With respect to the bulldog, it has been suggested that both mormyrids, *M. macrolepidotus* and *Pterocephalus catostoma* are unable to tolerate high conductivities as this effects their ability to electrolocate (Kok, 1980). In general, pools in this study were characterised by increasing conductivities and this could explain the disappearance of these species.

In a number of cases only one individual of a species remained, and thus it could be argued had been severely affected by the drought. These were the large-scale yellowfish *(B.marequensis)*, the silver robber *(M.acutidens)*, the river sardine *(M.brevianalis)*, and the Churchill *(P.catostoma)*. Although an attempt was made to sample diverse pool types, all of these species may well have persisted in other reaches of the Sand River. These data indicate only that these species appear to be more sensitive to the extreme conditions imposed by the drought. Possible reasons for the disappearance of *P.catostoma* have been discussed above. The other species are motile species associated with depth and volume. As pools became shallower, certain species such as the large-scale yellowfish showed signs of stress manifesting in disease.

A number of species appeared to be particularly susceptible to disease. These were the large scale yellowfish, *B.marequensis*, the plumbeous labeo *Labeo molybdinus*, the threespot barb, *B.trimaculatus* and the bowstripe barb, *B.viviparus*. The latter three species all feed on benthic algae and associated invertebrates (Bell-Cross, 1988). The lack of benthic algae in these pools suggests that the onset of disease could be explained by lack of food and the concomitant physiological stress being placed on resident, sensitive fish. *O.mossambicus* also showed signs of scalar fungus.

The onset of disease may also relate to physiological stresses precipitated by factors such as low oxygen concentrations. In pools that exhibited low oxygen levels, the onset of disease was pronounced, indicating that physiologically stressed fish are more likely to succumb to disease. Species showing evidence of disease in this case, were again the Plumbeous labeo (*L.molybdinus)*, the large-scale yellowfish (*B.marequensis)* and the threespot barb (*B.trimaculatus)*. The former two species both possess ventral mouths which would limit their ability to supplement their oxygen demand by surface respiration (Tramer, 1977). Species that persisted in pools with low oxygen concentrations were the catfish (*Clarias gariepinus*) and Toppins barb (*B.toppini)*.

The threespot barb, *B.trimaculatus* has been recognised in this project as a robust species and persisted in most pools until they dried up. It appeared to tolerate relatively low oxygen concentrations. Both the catfish *C.gariepinus* and Toppins barb, *B.toppini* and to a lesser degree the straightfin barb, *B.pauldinosus* survived in pools in which ammonia concentrations were extremely high, indicating a tolerance to this variable.

A suite of minnows disappeared at Londolozi in the latter months. These were *B.annectens, B.trimaculatus, Barbus eutaenia* and *B.radiatus*. In contrast, the only minnow that persisted was *B.viviparus*. This study clearly highlighted the fact that *B.viviparus* behaves quite differently from other minnows, and is a very successful species in both lentic and lotic conditions. It was the most abundant of all minnows and ubiquitous in all pool types. It was however, never found in off-stream pools. At the division of pools it tended to move into deeper sections. A conspicuous feature distinguishing this species from other minnows in this pool series, was its behaviour of shoaling on the edges of pools whilst the other minnows tended to remain in the deeper sections of pans. At a point where predatory pressures were high, with minnows, eels and *Clarias* being concentrated in the same microhabitat, the other minnows may have been subjected to intense predation which *B.viviparus* avoided in part by congregating in shallow waters.

With respect to invertebrates, disappearance of taxa such as Ephemeroptera and Trichoptera very early in the study period revealed that conditions for their survival had already deteriorated prior to the commencement of the study. It is therefore imperative to link this study with the previously collected data over the last three years, in order to establish the point at which the community structure began to alter. The changes in the invertebrate community recorded during the present study nevertheless indicate some of the effects which flow reduction will have on this community.

5. The quality of refuge pools

It appeared therefore that a suite of physical variables characterised and defined pools differentially in terms of their value as refuges; i.e. as "poor" or "good" quality refuges. Superimposed on this is a species inherent ability (behavioural or physiological) to tolerate certain conditions.

A number of pools possessed characteristics that appeared to be unfavourable for the survival of fish: long-term isolation, massive algal blooms, no overhead cover and constant exposure to solar radiation resulting in high and fluctuating temperatures . However, our results indicate that these pools housed a healthy population of fish and invertebrates. A number of factors contributed to this:

(1) The substratum of bedrock ensured that unlike some of the other pools, no water was lost due to seepage.

(2) The pool possessed some degree of boulder/bedrock cover.

(3) The algal blooms contributed to faunal survival by a) providing cover from terrestrial and aerial predation, and b) providing a source of oxygen replenishment by acting as an oxygen pump during the day.

Reaches with bedrock, such as Londolozi and Mlondozi resulted in numerous pools characterised by a high degree of habitat heterogeneity generally favouring a greater degree of species diversity. This was illustrated by the fact that larger pools housed a more diverse species assemblage at isolation. Nevertheless, a number of smaller pools comprised the same number of species as their larger counterparts. In physical terms these pools were shallow but complex, with a high proportion of in-pool cover.

In the lowveld system, exposed pools generally comprised better quality habitat. This was related to dense algal blooms and high oxygen concentrations. The general paradigm holds that oxygen deficiency commonly characterizes the progression of the dry season in shallow and stagnant freshwaters of tropical regions (Kramer et al, 1978). Oxygen depletion is also a factor frequently cited as being responsible for fish kills, with the exception of those species tolerant of low oxygen levels (Chapman & Kramer, 1991 (a); Larimore et al., 1959; Tramer, 1977). In this system, unlike the results of other studies that focused on the effects of droughts, low oxygen concentrations were not a characteristic of most pools in this work until the final stages of desiccation. Low oxygen concentrations, therefore were not a principal factor, at least initially, in causing mortalities.

It is suggested that in this unshaded sub-tropical system, two factors accounted for high levels of oxygen.

(i) Oxygen concentrations correlated with a number of variables and data from July indicated a negative relationship between overhead cover and oxygen. Various authors have reported high litter levels in pools during drought (Larimore et al., 1959; Chapman & Kramer, 1991(c)), and microbial respiration has been implicated as the main factor contributing to a decline in DO.

(ii) Oxygen levels in pools reflected an intimate feedback between solar radiation and algal growth. We propose that an additional factor accounting for high oxygen levels in pools, was the high levels of algal growth, with primary production causing a temporary daytime reversal of oxygen concentrations. Readings taken at sunrise and sunset illustrate that although oxygen levels decrease substantially at night, the reduction was probably to a level well within tolerable limits.

Water quality parameters play an important role in characterising the availability and suitability of habitat for aquatic fauna. The most stable chemical parameters were exhibited at The Confluence where pools were connected to the main channel through the sandbed. The widest ranges of variables were found in pools at Londolozi. In the case of pH, values ranged between 6.8 and 9.8. Conductivity varied between 110 and 900 μScm^{-1}, turbidity between 1 and 750 NTU's, and temperature between 8.5°C and 34°C. Most levels of SRP were relatively low in all pools. Ammonia levels in some pools in the latter months were extremely high although these values should be treated as relative, rather than absolute values (Day, *pers comm.*)

5. Persistence of pools and biota

Generally, the lowveld fish assemblage is robust and the survival of fish in our system was dependent primarily on the survival of the pools. After isolation, the survival of pools as physical entities largely determined the survival of species. As discussed above, depth, which generally defined the persistence of a pool, was of primary importance both in determining species distribution and persistence. Deeper pools persisted for longer in general, and this in turn dictated the persistence of a species. The rate at which this happened was dependent on the physical characteristics of the pools in question.

Pools that did not fare well in terms of persistence and species assemblage ("poor quality" refuges) were generally either (1) small and simply evaporated, or (2) comprised sandy substrata that led to seepage from the pool, or (3) shaded pools, characterised by rapidly increasing hypoxia.

Large pools with lots of emergent vegetation appeared to provide the best chance for flow-sensitive invertebrate species to survive periods of flow cessation. Fish that were found in small pools were either specialist species such as *C.paratus*, which were trapped as the riffles disapperaed, or were there because of physical characteristics such as cover. At times, a particular characteristic that appeared to be favourable, such as cover, actually resulted in fish being trapped in "poor quality" refuges, generally characterised by shallow depth. This was particularly evident in the case of the Labeos'.

6. Implications for management

In contrast to flooding, the drying of stream channels normally occurs gradually allowing time for behavioural adaptations (Yount and Niemi, 1990). In this case, many species appeared to select certain areas. Many species have evolved either behavioural or life history characteristics allowing them to survive drought conditions where such events are predictable, as is the case within the lowveld. In the light of this and through results of this study, preliminary recommendations for management are as follows:

- The **rate of decrease of flow** is potentially very important. This study indicated that certain species showed a preference for certain physical variables and selected potential pools accordingly. From our study it appears that fish, subjected to the onset of increasingly stressful conditions as flow decreases, select certain habitats that will favour their survival. If drydown is rapid, fish could be stranded in unfavourable pools with negative consequences for survival.

- The **duration of no-flow** is critical. Beyond this, isolated pools cease to function as effective refuges and catastophic reductions in fish populations occur. For the Sand River at Londolozi, this point was evident between two to three months. Flushing flows as a management option needs to be addressed.

- Under present conditions of periods of no-flow, not all species presently found within the lowveld will survive, notably *C.anoterus* and *O.zambezensis*.

- Changes in the abundance of flow-associated species and those resistant to drought, result in markedly different species assemblages over time. This indicates that management should focus of the **proportional make-up of community assemblages** rather than merely species presence.

- Of particular concern is the fate of biota in the **Sabie River** under similar conditions. Although largely inferrential at present, similar trends are likely to be reflected in the Sabie River since species assemblages are generally shared in the lowveld zone. As has been seen in the Sand River, the fish community appears to be sufficiently robust to tolerate short periods of no-flow. However, the same catastrophic mortalities and substantial changes in cummunity composition are likely to occur within a month of cessation of flow. Preliminary results from the Marite River, which dropped to very low levels during the drought but never ceased flowing, indicate that populations of flow-associated species such as *Chiloglanis anoterus* severely affected by the drought. Although they never disappeared from the river, individuals showed marked signs of stress, manifest in an increase in parasites, a reduction in weight, disappearance from the community of an entire year class, and a marked decrease in egg production. The long-term effects would therefore be clearly evident in recruitment during the following breeding season. Predictions of the effects in the Sabie River will be further addressed in the final report of the Sabie River Project.

- Some invertebrate taxa demonstrated the ability to recover rapidly following resumption of flow. Recovery rate will, however, ultimately depend on availability of suitable sources for recolonization. Taxa were not able to recolonize equally well from all pools. Available habitat was very quickly recolonized after the river briefly started flowing again.

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* distinguishes those species which were never given the opportunity to populate pools that differed with respect to that criteria, since the variable in that particular pool remained constant as the pool divided.

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LIST OF ACRONYMS

CPUE:	Catch Per Unit Effort
DO:	Dissolved Oxygen
GIS:	Geographical Information System
KNP:	Kruger National Park
mASL:	Meters Above Sea Level
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
TNI:	Total Number of Invertebrates
TSS:	Total Suspended Solids

1. INTRODUCTION

In 1992, Southern Africa experienced the most severe drought in recorded history. The effects of this drought were wide-ranging and exacerbated the already precarious water resources of the region. The Sabie River in the Eastern Transvaal, experienced a reduction in flow to previously undocumented levels.

Episodic events such as drought are natural disturbances that may have a severe effect on stream ecosystem dynamics. Disturbance may be defined as any change in the environment which exceeds the normal range of conditions experienced by a substantial number of organisms (Minshall, 1988) and is discussed in detail by Resh et al. (1988). The effects of disturbance, particularly in shaping the structure of communities, is now recognised as an important area of ecological research (Chapman et al., 1991; Fausch & Bramblett, 1991; Gerritsen & Patten, 1985;), although it has received surprisingly little attention from aquatic ecologists. Many fish and invertebrates have very specific flow regime requirements and large flow fluctuations can greatly affect community composition (Saltveit et al., 1987). In general, invertebrates are considered more robust in terms of withstanding the effects of drought because of different life-stage requirements and the ability to recolonise rapidly (Canton et al., 1984).

During high water conditions, biota can move among a wide variety of habitats, while low flow or no-flow conditions restrict them to habitats that are less than ideal, forcing them into conditions of deteriorating habitat quality due to desiccation, organic decomposition, loss of refuges from predation and reduced food availability (Chapman, 1990; Chapman & Kramer, 1991 (a & b), Larimore, 1959; Lowe-McConnell, 1975, 1987; Welcomme, 1989). The importance of aquatic invertebrates as food items for other animals cannot be overemphasized. Many fish, amphibians, water fowl and other animals depend heavily on the aquatic and terrestrial stages of aquatic invertebrates for food.

Recovery from drought is of particular interest. Where droughts are predictable, many species have evolved life history or behavioural characteristics that enhance their survival. As such, monitoring of the drought period provides insight into a species ability to survive such periods. Most studies indicate that invertebrate recovery is more rapid than that of fish communities, normally occurring in less than a year (see *inter alia* Hynes, 1958; Harrison, 1966; Canton et al., 1984; Larimore et al.,1959, Williams & Hynes, 1977). This is attributed to the suite of recolonisation mechanisms employed by invertebrates. With respect to fish, the importance of pools or pans as refugia for fish during periods of extreme stress has been highlighted (Chapman et al., 1991; Canton et al., 1984; Chutter & Heath, 1991; Coke & Pott, 1970; Merron & de Lalouviere, 1987; Yount & Niemi, 1990). These refugia then act as centres of inocula for future recolonisation.

As a result of these factors, a comprehensive monitoring programme was initiated at the start of the dry season to assess the effects of the drought on fish and macro-invertebrate communities in the Sabie and Sand Rivers. The Drought Monitoring Programme formed part of an ongoing three year ecological survey of these rivers, which provided ideal baseline data of faunal distribution and abundance prior to the drought. Conditions through this period offered an opportunity to address species and community responses to shrinking habitats and vastly fluctuating chemical environments - in effect a unique natural experiment in progress, with potential to supply important information on the habitat requirements of the river fauna. This type of information is directly applicable to the planning and management of impoundments so as to minimize impacts on river systems.

Two primary objectives were identified. The first objective was to gather baseline information on the fauna during the low-flow/ cessation of flow period. The second objective was to study how and where refuge populations establish and their fate through time. Here, we addressed the physical heterogeneity of pools in providing refuges for species whilst considering the original community assemblage just prior to or at isolation. We document changes in population size and composition in relation to pool volume, substrate, cover (instream and offstream), linkage (distance of pool from main channel) and water quality in a series of isolated pools over a five month period. An understanding of factors that allow certain species to persist or inhibit their distribution or survival is of considerable importance in the formulation of sound management strategies for rivers in general. At present such periods of low flow, or cessation of flow, are not well understood in the Sabie-Sand system.

These research objectives provided the basis for the following specific questions:

1. How will the distribution and abundance of the present species assemblage respond to decreasing flows and final isolation in pools?
2. Are all species able to survive for limited periods in pools?
3. Three fish species typify the final stages of isolated seasonal warm water pools (Jackson, 1989). Are these results consistent with this thesis and what underlies this conclusion?
4. What physical and biotic variables govern the value of pools as refuges within and between sites?
5. Is water quantity, quality, predation or food resource availability the major factor governing the fate of isolated fish populations?
6. During drought, do all stream reaches provide equally good refuges?
7. At what range of low flow values is there a significant decrease in diversity?
8. What do taxa in isolated pools tell us about their tolerance limits to water quality variables?

2. STUDY-SITES

2.1 SITE SELECTION

Study sites were chosen using the following criteria:

- **Continuity**. The objectives of the project demanded comparative results and for this reason only study sites on which previous data had been collected were considered. All selected sites form part of the ongoing pre-impoundment study of the Sabie-Sand catchment with a data base spanning three years.

- **Sites should be representative of the lowveld reaches of the Sabie River and its biotic assemblage**. It was predicted that should the Sabie River stop flowing in the Kruger National Park (KNP), this would proceed from the eastern to western boundary. The sites chosen spanned the breadth of the park (Fig. 1) and represent three of the five reaches identified within the KNP by Venter (1990).

A fourth station was chosen on the Sand River at Londolozi. The lower reaches of the Sand River have stopped flowing in the dry season intermittently since 1980, and it was anticipated that this would occur early in the dry season. Wells (1992) showed that the macro-invertebrate diversity at the genus level is shared. The Sand River further supports 32 of the 36 fish species characteristic of the Sabie River lowveld. Inclusion of this site would allow the effects of drought on the shared lowveld biota to be followed over an extended period.

2.2 SITE DESCRIPTION

The relative positions of the four study sites within the catchment are shown in Figure 1. All are situated within the lowveld below 600mASL (Chunnett, Fourie and Partners, 1987) within the midland river zone (Noble and Hemens, 1978).

Site 9: Confluence (24°58'S, 31°44'E)

This site lies on the Sabie River 2 km below the confluence with the Sand River, at an altitude of 220mASL. It has a gradient of 2.5m km^{-1}. The channel is braided, with both a slow deep flowing channel and a broad chute over scattered unfractured bedrock. The reach is typically sandy with large isolated bedrock boulders and little loose cobble. A series of isolated pools connected to the main channel through the alluvial sandbed were present at the start of the drought monitoring. Extensive reedbeds flank the right bank and well-developed riparian trees occur in sections along the far bank.

Site 14: Londolozi (24°47'S, 31°32'E)

This site lies on the Sand River at 315mASL, with a gradient of 4m km^{-1}. The river flows over and through a massive granite outcrop in the alluvial sandbed channel (200-500m). This results in a series of deep pools, small bedrock runs and complex braids. The substrate is largely fractured bedrock and sand with some loose substrate. The channel is bordered by reeds, a narrow band of *Breonadia salicina* along the waters edge and scattered thorn scrub along the banks. The complex and rocky nature of the site was ideal for the formation of pools when the flow stopped. Off stream pools in complexes joined to the main channel at different flood heights increased the diversity of pool types available for study.

Site 20: Mlondozi (25°10'S, 31°60'E)

This site lies at the mouth of the Mlondozi River, a tributary of the Sabie River 5km from the eastern boundary of the KNP and the Corumana Dam, Moçambique. This reach has a gradient of 3.7m km^{-1} at an altitude of 140mASL on entering the Lebombo mountains and is highly braided. Sampling took place in a narrow channel (10-50m) which flows over bedrock slabs and through slow sand filled pools. There is little loose substratum available. Scattered reed and scrub interspersed by larger riparian trees constituted the riparian zone. The mouth of the ephemeral Mlondozi was isolated from the Sabie at the start of the monitoring. This braided section stopped flowing when the flow recorded at Lower Sabie weir was less than $1m^3s^{-1}$.

3. DATA COLLECTION AND METHODS

3.1 MAPPING AND FIXED POINT PHOTOGRAPHY

Londolozi and Mlondozi were mapped as the reach stopped flowing with the objective of identifying and characterizing the first series of pools formed. A manageable section of the site reach was chosen (approximately 600m) and every pool recorded. Offstream pools within the reach were included.

Pools, defined the moment they separated from parent water bodies, were uniquely numbered *in situ* with ink on painted disks. Clearly, offstream pools dated back to higher flow events. The numbering system was designed to allow pools with a shared history to be linked into complexes so that initial pools were numbered 1, 2 etc., and thereafter 1A, 1B and 1A1, 1A2 at subsequent divisions. Pool evolution was updated in the field through subsequent trips for use with a Geographical Information System (GIS). A number of pools were photographed throughout the survey using fixed point photography.

Physical characteristics of the pool, namely substratum type, overhead cover and depth were estimated for each pool as percentages. The physical variable of overhead cover refers specifically to percentage canopy cover. Instream cover provided was described in the substrate descriptor.

3.2 SAMPLING REGIME

Starting in June, 1992 a monthly sampling regime was initiated with 1) June to October constituting the Drought Monitoring phase and, 2) November to March, the Recovery phase.

Results of the latter will be reported in a later document (December, 1993). Table 1. lists all stations sampled over six months.

Table 1: Sampling regime for the drought monitoring programm. Stations sampled indicated as (*). ▨ = river reach flowing.

FIELD STATION	SURVEY TRIP				
	M1	M2	M3	M4	M5
	JUNE	JULY	AUG	SEPT	OCT
LONDOLOZI	*	*	*	*	*
MLONDOZI	*	*	▨ *	*	▨
CONFLUENCE	▨ *	▨ *	▨ *	▨ *	▨

3.3 POOL VOLUME

Every existing pool volume was estimated from field measurements at each survey trip. Measurements included; length, breadth, the depth at the intersection (generally the deepest point), and at least 4 other depths on the transects.

The volume for each pool was calculated using the formula (Tramer, 1977):

$$\pi r^2 d$$

where d = mean depth and r = the radius. The radius was estimated as half of the average of the length and breadth.

3.4 PHYSICAL AND CHEMICAL VARIABLES

A number of measurements were taken on site. Dissolved oxygen (expressed as percent saturation) and water temperature were measured using an Aqua-lytic Oxi 921 oxygen meter, calibrated against atmospheric pressure. Conductivity (at 25°C) was measured using a DiST 3 ATC dissolved solids tester with a range of 100 to 19900µS and pH was measured using a pHep pH meter. Turbidity was measured using the Analite 150 Mk 2 nephelometer with a range of 10 - 20 000 NTU, pre-zeroed in distilled water. All readings were taken close to the surface unless stated otherwise. Minimum-maximum temperatures were recorded using concealed thermometers submerged in selected pools.

Total suspended solids (TSS) were determined by the weight difference after passing a known volume of water through a pre-combusted (450°C, 5h), tared Watman GF/F filter and drying at 105°C for a minimum of three hours. The organic fraction was determined after further combustion.

Water for chemical analysis of nutrients was collected, filtered through Watman GF/F filters (450 µm) and preserved on site using a 1% solution of mercuric chloride. These samples were analysed for nitrite, nitrate, soluble reactive phosphate (SRP) and ammonia using standard auto-analytical techniques at the Hydrological Research Institute, Pretoria.

In order to ascertain overnight changes in oxygen concentrations, sunset and pre-dawn readings were taken from all pools on one occasion at Londolozi. Further readings were precluded due to logistical constraints.

In order to avoid endless lists of chemical data which can be confusing to the reader unfamiliar with the study sites, progressive results of selected variables were plotted on maps of the area using the Geographical Information System (GIS).

3.5 FISH

Electrofishing was the primary sampling procedure used, although additional methods were occasionally employed in conditions that precluded the use of electrofishing. Pools were sampled using a portable 550 watt Robin generator with coiled copper electrodes 20cm long and 50cm apart. A single handnet with a mesh size of 1cm was used. The time fished and numbers of each species captured were recorded. Lengths (SL) and the reproductive state of all fish were recorded and a representative sample of common species were weighed using Pesola spring balances. Finally fish were checked for signs of disease before release, and mortality due to sampling recorded.

A pop net (Dewey *et al*, 1989) was made and used for sampling some of the deeper pools with limited success. Gill nets supplemented samples at the difficult and deep pools at Mlondozi. Valved wire traps were useful for minnows in deep pools at Londolozi.

3.6 MACRO-INVERTEBRATES

The three sampling sites described in Table 1 were selected to examine the effects of the drought on the invertebrate fauna. Three instream pools linked by riffles were chosen per site. Five habitat types were sampled in each pool, namely 1) riffle, 2) emergent vegetation, 3) bedrock gullies, 4) sandy substratum and, 5) the water column.

Sampling commenced in May 1992 and continued until October 1992. Fifteen samples were taken per site to cover the five habitat types. Habitat type, flow and substratum cover were noted. Physical and chemical parameters of the river and the pools (after cessation of flow) were measured and included dissolved oxygen content, temperature, turbidity and pool volume.

Sampling of riffles and bedrock gullies was performed using a Surber-sampler (mesh size 80µm), brushing off any fauna inside the designated area (625 cm^2). Vegetation samples were taken with 5 sweeps over a 1m stretch of vegetation with a hand held net (mesh size 250µm). Water column samples were obtained with a hand net (250µm) by a 1m sweep of the water column from the surface to a depth of 30cm. Substratum samples were taken with the same hand net by pressing the net into the sandy bottom and dragging for 1m, taking up approximately 2cm depth of sand into the net. Contents of the net were washed in a bucket by swirling water (10 times) and pouring the water through a 250µm mesh net (10 times) after each wash. Sand and gravel were afterwards inspected visually for molluscs and other large invertebrates.

Samples were fixed in 4% buffered formalin and transferred to 70% ethanol in the laboratory. They were then separated into different size classes (2000µm, 850µm, 500µm and 250µm) to aid identification and identified to species level where possible.

3.7 DATA ANALYSIS

For fish, statistical analyses of data employed a one-way analyses of variance by ranks (Kruskal-Wallis) for unequal sample sizes (Zar, 1984) in order to compare monthly variations in species abundance. Calculations were made using the Statgraphics System.

For the estimation of population structure, each random sample was considered to be independent. All data analyses were based on the assumption that each pool could potentially have housed the full complement of species present at that site prior to the drought. Thus all pools were considered equal with respect to species composition at the point of isolation with the exception of two offstream pools, L2A and L2B. Both these pools are potentially only flooded at extremely high flows and at the start of the programme had been isolated for some time. The species composition of these two pools was considered independently. However for

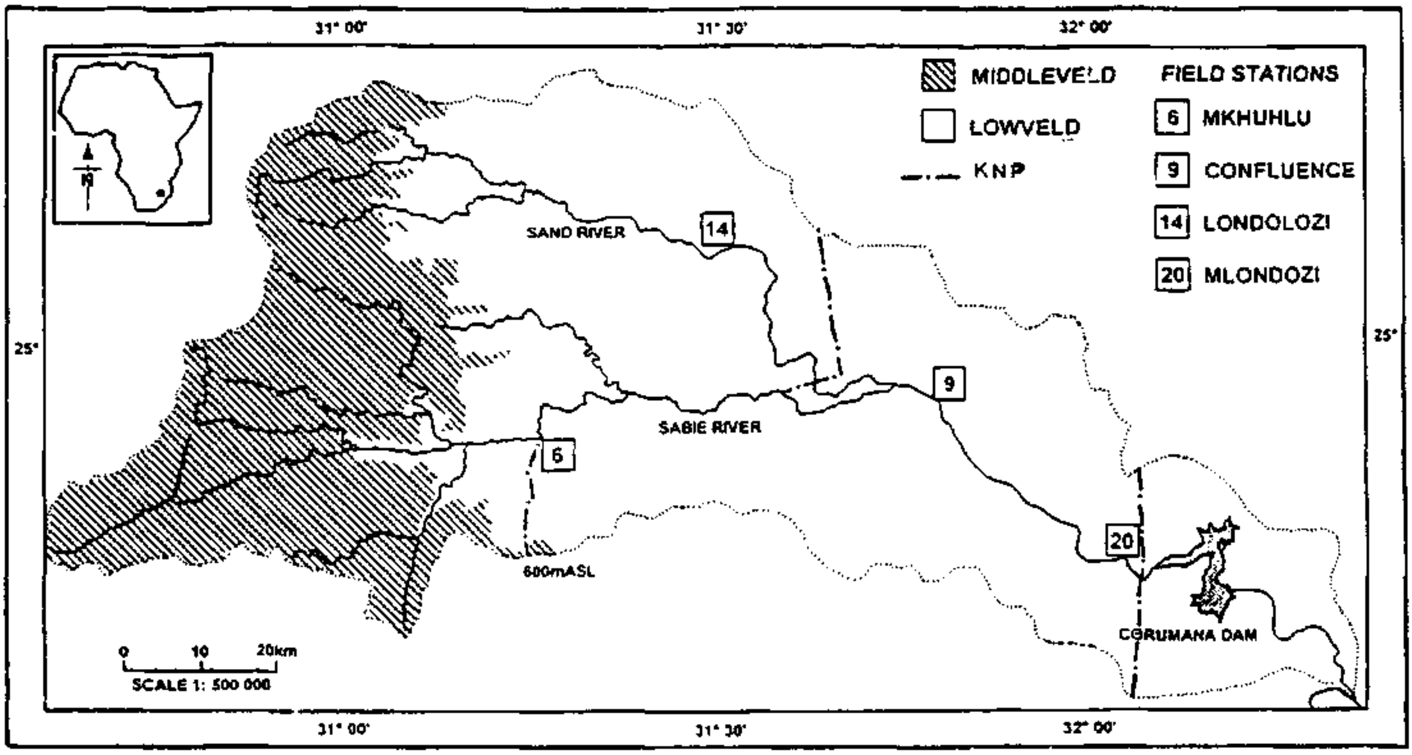

Figure 1: Map of the Sabie River catchment indicating the positions of the drought monitoring stations.

species common to these pools and instream pools, data were included for estimations of tolerance to water chemistry and physical variables.

In considering relationships between physical variables and species, data analyses were largely constrained by low numbers of certain species. This was partly overcome by grouping the data from Londolozi and Mlondozi sites. Data from the Confluence sites was considered separately however, due to the distinctly different species assemblage and physical characteristics unique to this site. At no stage did the main river cease to flow, and thus species with a "preference" for lentic conditions were never forced into pools. It was thus recognized that those species found in pools at the Confluence were characteristically pool species.

At the point of isolation, pools comprised a suite of environmental conditions to those species persistent in the river. In considering so-called "choice" by a particular species, the critical factor in defining "choice" was the availability of two or more level codes of a particular variable at the time of isolation or division of a pool. Thus in exploring particular variables considered important in this "choice", only those pools that proffered a variation of a particular variable were considered. This was most discernible as the river ceased to flow and split into pools.

Correlations of potentially interdependent chemical variables were performed in order to highlight relationships over time.

4. RESULTS

The physical appearance of selected pools is presented in Plates 1 - 4, in order to highlight the more salient physical features discussed in the text. The species found at each of the three sites over the sampling period are summarised in Tables 2, 3 and 4 (a) & (b). A summary of the algal taxa found in a number of pools is presented in Appendix IV, Table 1.

Table 2: Species found at Mlondozi throughout the sampling period

	SPECIES	COMMON NAME	FIELD TRIP			
			JUNE	JULY	AUG	SEP
1	*A.mossambicus*	long fin eel	1			
2	*B. afrohamiltoni*	Hamiltons barb	*			*
3	*B. annectens*	broadstriped barb	1	*		
4	*B.imberi*	spot-tailed robber	*			
5	*B. paludinosus*	straightfin barb	*			
6	*B. radiatus*	Beira barb	1	*		
7	*B. toppini*	Toppins barb	+	*	*	
8	*B. viviparus*	bowstripe barb	*	*	*	*
9	*C. gariepinus*	sharptooth catfish	*	*	*	*
10	*G. callidus*	Freshwater goby	+	*	1	*
11	*G.giurus*	Tank goby	*	*		*
12	*H.vittatus*	Tiger fish	1			
13	*M. acutidens*	Silver robber	*	*		*
14	*M. macrolepidotus*	Bulldog	*	*	*	*
15	*P. Catastoma*	Churchill	+	*		*
16	*O. mossambicus*	Mozambique tilapia	*	*	*	*
17	*P. philander*	Dwarf tilapia	*	*	1	
18	*S. meridianus*	Lowveld largemouth	+	*		*
19	*T. rendalli*	Redbreasted tilapia	*	*	*	*

* Present
1 Only one individual
\+ Assumed present due to subsequent capture

Table 3: Species found at Londolozi throughout the sampling period.

	SPECIES	COMMON NAME	FIELD TRIP				
			JN	JL	AU	SE	OC
1	*A. bengalensis*	Mottled eel			*	*	*
2	*A. mossambica*	Long fin eel				*	
3	*B. afrohamiltonii*	Hamiltons barb	+	*			
4	*B. annectens*	Broadstriped barb	*	*	*	*	*
5	*B. eutaenia*	Orangefin barb	*	1	+	1	
6	*B. marequensis*	Large scale yellowfish	*	*	1	*	1
7	*B. paludinosus*	Straightfin barb	*	*	*	*	
8	*B. radiatus*	Beira barb	*	*	*	*	
9	*B. toppini*	Toppins barb	*	*	*	1	*
10	*B. trimaculatus*	Threespot barb	*	*	*	*	*
11	*B. unitaeniatus*	Bearded barb	*	*	*		
12	*B. viviparus*	Bowstripe barb	*	*	*	*	*
13	*C. gariepinus*	Sharptooth catfish	*	*	*	*	*
14	*C. paratus*	Sawfin rock catlet	*	*	+	*	*
15	*G. callidus*	River goby	+	*	*	*	*
16	*L. molybdinus*	Plumbeous labeo	*	*	*	*	*
17	*L. rosae*	Rednose labeo	*	*	1	1	
18	*M. acutidens*	Silver robber	*	*	1	*	1
19	*M. brevianalis*	River sardine	*	*	*	1	1
20	*M. macrolepidotus*	Bulldog	*	*	+	*	
21	*O. mossambicus*	Mozambique tilapia	*	*	*	*	*
22	*P. catostoma*	Churchill	*	*	*	*	1
23	*P. philander*	Dwarf tilapia	+	+	+	1	
24	*S. meridianus*	Lowveld largemouth	*	*	*	1	1
25	*S. zambezensis*	Brown squeaker	+	+	+	*	
26	*T. rendalli*	Redbreasted tilapia	*	*	*	*	

1 Only one individual caught.
+ Assumed present due to capture on subsequent field trips.
* Present

Table 4a: Species found at the Confluence throughout the sampling period

	SPECIES	COMMON NAME	FIELD TRIP			
			JUNE	JULY	AUG	SEP
1	*G. callidus*	River goby	*	*	*	*
2	*M. brevianalis*	River Sardine	*	+	!	!
3	*M. acutidens*	Silver Robber	+	+	!	
4	*O. mossambicus*	Mozambique tilapia	*	*	*	*
5	*P. philander*	Dwarf tilapia	*	*	*	*
6	*S. meridianus*	Lowveld largemouth	1	1	!	1
7	*T. rendalli*	Redbreasted tilapia	*	*	*	*

* Present
1 Only one individual
\+ Assumed present due to subsequent capture

4.1 WATER CHEMISTRY VARIABLES

Results of the progressive readings of a number of physico-chemical parameters are presented in Appendix I, as follows: Londolozi:- Tables 1 to 8; Mlondozi:- Tables 9 to 16 and the Confluence:- Tables 17 to 24. No results are presented for Mlondozi for August as the river was flowing at this point[1].

All pools decreased in volume over time, although rates of decrease varied (Fig. 2). Pools were generally characterised by high oxygen values; exceptions are discussed under individual pools. Particularly high readings were found in Pools L2B, L6B and L16. The Confluence pools were characterised by marginally lower % oxygen saturation relative to other sites. Results from the overnight oxygen readings (sunset and pre-dawn) of individual pools at Londolozi are presented in Fig. 3. All pools showed a decrease in nocturnal oxygen concentrations.

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[1] A synopsis of these readings was prepared as colour maps in order to present visually the changes in physical and water quality conditions, since pools underwent rapid changes and it was felt that such representation assisted the reader in appreciating these changes. Due to prohibitive reproduction costs, copies of these maps could not be included herein. A full set of these maps is housed at the Institute for Water Research, Rhodes University, Grahamstown, and are available upon request. Details of maps are provided in Appendix V.

Table 4b: Species found in the run and riffle of the main channel at the Confluence throughout the sampling period.

	SPECIES	COMMON NAME	FIELD TRIP							
			SANDY RUN				RIFFLE			
			JUN	JUL	AUG	SEP	JUN	JUL	AUG	SEP
1	*A.mossambicus*	Long fin eel					1			1
2	*B.marequensis*	Large scale yellowfish				*	*	*	*	*
3	*B.radiatus*	Beira barb							1	
4	*B.trimaculatus*	Threespot barb			1		*	1	1	
5	*B.viviparus*	Bowstripe barb			*	*	*	*	*	*
6	*C.anoterus*	Penant tailed catlet					*	*	*	*
7	*C.paratus*	Sawfin rock catlet					*	*	*	*
8	*C.swierstrai*	Lowveld catlet	*	*	1		1	*	*	*
9	*G.callidus*	River goby		*		*	1			
10	*L.molybdinus*	Plumbeous labeo	*	1	*		*	*	*	*
11	*M.acutidens*	Silver robber		*	*	*	*	*	*	*
12	*M.macrolepidotus*	Bulldog			1					
13	*O.mossambicus*	Mozambique tilapia	1	*	*	*		*	*	1
14	*O.zambezense*	Barred minnow					*	*	1	*
15	*P.philander*	Dwarf tilapia	*	*	*	*		*	*	1
16	*S.meridianus*	Lowveld largemouth		*	*	*		*	*	
17	*T.rendalli*	Redbreasted tilapia		*	*	*		*	*	1

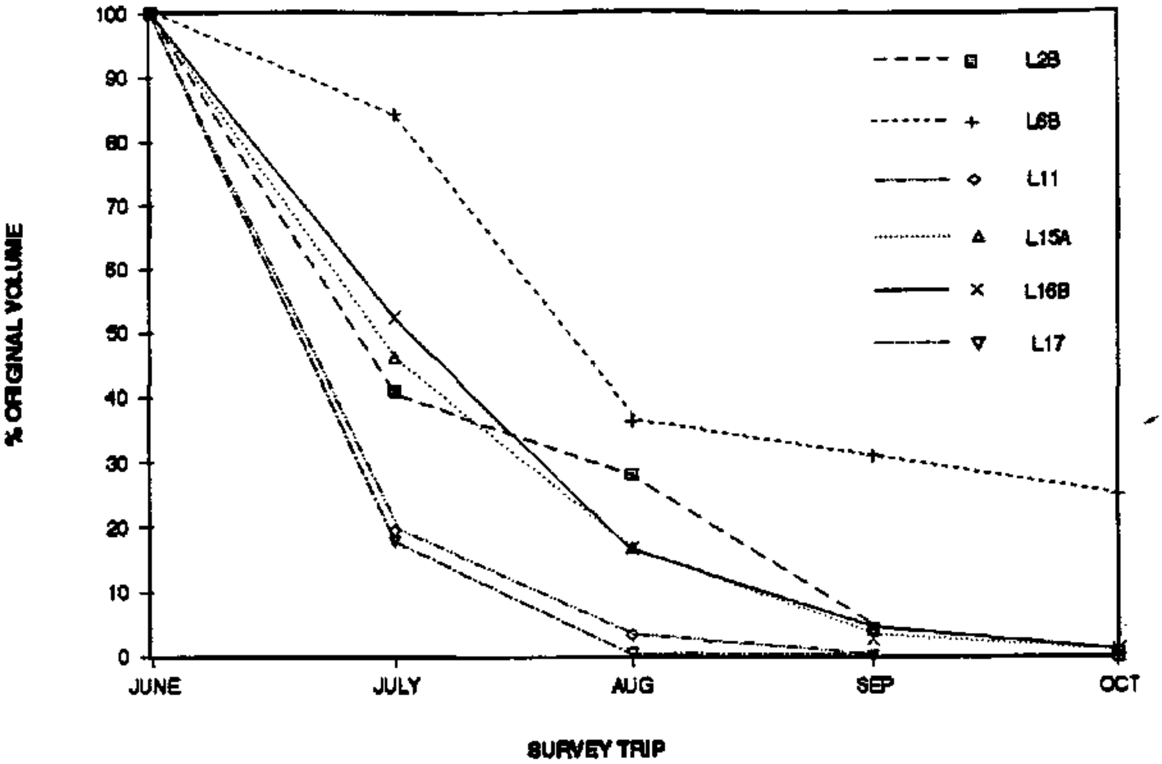


Figure 2: Residual pool volumes (as a percentage of initial volumes) for persistent pools at Londolozi.

In general pH indicated a neutral or slightly alkaline environment, varying between 6.8 and 9.7. The pH generally increased over time, with the highest values being consistently displayed in pools L2B, L6B and in the latter months in L16. Conductivity commonly increased with time and ranged between 140μSm^{-1} and 1720μSm^{-1}. Turbidity fluctuated between pools and months and ranged between 0 NTUm^{-1} and 750 NTUm^{-1}.

Temperatures readings showed a general increase, with the lowest reading being 8.5 °C and the highest being 34 °C. The highest temperatures and the widest range of temperatures, were recorded from Londolozi. The narrowest range of temperatures was exhibited at the Confluence (17 °C to 24 °C).

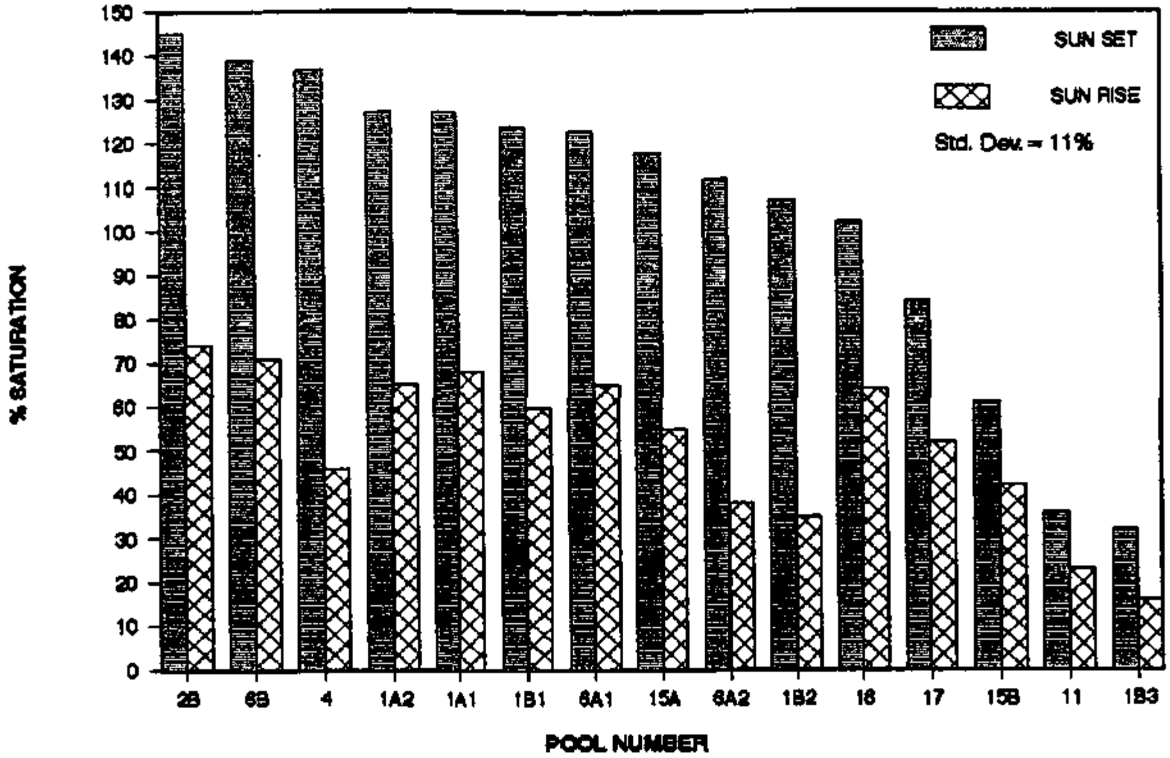


Figure 3: Oxygen profiles (% saturation) of all pools at Londolozi at sunset and sunrise. The mean difference between sunrise and sunset was 49%, Std. Dev.= 11%.

A summary of the variation in conductivity, percent saturation of oxygen, temperature and turbidity is shown in Fig. 4.

The Total Suspended Solids (TSS) varied between $2\mu gl^{-1}$ and $815\mu l^{-1}$ and percent organics between 25% and 80% (see App.I, Tables 7, 15 & 23).

The NH4-N values generally increased over time but values should be treated as relative readings only. NO3-N and NO4-N either remained stable or increased slowly over time at Londolozi. Values at Mlondozi and at the Confluence remained stable ($40\mu gl^{-1}$). Soluble reactive phosphate (SRP) generally increased over the study period and values ranged between $9\mu gl^{-1}$ and $330\mu gl^{-1}$.

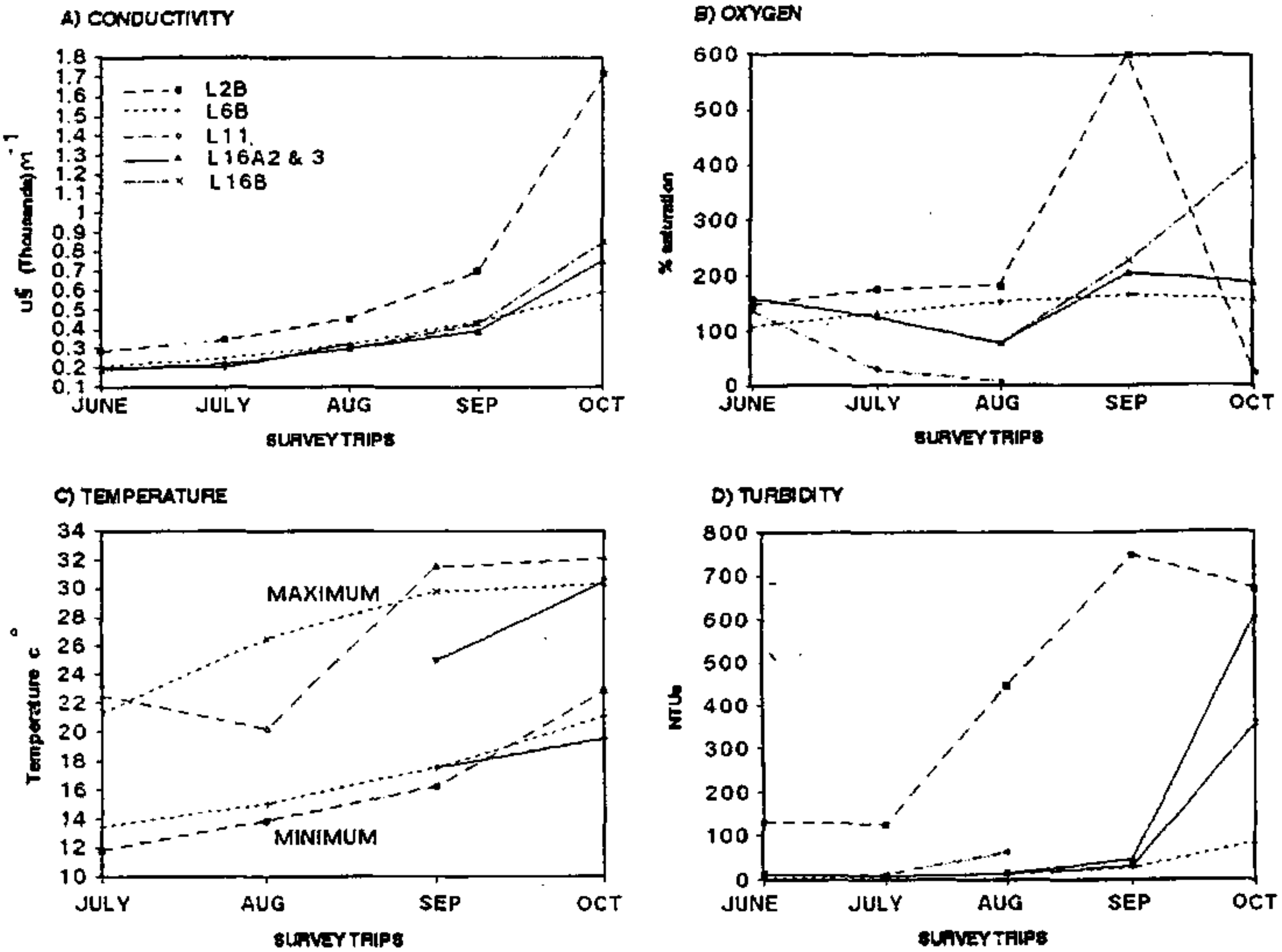


Figure 4: Progressive changes in (A) conductivity, (B) oxygen, (C) temperature and (D) turbidity for selected persistent pools at Londolozi.

The main channel at the Confluence was characterised by generally stable chemical variables. The system remained oxygenated and clear throughout this period. Temperature increased by approximately 6°C over a four month period and pH appeared to increase slightly.

Table 5: Londolozi. Significant correlation coefficients indicating individual relationships between various water quality and physical variables ($p<0.05$), between June and October, 1992.

VARIABLES	LONDOLOZI				
	JUNE	JULY	AUG	SEPT	OCT
TSS & TURBIDITY	0.98	0.99	0.99		
TEMPERATURE & COVER	-0.69	-0.81	-0.62		
OXYGEN & COVER		-0.87			
OXYGEN & TEMP		0.83			
CONDUCTIVITY & TSS		0.91			0.87
CONDUCTIVITY & OXYGEN		0.62		0.97	
OXYGEN & TURBIDITY				0.99	
TEMPERATURE & CONDUCTIVITY		0.63			
TEMPERATURE & DEPTH					-0.94
CONDUCTIVITY & TURBIDITY				0.98	
OXYGEN & VOLUME	0.45				
OXYGEN & ORGANICS		0.76			
OXYGEN & TSS		0.72			

Correlations ($p<0.05$) between the various water quality and physical variables for five months are presented in Tables 5, 6 and 7. Correlations obtained for June should be treated with discretion as pools had only just isolated and full interactive relationships were not yet evident.

Table 6: Mlondozi. Significant correlation coefficients indicating individual relationships between various water quality and physical variables ($p<0.05$), between June and September, 1992. Note that the river was flowing in August.

VARIABLES	MOLONDOZI			
	JUNE	JULY	AUGUST	SEPTEMBER
TSS & TURBIDITY	0.99	0.99		
TURBIDITY & VOLUME		0.97		
TSS & VOLUME		0.98		0.96
TEMPERATURE & CONDUCTIVITY		0.78		0.90
OXYGEN & COVER		-0.75		
CONDUCTIVITY & TSS	0.95			

Table 7: Confluence. Significant correlation coefficients indicating individual relationships between various water quality and physical variables ($p<0.05$), between June and September, 1992.

VARIABLES	CONFLUENCE			
	JUNE	JULY	AUG	SEPT
OXYGEN & DEPTH	-0.87	-0.98	-0.87	
OXYGEN & TEMPERATURE	0.86	0.91	0.98	
TEMPERATURE & COVER	-0.91	-0.86		
TEMPERATURE & DEPTH		-0.88	-0.87	
OXYGEN & VOLUME		-0.93		
CONDUCTIVITY & DEPTH		0.92		
ORGANICS & VOLUME		0.94		
TSS & TURBIDITY		0.9		
ORGANICS & TURBIDITY				0.96
TEMPERATURE & TURBIDITY	0.87			

Table 8 summarises these results for all sites and all field trips, in order to emphasise those relationships that were repeatedly significant. Consistent negative relationships were displayed between oxygen and depth, temperature and cover and temperature and depth. Consistent positive relationships were exhibited between turbidity and TSS and oxygen and temperature. Highly significant negative relationships were displayed between overhead cover and oxygen, and positive relationships between turbidity and volume.

Table 8: Summary of significant relationships between water quality/physical variables at all sites for all trips. Shaded blocks indicate sites at which specific variables were correlated. The numbers in parentheses indicate the number of months in which relationships were displayed.

	VARIABLES	LONDOLOZI	CONFLUENCE	Mlondozi
1	OXYGEN & DEPTH		-(3)	
2	OXYGEN & COVER	-		-
3	OXYGEN & TEMPERATURE	+	+(3)	
4	OXYGEN & VOLUME	+	-	
5	OXYGEN & ORGANICS	+		
6	OXYGEN & TURBIDITY	+		
7	OXYGEN & TSS	+		
8	TURBIDITY & TSS	+(3)	+	+(2)
9	TURBIDITY & ORGANICS		+	
10	TURBIDITY & VOLUME			+([illegible])
11	TSS & VOLUME			+(2)
12	TEMPERATURE & COVER	-(3)	-(2)	
13	TEMPERATURE & DEPTH	-	-(2)	
14	TEMPERATURE & TURB.		+	
15	CONDUCTIVITY & TEMP.	+		+(2)
16	CONDUCTIVITY & OXYGEN	+(2)		
17	CONDUCTIVITY & TSS	+(2)		+
18	CONDUCTIVITY & TURB.	+		
19	CONDUCTIVITY & DEPTH		+	
20	ORGANICS & VOLUME		+	

4.2 ICHTHYOFAUNA

4.2.1 PREFERENCE DATA

Preference data indicating physical variables on which certain species may select a particular pool at isolation or division, are summarised in Table 9 ($p < 0.05$). Depth and volume appeared to most frequently play a significant role in explaining the initial distribution of fish in pools. Overhead cover appeared to be important for five species and turbidity conditions for three species. Conductivity appeared to be an unimportant criterion. Oxygen and temperature were similar in all pools at isolation and therefore not considered as potential criteria.

Certain species were unique to or characteristically more frequently found in either offstream pools or instream pools. Pools that formed within the main channel as a direct result of cessation of flow were considered to be instream pools. Marginally offstream and offstream pools were defined according to the distance from the main channel (linkage distance). Both *Barbus toppini* and *Barbus paludinosus* were **only** found in offstream pools that were seasonally flushed and therefore no conclusions can drawn with regard to their survival under other conditions. *Barbus afrohamiltonii* and *Synodontis zambezensis* were only recorded in L2B but are known to occur in the main channel at Mlondozi. Conversely, *Serranochromis meridianus* was never caught in offstream pools and appeared to be restricted to instream pools. Although *Barbus viviparus* was abundant, it appeared to be restricted to instream or slightly offstream pools (at Londolozi this species consistently comprised the second most abundant species). *Oreochromis mossambicus* is recognised as a tolerant species but appeared to be more abundant in offstream pools. *Mesobola brevinalis* appeared to prefer marginally offstream pools.

Since it is of interest to know what physico-chemical ranges different species were found in, the ranges of selected variables at which fish were found at *these* study sites are summarised in Figs.5 (a-d). A number of variables remained relatively constant (e.g. pH), and are not included. It must be stressed that this in no way implies tolerance limits; and it is not comprehensive since some fish were not originally found in pools that underwent extensive physico-chemical changes.

Table 9: Individual relationships between species and water quality/physical variables of data from Londolozi and Mlondozi for June 1992 ($p<0.05$). Cover refers to overhead cover and linkage refers to the distance of a pool from the main channel (see text). Only species that occurred in sufficient numbers were included.

SPECIES	VARIABLE					
	turbidty	conductivity	cover	depth	volume	linkage
B.annectens	0.04			0.009	0.02	
B.marequensis			0.04	0.02	0.02	
B.radiatus				0.004	0.02	
B.trimaculatus			0.02	0.03		
B.viviparus						-0.02
G.callidus	0.02			0.02	0.004	
G.giurus						
L.molybdinus						
M.acutidens			0.03	0.02		
M.brevinnalis				0.01	0.04	0.04
M.macrolepidotus						
O.mossambicus	0.03		-0.04			0.0007
P.catostoma						
S.meridianus			0.04			-0.09
T.rendalli						

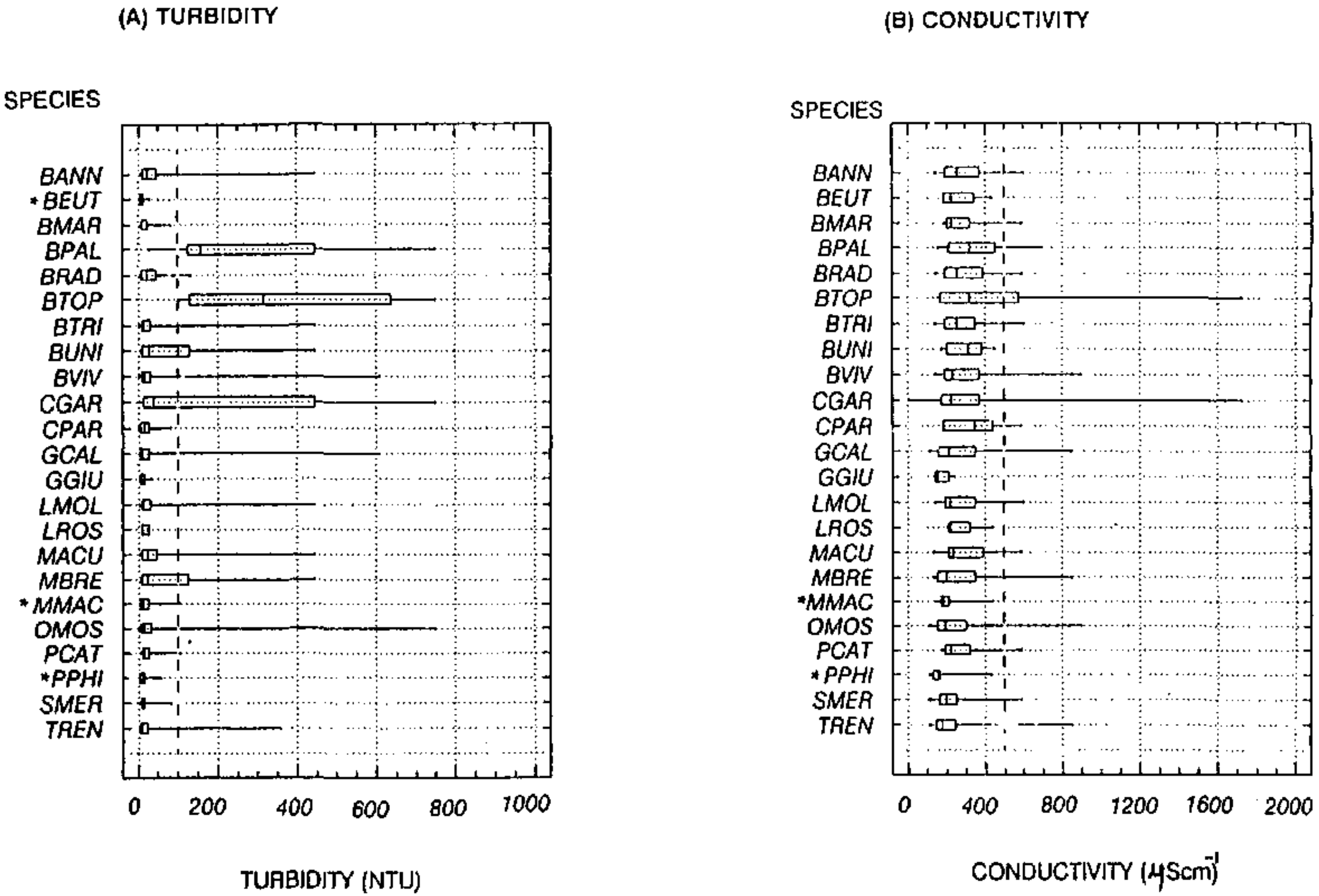


Fig. 5. Ranges of a number of physico-chemistry variables in which individual species were found over the drought period; (A) Turbidity and (B) Conductivity. Box denotes the inter-quartile range. Vertical line in box denotes median values. The dashed vertical line represents the rank value above which that particular variable was considered to be "high".

* distinguishes those species which were never given the opportunity to populate pools that differed with respect to that criteria, since the variable in that particular pool remained constant as the pool divided.

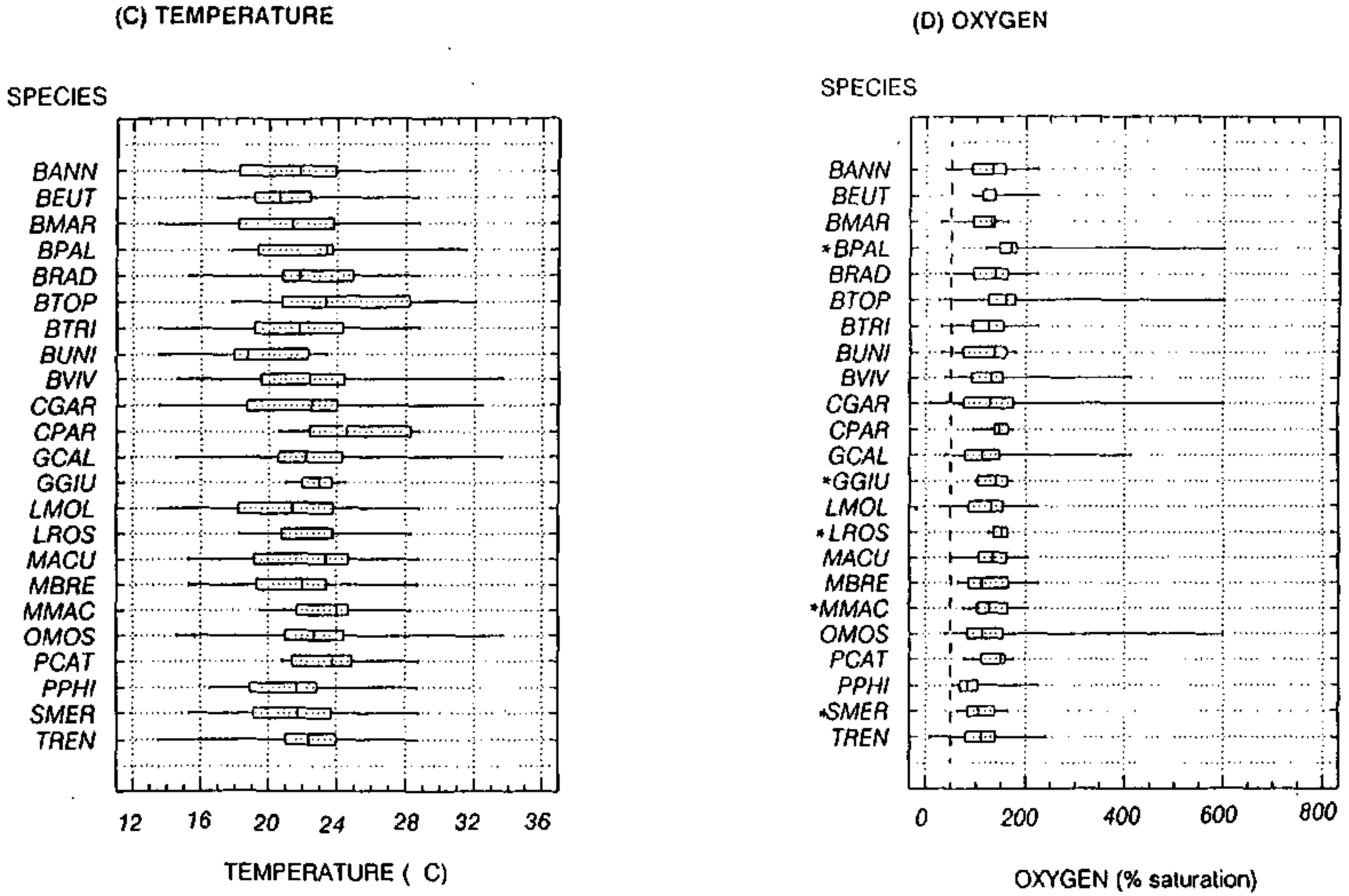


Fig. 5. Ranges of a number of physico-chemistry variables in which individual species were found over the drought period; (C) Temperature and (D) Oxygen. Box denotes the inter-quartile range. Vertical line in box denotes median values. The dashed vertical line represents the rank value above which that particular variable was considered to be "high". * distinguishes those species which were never given the opportunity to populate pools that differed with respect to that criteria, since the variable in that particular pool remained constant as the pool divided.

4.2.2 SPECIES ABUNDANCE

Regression analysis indicated a certain degree of dependence between consecutive catches from one month to the next and therefore no joint statistical analysis was performed as the assumption of independence could not be met. Considering months individually resulted in numbers that were too low to produce meaningful results. Consequently, conclusions regarding species abundance remain largely qualitative in nature and are presented under individual sites.

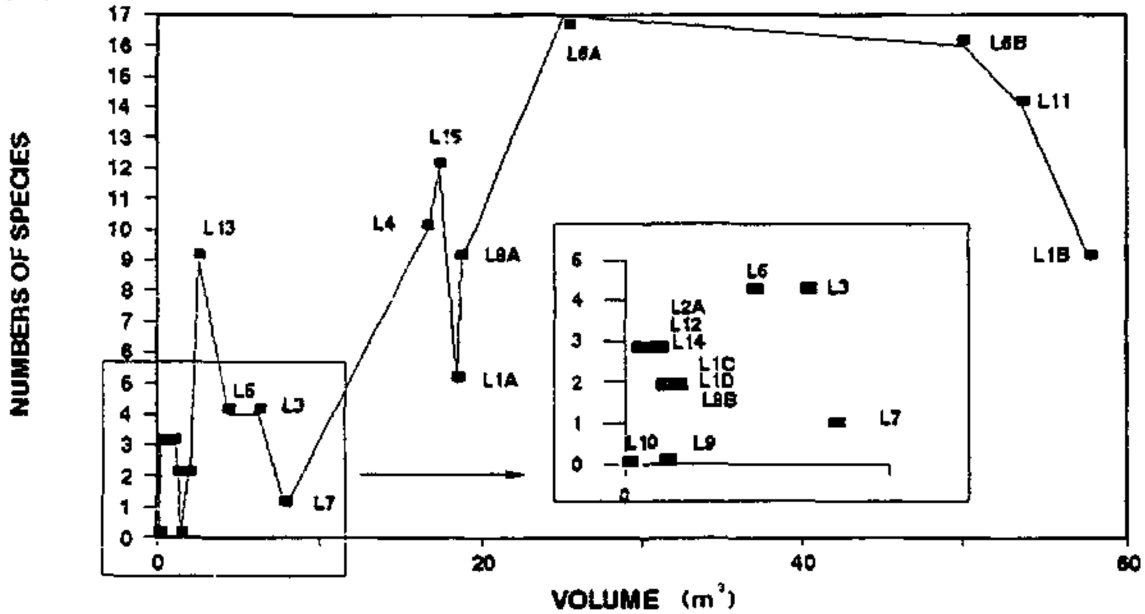


Figure 6: Numbers of species found at isolation as a function of pool volume. Pool L16 with a pool volume of 1730 m^3 and 17 species, and Pool L2B with a volume of 109m^3 and 14 species, were not included.

A. LONDOLOZI

The results from the Londolozi site have been considered under the following divisions:

(1) **Transient pools** which persisted only for the first month and as such only provide an indication of the species assemblage at isolation.

(2) **Persistent pools** which were sampled over a three to five month period. Particular consideration was given as to whether pools were instream or offstream.

Persistent pools were further divided into the following:

(A) **Offstream pools** which isolated before flow ceased in the main channel.

(B) **Instream pools** which formed when the reach stopped flowing.
The species diversity and abundance (CPUE) for each pool is summarised in Appendix II, Tables 1 - 4. Generally, larger pools housed more species, as is evident in Fig. 6, with few exceptions. These appeared to be related to the degree of habitat heterogeneity, with more complex pools comprising greater species diversity.

In general, Londolozi, pools were dominated by the Mozambique tilapia, *O.mossambicus* ($\bar{x}$ = 36%) and the Bowstripe barb, *B.viviparus* ($\bar{x}$ = 15%) (Fig.7). This trend remained constant through June to September but in October, *O.mossambicus* numbers increased and accounted for 67% of the CPUE. Other species that frequently accounted for 5% of the CPUE were *Barbus trimaculatus Barbus annectens*, *Glossogobius callidus* and *Tilapia rendalli*.

(1) TRANSIENT POOLS

Twelve pools persisted in June only (App. II, Table 1). In general the larger, deeper pools housed more species. The most widespread species were *O.mossambicus* and *B.viviparus*, followed by *Barbus trimaculatus*. Fry of this species were found in three pools; probably young-of-the-year from the last rains.

(2) PERSISTENT POOLS

Five pools (L1A L1B, L6A, L11, L15) persisted from June to August, 1992, when they dried, and thus some indication of diversity and numbers could be examined. Both offstream pools, L1A and L1B maintained species diversity and exhibited stable or increasing numbers (App. II, Tables 2 (a) & (b)). Three pools persisted throughout the drought period, L2b (offstream), L6b and L16 (instream).

(A) OFFSTREAM POOLS

■L1A and L1B.

Both of these pools were isolated from the main channel at the start of the research period, although it appeared that they had very recently divided from each other. Although they were

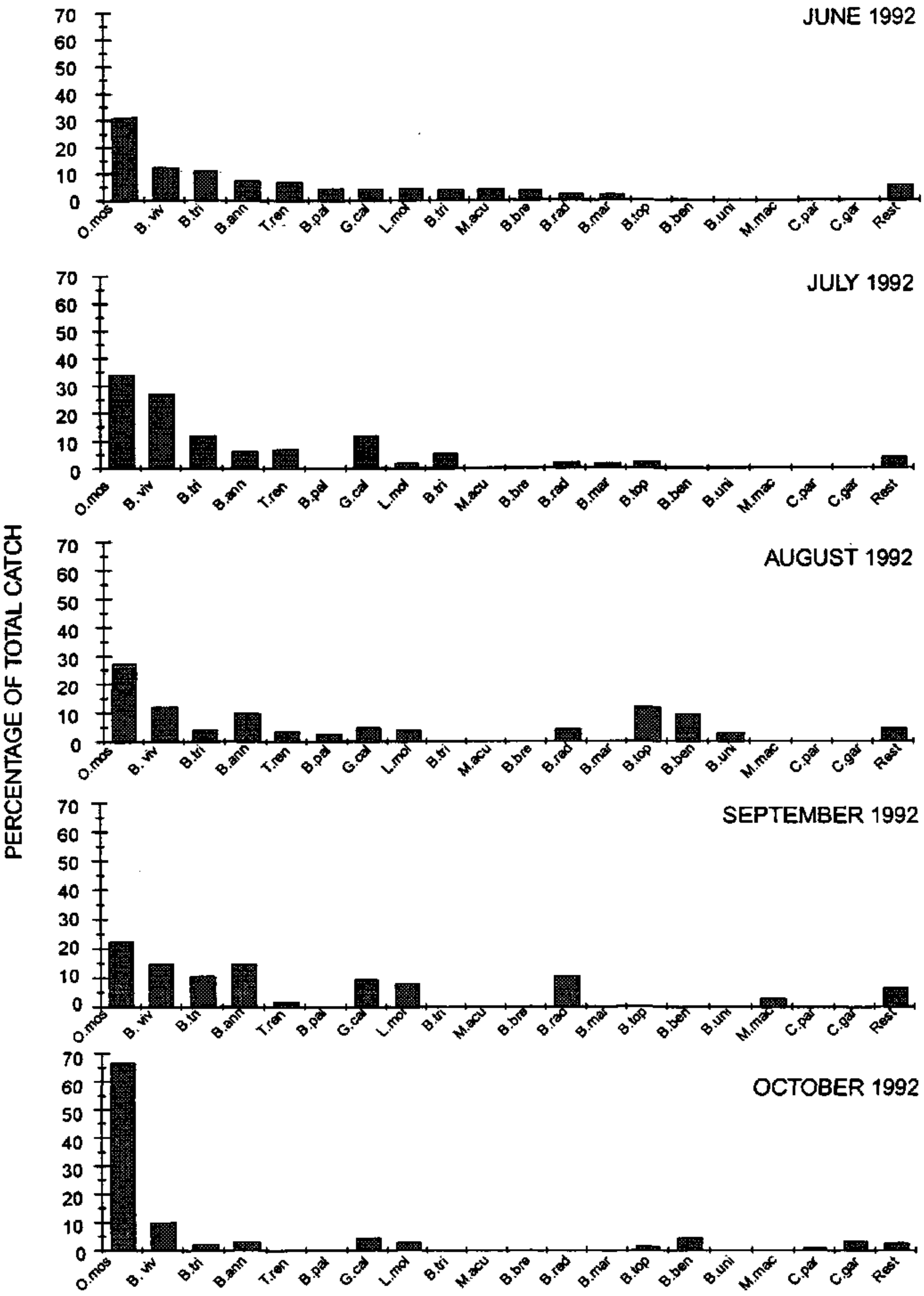


Figure 7: Species composition as a percentage of total catch at Londolozi over five months. Abbreviations as per Table 3.

physically similar to L2 series (bedrock substrata, little overhead cover), their proximity to the main channel indicated that they were linked to the main channel at lower flows than the L2 series.

Both pools were dominated by *O.mossambicus* and *G.callidus;* trends which remained consistent throughout with the exception of pool L1B2, in which CPUE of *G.callidus* dominated catches in July, but decreased noticeably by almost 90% in August. Low oxygen values (38%) would possibly explain this.

The smaller and shallower L1A, with no cover had a lower species diversity than L1B (5 and 9 respectively). Species unique to pool L1A1 were *B.viviparus* and *B.annectens.* Although pool L1A2 had a greater volume, pool L1A1 possessed a long ledge which provided inpool cover.

The species unique to the larger L1B were the minnows *Barbus radiatus, Barbus unitaeniatus, B.trimaculatus* and *M.brevinnalis,* possibly making use of the in-pool boulder as cover and greater depth. Abundance in L1B2 decreased substantially in August, 1992 by which time the pool was very small and the oxygen very low. Comparison of abundance in L1B2 in July and August was not possible as a number of species were not caught in July.

The additional pools in this series, L1C and L1D both had only two species, *O.mossambicus* and *B.trimaculatus* and both pools dried at the end of June, 1992. Initial data analysis indicates that depth and cover were the two factors that could potentially explain the different assemblages.

In both pools the abundance of *O.mossambicus* increased, most notably in L1B1 in July where the numbers increased from 1.2 to 27.7 (see App. II, Table 2(b)). Detailed size-frequency distribution of this species (Fig. 8(a)) suggests the presence of two or possibly three size classes. Sexual maturity varies in *O.mossambicus* between 10 and 15cm (Bell-Cross, 1964).

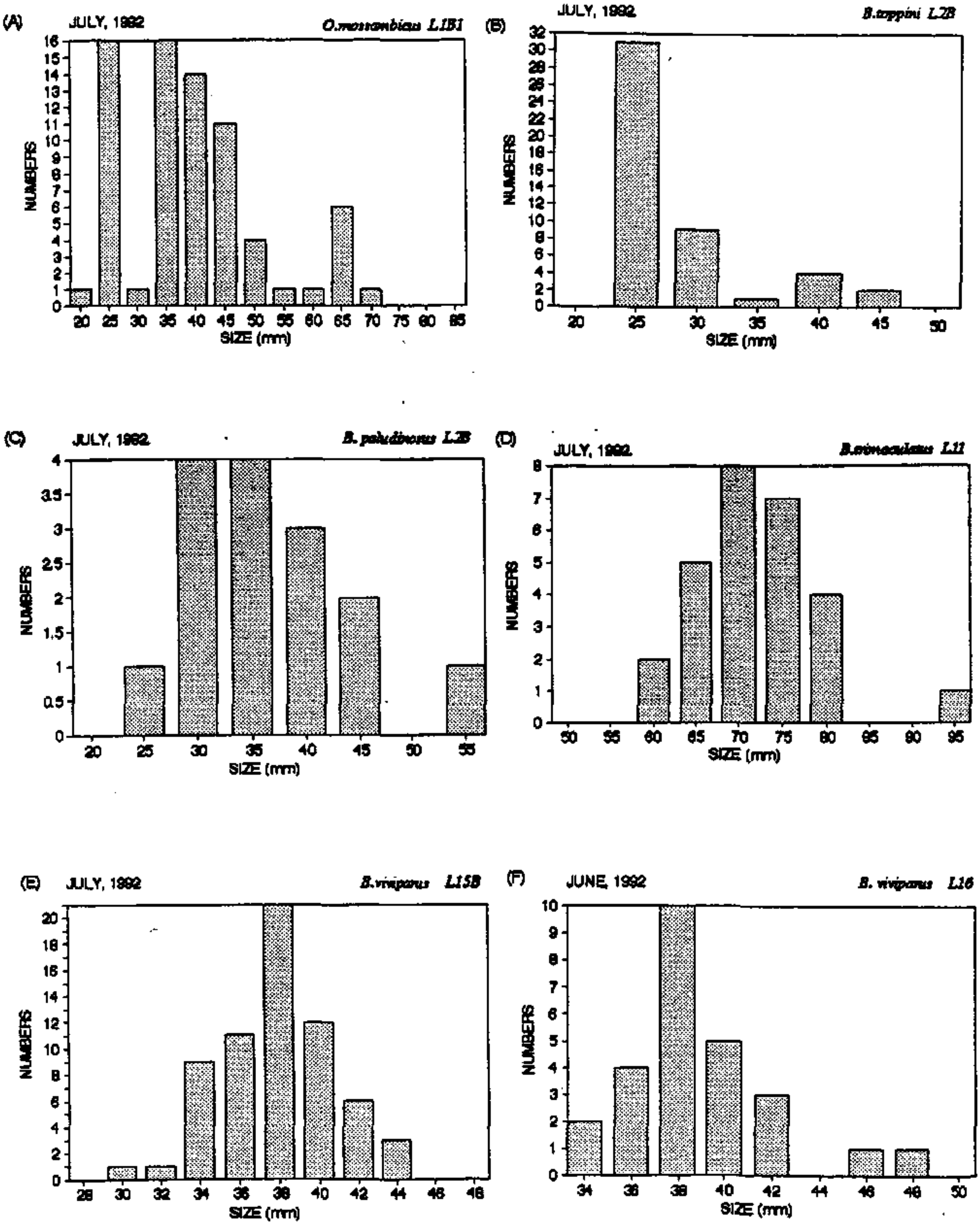


Figure 8: (A-F). Size frequency distributions for selected species at Londolozi. Species, pool numbers and months are indicated above each figure.

Thus, the smallest size class of 25mm may well be indicative of recent breeding but increased capture efficiency with a reduction in pool volume may have also been a contributory factor.

Of particular note is that after the pool had divided in July, 1992, L1B2 had a greater species diversity, which remained stable into August, although in terms of volume it was much smaller than L1B1. Species unique to this pool were *B.radiatus*, *B.viviparus* and *B.unitaeniatus*.

Physico-chemistry results (App. I, Tables 1 to 8) indicate a fairly stable environment, with the exception of oxygen which decreased dramatically in August, 1992. This was a plausible reason for the reduction in numbers of Pool L1B1. The extremely low oxygen values of Pool L1B2 in August (38%) suggest that the constant numbers is probably an erroneous result due to greater capture efficiency.

L1B3 offered a number of advantages due to extensive overhead cover by a large boulder. In-pool cover resulted in lower temperatures, a reduction in evaporation and increased cover from predators. However, the disadvantage would be a reduction in oxygen. Oxygen and overhead showed an extremely strong negative relationship in July and the oxygen was approximately 50% lower in this pool in comparison to L1B1 and L1B2.

■ Pool L2B.

This pool was isolated at the start of the research, and its position and linkage from the main channel indicate that it remains isolated throughout low flow periods (Plate 1 A-C).

As such, the species assemblage and persistence of that assemblage as a refuge population is of particular interest. A total of 14 species were represented in L2B (App. I, Table 3(b)), dominated by *O.mossambicus*, *M.brevinalis* and *B.annectens*. The CPUE remained constant in July, 1992 but numbers of *B.toppini* increased notably; this could however merely reflect greater capture efficiency due to reduced pool size and depth. The size-frequency distribution of *B.toppini* (Fig. 8(b)) suggests that the population is composed of one size class. Similarly, numbers of *B.paludinosus* increased in July and the size frequency distribution (Fig. 8(c)) indicates that a major proportion are sub-adult.

After June, *B.radiatus* was not caught (App. II, Table 3) and notably, *T.rendalli* was not caught after July, 1992. The species diversity and abundance of most species remained fairly constant for a three month period until September, 1992, after which a sharp decline in both diversity and CPUE was evident. In September, the pool size was substantially reduced from that of August by 85% (Fig. 2), TSS increased substantially, temperature rose by 25% to 31.5°C, conductivity and turbidity by approximately 36%. Thus it would appear that these factors, and a reduction in volume accounted for the decline and predation.

The final species assemblage was reduced to *B.toppini, O.mossambicus* and *Clarias gariepinus. B.paludinosus* only found until August. Oxygen declined to 25% in October and it can therefore be assumed that these species possess some sort of tolerance for low oxygen, although for how long is not known. Although only three *C.gariepinus* were caught in the last two months, many more were seen just under the surface and the importance of in-pool predation cannot be discounted. Large amounts of guano were also visible around the pool in August indicating that predation was an important factor at this point.

Although L2B shared a suite of species common to other pools, *Barbus afrohamiltonii* and *S.zambezensis* were unique to this pool. A further two species, *B.paludinosus* and *B.toppini* were only found in this and in a sister pool, L2A which dried at the end of June, 1992. With respect to the preferred microhabitats of these species, this indicates a selection for offstream pools and a tolerance to conditions that may occur in these pools.

Physico-chemistry results indicate that between 40 and 70% of the TSS was composed of organics, relatively higher than any of the other readings taken. This is probably as a result of high algal densities. pH readings declined in October reflecting the decrease in oxygen concentrations from a super-saturated water body to one of low oxygen concentrations. Table 2 (App. I) shows that the daytime oxygen readings remained consistently high over a four month period. Readings taken at sunrise and sunset (Fig. 3) in July, illustrate that although oxygen levels decrease substantially at night, the reduction was to a level well within tolerable limits.

The remaining pools, all instream were characterised generally by decreasing diversity and abundance in the latter part of the study (App. II, Table 4,(a-e)).

B. INSTREAM POOLS

Unique to instream pools were *Barbus eutaenia, Barbus marequensis, Chiloglanis paratus, Labeo rosae, Marcusenius macrolepidotus* and *S.meridianus.*

■Pool L6A.

Pool L6A initially comprised 17 species (App. II, Table 4(a)), predominantly *O.mossambicus* and *B.viviparus.* In physical terms this pool was an exposed bedrock pool, with a large undercut bank, characterised by high evaporation and increasing conductivity. By July, 1992 this pool had split into two pools- L6A1 and L6A2, the former being very much larger and deeper, with almost a full complement of initial species. Species that showed a strong preference for depth and volume were only found in L6A1. Species that had disappeared from both pools were *Micralestes acutidens, M.brevinalis, M.macrolepidotus* and *P.catostoma.* Species common to both pools were *C.paratus, G.callidus* and *B.trimaculatus,* and these were the only species found in L6A2. However, by August, L6A2 had dried up and species in L6A1 had been reduced to six, a concomitant reduction in abundance. Although with *O.mossambicus* was the most numerous species in L6A1, no *O.mossambicus* were found in L6A2.

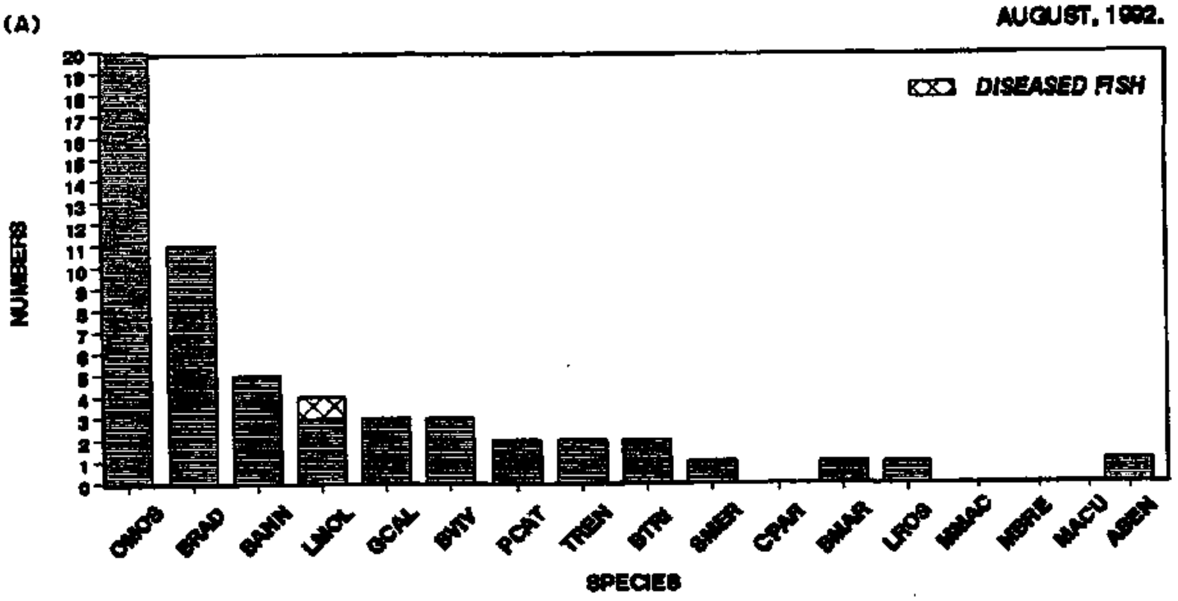
No evidence of disease was found in any of these pools. Physico-chemistry results (App. I, Tables 1 - 8) indicate a particularly stable environment. It is suggested therefore that terrestrial and aerial predation would be the primary factor in the reduction of the population, facilitated by the decreasing volume (which decreased by 80%) and high water clarity. No *C.gariepinus* were found in this pool and although *O.mossambicus* are known to become predatory under conditions of poor food supply, all *O.mossambicus* were smaller than 24mm in August.

■ Pool L6B.

Plate 1 D-F. A total of 17 species were caught in L6B in June. Species diversity and numbers remained relatively constant throughout the study period. However, in October four species were not captured: *L.rosae*, *M.brevinnalis*, *T.rendallii* and *M.macrolepidotus*. With the exception of the latter, CPUE of these species were very low from the onset. However, with regard to *M.macrolepidotus*, decreasing volumes greatly increase capture efficiencies, as shown by the greater number caught in September. Increases in the numbers of *O.mossambicus* appeared to reflect greater numbers due to breeding.

The importance of terrestrial predation was probably greatly reduced due to the substantial cover. The lack of *C.gariepinus* in L6B could have contributed towards numbers remaining fairly constant. Another contributory factor to the persistence of a complex assemblage was probably depth. Although the surface area decreased, the depth under the bank remained sufficient (90-60cm) to confer the advantages of reduced predation and lower temperatures by providing shading and cover.

The physico-chemistry results indicate a stable environment throughout the monitoring period (see Fig. 4, and App.I, Tables 1-8). However, there was some evidence of diseased fish in August (*L.molybdinus*) and in September (*M.macrolepidotus*, *C.paratus* and *P.catostoma*) (Fig. 9).



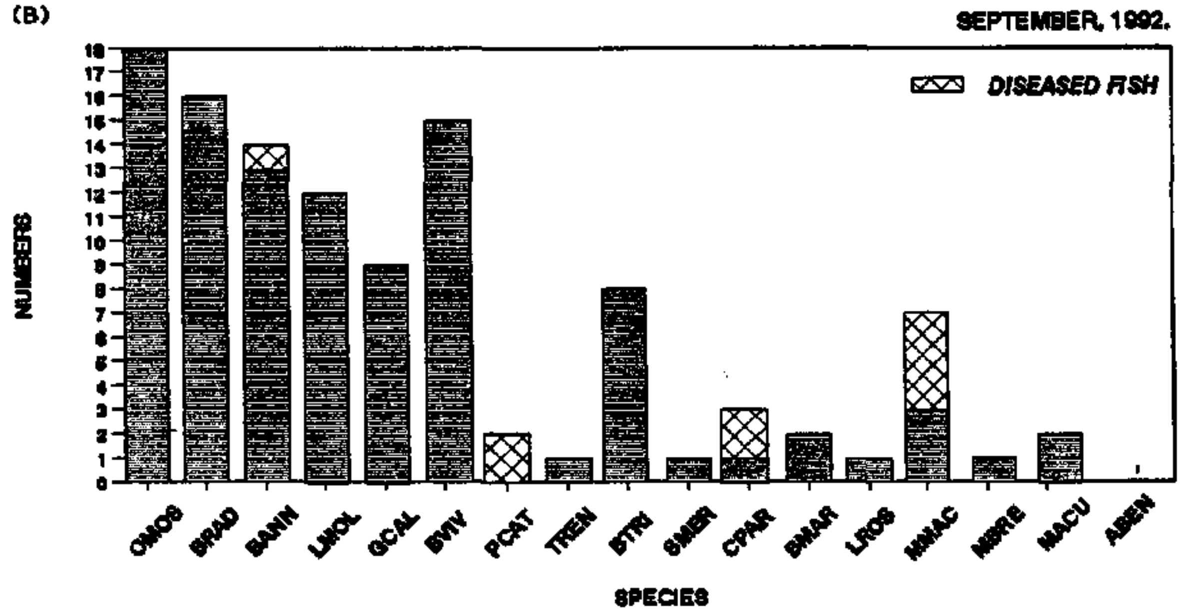


Figure 9: Numbers of diseased fish caught in Pool L6B in August and September. Species names are abbreviated as follows: OMOS= *O.mossambicus*, BRAD= *B.radiatus*, BANN= *B.annectens*, BVIV= *B.viviparus*, CPAR= *C.paratus*, LMOL= *L.molybdinus*, GCAL= *G.callidus*, BTRI= *B.trimaculatus*, MACU= *M.acutidens*, MMAC= *M.macrolepidotus*, MBRE= *M.brevianalis*, PCAT= *P.catostoma*, TREN= *T.rendalli*, SMER= *S.meridianus*, ABEN= *A.bengalensis*, BMAR= *B.marequensis* and LROS= *L.rosae*.

■ Pool L11.

This sandy instream pool was over 90% shaded, (Plate 2D). Although L11 possessed a diverse assemblage initially with 14 species (App. II, Table 4(c)), this was reduced to 6 and 2 on subsequent field trips. Initially this pool was dominated by *M.acutidens* and *B.viviparus*. This trend did not remain consistent, and in July *B.trimaculatus* was the most numerous species. *O.mossambicus* were low from the start and it seems likely that this species avoided this pool of high overhead cover. Total numbers of fish caught (CPUE) also decreased dramatically in August.

The abundance of *B.trimaculatus* increased in July, 1992 captured principally in wire traps, more effective for bottom-dwelling species. However, analysis of size frequency distribution (Fig. 8(d)) suggests that this increase in numbers merely reflects increased capture efficiency, since the size class represented was that of adults.

Physico-chemistry results indicate that whilst most parameters remained stable, both volume and oxygen decreased dramatically in July (Fig.4). In July oxygen had dropped to 29%. Moribund individuals of *B.viviparus* were found at the surface and no further individuals of this species were caught. The pool remained consistently clear and predation is likely to have resulted in the decline in numbers of *G.callidus*, *B.annectens*, *B.radiatus* and *B.viviparus*. By July three species (*Labeo molybdinus*, *B.trimaculatus* and *B.marequensis)* all showed evidence of disease (Fig. 10).

In August oxygen readings in the pool were extremely low (7%), but higher readings of 39% were taken in a small sunny potion of the pool. This pool contained only two individuals, *C.gariepinus* and *T.rendalli*. One large dead *T.rendalli* was found floating at the surface.

■ Pool L15.

Pool L15 had 12 species in June, 1992 (App. II, Table 4(d)), dominated by *B.viviparus* and *B.annectens*. In July, L15 had split into L15A and L15B, each exhibiting quite a different

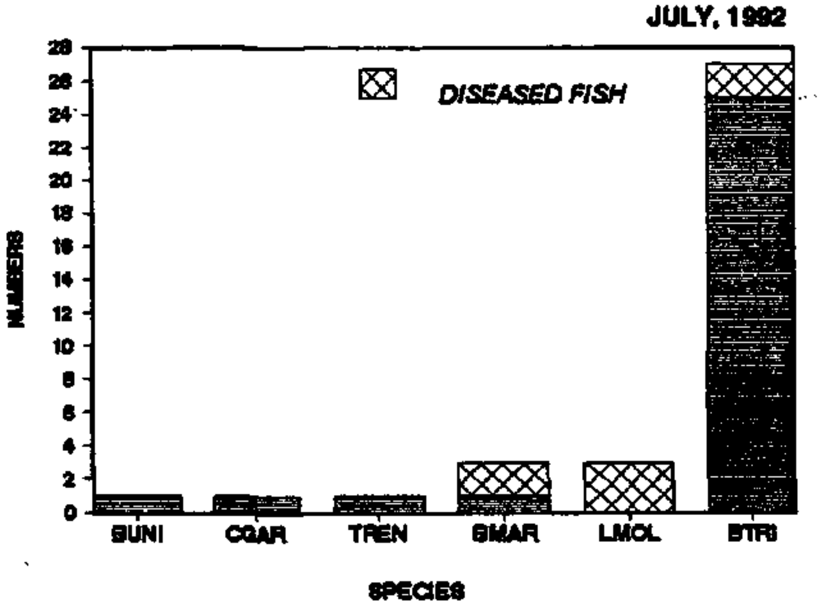


Figure 10: Numbers of diseased fish caught in Pool L11 in July. Species names are abbreviated as follows: BUNI= *B.unitaeniatus*, CGAR= *C.gariepinus*, TREN= *T.rendalli*, LMOL= *L.molybdinus*, BTRI= *B.trimaculatus* and BMAR= *B.marequensis.*

species complement, except for *O.mossambicus* and *B.viviparus*. Both pools were of a similar surface area but L15A was deeper than L15B (45cm & 19cm respectively).It appears that a large percentage of the fish "choose" L15A at splitting (Plate 2E); a pool with greater depth and volume (all other physico-chemical variables being equal).

Of interest is that by August, two months after isolation, no fish were found in L15A although it was still larger than L15B. In L15B numbers had dropped dramatically and only four individuals remained; three *B.viviparus* and one *O.mossambicus*. General physico-chemical readings were stable with the exception of oxygen. These results suggest that the most plausible explanation for species decline was disease (possibly precipitated by stress due to low oxygen) and/or predation.

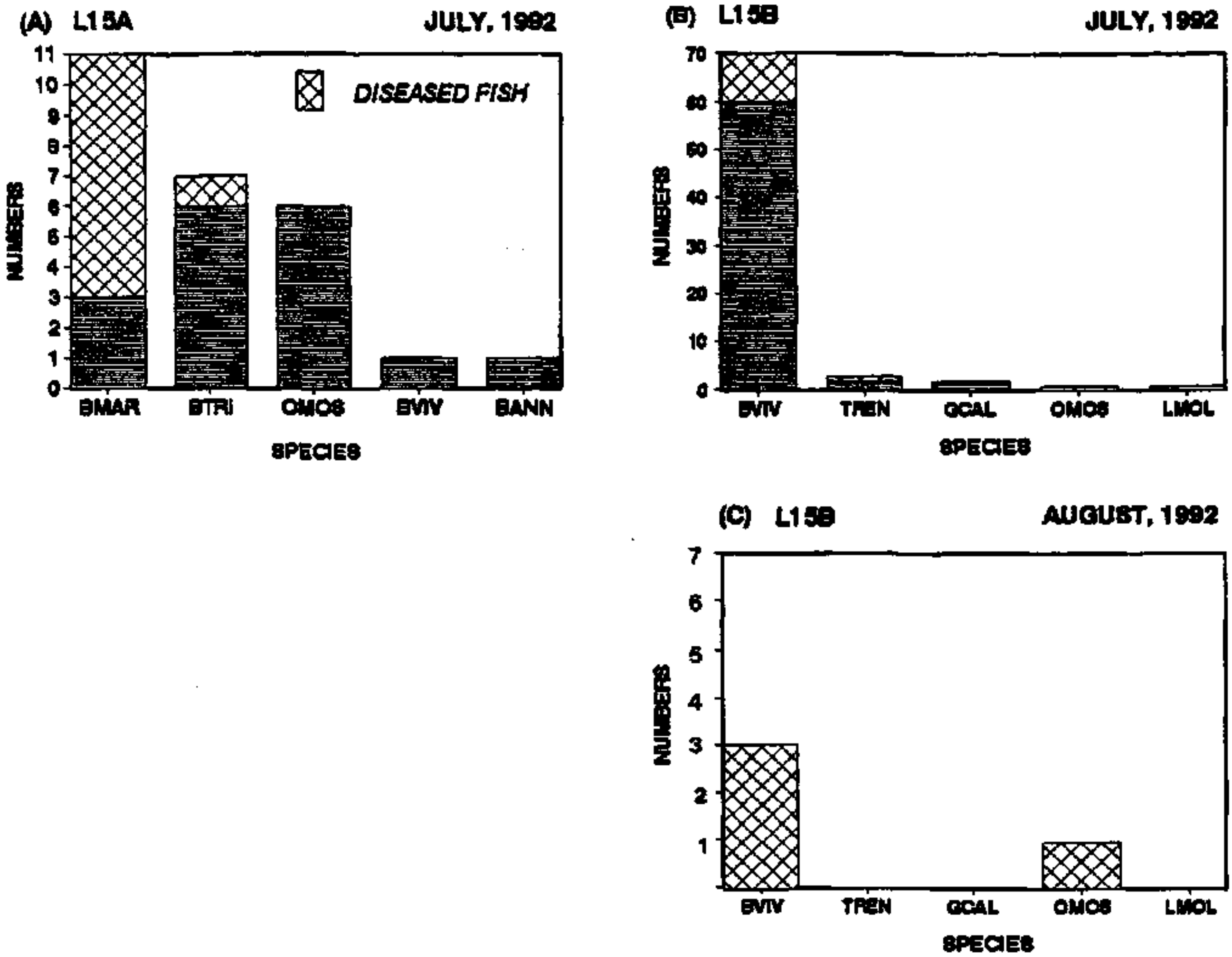


Figure 11: Numbers of diseased fish caught in (A) Pool L15A in July; (B) Pool L15B in July, and (C) Pool L15B in August. Species names are abbreviated as follows: OMOS= *O.mossambicus*, BRAD= *B.radiatus*, BANN= *B.annectens*, BVIV= *B.viviparus*, LMOL= *L.molybdinus*, GCAL= *G.callidus*, BTRI= *B.trimaculatus* and BMAR= *B.marequensis*.

In July, oxygen readings indicate that although daytime values were not low, oxygen concentrations dropped considerably at night, from 118% at sunset to 50% at sunrise. At this stage, four large moribund *B.marequensis* were found floating on the surface of the pool. In July, a number of dead mussels were found in pool L15B.

The analysis of disease in July, 1992 (Figs. 11(a) & (b)) indicates that a number of species (*B.trimaculatus*, *B.viviparus*, *B.marequensis* and *T.rendalli*) showed evidence of blood in the fins and scalar lesions. Although, L15A was still persistent in August, 1992 no fish were found. By August, only two species (three fish) remained in L15B: *B.viviparus* and *O.mossambicus*, all individuals of which showed evidence of disease (Fig. 11(c)). *B.trimaculatus* had disappeared from L15B and the numbers of *B.viviparus* decreased dramatically, possibly as a result of disease.

Numbers of *B.viviparus* increased substantially in L15B. Analysis of the size frequency distribution (Fig. 8(e)) indicates that the majority of the population were sub-adults. It is likely that this size class are from the summer breeding and thus approximately six months old. Therefore, the increase in numbers was probably due to greater capture efficiency.

■ Pool L16.

This pool provided an opportunity to follow the fate of a large (31m * 11.5m) but fairly shallow pool, as well as species composition of the daughter pools resulting from the division of the main pool (Plate 2A-C).

A total of twenty species were found in L16, two of which were eels. (App. II, Table 4(f)). Species diversity remained relatively constant although *B.marequensis* and *L.rosae* were never found after July, 1992; their original numbers were very low. Before the pool split, numbers of *B.viviparus* increased substantially; however no indication of breeding is suggested by the size-frequency distribution (Fig.8(f)), and is again probably a result of increased capture efficiency.

In September, when the pool had split in two (L16A and L16B), the species assemblage of both pools was similar with the notable exception of *L.molybdinus* which was only found in L16B. In October, L16A had split into three pools, all characterised by a substantial reduction in diversity with only four species persisting: *G.callidus*, *O.mossambicus*, *C.gariepinus* and *B.viviparus*. In L16B there was a notable absence of *B.annectens*, *B.radiatus*, *B.trimaculatus* and *L.molybdinus*. The reduction in volume compounded by the shallowness of the pool caused a decrease in habitat available as cover, possibly precipitating increased predation by *C.gariepinus* and eels.

■ Pool L17

This shaded pool was not sampled in June (Plate 2F). In July, in contained six species, dominated by *B.viviparus*. In July a number of fish were seen coming to the surface possibly indicating oxygen starvation. Three dead *B.viviparus* with ick were collected and a further four were found with blood in fins.

Since oxygen concentrations were low, it is suggested that stress-induced disease is implicated as a major cause of mortality. In August no fish were present in this pool although it was still extant.

B. Mlondozi

Note that in August the main channel started flowing. Previously isolated pools were fished as individual units and data are presented as such. However, although links between pools were small, there was a possibility that fish moved between pools and data should be interpreted as such.

All physico-chemical parameters are summarised in Appendix I, tables 9 to 17 while species composition and abundance of individual pools are presented in Appendix II, Tables 5 & 6.

Again, larger pools were generally characterised by a greater species diversity at isolation (Fig. 12).

Mlondozi pools were dominated by *O.mossambicus* ($\bar{x}$= 33%) and *T.rendalli* ($\bar{x}$= 32%) (Fig. 13). Although *Glossogobius giurus* constituted the next most abundant fish at isolation (31%) this pattern was not repeated in subsequent months.

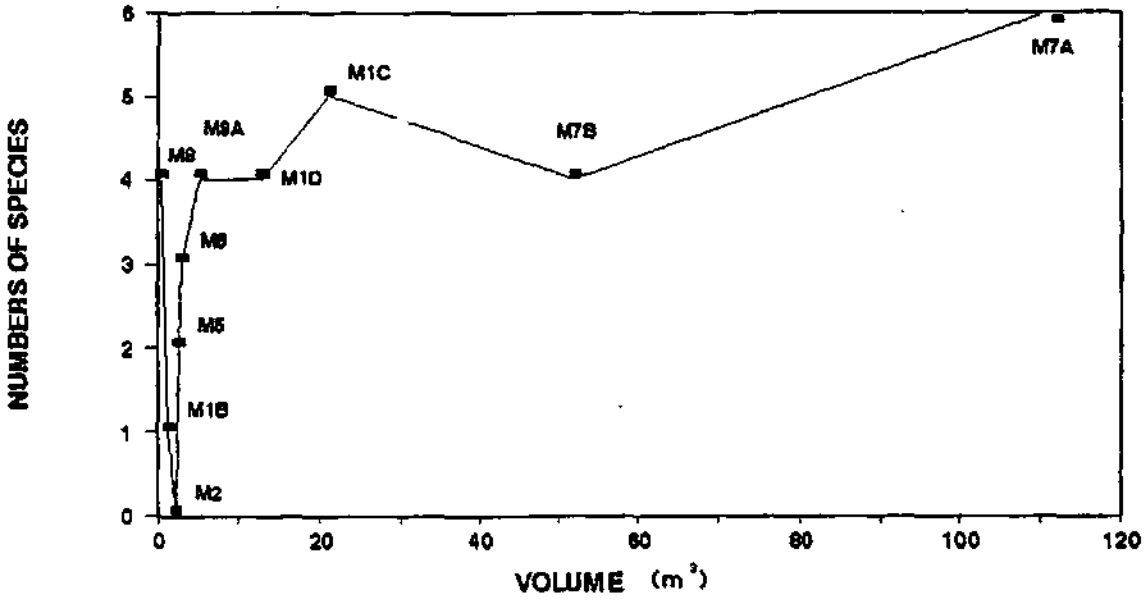


Figure 12: Numbers of species found at isolation at Mlondozi as a function of pool volume. Pool M1A, with a volume of 1560m^3 and 8 species, is not included.

The largest of the pools that persisted in June only (see App. II, Table 5), Pool M1E, housed 14 species, but the relative CPUE was low. Again, those species in which depth and/or volume appeared to explain distribution were found in the larger M1E. Although *B.paludinosus* was found in this pool, *B.toppini* was absent. The highest abundance was found in M1D and M1C, dominated by *O.mossambicus* and *G.giurus* respectively.

Fewer species were found at Mlondozi relative to Londolozi, 19 and 26 respectively. Unique to Londolozi were the minnows *B.eutaenia*, *B.marequensis*, *B.trimaculatus*, *B.unitaeniatus* and *M.brevinalis;* the labeos *L.molybdinus* and *L.rosae*, the catlet *C.paratus* and the squeaker, *S.zambezensis*. Species unique to Mlondozi were the goby *G.giurus* and the tigerfish, *Hydrocynus forskhalli*.

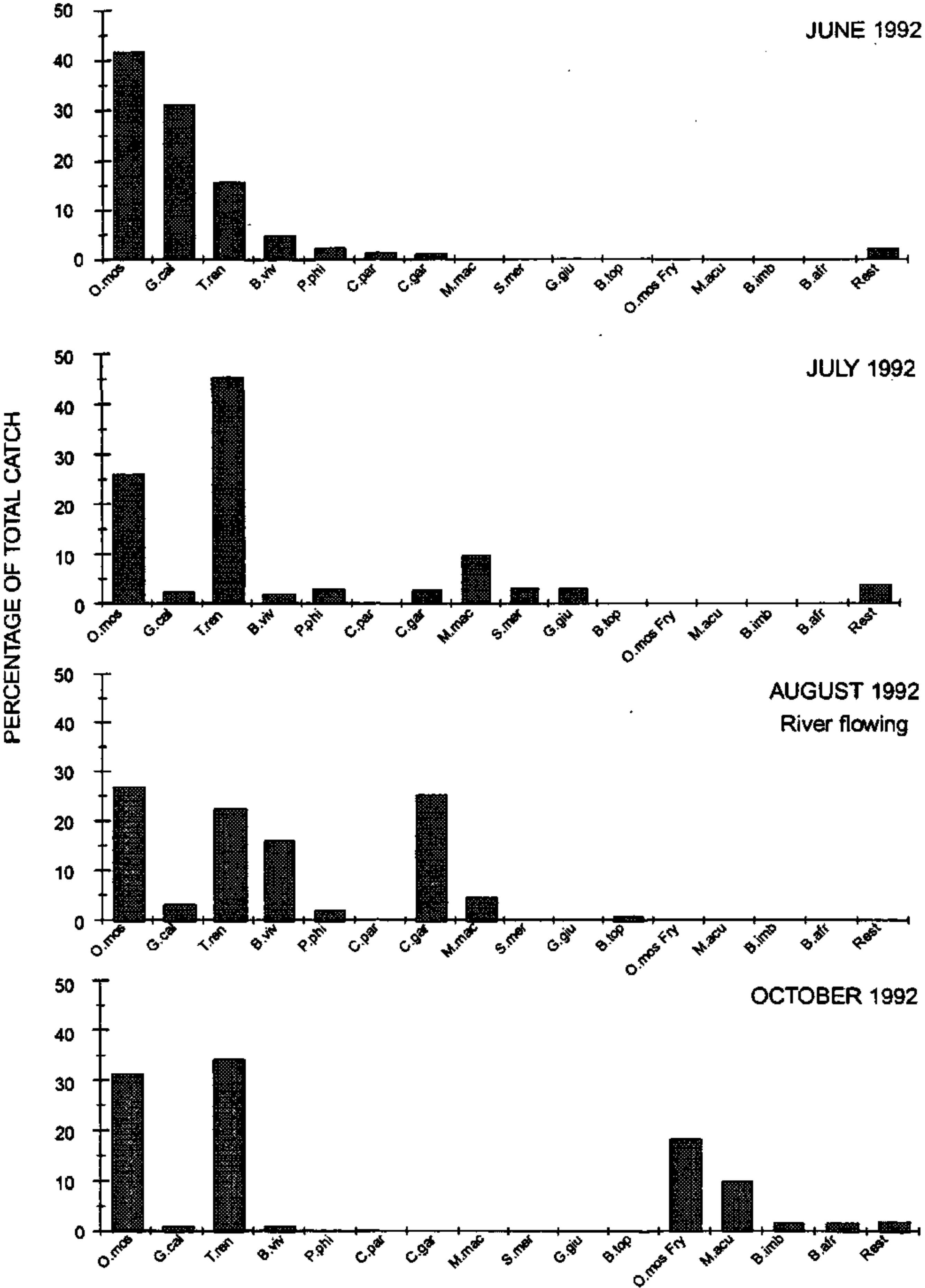


Figure 13: Species composition as a percentage of total catch at Mlondozi over four months. Abbreviations as per Table 2.

(A) OFFSTREAM POOLS

■ M1A series (Plate 4A&B)

This pool was not sampled in June due to logistical constraints and the original species composition is not known.

M1A constituted the largest pool at isolation with a volume of approximately 1560 m^3. Over the sampling period it split into a number of smaller pools which were characterised by dense algal blooms and consistently high oxygen concentrations (App. I, Table 10), high silt loads (table 15) and high turbidity readings (table 16). Turbidity and TSS were extremely high in comparison to other pools.

In July, 8 species were caught in pool M1A (App. II, Table 6(a)). By August, M1A had split into two pools M1A1 and M1A2; again only M1A1 was sampled due to sampling constraints. At this point, the main channel was flowing but the M1A series remained isolated. Only four species remained in this pool including the barbs *B.toppini* and *B.viviparus*. In September, with extreme TSS and turbidity readings, only *C.gariepinus* was found in high numbers. These individuals were in extremely poor condition.

(B) INSTREAM POOLS

■ M4 series

This relatively large bedrock and sand pool was almost totally covered by *Pistia* in June. This posed sampling limitations and was partly cleared. By July this pool had split into two- M4A and M4B. The larger M4A contained 8 species, whilst M4B contained only *Pseudocrenilabrus philander* (App. II, Table 6(b). Physico-chemical data indicated consistent, stable results for the two pools (see App.I, Tables 9 to 16) with the exception of TSS and oxygen concentrations. Although both pools had low TSS values, almost 80 % was organic in M4A,compared to 41% in M4B. Oxygen concentrations were 50 % lower in M4B. Pool M4B, with 40 % *Pistia* cover contained relatively large amounts of decaying vegetation.

In September, pool M4B had dried; M4A housed species comparable to July, with the exclusion of *G.giurus* and *P.philander*. An additional species, *P.catostoma* was found and could have moved in from another pool during the August flow.

■ Pool M6

This small bedrock pool persisted in June and July. It housed three species (App. II, Table 6(c)). *G.giurus* was no longer caught in July. Physico-chemical data showed a stable environment in both months; and benthic algae was extensive.

■ M7 series (Plate 4C&D)

This pool had just split into M7A (bedrock/ cobble substrate) and M7B (bedrock/ silt substrate) at the start of the monitoring period and thus were treated individually. The larger M7A (App. II, Table 6 (d)) included two additional species, *B.viviparus* and *G.callidus*. Although the relative CPUE was higher in M7B this may merely reflect a greater sampling efficiency due to reduced size (Mahon, 1980). All chemical parameters were similar in June.

In July the extant, shallow (20cm) M7A1 and very shallow M7A3 (6cm) contained no fish. The lack of species in the smaller pools would appear to be related to the shallowness. M7A2 (60cm) housed most of the species found in June with the exception of *G.giurus*. Physico-chemical data indicate nothing untoward that could account for this demise. Three species had disappeared from M7B and only *T.rendalli* remained in this pool. Evidence of predation in the form of guano was extensive and may have been the principal factor in causing decreasing numbers.

In September, *M.macrolepidotus* was no longer found in M7A2. The overall CPUE had increased due to increased abundance of *O.mossambicus*. At this point, large *O.mossambicus* were showing evidence of disease with scalar fungus. Pool M7A1 was still extant but no fish had repopulated this pool during the August flow.

■ M9 series (Plate 4E&F)

At the start of the sampling period, the M9 series comprised two pools, a small M9A (15cm deep) and a very large M9B (120cm deep) which were still linked. M9A which dried up in July, housed four species: *G.giurus*, *B.viviparus*, *O.mossambicus* and *T.rendalli*. However, in August when the river was flowing *G.callidus*, *O.mossambicus* and *T.rendalli* moved back into this pool, effectively a backwater of the larger M9B.

Pool M9B was not sampled in June due to logistical constraints. In July five species were caught (App. II, Table 6 (e)), notably *S.meridianus*. This abundance of this species may be underestimated due to sampling inefficiency as a result of the large size of the pool. In September, M9B divided into two pools with M9B1 being slightly larger and deeper; however M9B2 exhibited greater habitat heterogeneity and in-pool cover than M9B1. Although both pools exhibited similar physico-chemistry readings, the oxygen concentration was 50% lower in M9B1. An interlinking channel still existed, affording movement between these two pools and consequently, the distribution of species should be interpreted cautiously.

Of interest is the fact that the popnet appeared to be biased in the capture of the following species: *B.afrohamiltonii; C.gariepinus; B.afrohamiltonii; M.acutidens; Brycinus imberi* and *T.rendalli*.

C. CONFLUENCE

This was the only site at which the river was sampled as a lentic system and thus included riffle and run habitats. In general the species diversity and abundance was greater in the riffle area with the notable exception of *O.mossambicus* and *T.rendalli* (Tables 4(a)&(b)). In addition, the two sensitive species, *C.anoterus* and *S.zambezensis* were only found in the riffle area.

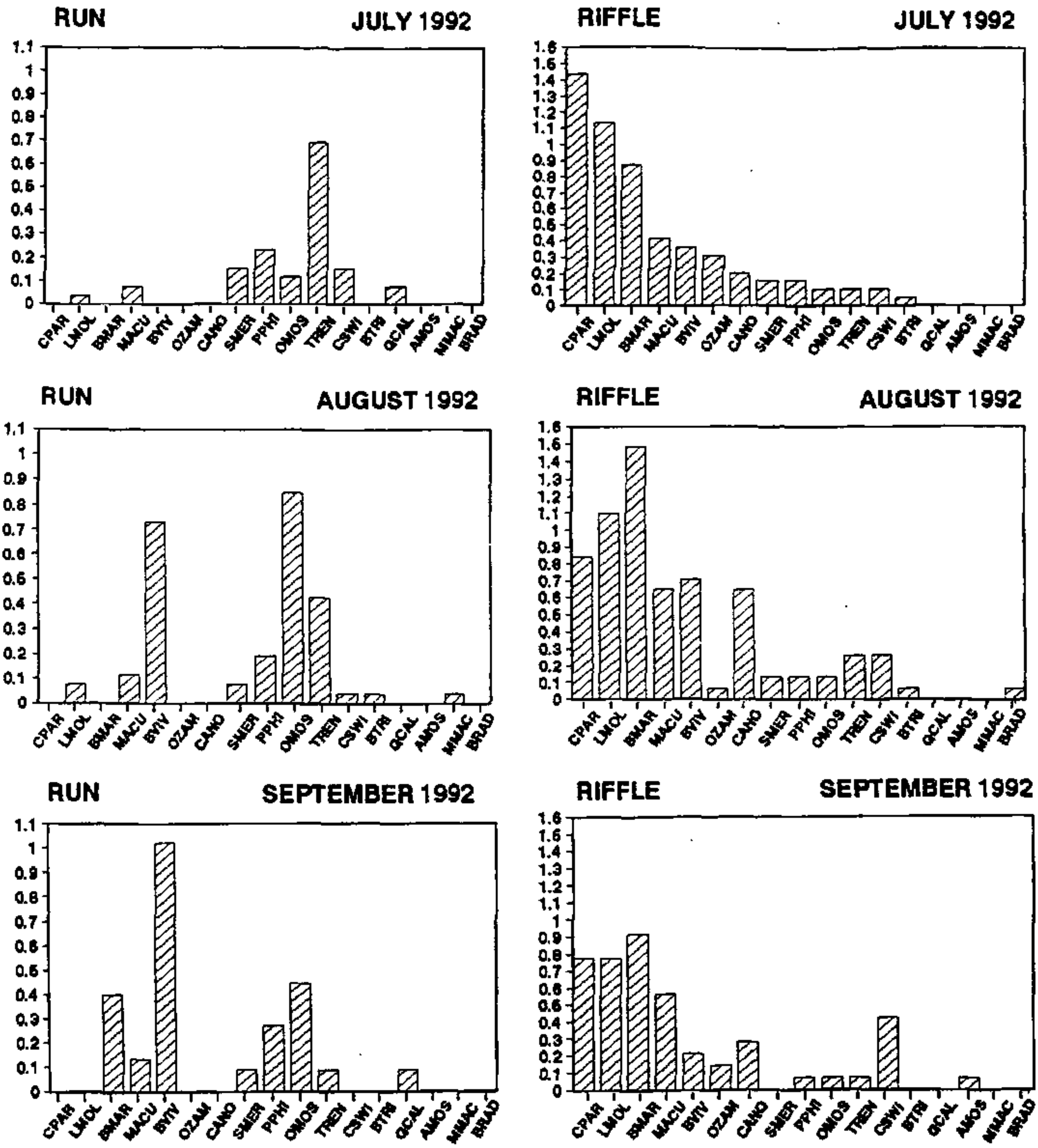


Figure 14: Species assemblage and abundance of the main channel run and riffle habitats at the Confluence, between July and September. Species names are abbreviated as follows: CPAR= *C.paratus*; LMOL= *L.molybdinus*; BMAR= *B.marequensis*; MACU= *M.acutidens*; BVIV= *B.viviparus*; OZAM= *O.zambezense*; CANO= *C.anoterus*; SMER= *S.meridianus*; PPHI= *P.philander*; OMOS= *O.mossambicus*; TREN= *T.rendalli*; CSWI= *C.swierstrai*; BTRI= *B.trimaculatus*; GCAL= *G.callidus*; AMOS= *A.mossambica*; MMAC= *M.macrolepidotus*; BRAD= *B.radiatus*.

■ Run and Riffle habitats:

The progression of the drought was characterised by decreasing abundances, again with the exception of *O.mossambicus* and *B.viviparus* (Fig. 14). Although *B.marequensis* was found in the run in September, this was generally limited to areas just below the riffle. The abundance of *T.rendalli* and *Chiloglanis swierstrai* decreased in the runs but appeared to remain relatively stable in the riffle areas with *C.swierstrai* limited to the sandy portion of the riffles.

■ Pools:

All pools at this site were of sand bed substrates and fed by underground water from the main channel. The species assemblage of all pools were consistently dominated by *O.mossambicus*, *T.rendalli* and *P.philander* (Fig. 15). Results of the species assemblages and abundance of five pools over the study period are summarised in Fig. 16 (a-e).

In general, the larger Confluence pools C1, C2 (Plate 3A) and C5 contained more species than the two smaller pools (Fig. 16). In addition these pools possessed a higher degree of habitat heterogeneity in terms of inpool cover and vegetation.

The only pool in which *G.callidus* was not found was pool C3 (Plate 3B), a small shallow exposed pool. Pool C3 only contained fry. *S.meridianus* was restricted to the three larger pools and was not found in pool C1 after June, 1992. *M.brevinalis* and *M.acutidens* were only present in pool C2. *M.acutidens* abundance was low at the outset (Fig. 12). Pool C5 split into C5A and C5B in September. C5B was deeper and exhibited more cover in the form of boulders and reeds. Species unique to this pool were *G.callidus* and *S.meridianus*.

Physico-chemistry results show conditions similar throughout the pools at each trip.

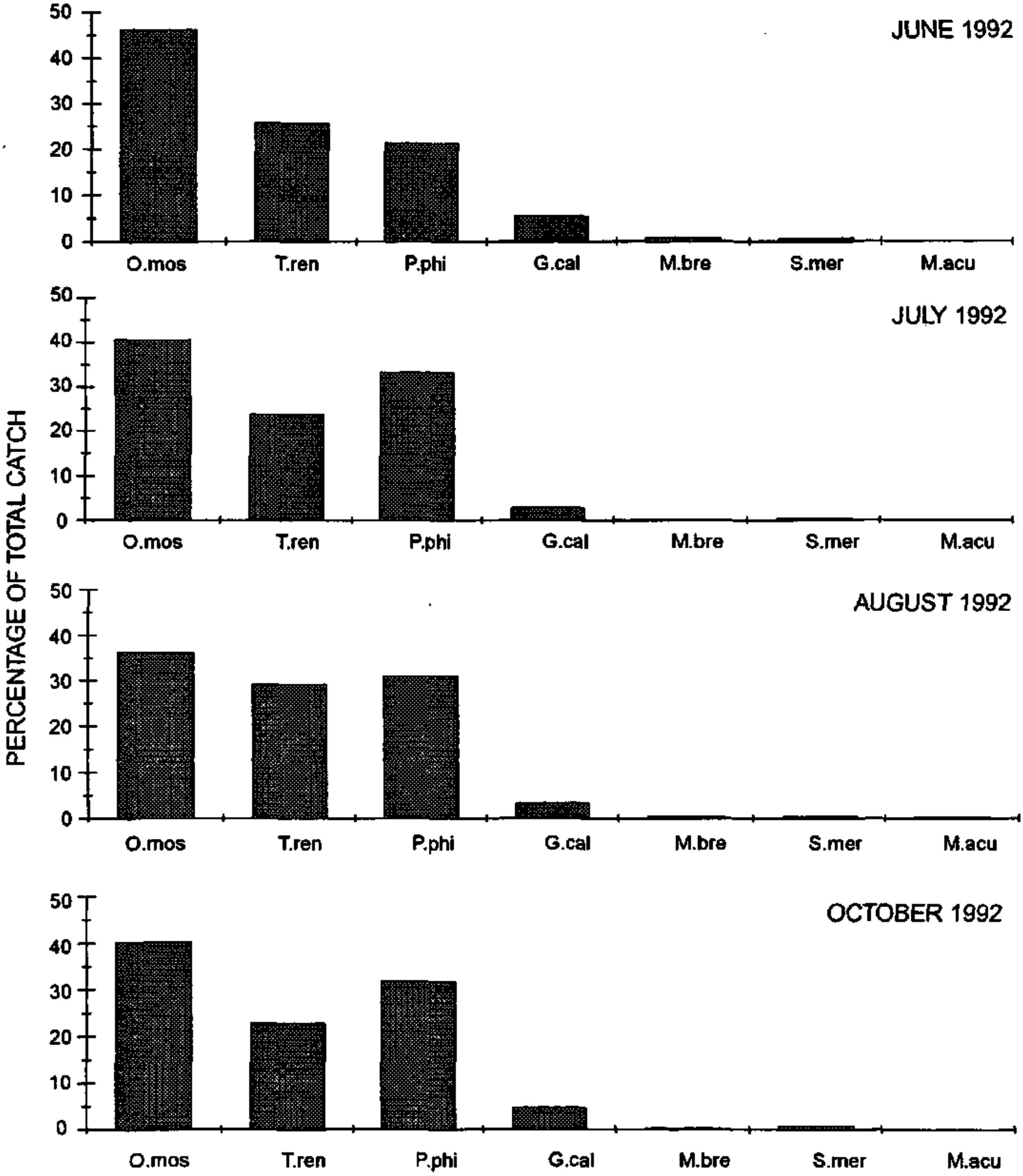
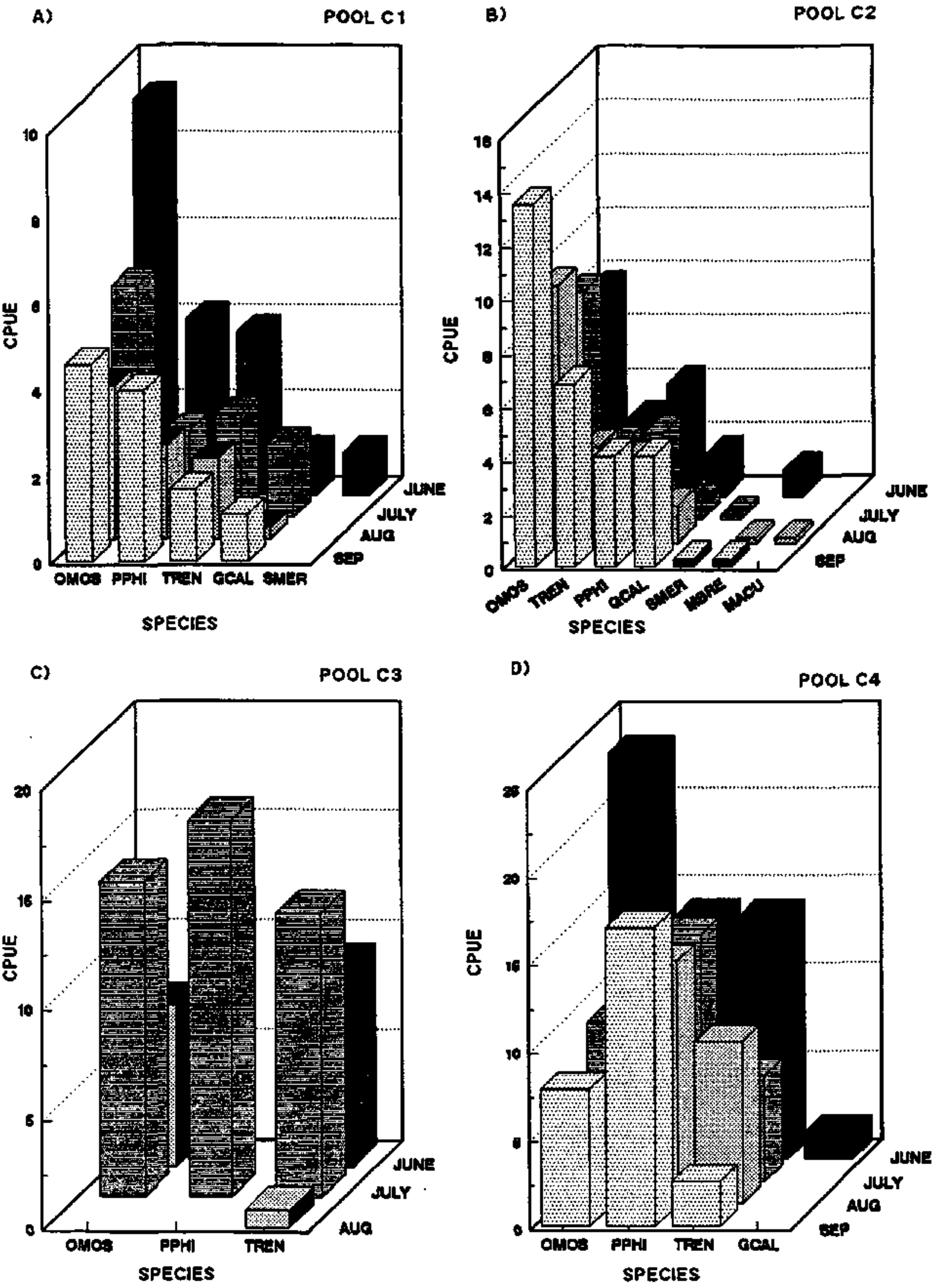


Figure 15: Species composition as a percentage of total catch at the Confluence over four months. Abbreviations as per Table 4a.


A)
POOL C1
CPUE
0
2
4
6
8
10
OMOS
PPHI
TREN
GCAL
SMER
SPECIES
JUNE
JULY
AUG
SEP
B)
POOL C2
CPUE
0
2
4
6
8
10
12
14
16
OMOS
TREN
PPHI
GCAL
SMER
MBRE
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SPECIES
JUNE
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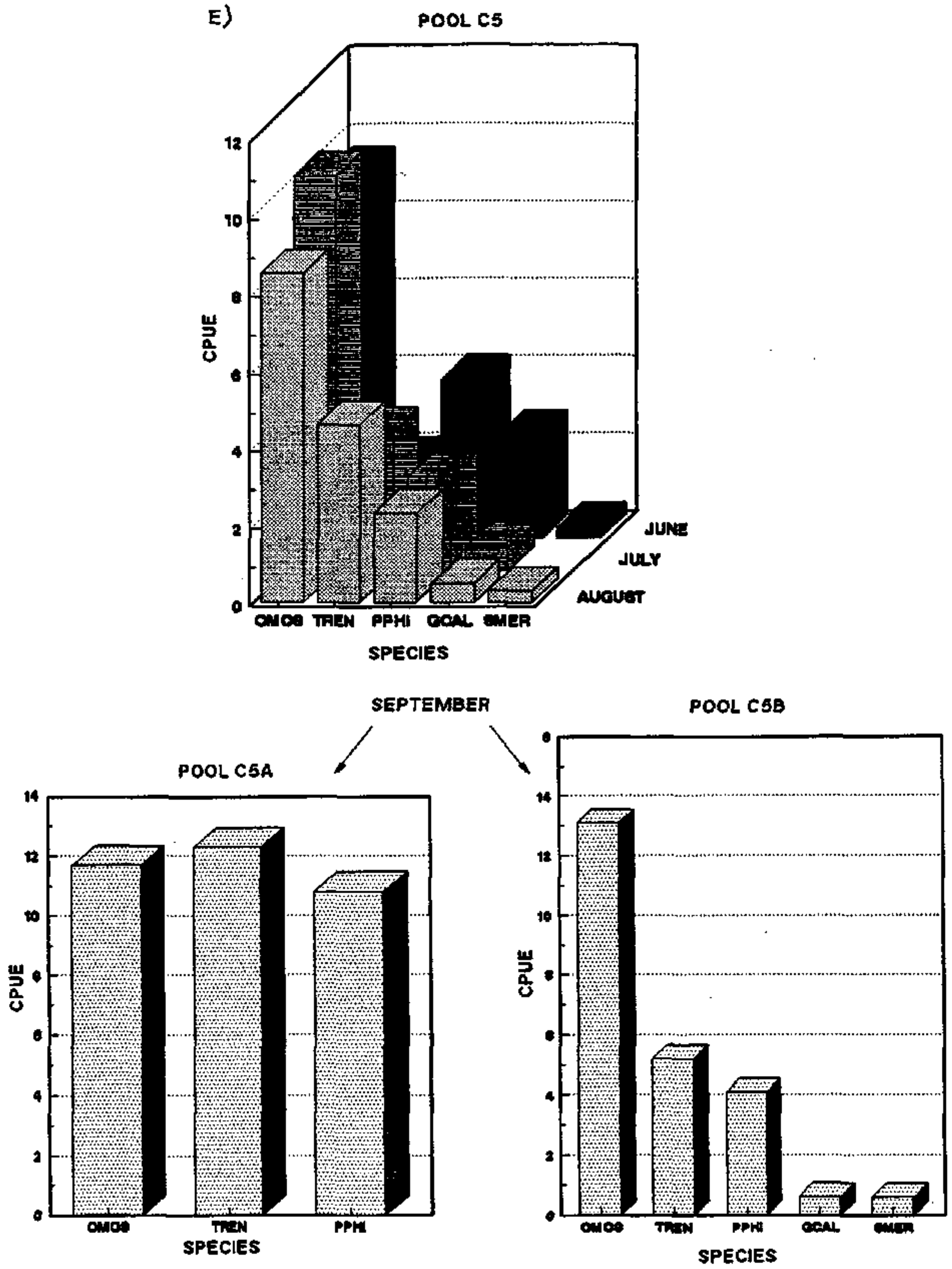

Figure 16: Species composition as a percentage of total catch at the Confluence over four months.

4.3 MACRO-INVERTEBRATES

Only the Mlondozi (Sabie River) and Londolozi (Sand River) sites will be reported on as the river did not cease flowing at the other two sites. Because of the very time consuming process of sorting and identifying invertebrates, the samples from the August field trip have not been identified and will not be included in this report.

4.3.1 HABITATS

A. SANDY SUBSTRATUM

There was little change in number of taxa (NT) at Londolozi or Mlondozi during the monitoring period (Fig. 17). The total number of invertebrates (TNI) at Mlondozi declined sharply during July, but recovered slightly thereafter (Fig. 17(A)). At Londolozi, TNI increased over the whole monitoring period (Fig. 17(B)). Very few Ephemeroptera were present in the sandy substratum at the early stages of the monitoring period, and the few baetids and caenids present disappeared completely as the drought progressed (App. III, Table 1). Chironomids increased considerably in the Sand River (Londolozi) as the drought progressed. The opposite occurred in the Sabie River (Mlondozi), with chironomid numbers decreasing sharply. Corixids increased during the early stage of the drought, but decreased again as drought conditions intensified in the Sand River. Lumbriculid worms at Londolozi increased markedly as the drought intensified and water levels dropped. (Refer to App. III, Table 1).

B. WATER COLUMN

At both sampling sites, NT increased throughout the study period (Fig. 18). TNI increased at both sites until July, whereafter it continued to increase at Londolozi while dropping slightly at Mlondozi (Fig. 18). The only noticeable trend in the water column was the sharp increase in numbers of Copepoda at both the Sabie and Sand River sites (App. III, Table 1).

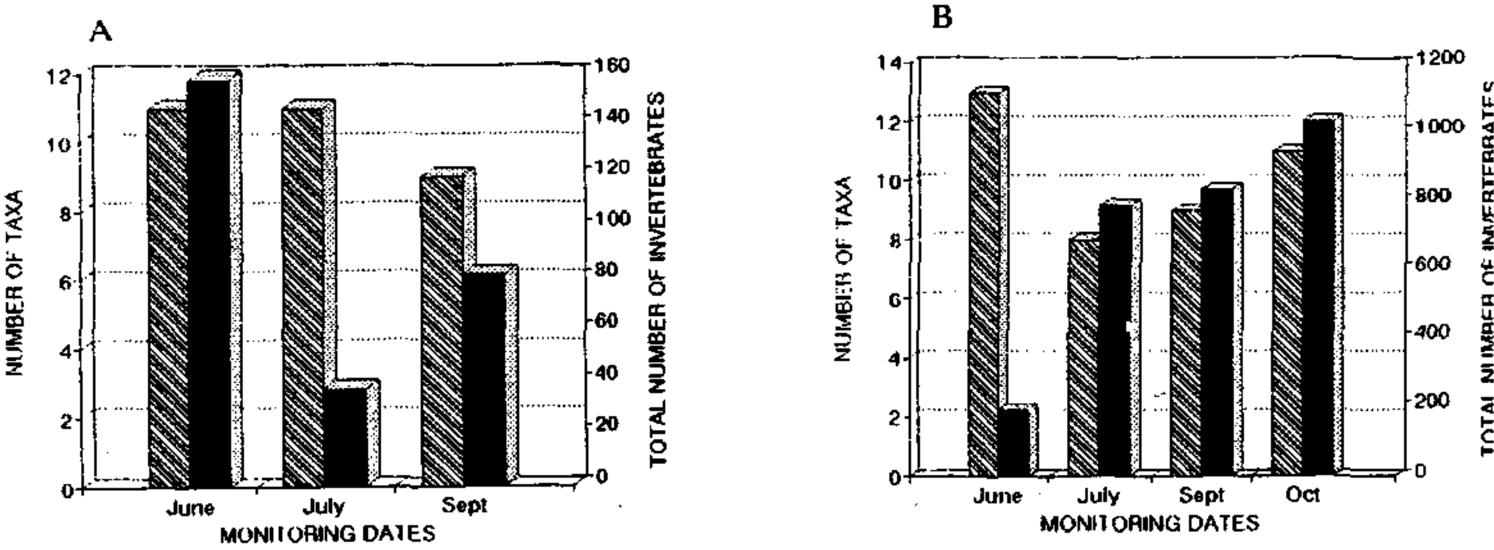

Figure 17: Number of taxa and total number of invertebrates in the sandy substrata at (A) Mlondozi, and (B) Londolozi from June 1992 to September 1992.

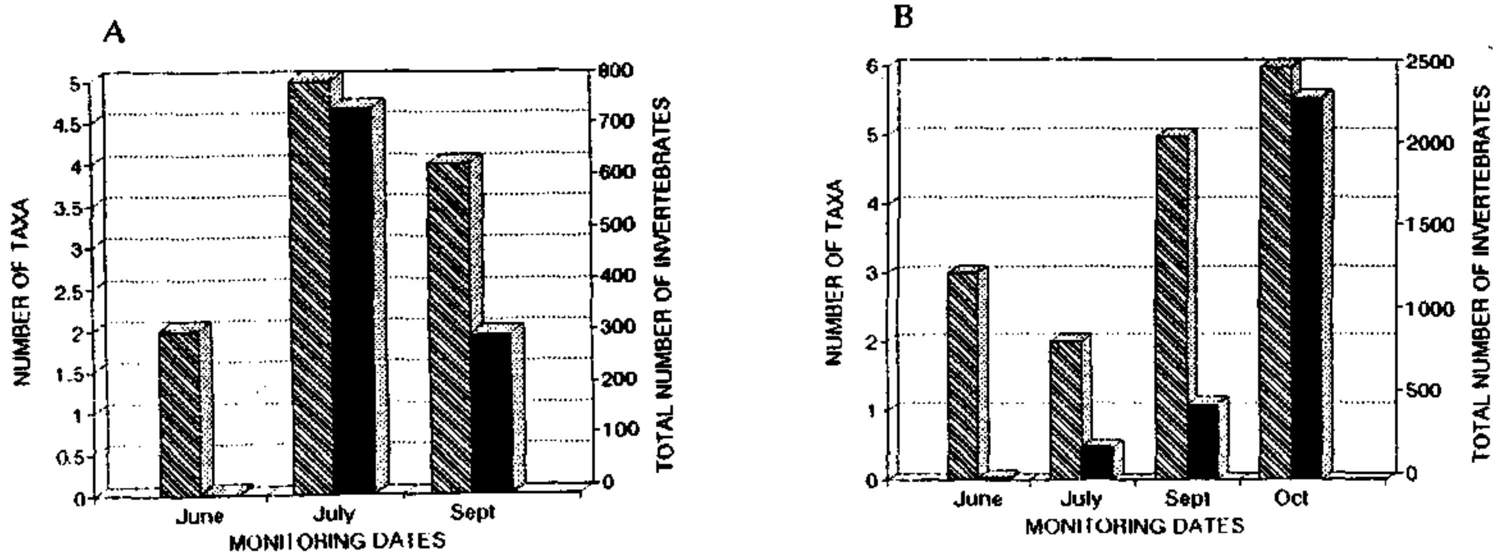

Figure 18: Number of taxa and total number of invertebrates in the water column at (A) Mlondozi, and (B) Londolozi from June 1992 to September 1992.

C. *VEGETATION*

At Londolozi there was not much change in NT throughout the study period, while at Mlondozi, NT had decreased slightly by July but recovered by September (Fig. 19). There was an increase in TNI at Londolozi in July and at Mlondozi, TNI increased throughout the study period (Fig. 19). Ephemeropterans were well represented in this habitat with numbers of caenids peaking halfway through the study period (App. III, Table 2). Centroptilium and the *Cloeon* complex were prevalent to the end of the monitoring period wherever vegetation was available. Trichoptera, although represented early in the drought, disappeared completely in the later stages. Chironomidae, Mollusca, Ostracoda, Cladocera, Copepoda and Hirudinea all showed marked increases in numbers as conditions deteriorated. (Refer to App. III, Table 2).

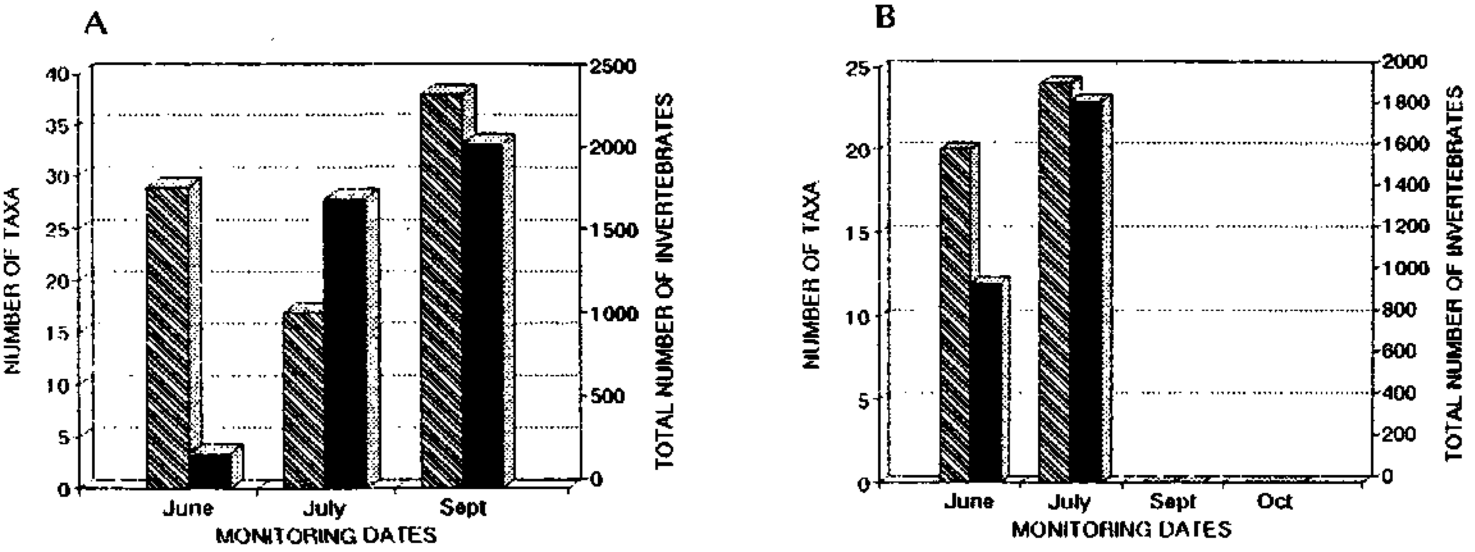

Figure 19: Number of taxa and total number of invertebrates in the emergent vegetation at (A) Mlondozi, and (B) Londolozi from June 1992 to September 1992.

D. RIFFLE

As flow ceased at a very early stage of the monitoring programme, limited data were available for interpretation. At Londolozi a sharp decrease in both NT and TNI could be seen before pools dried up (Fig. 20). Most Ephemeroptera and Trichoptera had decreased in number, although a few individuals were found under wet rocks and last sections of riffle (App. III, Table 2). The polymitarcid mayfly (*Povilla*) appeared as habitat disappeared. Simulidae and Chironomidae numbers decreased strongly as riffles dried up and habitat was lost (App. *III*, Table 2).

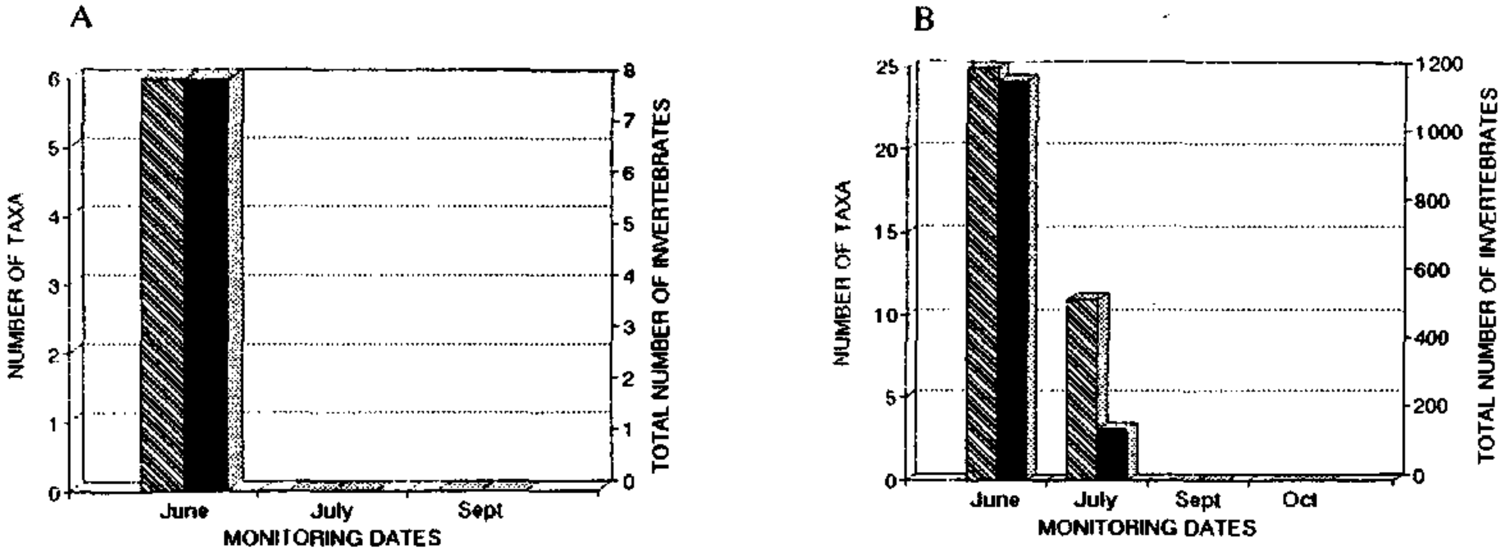

Figure 20: Number of taxa and total number of invertebrates in the riffle at (A) Mlondozi, and (B) Londolozi from June 1992 to September 1992.

E. BEDROCK GULLIES

NT decreased throughout the study period at Londolozi while at Mlondozi, these numbers did not change much (Fig. 21). At both sites, TNI peaked in July and declined thereafter (Fig. 21). This habitat was also marked by the general disappearance of Ephemeroptera in the early stages after cessation of flow, with the exception of *Centroptilium* (Baetidae)(App. III, Table 2). Corixid numbers increased and peaked halfway through the drought and

Chironomidae showed a similar peak. Copepoda and Cladocera numbers also peaked strongly at about the same time, with the ostracods and Hirudinea (Sand River) increasing throughout the drought. (Refer to App. III, Table 2).

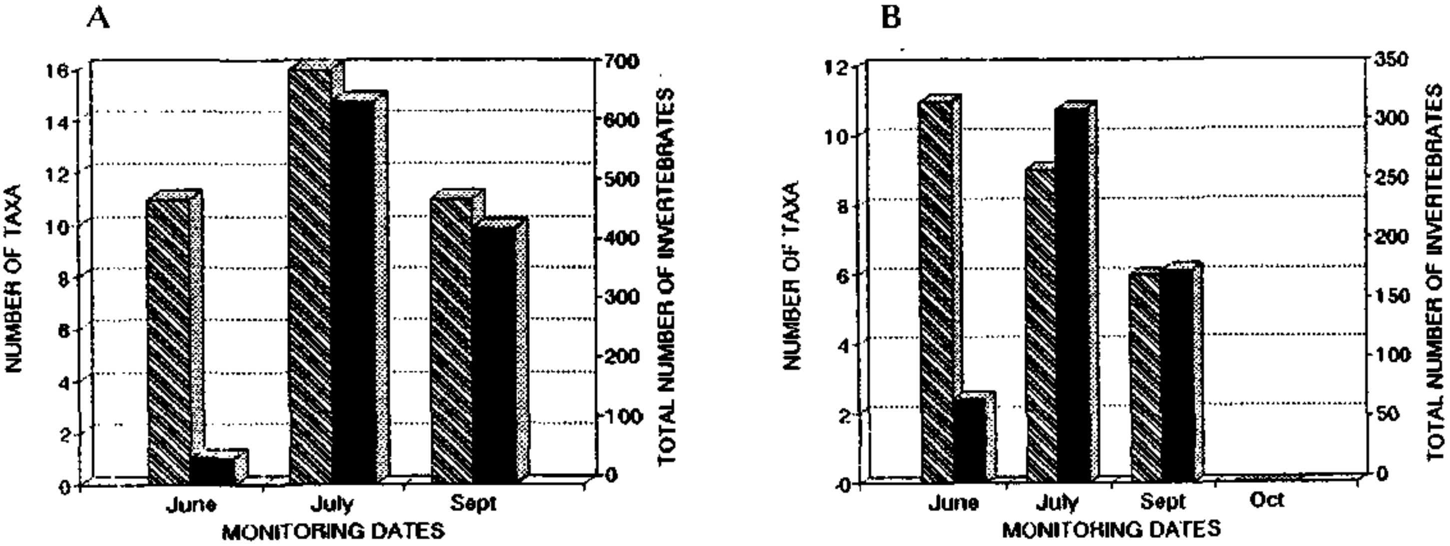

Figure 21: Number of taxa and total number of invertebrates in the bedrock gullies at (A) Mlondozi, and (B) Londolozi from June 1992 to September 1992.

F. POOLS

(1) Londolozi

■ POOL L6A

A strong reduction in the number of taxa (NT) and total number of invertebrates (TNI) occurred in the remnants of the riffle (mainly wet rocks) (Fig. 22(A)) and was accompanied by the appearance of the Polymitarcid mayfly, Povilla (App. III, Table 3). No profound changes in pool chemistry were recorded, as the pool dried up rapidly (App. I, Tables 1-8).

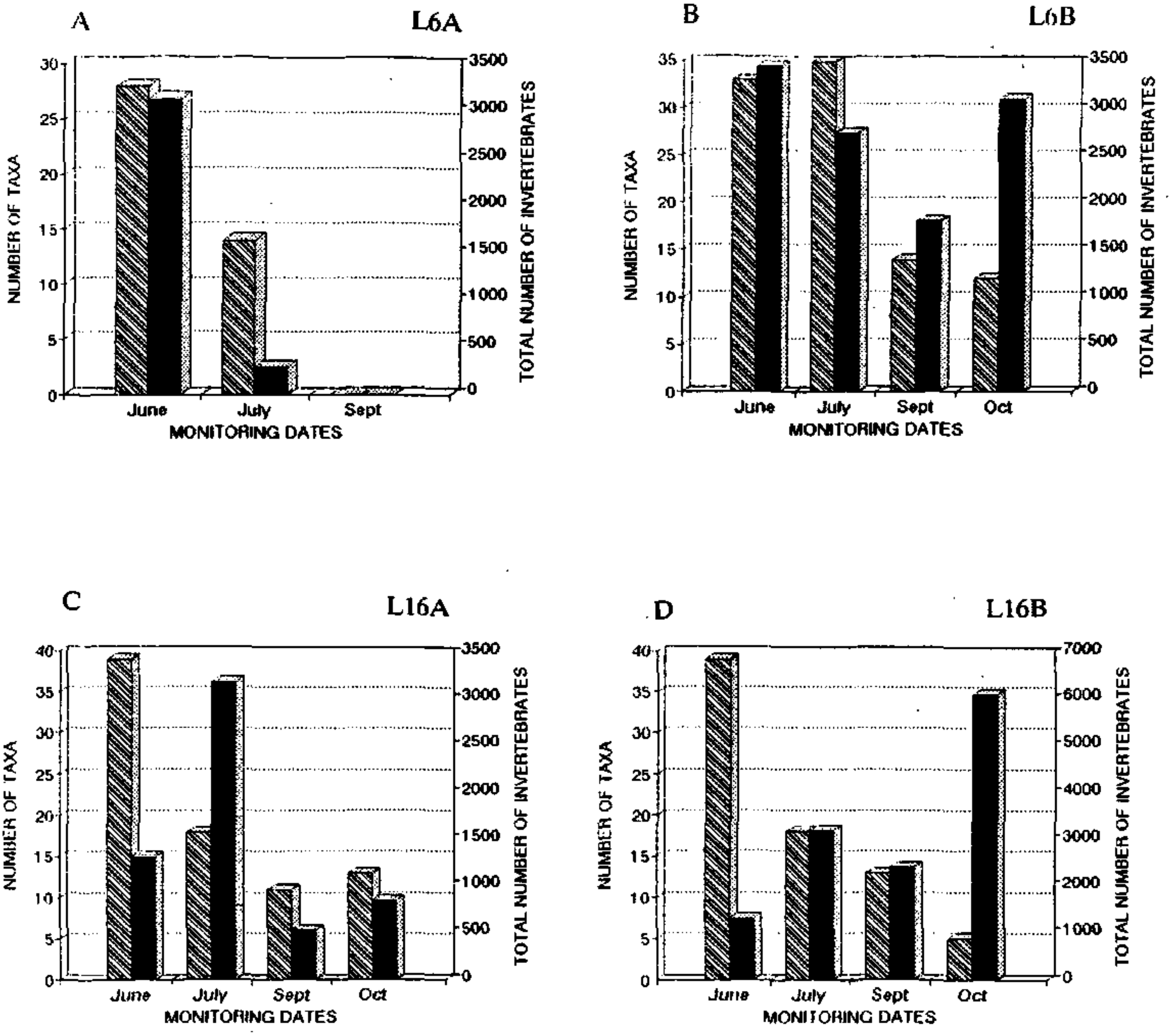

Figure 22: Number of taxa and total number of invertebrates in pools L6A(A), L6B(B), L16A(C), L16B(D), at Londolozi (June 1992 to September 1992).

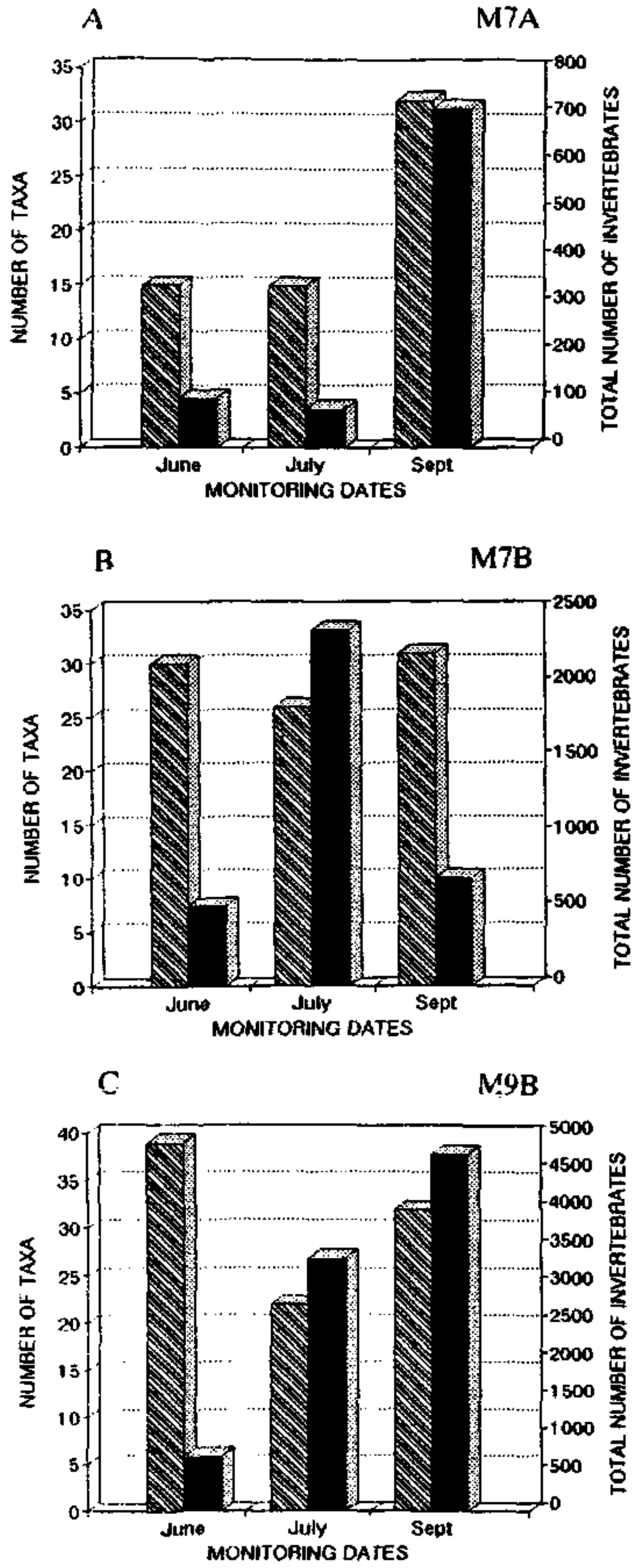

Figure 23: Number of taxa and total number of invertebrates in pools M7A(A), M7B(B) and M9B(C) at Mlondozi. (June 1992 to September 1992).

■ POOL L6B

There was a general reduction in TNI up to September, followed by a substantial increase in October (Fig. 22(B)). This was due to large numbers of Cladocera present (App. III, Table 4). This trend was not, however, reflected in NT. Number of taxa showed an initial increase followed by a dramatic decrease after July, 1992 (Fig. 22(B)). Chironomid numbers increased sharply over time in the sandy substratum while decreasing in the other habitats. The Baetid mayflies disappeared completely after the riffle and vegetation habitats were lost and did not utilise the other habitats as refuge. (Refer to App. III, Table 4). Conductivity increased while volume decreased dramatically during the study period (App. I, Tables 1 & 3).

■ POOL L16A

A general peak in TNI and NT was evident over the first two sampling periods. A severe reduction in both then occurred over the following months (Fig. 22(C)). Hirudinea and Hydracarina numbers increased over time, with Chironomids, Corixids and Copepods following the general trend of NT. Ephemeroptera and Trichoptera disappeared completely after July when the riffle and vegetation habitats were lost. Povilla made a brief appearance in the remnants of the riffle showing an opportunistic colonization of this habitat. (App. III, Table 5). Turbidity, conductivity and temperature showed a general increase over the study period but a very marked increase between July and September concurrent with a shrinking of pool size (App. I, Table 1).

■ POOL L16B

Although a general increase in TNI over the study period was noted, this again coincided with a sharp decrease in NT over the same period (Fig. 22(D)). The same trend seen in pool L16A was displayed, with Mayflies and Caddisflies disappearing after July when vegetation habitat was lost (App. III, Table 6), and turbidity, conductivity, oxygen and temperature showed a sharp increase (Fig.4).

(2) Mlondozi

■ POOL M7A

Prior to September, TNI and NT were very low but showed a marked increase after this time (Fig. 23(A)). Similarly, no Ephemeroptera or Trichoptera were found in the riffle or vegetation before September. After July, a number of Mayflies of the Chloen complex were present in the vegetation (App. III, Table 7). The only chemical parameters which changed significantly were oxygen content, which decreased dramatically after July and pool volume, which decreased steadily over the study period (App. I, Table 9 & 10).

■ POOL M7B

NT was reduced slightly before September with a concomitant increase in TNI. After July, both NT and TNI returned to their original state (Fig. 23(B)). The riffle disappeared very early in the study period. A few Ephemeroptera and Trichoptera were present in the other habitats (App. III, Table 8). These numbers decreased before September and mostly did not reappear. Baetids from the Cloeon complex did, however, appear after July. Chironomid numbers decreased until September and thereafter showed a marked increase. Both Cladocerans and Copepods were present before September but disappeared thereafter. (Refer to App. III, Table 8). Chemistry of this pool was very similar to that of Pool M7A (App I, Tables 9-18).

■ POOL M9B

TNI increased strongly over the study period while NT decreased until September but recovered rapidly thereafter (Fig. 23(C)). Centroptilium and mayflies of the Cloeon complex were the only Ephemeropterans that recolonized after July (App. III, Table 9). All other Ephemeroptera and Trichoptera either disappeared or were present in very low numbers after July. Diptera, copepods and cladocerans were again present in large numbers after July. (Refer to App. III, Table 9). Increased turbidity and temperature accompanied by a decrease in oxygen, constituted the major pool changes during the study period (App. I, Tables 9-16).

Plate 1: The appearance of two exposed pools at Londolozi during the 1992 drought. Photographs show (A) the offstream Pool L2B for May, (B) September and (C) October. Note the dense algal growth in all months and recent guano surrounding Pool L2B in September. The instream Pool L6B is shown for the same period, (D) May, (E) September and in (F) October, where the pool still affords a degree of depth and cover (provided by the boulder).

Plate 2: The appearance of four instream pools at Londolozi during the 1992 drought. The development of the Pool L16 series is shown for (A) July (B) September and (C) October. Additional pools shown include Pool L11 (D), L15A (E) and L17 (F). Pool L16 is exposed whereas the remaining pools are shaded in a deep wooded gulley with Pool L11 being almost totally shaded. All shaded pools were characterised by organic debris.

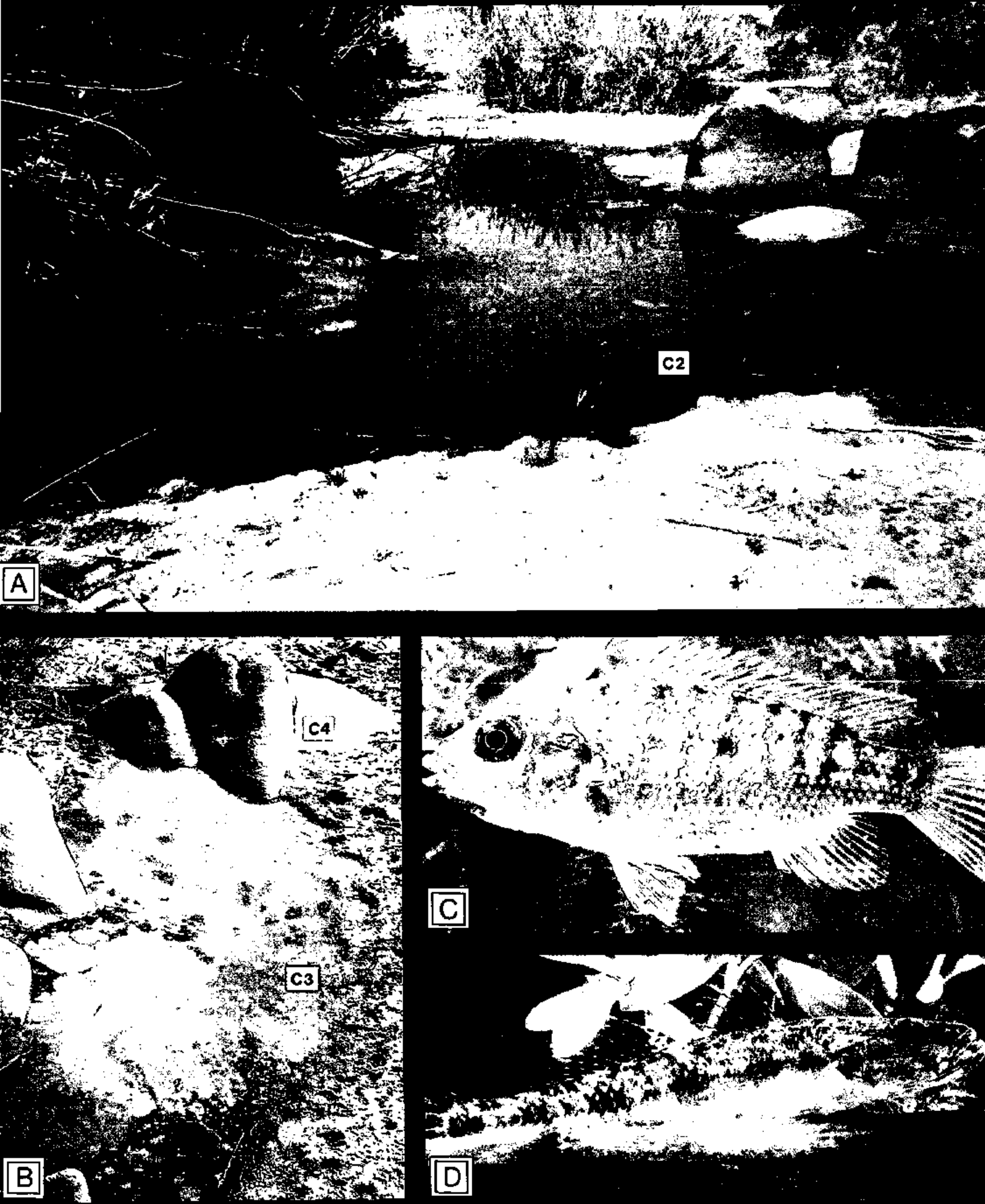

Plate 3: The stable pools at the Confluence showing (A) C2 and (B) pools C3 and C4 for August, 1992. Water percolating from the main channel through the sandy bed linked the pools throughout the drought. The Mozambique tilapia O.mossambicus (C), and The River goby G.callidus (D) were two species that bred in pools over the study period.

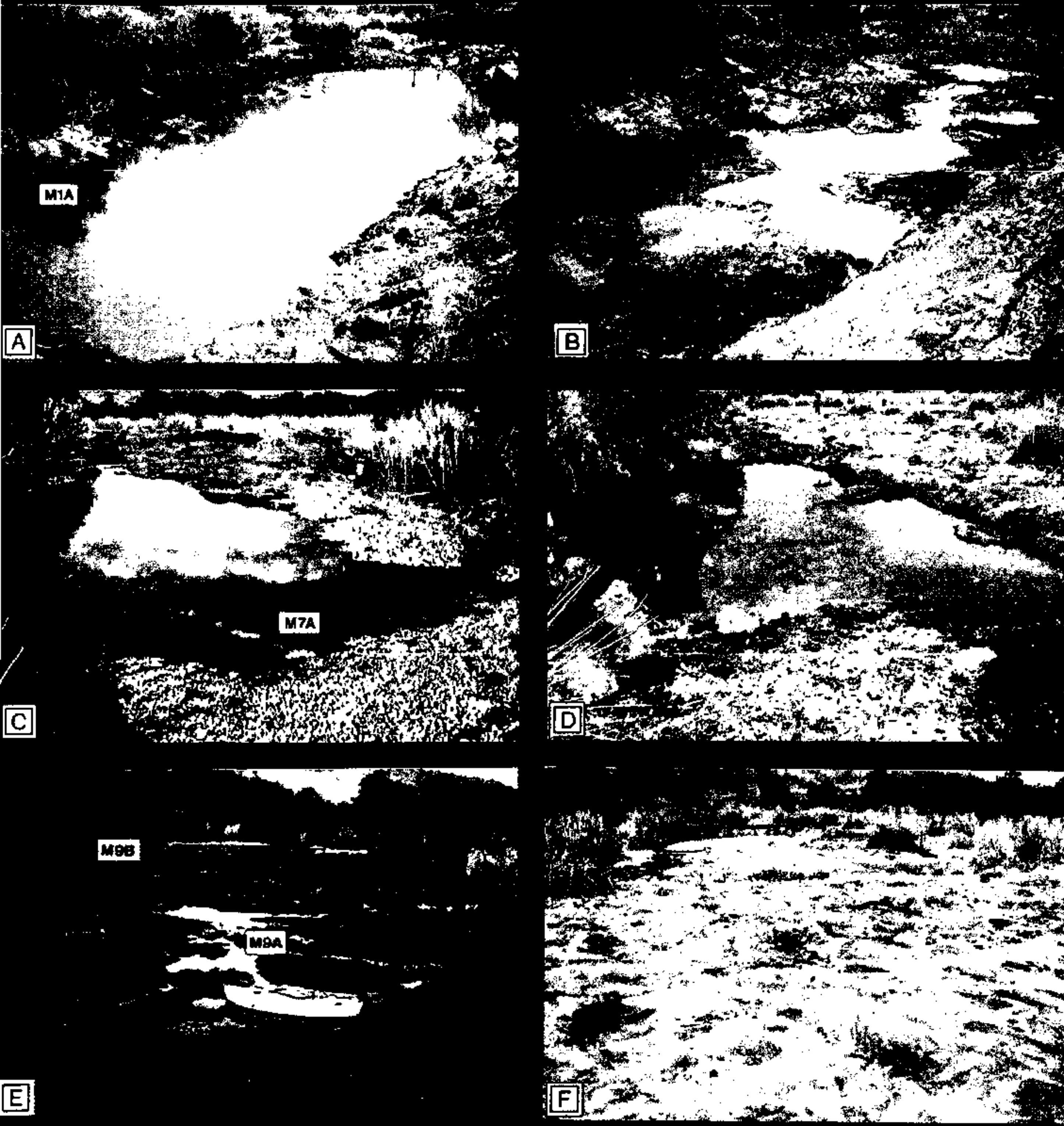

Plate 4: The appearance of three pools at M londozi over the 1992 drought. Pool M1A was situated in the mouth of the Molondozi, a tributary of the Sabie river and is shown for (A) August and (B) September. Pool M7A shown in (C) May and (D) September, and Pools M9A and M9B shown in (E) May and (F) September, lie in a braided channel of the Sabie river. Note that Pool M1A is silt-laden, and the early <u>Opistia</u> cover in Pool M7A in May.

5. DISCUSSION

5.1 WATER CHEMISTRY

Water quality parameters play an important role in characterising the availability and suitability of habitat for aquatic fauna. Coincident relationships between individual variables across sites demonstrated consistent trends.

Oxygen concentrations correlated with a number of variables. Of particular interest to the ensuing arguments regarding consistently high levels of oxygen found in this study, are the data from July that indicate a negative relationship between overhead cover and oxygen. Such results were not anticipated for June since pools were only just isolating and hence insufficient time had passed for the development of this relationship. By August, shaded pools had all but disappeared and no further correlations were obtained. This relationship was most apparent at Londolozi with a distinct suite of exposed and shaded pools, producing highly significant results that were paralleled at Mlondozi. The Confluence pools possessed no distinctly shaded or exposed pools and hence no clear relationship was expected.

Oxygen levels in pools reflected an intimate feedback between solar radiation and algal growth. Pools high in oxygen showed a positive relationship with suspended organic material which in turn correlated strongly with TSS and turbidity; these factors probably reflecting increased algal growth. A strong positive relationship was demonstrated between TSS and turbidity. Both of these predominantly comprise silt and algae.

The data also suggested that oxygen levels would increase as temperature increased. This may be explained by higher temperatures favouring greater algal growth and hence greater daytime oxygen production (see following discussion). However, if the sites had been characterised by high leaf litter, this trend would be reversed since higher temperatures would have resulted in greater microbial activity and decomposition, with subsequent conditions of deoxygenation. Spatially, higher temperatures generally indicated greater exposure of pools which in turn signified greater algal growth and hence increased oxygen levels. The positive correlation between oxygen and percentage organics is probably a reflection of this process.

On first inspection, the apparent relationship between conductivity and oxygen levels (and conductivity with temperature, TSS and turbidity) is erroneous since no plausible explanation for this is evident (B.Davies, J.Day, Freshwater Research Unit, University of Cape Town, *pers. comm.*). However, results for conductivity were frequently repeated both temporally and spatially and beg further explanation. An increase in conductivity over time characterised all the pools independently, as a result of progressive evaporation. As explained above TSS, turbidity, oxygen and temperature are intimately related and conductivity is related to each of these. It would appear therefore that conductivity is a relatively good measure of the time a pool has been isolated. Increasing isolation generally signifies increasing oxygen levels, increasing temperatures and increasing TSS. When all sites for all months were considered in conjunction, conductivity was highly significantly correlated with temperature and oxygen.

Turbidity and volume, and TSS and volume seem to reflect unlikely correlations for Mlondozi. Here two distinct groups of pools existed which would be characterised by different conditions of turbidity and TSS:

1) a series of large pools in the mouth of the ephemeral Mlondozi, filled at floods and hence silt-laden, and

2) a series of instream pools with low silt loads

van Veelen and Swart (1992) recognised the need to develop a multivalue criteria to water quality assessment, and adopted a number of objectives in this respect. These were a) NOEL ("no observed effect level"), being that value of a variable that should ideally be achieved or maintained, and b) MLA ("maximum level of acceptability"), being that value that should not be exceeded. Due to the paucity of tolerance limits of species in South Africa, setting values as guidelines is difficult and obviously therefore iterative. Under drought conditions, values of water quality levels may be exceeded, but the length of time is of utmost importance. Therefore it is essential that the use of these levels in such a study is done so with caution. It is of interest however, to examine how pool values compared to these guidelines.

In the case of pH, the alkaline MLA values (6 - 8.4) were frequently exceeded at Londolozi (7 - 9.8) and Mlondozi (6.8 - 9.3). The marginally higher pH values found in the Londolozi pools at the start of the programme appear to be consistent with conclusions drawn by van Veelen (1990) that the Sand River is slightly more alkaline than the Sabie River.

The maximum MLA value for conductivity (60 mSm^{-1} or 600 μScm-1) was exceeded toward the end of the drought when environmental conditions in pools were extreme with regard to most variables.

Temperature MLA values (8°C - 25°C) were exceeded after August but it is believed that the lowveld assemblage is capable of surviving higher temperatures. The minimum temperature recorded was 8.5°C. This highlights the importance of developing criteria that take into account the zonation of the river since these MLA temperature values are potentially more appropriate for the middle-veld zone.

Again, turbidity MLA values (8 - 20 NTU) were exceeded at Londolozi and the Confluence, but not at Mlondozi. Generally, the Sand River is more turbid than the Sabie due to upstream land use practices and the maximum value is possibly marginally low for the Sand River.

Most levels of SRP were relatively low in all pools. Higher levels were noted in Pool L2B and in L11 in June. The median levels reported by van Veelen (1990) for PO_4 in the Sabie River is 10 μgl^{-1}.

Nutrient levels in some pools (e.g. L1B1 and L2B) in the latter months were extremely high. Median ammonium concentrations for the Sabie River were reported to be 0.01 mgl^{-1} (Moore *et al.*, 1991). These values should be treated as relative rather than absolute values (Day, *pers comm.*)

5.2 FISH

5.2.1 FACTORS INFLUENCING SPECIES DISTRIBUTION AND ABUNDANCE IN REFUGE POOLS

In considering the formation of pools, a number of factors have been highlighted as influencing the distribution of species in isolating pools. Once isolated, fish are forced into potentially deleterious conditions of diminishing volumes, fluctuating environmental variables and increased risks of predation and disease. A suite of physical and chemical variables define pools as "poor" or "good" quality refuges. Superimposed on this is a species inherent capacity to tolerate certain conditions.

A. WATER QUALITY

The above discussion elucidated the complex interaction between water quality variables over time, and indicated a changing physico-chemical environment to which aquatic biota were subjected.

One trend inconsistent with that of other studies that considered the effects of droughts, was that of stable or increasing oxygen over time.

The general paradigm holds that oxygen deficiency commonly characterizes the progression of the dry season in shallow and stagnant freshwaters of tropical regions (Kramer *et al*, 1978).

Chapman and Kramer (1991 (b)) report that oxygen concentrations of an intermittent tropical stream in Costa Rica decreased over the dry season, and their study site was characterised by an overall oxygen deficiency. Conditions cited for producing deoxygenation in tropical waters include stagnation, lack of diurnal overturn, shading by forests, large amounts of dead vegetation and the high rate of respiration by microorganisms. They reported very high litter levels in the pools, and pointed to microbial respiration as the main factor contributing to a decline in DO. Likewise, in temperate intermittent streams, autumnal leaf fall is often associated with protracted periods of low oxygen (Larimore *et al.*, 1959).

With few exceptions, low oxygen concentrations were not a widespread characteristic of our pools at the end of the dry season. This may be explained in part by a high proportion of exposed pools and consequently almost no accumulation of litter. As stated by Schlosser (1990), in flowing streams oxygen levels are a balance between respiration, photosynthesis, temperature, volume and turbulence. However, in intermittent flows the resultant low oxygen levels are worsened by high leaf litter and temperatures. In exposed pools, the little organic matter that was noted was generally dung. We propose that an additional and important factor in the pools, was the high levels of algal growth. Chapman & Kramer (1991 (b)) did note that primary production caused a temporary daytime reversal of oxygen concentrations, and it is suggested that in this unshaded sub-tropical system, this was the primary factor accounting for high levels of oxygen. This argument merits a more detailed explanation by considering two pools, L2B (exposed) and L11 (shaded) which both exhibited particularly interesting results (see Fig. 3, and Appendix I, Table).

On initial inspection, L2B visually possessed a number of characteristics that appeared to be unfavourable for fish survival: long-term isolation, massive algal blooms, no overhead cover and constant exposure to solar radiation resulting in high and fluctuating temperatures . However, our results indicate that until September, this pool housed a healthy population of fish and invertebrates. We argue that a number of factors contributed to this:

(1) The substratum of bedrock ensured that unlike some of the other pools, no water was lost due to seepage. All reductions in water volumes were as a result of evaporation which only increased substantially with the onset of the summer season (see Appendix I (Table 1), and Fig. 2).

(2) Secondly, the pool was characterised by a deep section overhung by a bedrock ledge, offering ample cover.

(3) Thirdly, the algal blooms contributed to faunal survival in two ways: a) it provided highly effective cover from terrestrial and aerial predation, and b) it provided a source of oxygen replenishment by acting as an oxygen pump during the day.

Oxygen depletion is a factor frequently cited as being responsible for fish kills, with the exception of those species tolerant of low oxygen levels (Chapman & Kramer, 1991 (a); Larimore *et al.*, 1959; Tramer, 1977). Table 2 (Appendix I) shows that the daytime oxygen readings remained consistently high over four months. Readings taken at sunrise and sunset (Fig. 3) in July illustrate that although oxygen levels decrease substantially at night, the reduction was probably to a level well within tolerable limits.

Initial examination of Pool L11 suggested that this pool would be likely to maintain a healthy assemblage. The pool was relatively deep; both in-pool and off-pool cover was excellent, provided by an undercut bank and overhanging vegetation. The offstream cover suggested that the fluctuations in temperature would be buffered, as well as reducing the effects of aerial predation and initial water quality measurements were "good".

Total CPUE of fish of pool L11 decreased dramatically between July and August. We argue that a number of factors contributed to this demise. Firstly, the pool was well shaded, precluding the development of algae. As discussed above, this acts as an oxygen pump, replenishing low nocturnal levels. Although most chemical variables remained stable, oxygen readings plummeted dramatically in July (Fig. 3). On the evening of the 21st July, large numbers of fish gasping at the surface were visible with two *B.viviparus* mortalities. Overnight oxygen readings were very low (Fig. 3) and clearly illustrate this point. Secondly, three species showed evidence of disease in July (Fig. 9): *L.molybdinus*, *B.marequensis* and *B.trimaculatus*. This evidence, combined with that from physico-chemical analyses, suggest that physiologically stressed fish are more likely to succumb to the onset of disease. Thirdly, terrestrial predation was evident from fish remains near the pool. Finally, the sandy substratum appeared to lead to rapid "leakage", visible in the 80% reduction in pool volume by August.

Chapman & Kramer (1991 (b)) reported huge variations, both spatially and temporally, in oxygen concentrations. Our results tend to support this although this generally tended to mirror the occurrence of exposed or shaded pools.

Since all oxygen levels were high at the outset, no species displayed a direct relationship with oxygen at isolation. Consequently, it is difficult to draw definitive conclusions regarding the role of oxygen in explaining the distribution or persistence of a species. Single individuals of *B.unitaeniatus* and *B.viviparus* were found in pools with 40% oxygen possibly indicating that these individuals were at this limit of tolerance. The barb, *B.viviparus,* did not persist in Pool L2B in October by which stage oxygen had dropped to 25% saturation. Species that persisted under these conditions were *C.gariepinus* and *B.toppini.* In Pool L11, *B.trimaculatus, B.marequensis*, *L.molybdinus* and *T.rendalli* were recorded in oxygen levels of 30%. However, *L.molybdinus, B.marequensis* and to a lesser degree *B.trimaculatus,* showed signs of stress and disease, and were concentrated in a section of the pool with relatively higher local readings. It is suggested that considering low numbers of fish and signs of stress, most species would be unable to withstand such conditions for long periods.

An interesting thesis arose out of a paper presented by Tramer (1977). It was suggested that fish with terminal or dorsal mouths fare better under conditions of oxygen depletion as they are able to come to the surface and supplement their oxygen demand by surface respiration. Kramer and Mehegan (1981) found that poeciliids inhabiting highly seasonal streams in Costa Rica meet their oxygen demands in part through surface aquatic respiration. In addition hypoxia reduces feeding and growth in these fish. Thus, those fish with ventral mouths (generally reflecting feeding mechanisms) found in our system would be at a disadvantage in such conditions of extremely low oxygen ; namely the barbs *B.marequensis, B.unitaeniatus,* the catlet *C.paratus,* the labeos' *L.molybdinus* and *L.rosae,* the mormyrid *P.catostoma* and the squeaker *S.zambezensis.*

Very little data exist regarding the ranges of temperatures or tolerances in which species peculiar to this system are found, although the zonation of species into cold- and warmwater assemblages is receiving considerable focus in the Sabie River Project. All of the sites selected for the Drought Programme fall into the warmwater zone as defined by one of the authors of this report (Weeks) and, hence, resident species would be expected to tolerate relatively high temperatures. None of the temperatures recorded appeared to be excessive; indeed fish have been kept in higher temperatures in the laboratory of this project. However, the shaded Pool L11 did exhibit relatively low temperatures of 8.5°C in June, 1992.

Daily variations in temperature were not recorded, although it has been reported that pools exposed to direct sunlight may vary by as much as 13°C-18°C each day, while shaded small forest streams as little as 2°C (Kramer *et al.*, 1978). At the Confluence, temperatures decreased during July; most pools were characterised by an increase in temperature. This can be explained by an increase in flow levels in the main channel which were reflected in increased pool levels.

The disappearance of *T.rendalli* from a number of pools at Londolozi was of particular interest. Whitfield and Blaber (1976) showed that the distribution of *T.rendalli* is governed by temperature and salinity. Although salinity was not measured, conductivity would in part reflect increasing salinities. Pools at Londolozi were generally characterised by increasing salinity, whilst those at Mlondozi in which the populations of *T.rendalli* were more stable, remained relatively stable.

With specific reference to the mormyrids, both species *P.catostoma* and *M.macrolepidotus* disappeared simultaneously. Kok (1980) noted the absence of mormyrids from two pans in the Pongolo Floodplain and suggested that their disappearance may be explained by high conductivities found in these pans (700μs cm^{-1}); they were found in pans with 300μs cm^{-1}. He proposed that high conductivities would inhibit their ability to electrolocate, not only in general surroundings, but also prey items. In general, our pools were characterised by increasing conductivities and therefore this would appear to be a plausible explanation for their disappearance. The highest conductivities in which we recorded mormyrids was 590μs cm^{-1}.

B. CHANGING PHYSICAL HABITAT

In the area of continuous flow at the Confluence, the water chemistry indicated a fairly stable environment throughout the four month drought period. However, the physical habitat changed as a function of progressively declining flows. This was more evident in riffle areas, as velocities and depth decreased. In general, both the run and riffle areas maintained a constant species diversity, although abundances of most species had declined by September. What is interesting is that as the abundance of *C.swierstrai* declined in the run in August, a concomitant increase was noted in the riffle area, indicating that this species was moving into riffle areas under conditions of decreasing flow. The absence of *B.viviparus* from the run in July is probably the result of sampling difficulties, as this species occurs in shoals and may be missed.

With time, the run shifted from domination by *T.rendalli* to that of *B.viviparus*. The riffle area, initially dominated by *C.paratus* was later dominated by *B.marequensis*.

At pool isolation, some species such as the abundant and generalist *B.viviparus* were widespread in all pool types. The other extreme is shown by the catlet *C.paratus,* which was restricted to pools that lay directly below riffles. This indicates that this species remained in the riffle area until flow ceased and then moved into the only remaining option. This species has been reported from stationary pools (Bell-Cross, 1988) and has survived such conditions.

Depth and volume most consistently explained the spatial distribution of fish species in different pools. Generally, these variables underscored the distribution of highly motile species such as the minnows and cyprinids, particularly the open water species. Depth largely explains the persistence of a pool; a shallow but voluminous pool such as the L16 disappeared rapidly, whereas the deep Pool L6B persisted for the entire study period. Clearly, this is dependent on the nature of the substratum and surface area.

What is surprising is that neither depth nor volume appeared to account for the distribution of the larger labeos' which were widespread. In fact, at pool isolation they were found in some very shallow pools. However, on closer inspection, depth and volume seemed to have little influence on sedentary species in general. Although difficult to quantify, these species were consistently found to be associated with in-pool cover such as undercut ledges or boulders. This may in part reflect their feeding requirements; *L.molybdinus* for example, is reported to subsist on algae and animals attached to rocks (Bell-Cross, 1988). In-pool cover would also confer the advantage of reduced predation.

Increased in-pool cover also delimited pools as complex heterogenous habitats and generally allowed a greater degree of species diversity. This was illustrated by the fact that, in general terms, larger pools housed a more diverse species assemblage at isolation (see Figs. 6 & 13), with notable exceptions; for example, Pools L13 and M8 which comprised the same number of species as larger counterparts. In physical terms both these pools were shallow but complex, with a high proportion of in-pool cover as cobble or boulder. This highlights the importance of habitat heterogeneity at isolation. Fausch and Bramblett (1991) found that species composition and abundance remained relatively constant in deep complex pools but changed markedly in shallow simple pools.

After isolation, the survival of pools as physical entities largely determined the survival of species. The rate at which this happened was dependent on the physical characteristics of the pools in question. Pools that did not fare well in terms of persistence and species assemblage ("poor quality" refuges) were generally either (1) small and simply evaporated, or (2) comprised sandy substrata that led to seepage from the pool, or (3) shaded pools, characterised by rapidly increasing hypoxia. Fish that were found in small pools were either specialist species such as *C.paratus*, which were trapped as the riffles disappeared, or were there because of physical characteristics such as cover. At times, a particular characteristic that appeared to be favourable, such as cover, actually resulted in fish being trapped in "poor quality" refuges, generally characterised by shallow depth. This was particularly evident in the case of the Labeos'.

Merron and LaLouviere (1987) identified certain Pongolo Floodplain pans as important refuges for fish stocks. Consistent with this, certain pools in this study persisted for longer periods and housed a more stable population in latter months, namely the Confluence pools, Pool L6B, L2B, M9B and the L16 series. The latter two pools persisted as a function of size, being the two largest pools. Neither pool was particularly deep in October or housed a very varied suite of species. The Confluence pools persisted as a function of main channel flow and cessation of flow would have resulted in the extinction of these pools.

The rate of decline in pool volume of L6B was relatively slower than most other pools. Although the surface area was small in October, it still contained a deep area protected by a large undercut bank. Furthermore, its chemistry was indicative of a stable environment and it still housed 12 of the original 16 species. As such, L6B could be defined as the most successful pool.

The importance of centres of inocula has been outlined in a number of studies. Canton *et al.* (1984) found that although fish population densities were significantly reduced by drought, increased abundance after resumption of normal discharge was probably as a results of migration from a refuge lake population. It is suggested that pools of a similar nature to Pool L6B will provide the recovery stocks for the Sand system as well as upstream migration from the Sabie River. Offstream pools such as Pool L2B are probably also very important in the dry season, but as is discussed may not endure protracted droughts.

Pool L2B at Londolozi offered the only opportunity to look at the effects of long term isolation, i.e. longer than five months, and is probably also a good indication of the fate of fish in hippo pools in the area.

Our results indicate that this pool housed a stable and complex species assemblage until September, when the population crashed. Considering the physico-chemistry, this would appear to be explained by two factors.
(1) One was quite simply an enormous reduction in pool volume. Although this obviously characterised all persistent pools, such as L6B and M9B; the extremely high silt loads, resulted in the pool being reduced to a concentrated sludge. This was as a direct consequence of nature of floods flushing this pool; very high flows of the Sand River are typified by high silt loads. This silt, normally washed out of instream pools, was deposited in these offstream pools and became detrimental at very low water levels. Such processes were mirrored in the large Pool M1A. The high turbidities precluded the development of algae at this stage, and oxygen levels subsequently declined dramatically. Of the two extant fish species in October, *C.gariepinus* is known to tolerate conditions of high turbidity (Bruton, 1979). However, small individuals of *B.toppini* were seen on the surface at the edges of the pool; the only free water remaining at this point. (2) The other variable that increased dramatically in September and October was ammonia, and although actual readings should be interpreted with caution, it is evident that the levels of ammonia increased enormously relative to other pools.

In summary, a suite of abiotic variables characterise and define pools differentially in terms of their value as refuges. When discussing the value of pools as refuges, Larimore *et al.*(1959) pointed out that the reduction of aquatic habitat was related to the character of the stream basin, the gradient, the ratio of riffle area to pool, and the proportion of the total volume of water that was lost. Generally, the lowveld fish assemblage is robust and the survival of fish in our system was dependent primarily on the survival of the pools.

5.2.2 DISEASE AND PREDATION

The effects of disease first became evident in July in certain pools and particular species appeared to be particularly susceptible to disease. These pools were generally clear with little floating or benthic algae. Species in which disease was noted were the large scale yellowfish, *B.marequensis,* the plumbeous labeo *L.molybdinus,* the threespot barb, *B.trimaculatus* and one individual of the bowstripe barb, *B.viviparus*. The latter three species all feed on benthic algae and associated invertebrates (Bell-Cross, 1988). The lack of benthic algae in these pools suggests that the onset of disease could be explained by lack of food and the concomitant physiological stress being placed on resident, sensitive fish. The incidence of disease in August and September in L6B is more difficult to explain, but once again *L.molybdinus* showed signs of disease. In addition, disease was also very conspicuous in the mormyrids which were absent after September. Large individuals of *O.mossambicus* were found with scalar fungus at Mlondozi in July.

Without controlled exclusion experiments, the importance of predation is difficult to quantify. However, evidence of terrestrial and aerial predation was noted, particularly around the clearer pools where guano deposits and fish remains on rocks and otter spoor were recorded. Furthermore, in-pool predation in the presence of *C.gariepinus* was likely and, *O.mossambicus* is known to switch to a piscivorous diet under drought conditions, may have increased predation pressure.

5.2.3 BREEDING

All the cichlid species recorded during the drought survey bred during the drought, with the exception of *S.meridianus*.

The tilapia, *O.mossambicus* bred throughout the drought and seemed to be able to exploit most conditions. Bruton & Boltt (1975) demonstrated that *O.mossambicus* breeds at a small size in confined conditions, and we noted an individual breeding at 65mm, in laboratory tanks. It is well-known as non-flood dependent multiple spawner, limited only by temperature (Kok, 1980).

T.rendalli breeding nests were photographed in shallow water at Mkhuhlu (Fig.1) in September within the main channel of the Sabie River. While *T.rendalli* did not breed in isolated pools and succumbed early in pools at Londolozi. Mouthbrooding *P.philander* were record within healthy isolated pools throughout the drought.

The only non cichlid that definitely breed within isolated pools during the drought was *G.callidus*. Small juveniles were present at Londolozi where CPUE increases are reflected (Fig.7). Ripe *G.callidus* were found in September and October in Pools L6B, L16A and L16B.

Within the minnows, *B.paludinosus* and *B.toppini* are two species peculiar to the offstream Pool L2B and are likely non-flood dependent spawners. However, the size-frequency distribution of *B.toppini* suggests that the population was composed of only one size class. Nothing is known of the biology of the species (Bell-Cross, 1988) and it was difficult to ascertain the age of this size class although it was quiet small. Numbers of *B.paludinosus* increased in July and the size frequency distribution indicates that a major proportion were sub-adult. Furse (in Crass, 1964) states that sexual maturity is reached at approximately 50mm, and spawning occurs in November and December.

Ripe female *B.viviparus* and *B.trimaculatus* were recorded in October at Londolozi but no breeding in the early part of the drought was noted from size-frequency distributions. These species reach sexual maturity at 40mm and 70mm respectively (Bell-Cross, 1964). It is likely that the size class of both these species were representative of summer breeding with the fish approximately six months old. *B.annectens* individuals were in very poor condition prior to the first rains in November, but had recovered well and were ripe within a month.

5.2.4 OVERALL SPECIES COMPOSITION

The overall trends from this study are consistent with those of Merron & Lalouviere (1987) from the Pongola in which *O.mossambicus* substantially dominated almost all habitats during drought. *O.mossambicus* possesses a wide physiological tolerance and reproductive strategy facilitating its survival in adverse conditions. They exhibit a non-flood dependent breeding with multiple spawning throughout year, limited only by temperature (20°C (Kok 1980); Merron & Lalouviere (1987)) found that *G.giurus* comprised the second most abundant species during the drought. At Mlondozi, *G.callidus* dominated catches in June, but subsequently *T.rendalli* became dominant. The second most abundant species at Londolozi was *B.viviparus*, comprising between 10 and 25% of the catch.

However, although *O.mossambicus* dominated overall catches, closer inspection revealed that shaded pools were never dominated by this species. These pools were alternatively dominated by *M.acutidens*, *B.annectens* or *B.viviparus*. Shaded pools were few and the only valid conclusions arising from this trend is that shaded pools are unlikely to be dominated by *O.mossambicus;* consistent with the theory that this species tends to avoid shaded pools.

Results for *B.annectens*, indicate that volume and particularly depth are important criteria in explaining initial distributions of this species. It was relatively widespread, often accounting for some of the highest CPUE for a pool and persisted in those pools that maintained depths or volumes (eg. Pool L6B and Pool L16). At Mlondozi, their distribution was limited to two large pools, reflecting the trend that minnows are always found in low numbers at this site. Although widespread, this species had disappeared from all remaining pools by October, even those that apparently afforded a relatively stable environment. Although this species survived in tanks in the laboratory, they became thin and never appeared to do very well. Looking at their feeding habits, that of picking food from the bottom, it is suggested that this species may well have starved to death due to diminishing benthic food supplies.

Interestingly, this species was never found in pools of conductivities of over 500 μs cm^{-1}. It was also absent in from Pool L11 in July and Pool L2B in October when oxygen concentrations were very low although the latter case may reflect a sensitivity to the high ammonia levels.

5.2.5 NOTES REGARDING SPECIFIC SPECIES

The threespot barb, *B.trimaculatus* has been recognised in this project as a robust species and persisted in most pools until they dried up. It appeared to tolerate low oxygen concentrations with the exception of the extremely low values found in Pool L11 in August of approximately 10%. It disappeared from pools in which ammonia concentrations were high (L1B1 and L2B) and this may indicate a sensitivity to this variable.

As regards the minnows, it is interesting to note that a suite of minnows disappeared from the Pool L16 series in October. These were *B.annectens, B.trimaculatus, B.eutaenia* and *B.radiatus* . In contrast, the only minnow that persisted in this pool was *B.viviparus.* A conspicuous feature setting this species apart from other minnows in this pool series was its behaviour of shoaling on the edges of pools whilst the other minnows tended to remain in the deeper sections of pans. At a point where predatory pressures were high with minnows, eels and *Clarias* being concentrated in the same microhabitat, these minnows may have been subjected to intense predation which *B.viviparus* avoided in part by congregating in shallow waters.

This study highlighted the fact that *B.viviparus* behaves quite differently from other minnows, and is a very successful species in both lentic and lotic conditions. It was the most abundant of all minnows and ubiquitous in all pool types. It was however, never found in off-stream pools, such as the L2 series. At the division of pools it tended to move into deeper sections. In the L15 series, individuals of this species showed evidence of disease.

The goby *G.callidus* was relatively numerous throughout the study but interestingly, was never found in transient pools at Londolozi, which tended to be shallower than the persistent pools. It disappeared from Pool L11 in July, at a time when the oxygen concentration was low (30%) and the NH_4-N was relatively high. This is corroborated by its disappearance from Pool L2B in September when NH_4-N levels were relatively speaking, extremely high.

The red data species, *S.meridianus* (Skelton, 1987) is only found in the Sabie and Sand Rivers and is therefore of particular interest. This species was found in very low numbers and it is therefore difficult to draw definitive conclusions. Although it persisted throughout the drought, it disappeared from small, shallow pools; infact it was only found in a single deep pool at the end of the drought.

The Silver robber, *M.acutidens* exhibited a highly significant correlation with depth and volume and only persisted in Pool L6B in October. In general, it was never found in transient pools, with the exception of two deep pools, M1E and L13. What is interesting is that although it dominated the catch in Pool L11 in June, it had disappeared a month later. Gaigher (1973) states that this species is unable to withstand deoxygenated conditions and its disappearance from this pool may be as a result of low oxygen concentrations coupled with high NH_4-N levels.

The large-scale yellowfish, *B.marequensis* was never found in off-stream pools and persisted through to October, but only in the deeper Pool L6B. It was still present in the conditions of low oxygen concentrations (approximately 50% at night) and high NH_4-N levels of Pool L11 in July, but was showing signs of extreme stress. At this time, four dead individuals were recorded, and a number of the surviving individuals showed signs of disease. In addition, low levels of light penetration probably precluded the growth of benthic algae (and hence associated invertebrates), a major food source of this species (Crass, 1964; Bell-Cross, 1988). This species was also absent from Pool L6A1 in August at a time when its physico-chemistry indicated a relatively stable environment. The pool was however, shallow and clear, and predation may have accounted for the demise of this species.

In general, the distribution of *O.mossambicus* and *B.viviparus* tended to remain relatively consistent over time. Numbers of *O.mossambicus* tended to increase whilst the numbers of *B.viviparus* decreased substantially after September but with all size-classes being affected. Similarly, populations of *B.toppini* and *B.paludinosus* remained fairly stable until September when there was a noticeable reduction in large individuals.

Results reported by other researchers indicate that a large proportion of fish remain in a particular pool for consecutive years (Chapman and Kramer, 1991(a); Gerking, 1959). Possibly, a number of the characteristically offstream species such as *B.paludinosus* and *B.trimaculatus* were resident in Pool L2B for a number of seasons.

Research by Larimore *et al.*, (1959) led them to conclude that most fish could survive extreme drought conditions, provided that conditions did not reach lethal limits. Caution should be applied in interpreting any of the stated chemistry values as tolerance ranges, since as stated by Whitfield *et al.*, (1981) ranges do not imply tolerance. A number of factors, often synergistic, will determine how long a fish can survive certain regimes.

5.3 MACRO-INVERTEBRATES

5.3.1 *HABITATS*

A. SANDY SUBSTRATUM

At Londolozi, there was not much increase in the number of taxa (NT). The total number of invertebrates (TNI) increased strongly over the study period, due mainly to the increase of Chironomids and other invertebrates (e.g. molluscs and lumbriculid worms) preferring lotic conditions. At both sampling sites, very few Ephemeroptera were present early in the study period due mainly to the disappearance of the riffle habitat at this time. Trichoptera did not use the sandy substratum as a refuge habitat. At Mlondozi, NT was low at the commencement of the study and did not change substantially, but TNI decreased prior to flushing of the pools and recovered to some extent after this event. The sandy substratum habitat did not show a very high species diversity and also did not appear to be utilized as a refuge habitat.

B. WATER COLUMN

At Londolozi, NT increased marginally while the increase in TNI was spectacular over the study period. The high numbers of crustaceans (Copepoda) indicate that the habitat had changed from a lentic to a lotic one with deteriorating water quality. At Mlondozi, TNI increased sharply before flushing but decreased noticeably after flushing due to the resetting of the chemical parameters in the pools to pre-cessation levels.

C. VEGETATION

Initially, NT at both sites was high, indicating this to be a habitat utilized by a diverse set of invertebrates. TNI increased strongly at both sites but this increase was largely due to taxa thriving on deteriorating water quality and absence of flow. This habitat was used as a refuge by some Trichoptera and Ephemeroptera early in the study period, but their numbers decreased strongly as the drought progressed and habitat was lost. Cloeon complex and *Centroptilium* were prevalent to the end of the study, although Cloeon's numbers decreased while those of Centroptilium increased. These two taxa were therefore not substantially affected by deteriorating water quality and loss of habitat, and could use the lack of competition to their own advantage.

D. RIFFLE

At Londolozi, both NT and TNI decreased strongly as habitat was lost. Notable at both sites was the absence of Trichoptera in the remains of the riffle. Flow preferred by Trichopterans had thus probably already been reached before the study had begun. This very strong preference of certain Trichoptera to particular flow rates was illustrated by Edington (1965). The appearance of the wood boring Polymitarcid mayfly (*Povilla*) was opportunistic and indicative of serious change to habitat due to decreasing flow. The very strong decrease in Chironomid and Simulid numbers was probably due to a combination of deteriorating water quality, predation and habitat loss. At Mlondozi, the riffle dried up very soon after the start of the study and did not recover after flushing.

E. BEDROCK GULLIES

Both the sites showed an increase in TNI until July with a consequent decrease after July, indicating the utilization of bedrock gullies mainly as a refuge habitat. Flushing of the pools at Mlondozi resulted in a slight decrease in both TNI and NT, suggesting the movement of invertebrates to more suitable habitats. At Londolozi, although the same trend was apparent, this could have been due to the substantial shrinking of pools with subsequent loss of other habitat.

F. POOLS

1. Londolozi

All pools at Londolozi showed a similar trend of reduction of taxa during the study period. Ephemeroptera and Trichoptera were the first taxa to show a substantial decline as they are the preferred food source of some of the fish species, and are the most flow-dependant taxa.

Vegetation as a refuge habitat seemed to be very important to these taxa as they disappeared completely after the vegetation and riffle habitats were lost. Chironomidae may use the sandy substratum as a refuge as indicated by their appearance here. This could indicate a temporary escape into the hyporheos, as was reported for some Ephemeroptera and Trichoptera (Larimore *et al.* 1959).

2. Mlondozi

The flushing of the pools at Mlondozi between July and September had very different effects on the three pools sampled and these will therefore be discussed separately.

■ Pool M7A

This pool showed the most marked change after it was flushed, with both NT and TNI increasing dramatically. Recolonization of the available vegetation habitat was responsible for this increase in NT. Ephemeroptera and Trichoptera were found in vegetation after flushing, illustrating a rapid recovery response to an improvement in habitat availability and water quality. The increase in NT in the sandy substratum after the disappearance of riffle and vegetation and also the sudden decrease in numbers as habitat became available again, suggests that this habitat is used as a refuge habitat by these invertebrates. Physical and chemical parameters of the pool were reset after flushing and did not reach the extreme conditions found at Londolozi (Table 4). Oxygen concentration decreased sharply after flushing, possibly due to the flushing of algae from the pool.

■ Pool M7B

The marked increase in TNI before flushing was mainly due to flourishing Copepoda and Cladocera, which disappeared after flushing. Numbers of Chironomidae increased markedly after flushing, illustrating the effect of the improved habitat and water quality.

■ Pool M9B

The size of this pool proved to be a buffer against the effects of flushing. Conductivity and temperature increase were comparable to the pools at Londolozi with the same marked increase in TNI over the study period. This increase was also due to the marked increase in numbers of Crustaceans indicating a deteriorating water quality. The presence of some Trichoptera and Ephemeroptera indicated that the availability of suitable habitat, even if only refuge habitat, plays a bigger role in the survival of these flow-dependent taxa than deteriorating water quality.

5.3.2 GENERAL

The general trend accompanying large reductions in flow is a change in community structure with some species disappearing while others flourish, rather than a reduction in the total number of taxa (Lillehammer & Saltveit 1984). In the present study, this trend was seen only at pool 7B at Mlondozi. All other pools showed a marked reduction in number of taxa, as was found by Jensen & Jensen (1984). These authors recorded a 50% reduction in the number of taxa after a 66% reduction in flow for two weeks in a Danish stream. Similarly, in the regulated Tongue River in Montana, a 30% reduction in discharge resulted in a dramatic increase in invertebrate drift. A further 10% reduction in discharge gave rise to massive drift, suggesting that the minimum discharge sufficient to maintain that community had been reached (Gore, 1977).

Invertebrate community structure in pool M9B at Mlondozi showed the disappearance of most Ephemeroptera and Trichoptera, while *Centroptilium* and *Cloeon* complex became prevalent and Diptera, Mollusca and Crustacea thrived. A similar change was noted on a Norwegian river, eight years after the construction of a weir (Fjelheim *et al.* 1989). The invertebrate community changed after weir construction as follows: *Baetis rodani* numbers decreased while other Ephemeroptera taxa increased, and Chironomidae, Crustacea and Nematoda numbers also increased (Fjelheim *et al.*, 1989). In a separate study, an increased winter flow and reduced summer flow in a Norwegian river (Suldalslågen) caused Plecoptera, which comprised

33 - 37% of the total fauna, to virtually disappear. There was a concomitant increase in certain Trichoptera and Chironomidae and a change in the dominant *Baetis spp.* (Lillehammer & Saltveit 1984). A flow reduction of 90% during winter and between 10 and 70% during summer in a Norwegian river, the Sore Osa, resulted in a dramatic decrease in two stonefly species (*Isoperla* and *Dinocras cephalotes),* and a large increase in a third (*Protonemura meyeri*). Mayflies increased in density and biomass but species composition shifted from fewer large species to more numerous small species (Garnas, 1985).

All of the pools showed a change in community structure, where flow-dependent species were reduced or disappeared completely and species preferring lotic conditions thrived. This was similar to findings by several authors. In a Colorado stream in which surface flow ceased for two weeks, mayfly numbers decreased severely while numbers of Diptera, Hydracarina and Oligochaeta increased markedly (Canton *et al.*, 1984). One such taxon found to be very sensitive to loss of habitat and flow reduction at Londolozi and Mlondozi was the Trichoptera. This also proved the case in an experiment in which obstacles were placed in a river to reduce flow, where riffle-dwelling Trichoptera moved and colonized an area of preferred flow (Edington, 1965). In the present study, most Ephemeroptera numbers were drastically reduced over the study period, indicating their sensitivity to habitat loss and flow reduction. Similarly, Brittain *et al.* (1984) found that low winter flows virtually eliminated the winter generation of *Baetis rodani* downstream of a dam on the Norwegian River, Glomma.

The appearance of the Polymitarcid mayfly (*Povilla*) in the riffle of pools L6A and L16A, indicated an opportunistic replacement of a flow-sensitive mayfly species by a more tolerant one, following severe habitat change. Similar results accompanied severe flow reductions in the Strawberry River, Utah, which resulted in the dominant *Drumella grandis* (Eaton) being replaced by a *Baetis spp.* (Williams & Wingert, 1979).

Recovery rate is very dependent on length of flow cessation (Zelinka, 1984). Pools M7A and M7B showed a rapid recovery of some Ephemeroptera after flushing, but Trichoptera did not recolonize these pools. Similarly, a two week cessation of flow of a Danish stream caused a rapid decline in *Baetis rhodani*, *Hydropsyche angustipennis* and *Limnius volkmari*, but recovery was rapid after flow resumption. Iversen *et al.*, (1978), found that a flow cessation of three months, with desiccation of sections of the river, resulted in the disappearance of *Hydropsyche angustipennis*, *Gammarus pulex* and *Goera pilosa;* they were not recorded during later field trips.

6. KEY QUESTIONS

In conclusion, it is opportune to address the specific questions posed at the outset of this research project:

■ *1.* ***How will the distribution and abundance of the present species assemblage respond to decreasing flows and final isolation in pools?***

Fish

From our study it appears that fish, subjected to the onset of increasingly stressful conditions as flow decreases, select certain habitats that will favour their survival. Given this, particular physico-chemical variables do appear to play an important role in determining the distribution of certain species at isolation. In this study we were able to underscore a number of these variables in species which occurred in sufficient numbers at our sites. This in no way suggests that these species cannot survive under alternative conditions; merely that given the choice they will move to favourable areas.

Not surprisingly, depth and volume were the most frequently implicated criteria in explaining the initial distribution of the following species: *B.annectens, B.marequensis, B.radiatus, M.brevianalis* and *G.callidus*. Depth alone appeared to be important in the case of

M.acutidens. All these species are highly motile with the exception of *G.callidus*. In contrast, cover appeared to be important in the case of the more sedentary species.

Certain species were widespread whilst others appeared to be restricted to instream or offstream pools. Most notably *B.toppini* and *B.paludinosus* were never recorded in instream pools. Other species more common in offstream or "marginally" offstream pools were *M.brevianalis* and *O.mossambicus,* while both *B.viviparus* and *S.meridianus* were typically found in instream pools.

In this study, the distribution of *B.marequensis, B.trimaculatus, M.macrolepidotus* and *S.meridianus* was positively correlated with offstream cover whilst *O.mossambicus* appeared to avoid shaded pools. Where possible, *B.annectens, G.callidus* and *O.mossambicus* "chose" turbid pools.

The consistently most abundant barb, *B.viviparus* appeared to behave very differently to other minnows. The key to its relative success seems to be its generalist nature; it is widespread throughout most habitat types, showing a propensity for a range of habitat types from fast, flowing waters to stagnant backwaters.

Thus in summary, the broadstripe barb (*B.annectens*) and the river goby (*G.callidus*) appeared to choose slightly turbid, deep pools. The threespot barb (*B.trimaculatus*) and the large scale yellowfish (*B.marequensis*) preferred deep pools with overhead cover, whilst the Beira barb (*B.radiatus*) and the river sardine (*M.brevianalis*) were more commonly found in deep pools, exposed or shaded. The river sardine was more numerous in offstream pools and the Mozambique tilapia (*O.mossambicus*) in exposed, offstream pools. The Lowveld largemouth (*S.meridianus*), endemic to the Sabie-Sand system, was commonly caught in shaded instream or slightly offstream pools. Although the bowstripe barb (*B.viviparus*) was ubiquitous it was never found in offstream pools in this study. The labeos and gobies appeared to be fairly widespread.

Macro-invertebrates

Flow-dependant species such as most Trichoptera and Ephemeroptera respond very rapidly to flow reductions, as shown by this and other studies. We propose that the optimum flow conditions necessary for the survival of these taxa had been passed before this study started. These taxa were forced to utilize pools as refuge areas and their numbers were reduced rapidly as the drought worsened. Depending on the duration of the drought and the availability of suitable refuges, these taxa could disappear completely from the species assemblage.

Once cessation of flow had occurred, the species assemblage changed rapidly from a lentic to a lotic system, with the loss of the aforementioned taxa and the emergence of large numbers of Crustacea, Hirudinea, Mollusca and Annelida.

■2. *Are all species able to survive for limited periods in pools?*

Fish

It is important to recognise that wet/dry cycles are characteristic of the sub-tropical lowveld region and it is therefore likely that most species inhabiting this area are fairly robust. Furthermore, cessation of flow has been reported in the lower Sand River (Londolozi) since 1980 and it would be expected that the species assemblage here represents a robust community. However, in this case the drought was far more protracted and severe than in other years and, in the case of the Sabie River low flows of the magnitude that persisted through the final months (0.5 m^3s^{-1}) were previously unprecedented.

We submit that a so-called 'normal' dry cycle would result in trends seen between June and August. However, patterns emerging in September, and in October at Londolozi were likely to reflect the extreme ends of the spectrum as temperatures and evaporation increased with the onset of warmer weather. Air temperatures of over 42°C were frequently recorded in the river channel in September.

In general, our results from June to August supported those of Merron & Lalouviere (1987) that, although overall abundance decreased markedly, species diversity was generally maintained. However, in September and more noticeably in October, species loss was noted.

At Londolozi, all species found in June were represented in August. In September two species were unaccounted for, namely Hamilton's barb *(B.afrohamiltonii)* and the bearded barb (*B.unitaeniatus*). However, since these species consistently occurred in very low numbers, no conclusive statements can be made regarding their apparent disappearance. In October, the species assemblage was reduced from 24 species (excluding eels) to 16. Species that disappeared and that had occurred in sufficient numbers for categorical statements to be made were the straightfin barb (*B.paludinosus*) and the bulldog (*M.macrolepidotus*). Species in which only one individual remained and thus, it could be argued, had been severely affected by the drought were the large scale yellowfish (*B.marequensis*), the silver robber (*M.acutidens*), the river sardine (*M.brevianalis*), the Churchill (*P.catostoma*) and the Lowveld largemouth (*S.meridianus*). Although an attempt was made to sample diverse pool types, all of these species may well have persisted in other reaches of the Sand River. These data only indicate that these species appear to be more sensitive to the extreme conditions imposed by the drought.

Of the 18 species (excluding anguillids) present at Mlondozi in June, 11 were still present in September. Again, of the species present in sufficient numbers, those that apparently disappeared were *B.annectens, B.radiatus, B.toppini, B.paludinosus* and *P.philander*. In the case of the latter two species, the results were consistent with records from Londolozi. In the case of *B.toppini,* it was caught in a pool that was reduced to thick sludge in September; *B.paludinosus* was only found in one pool that dried up at the end of June. Data from Londolozi indicate that both of these species are robust and can survive long periods in persistent offstream pools.

Macro-invertebrates

The duration of cessation will be the deciding factor here. Since flow-dependant species start disappearing before cessation of flow, frequent flow reductions below acceptable levels could well result in the permanent disappearance of some of these species.

Certain pools seemed to offer a better chance of survival to some of these flow-dependant species than others, as can be seen by the presence of some Trichoptera and Ephemeroptera in pool M9B.

- ***3. Three fish species (C.gariepinus, O.mossambicus and B.paludinosus) typify the final stages of isolated seasonal warm-water pools (Bruton, 1986; Jackson, 1989). Are results from this study consistent with this thesis and what pattern of events underlies this conclusion?***

During the dry-out phase, these three species generally survive longer, tolerating increasingly harsh environments. They have been described by Bruton (1986) as phenotypically plastic: they do exist in more stable environments with other fish, but thrive under harsher conditions.

In this study, large water bodies that concentrated over time were typified by *C.gariepinus, O.mossambicus, B.paludinosus* and *B.toppini*. *O.mossambicus* thrived and bred under such conditions, but did not survive the conditions of high turbidity of M1A.

Although *B.paludinosus* and *B.toppini* are robust, neither were widespread through pools in this study. They are characteristic of standing waterbodies (Russell & Rogers, 1988); whilst pools from this research concentrated on a riverine system with few backwaters. The smaller *B.toppini* appeared to persist for a longer time than *B.paludinosus.*

The catfish is known to endure hardy conditions, supplementing respiration by means of accessory breathing apparatus under conditions of desiccation (Bruton, 1979). The remaining two species are flexible in their life-history styles and succeed in an unstable, uncrowded environment not subjected to density-dependent mortality (Balon, 1985; Jackson, 1989). The remaining *B.toppini* probably also exhibits such flexibility and in this case, appeared to survive for a longer period than *B.paludinosus*. Both of these minnows survived very harsh abiotic conditions in Pool L2B, with the MLA limits being exceeded on pH, turbidity, temperature and ammonia. However, neither species survived the extreme values in October but at this point the waterbody had been reduced to a viscous sludge with free water remaining only in the top 5cm.

■ 4. *What physical and biotic variables govern the value of pools as refuges within and between sites?*

Fish

In the lowveld system, exposed pools generally presented better quality habitat. As discussed previously, this was related to dense algal blooms and high oxygen concentrations. Depth, which generally defined the persistence of a pool, was of primary importance both in determining species distribution and persistence.

Of the very small pools found at Londolozi (less than $3m^3$), a number contained a surprisingly diverse assemblage: pool L13 (9 species), Pool L1B2 (7 species), Pool L1B3 (5 species) and L15B (5 species). A common physical characteristic of all these pools was habitat heterogeneity in terms of instream cover; either in the form of undercut banks, boulders or ledges. Species that were never found in small pools at Londolozi were *B.marequensis* and *P.catostoma*. Other species such as *P.philander* and *S.zambezensis*, occurred in insufficient numbers for conclusions to be drawn.

In terms of sandy-bed pools, seepage losses led to their disappearance after approximately only two months. However, those that lay within the water table, or within the main channel, persisted for longer periods.

The rate of decrease of the flow is potentially very important. If fish are selecting habitats on certain criteria and flow cessation is rapid, fish could be stranded in unfavourable pools.

Invertebrates

The size and durability of pools, combined with the availability of suitable vegetation habitat, seem to be the most important factors governing suitability of pools. Pool M9B provided the best refuge for flow-sensitive taxa, as can be seen by the presence of Trichoptera and Ephemeroptera throughout the study period in the marginal vegetation habitat.

■ 5. *Is water quantity, quality, predation or food resource availability the major factor governing the fate of isolated fish populations?*

The fate of fish populations is governed by a complex suite of variables.
Primarily, water quantity as defined by depth was a major factor since this generally led to persistence.

Few pools exhibited low oxygen concentrations at our study sites. Pools with low oxygen concentrations, such as L1B2 and L1B3, which varied between 30% and 50% contained the barbs *B.annectens, B.trimaculatus, B.viviparus, B.unitaeniatus, B.radiatus,* the goby *G.callidus* and *O.mossambicus.* Pools with extremely low oxygen (10%), only housed *T.rendalli* and *C.gariepinus.* Since the length of time in which the above species could persist under such conditions is not known, these levels are not indicative of tolerance ranges. With prolonged isolation, a sudden increase NH4-N levels was noted in some pools with a concomitant reduction in species.

Although food resources were not quantified, qualitative observations indicated that most minnows, with the exception of *B.viviparus* and *B.trimaculatus,* were in poor condition in the latter months. This may reflect diminishing food resources.

Not all pools housed the predatory *C.gariepinus* and this may account for diverse species assemblages such as those seen in L6B in October.

Macro-invertebrates

Water quantity, intimately dependant on durability and availability of vegetation habitat, seem to be the factors most important to the survival of flow-dependant taxa. Water quality, although it never reached excessive levels, did not seem to be the deciding factor as far as habitat suitability was concerned.

■ 6. *During drought, do all stream reaches provide equally good refuges?*

Fish

Generally, rocky reaches provided the greatest suite of pools, with the greatest habitat heterogeneity as defined by substratum types. Within the study section, this reach type is limited and, by implication, reaches such as those at Londolozi are important refugia, and centres of inocula. In addition, large volume hippo pools are potentially important refuges.

Macro-invertebrates

As suitability of pools as refuge areas depends largely on pool size and durability and availability of emergent vegetation habitat, not all reaches will provide equally good refuges.

■ 7. *At what range of low flows is there a significant decrease in diversity?*

Fish

In September, the flow of the Sabie River decreased to 0.5m^{3s}-1, the lowest in recorded history. In the main channel, the species diversity was maintained but abundance was reduced in most species, noticeably the red-data species *O.zambezensis*. Higher diversity was exhibited in the riffles. Species unique to this habitat were the riffle specialists, *C.anoterus* and *C.paratus*. In addition, large numbers of flow associated species, such as *B.marequensis*, *L.molybdinus* and *M.acutidens* as well as the flow dependent *O.zambezense* were reduced as flow decreased.

■ ***8. What do taxa in isolated pools tell us about their tolerance to water quality variables?***

Fish

The lowveld community is generally robust, although sensitive species such as *O.zambezensis,* found in the headwaters of the Sand River and in the entire Sabie River, were absent from Londolozi. This suggests that this species may have disappeared recently as a result of flow cessation.

The determination of extreme ranges with respect to the physico-chemistry variables is difficult; for example, species from these sites were kept in tanks in conductivities far exceeding those found in any of the pools. Furthermore, water quality variables need to be considered synergistically; a suite of conditions may influence a species ability to tolerate other conditions.

Macro-invertebrates

As the effects of water quality probably has a synergistic effect on the different taxa, no one variable could be singled out for discussion. The chemical parameters of pool M9B at Mlondozi were comparable to those at Londolozi, and yet some Trichoptera and Ephemeroptera were found there throughout the study period. Conditions in the pools certainly became more acceptable to taxa preferring lotic conditions, but still these flow-dependant species could survive.

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APPENDIX I

Table 1: Londolozi. Changes in volume (m^3) of all pools over five months.

POOL No.	SURVEY TRIP				
	JUN	JLY	AUG	SEP	OCT
L1A	19	DIVIDES			
L1A1	*	2			
L1A2	*	3			
L1B	58	DIVIDES			
L1B1	*	9	1.6		
L1B2	*	1	0.2		
L1B3	*	0.6			
L1C	1.3				
L1D	2				
L2A	0.7				
L2B	109	45	31	6	0.6
L3	6.3				
L4	17	1.4			
L5	4.4				
L6A	25	DIVIDES			
L6A1	*	10	2		
L6A2	*	0.6			
L6B	50	42	18	16	12
L7	8				
L8A	19				
L8B	2				
L9	1.5				
L10	0.2				
L11	64	11	1.8		
L12	0.2				
L13	2.6				
L14	1.1				
L15	17	DIVIDES			
L15A	*	8	3	0.7	
L15B	*	3	0.1		
L16	1700	900	280	DIVIDES	
L16A	*	*	*	43	DIVIDES
L16A1	*	*	*	*	0.3
L16A2	*	*	*	*	4
L16A3	*	*	*	*	1.1
L16B	*	*	*	46	16
L17	35	6.4	0.1		

* Pool still part of main series

Table 2: Oxygen readings (% saturation) of all pools over five months.

POOL No.	SURVEY TRIP				
	JUN	JLY	AUG	SEP	OCT
L1A	109	*DIVIDES*			
L1A1	*	136			
L1A2	*	140			
L1B	110	DIVIDES			
L1B1	*	114	84		
L1B2	*	101	30		
L1B3	*	61			
L1C	116				
L1D	110				
L2A	118				
L2B	146	175	180	600	25
L3	67				
L4	136	176			
L5	80				
L6A	113	DIVIDES			
L6A1	*	139	136		
L6A2	*	176			
L6B	108	131	182	168	186
L7	128				
L8A	138				
L8B	120				
L9	79				
L11	136	29	7		
L12	92				
L13	114				
L14	125				
L15	76	DIVIDES			
L15A	*	86	156		
L15B	*	43	82		
L16	159	125	77	DIVIDES	
L16A	*	*	*	206	DIVIDES
L16A1	*	*	*	*	267
L16A2	*	*	*	*	186
L16A3	*	*	*	*	186
L16B	*	*	*	220	414
L17	7	92	45		

Table 3: Londolozi. Conductivity in µScm, for all pools over five months.

POOL No.	SURVEY TRIP				
	JUN	JLY	AUG	SEP	OCT
L1A	160	DIVIDES			
L1A1	*	400			
L1A2	*	370			
L1B	170	DIVIDES			
L1B1	*	240	530		
L1B2	*	400	420		
L1B3	*	320			
L1C	190				
L1D	180				
L2A	150				
L2B	200	350	450	700	1720
L3	170				
L4	160	280			
L5	360				
L6A	210	DIVIDES			
L6A1	*	340	600		
L6A2	*	350			
L6B	210	250	320	440	590
L7	200				
L8A	180				
L8B	200				
L9	180				
L10	200				
L11	200	200	320		
L12	180				
L13	220				
L14	190				
L15	190	DIVIDES			
L15A	*	240	340	?	
L15B	*	270	500		
L16	190	220	300	DIVIDES	
L16A	*	*	*	390	DIVIDES
L16A1	*	*	*	*	900
L16A2	*	*	*	*	760
L16A3	*	*	*	*	750
L16B	*	*	*	430	850
L17	?	250	400		

* Pool still part of main series

Table 4: Londolozi. Turbidity in nephalomic turbidity units (NTU's) for all pools over five months.

POOL No.	SURVEY TRIP				
	JUN	JUL	AUG	SEP	OCT
L1A	85	DIVIDES			
L1A1	*	23			
L1A2	*	6			
L1B	23	DIVIDES			
L1B1	*	8	107		
L1B2	*	14	28		
L1B3	*	10			
L1C	26				
L1D	33				
L2A	183				
L2B	130	125	446	748	670
L3	30				
L4	78	63			
L5	52				
L6A	5	DIVIDES			
L6A1	*	5	34		
L6A2	*	2			
L6B	5	5	10	25	82
L7	6				
L8A	9				
L8B	23				
L9	15				
L11	9	9	62		
L12	13				
L13	3				
L14	12				
L15	23	DIVIDES			
L15A	*	11	1	?	
L15B	*	4	10		
L16	10	8	14	DIVIDES	
L16A	*	*	*	46	DIVIDES
L16A1	*	*	*	*	63
L16A2	*	*	*	*	610
16A3	*	*	*	*	610
L16B	*	*	*	30	358
L17	?	15	69		

* Pool still part of main series

Table 5a: Londolozi. Spot temperatures for all pools over five months.

POOL No.	SURVEY TRIP				
	JUN	JYL	AUG	SEP	OCT
L1A	23.9	DIVIDES			
L1A1	*	25			
L1A2	*	22.7			
L1B	22.2	DIVIDES			
L1B1	*	21.8	25.3		
L1B2	*	26.5	18.1		
L1B3	*	17.5			
L1C	20.2				
L1D	22.6				
L2A	23.5				
L2B	19.3	17.6	23.4	31.6	32.1
L3	24.3				
L4	21.4	24.4			
L5	18.7				
L6A	21.4	DIVIDES			
L6A1	*	22.4	24.4		
L6A2	*	24.4			
L6B	24.7	21.8	23.6	28.9	28.8
L7	20.5				
L8A	20.6				
L8B	19.5				
L9	15.2				
L10	19.2				
L11	18.2	13.5	18.1		
L12	16.9				
L13	19.1				
L14	16.4				
L15	15.3	DIVIDES			
L15A	*	14.9	20.5	?	
L15B	*	14.6	20.9		
L16	21.8	20.8	21.3	DIVIDES	
L16A	*	*	*	25.2	DIVIDES
L16A1	*	*	*	*	32.2
L16A2	*	*	*	*	32.5
L16A3	*	*	*	*	32.5
L16B	*	*	*	28.7	33.6
L17	?	17.5	20.2		

* Pool still part of main series.

Table 5b: Londolozi. Minimum - maximum temperatures between June and October for selected pools.

POOL No.	SURVEY TRIP							
	JLY		AUG		SEP		OCT	
	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
L1B1	10.4	29.7	12.5	24				
L2B	11.8	22.6	13.5	20.2	16.2	31.6	22.8	32.1
L6B	13.4	21.3	16	26.5	17.8	29.8	21	30.3
L11	8.5	27	9	18				
L15A	9	24	10.5	18.5	?	?		
L16	10.8	18.5	?	?	DIVIDES			
L16A	*	*	*	*	17.5	25	DIVIDES	
L16A1	*	*	*	*	*	*	21	27.5
L16A2	*	*	*	*	*	*	19.5	30
L16A3	*	*	*	*	*	*	19.5	30
L16B	*	*	*	*	?	?	19.5	30.5

* pool still part of larger series.

Table 6: Londolozi. pH measurements between June and October, 1992.

POOL No.	SURVEY TRIP				
	JUN	JUL	AUG	SEP	OCT
L1A	8.4	DIVIDES			
L1A1	*	8.9			
L1A2	*	8.7			
L1B	8.2	DIVIDES			
L1B1	*	8.2	7.8		
L1B2	*	8.7	7.4		
L1B3	*	7.4			
L1C	8.6				
L1D	8.3				
L2A	7.2				
L2B	9.4	9.2	9.8	9.4	7.2
L3	7.6				
L4	8.5	9.3			
L5	6				
L6A	8.6	DIVIDES			
L6A1	*	8.7	8.5		
L6A2	*	9			
L6B	8.4	9	9.1	9.6	8.5
L7	8.4				
L8A	8.4				
L8B	8.4				
L9	6.9				
L11	7.6	6.9	7.8		
L12	7				
L13	8				
L14	?				
L15	?	DIVIDES			
L15A	*	7.8	8.21	?	
L15B	*	7.7	7.6		
L16	7.4	8.4	8.2	DIVIDES	
L16A	*	*	*	9.5	DIVIDES
L16A1	*	*	*	*	9.2
L16A2	*	*	*	*	9.3
16A3	*	*	*	*	9.3
L16B	*	*	*	9	9.7
L17	?	8.1	6.8		

* Pool still part of main series

Table 7: Londolozi. Changes in Total Suspended Solids in all pools over five months.

POOL No.	SURVEY TRIP JUN		JUL		AUG		SEP		OCT	
	TSS (mg/l)	%ORG	TSS (mg/l)	%ORG	TSS (mg/l)	6%ORG	TSS (mg/l)	%ORG	TSS (mg/l)	%ORG
L1B	0.032	68	DIVIDES							
L1B1	*	*	0.031	567	0.073	53				
L2B	0.154	43	0.184	67	0.305	67	?	?	0.815	?
L3	0.018	30								
L4	0.09	26								
L5	0.011	42								
L6B	0.024	24	0.015	53	0.018	41	0.034	59	0.159	42
L11	?	?	?	?	0.007	53				
L13	0.003	40								
L15	?	?	DIVIDES							
L15A	*	*	0.018	61						
L15B	*	*	0.005	23						
L16	?	?	0.011	54	0.015	62	DIVIDES			
L16A	*	*	*	*	*	*	0.058	67	DIVIDES	
L16A1	*	*	*	*	*	*	*	*	0.526	41
L16A2	*	*	*	*	*	*	*	*	0.48	34
L16B	*	*	*	*	*	*	0.066	53	0.233	49
L17	?	?	0.02	43						

* Pool still part of main series

Table 8: Londolozi. The nutrients ammonium, total nitrogen and soluble reactive phosphorus between June and October 1992.

NUTRIENT	POOL No.	JUN	JUL	AUG	SEP	OCT
NH$_4$-N (µgl^{-1})	L1B1	?	70	1000**		
	L2B	?	?	3020**	13400**	?
	L3	40				
	L6B	50	50	40	40	70
	L8B	50				
	L11	60	130	?		
	L13	50				
	L15A	*	40	60	?	
	L15B	*	250	?		
	L16	?	50	?	DIVIDES	
	L16A	*	*	*	200	DIVIDES
	L16A1	*	*	*	*	70
	L16B	*	*	*	70	150
	L17	?	110	?		
Combined NO$_3$-N & NO$_2$-N (µgl^{-1})	L1B1	?	60	40		
	L2B	?	?	50	210	?
	L3	40				
	L6B	40	40	40	40	40
	L8B	40				
	L11	110	180	?		
	L13	40				
	L15A	*	40	40	?	
	L15B	*	140	?		
	L16	?	40	40	DIVIDES	
	L16A	*	*	*	50	DIVIDES
	L16A1	*	*	*	*	40
	L16B	*	*	*	50	70
	L17	?	60	?		
PO$_4$-P (µgl^{-1})	L1B1	?	16	30		
	L2B	?	?	150	329	?
	L3	20				
	L6B	9	21	8	5	57
	L8A	9				
	L11	113	20	?		
	L13	17				
	L15A	*	11	12		
	L15B	*	14	?		
	L16	?	7	12	DIVIDES	
	L16A	*	*	*	15	DIVIDES
	L16A1	*	*	*	*	26
	L16B	*	*	*	9	49
	L17	?	15	?		

* pool still part of larger series

** exact value should be treated with caution

Table 9: Mlondozi. Pool volume in cubic meters (m^3) between June 1992 and September 1992.

POOL No.	SURVEY TRIP			
	JUN	JYL	AUG	SEP
M1A	1562	536	DIVIDES	▨
MIA1	•	•	96	9
MIA2	•	•	191	▨
M1B	1	▨	▨	▨
M1C	21	▨	▨	▨
M1D	13	0.04	▨	▨
M1E	233	▨	▨	▨
M2	2	▨	▨	▨
M3	3	▨	•	▨
M4	207	DIVIDES	•	▨
M4A	•	110	•	70
M4B	•	20	•	15
M5	2.5	0.08	•	▨
M6	2.8	1	•	▨
M7A	111	DIVIDES	•	▨
M7A1	•	2	•	2
M7A2	•	43	•	67
M7A3	•	0.1	•	▨
M7B	52	2	•	▨
M8	0.3	▨	•	▨
M9A	6	▨	•	▨
M9B	874	6	•	DIVIDES
M9B1	•	•	•	152
M9B2	•	•	•	106
CHANNEL	▨	▨	?	▨

• Part of larger series or channel flowing

Table 10: Mlondozi. Oxygen. Percentage saturation measured between June and September 1992.

POOL No.	SURVEY TRIP			
	JUN	JLY	AUG	SEP
M1A	163	176	DIVIDES	▨
MIA1	•	•	131	?
MIA2	•	•	131	▨
M1B	190	▨	▨	▨
M1C	155	▨	▨	▨
M1D	172	155	▨	▨
M1E	163	▨	▨	▨
M2	?	▨	▨	▨
M3	?	▨	•	▨
M4	?	DIVIDES	•	▨
M4A	•	104	•	150
M4B	•	51	•	39
M5	?	170	•	▨
M6	?	108	•	▨
M7A	100	DIVIDES	•	▨
M7A1	•	102	•	51
M7A2	•	124	•	135
M7A3	•	?	•	▨
M7B	?	240	•	▨
M8	?	▨	•	▨
M9A	?	▨	•	▨
M9B	?	140	•	DIVIDES
M9B1	•	•	•	50
M9B2	•	•	•	106
CHANNEL	▨	▨	75	▨

• Presently part of larger series

Table 11: Mlondozi. Conductivity measurements μScm^{-1} at 20°C between June and September 1992.

POOL No.	SURVEY TRIP			
	JUN	JLY	AUG	SEP
M1A	210	170	DIVIDES	▨
MIA1	*	*	160	?
MIA2	*	*	?	▨
M1B	300	▨	▨	▨
M1C	240	▨	▨	▨
M1D	210	330	▨	▨
M1E	210	▨	▨	▨
M2	130	▨	▨	▨
M3	190	▨	*	▨
M4	150	DIVIDES	*	▨
M4A	*	170	*	210
M4B	*	150	*	220
M5	160	270	*	▨
M6	150	300	*	▨
M7A	140	DIVIDES	*	▨
M7A1	*	180	*	290
M7A2	*	155	*	240
M7A3	*	180	*	▨
M7B	140	150	*	▨
M8	170	▨	*	▨
M9A	140	▨	*	▨
M9B	130	140	*	DIVIDES
M9B1	*	*	*	510
M9B2	*	*	*	230
CHANNEL	▨	▨	190	▨

* Presently part of larger series

Table 12: Mlondozi. Turbidity measurements in nephalometric turbidity units (NTU's) between June and September 1992.

POOL No.	SURVEY TRIP			
	JUN	JLY	AUG	SEP
M1A	26	102	DIVIDES	▨
MIA1	*	*	606	?
MIA2	*	*	?	▨
M1B	0	▨	▨	▨
M1C	32	▨	▨	▨
M1D	?	21	▨	▨
M1E	26	▨	▨	▨
M2	3	▨	▨	▨
M3	3	▨	*	▨
M4	3	DIVIDES	*	▨
M4A	*	15	*	19
M4B	*	6	*	2
M5	3	2	*	▨
M6	3	3	*	▨
M7A	6	DIVIDES	*	▨
M7A1	*	2	*	5
M7A2	*	3	*	3
M7A3	*	1	*	▨
M7B	6	3	*	▨
M8	1	▨	*	▨
M9A	5	▨	*	▨
M9B	5	11	*	DIVIDES
M9B1	*	*	*	9
M9B2	*	*	*	13
CHANNEL	▨	▨	0	▨

* Presently part of larger series

Table 13a: Mlondozi. Temperature measurements between June 1992 and September 1992.

POOL No.	SURVEY TRIP			
	JUN	JLY	AUG	SEP
M1A	23.7	24.9	DIVIDES	▨
MIA1	•	•	22.2	?
MIA2	•	•	?	▨
M1B	25.4	▨	▨	▨
M1C	22.5	▨	▨	▨
M1D	23	28	▨	▨
M1E	23.7	24.9	▨	▨
M2	21	▨	▨	▨
M3	21.5	▨	•	▨
M4	24	DIVIDES	•	▨
M4A	•	21.7	•	24.1
M4B	•	18.3	•	23.1
M5	24	27.5	•	▨
M6	23	27.7	•	▨
M7A	22	DIVIDES	•	▨
M7A1	•	22.7	•	24.4
M7A2	•	24.2	•	24.4
M7A3	•	25.7	•	▨
M7B	21	21.2	•	▨
M8	22.7	▨	•	▨
M9A	24.5	▨	•	▨
M9B	21.7	23.7	•	DIVIDES
M9B1	•	•	•	25.9
M9B2	•	•	•	23.7
CHANNEL	▨	▨	19.5	▨

* Presently part of larger series

Table 13b: Mlondozi. Minimum-Maximum temperature readings between July and September 1992.

POOL No.	SURVEY TRIP					
	JLY		AUG		SEP	
	MIN	MAX	MIN	MAX	MIN	MAX
M1A	12.5	24	DIVIDES		▨	▨
M4A	11.5	20	•	•	15.3	28
M4B	?	?	•	•	10.5	24
M9B	14.5	23	•	•	DIVIDES	
M9B2	•	•	•	•	15	29.2
CHANNEL	▨	▨	12.9	21	▨	▨

* Connected to larger series or channel flowing

Table 14: Mlondozi. pH measurements between June and September 1992.

POOL No.	SURVEY TRIP			
	JUN	JLY	AUG	SEP
M1A	8.5	9.1	DIVIDES	▨
MIA1	*	*	7.8	?
MIA2	*	*	?	▨
M1B	8	▨	▨	▨
M1C	8	▨	▨	▨
M1D	7.6	8.2	▨	▨
M1E	8.5	9.1	▨	▨
M2	6.7	▨	▨	▨
M3	8	▨	*	▨
M4	6.8	DIVIDES	*	▨
M4A	*	7.5	*	7.9
M4B	*	7.5	*	7.7
M5	7	9	*	▨
M6	6.9	8.2	*	▨
M7A	7.3	DIVIDES	*	▨
M7A1	*	8	*	7.7
M7A2	*	8.2	*	8.5
M7A3	*	9.3	*	▨
M7B	7.7	9	*	▨
M8	7.5	▨	*	▨
M9A	8	▨	*	▨
M9B	7.6	8.1	*	DIVIDES
M9B1	*	*	*	7.7
M9B2	*	*	*	7.8
CHANNEL	▨	▨	7.4	▨

* Presently part of larger series

Table 15: Mlondozi. Total suspended solids (TSS) and percentage organics between June and August 1992.

POOL No.	SURVEY TRIP							
	JUN		JLY		AUG			
	TSS(mg/l)	% ORG	TSS (mg/l)	% ORG	TSS (mg/l)	% ORG	TSS (mg/l)	% ORG
M1A	0.048	44	0.162	60	DIVIDES	▨	▨	▨
M1A1	*	*	*	*	0.98	25	?	?
M4	0.003	46	DIVIDES		*	*	DIVIDES	
M4A	*	*	0.011	79	*	*	0.012	66
M4B	*	*	0.016	41	*	*	0.003	61
M7A	0.004	50	DIVIDES		*	*	DIVIDES	
M7A2	*	*	0.002	67	*	*	0.01	46
M9B	0.007	47	0.007	43	*	*	0.023	40
CHANNEL	▨	▨	▨	▨	0.002	56.	▨	▨

* Part of larger series or channel flowing

Table 16: Mlondozi. The nutrients ammonium, total nitrogen and soluble reactive phosphorus between June and October 1992.

NUTRIENT	POOL No.	JUN	JLY	AUG	SEP
NH$_4$-N (µgl^{-1})	M1A	60	?	DIVIDES	
	M1A1	*	*	2200**	?
	M4	40	DIVIDES		
	M4A	*	40	*	50
	M4B	*	?	*	40
	M7A	80	DIVDES		
	M7A2	*	?	*	40
	M9B	50	?	*	DIVIDES
	M9B2	*	*	*	60
	CHANNEL			50	
Combined NO$_3$-N & NO$_2$-N (µgl^{-1})	M1A	50	?	DIVIDES	
	M1A1	*	*	70	?
	M4	40	DIVIDES		
	M4A	*	40	*	40
	M4B	*	?	*	50
	M7A	50	DIVIDES		
	M7A2	*	?	*	40
	M9B	40	?	*	DIVIDES
	M9B2	*	*	*	40
	CHANNEL			40	
PO$_4$-P (µgl^{-1})	M1A	14	?	DIVIDES	
	M1A1	*	*	14	?
	M4	12	DIVIDES		
	M4A	*	11	*	7
	M4B	*	?	*	19
	M7A	16	DIVIDES		
	M7A2	*	?	*	7
	M9B	12	?	*	DIVIDES
	M9B2	*	*	*	10
	CHANNEL			21	

* pool still part of larger series

** exact value should be treated with caution

Table 17: Confluence. Pool volumes in cubic meters (m^3) between June and September 1992.

POOL No.	SURVEY TRIP			
	JUN	JUL	AUG	SEP
C1	33	33	29	32
C2	32	47	43	26
C3	1.4	1.7	1.2	▨
C4	2.3	2.1	1.7	1
C5	32	43	38	DIVIDES
C5A	*	*	*	11
C5B	*	*	*	6.7

* Still part of larger series

Table 18: Confluence. Oxygen percent saturation between June and September 1992.

POOL No.	SURVEY TRIP			
	JUN	JLY	AUG	SEP
C1	84	66	81	68
C2	105	69	81	64
C3	160	95	113	▨
C4	122	96	113	?
C5	94	72	102	DIVIDES
C5A	*	*	*	65
C5B	*	*	*	65
CHANNEL	109	119	108	95

* Still part of larger series

Table 19: Confluence. Conductivity measurements in μSCM^{-1} AT 20°C between June and September 1992.

POOL No.	SURVEY TRIP			
	JUN	JLY	AUG	SEP
C1	110	130	140	150
C2	150	120	130	140
C3	150	110	130	▨
C4	150	110	130	160
C5	160	130	130	DIVIDES
C5A	*	*	*	160
C5B	*	*	*	160
CHANNEL	150	110	?	140

* Still part of larger series

Table 20a: Confluence. Temperature measurements between June and September 1992.

POOL No.	SURVEY TRIP			
	JUN	JUL	AUG	SEP
C1	17.7	16.5	17.4	22.7
C2	22.3	17.4	17.9	22.2
C3	25.3	23.4	22.4	▨
C4	24.4	23.7	21.2	?
C5	21.6	21.2	20.6	DIVIDES
C5A	*	*	*	22.7
C5B	*	*	*	22.7
CHANNEL	18.7	18.2	19.9	24.2

* Still part of larger series

Table 20b: Confluence. Minimum-maximum temperatures between July and September 1992.

POOL No.	SURVEY TRIP					
	JLY		AUG		SEP	
	MIN	MAX	MIN	MAX	MIN	MAX
C2	11	21.8	14	22.5	14.5	27.5
CHANNEL	?	?	?	?	18.6	25.8

Table 21: Confluence. pH measurements between June and September 1992.

POOL No.	SURVEY TRIP			
	JUN	JUL	AUG	SEP
C1	7.4	7.4	7.8	7.8
C2	7	7.6	7.4	7.6
C3	7.5	7.2	7.4	▨
C4	7.4	7.4	8.1	9.5
C5	7.3	7.2	7.5	DIVIDES
C5A	*	*	*	7.7
C5B	*	*	*	7.7
CHANNEL	7.6	8.1	8.2	8.4

* Still part of larger series

Table 22: Confluence. Turbidity measurements in nephalometric turbidity units (NTU's) between June and September 1992.

POOL No.	SURVEY TRIP			
	JUN	JLY	AUG	SEP
C1	2	3	0	1
C2	9	20	8	9
C3	25	56	87	▨
C4	12	15	4	14
C5	9	9	7	DIVIDES
C5A	*	*	*	6
C5B	*	*	*	6
CHANNEL	3	22	4	5

* Still part of larger series

Table 23: Confluence. Total suspended solids (TSS) and organic percentage measured between June and August 1992.

POOL No.	SURVEY TRIP							
	JUN		JLY		AUG		SEP	
	TSS (mg/l)	% OXY	TSS (mg/l)	% OXY	TSS (mg/l)	% OXY	TSS (mg/l)	% OXY
C1	0.006	31	0.006	46	0.003	56	0.004	41
C2	0.004	74	0.006	57	0.006	25	0.006	44
C3	0.011	34	0.013	33	0.021	26	?	?
C4	?	?	0.004	41	0.005	52	0.005	56
C5	?	?	0.004	53	?	?	0.008	42
CHANNEL	0.006	31	0.003	36	0.006	34	0.005	35

* Still part of larger series

Table 24: Confluence. Nurtrient readings for ammonium, total nitrogen and soluable reactive phosphate between June and September 1992.

NUTRIENT	POOL No.	SURVEY TRIP			
		JUN	JYL	AUG	SEP
NH_4-N (µgl^{-1})	C1	?	?	50	60
	C2	110	?	50	80
	C3	?	?	50	?
	C4	?	?	?	50
	C5	?	?	?	370
	CHANNEL	?	40	?	40
Combined NO_3-N & NO_4-N (µgl^{-1})	C1	?	?	40	50
	C2	50	?	40	60
	C3	?	?	40	?
	C4	?	?	?	50
	C5	?	?	?	60
	CHANNEL	?	40	?	60
PO_4-P (µgl^{-1})	C1	?	?	12	5
	C2	10	?	7	6
	C3	?	?	9	?
	C4	?	?	?	8
	C5	?	?	?	6
	CHANNEL	?	19	?	14

APPENDIX II

Table 1: Species composition and abundance (CPUE) of Londolozi pools that persisted in June, 1992 only.

SPECIES	POOL											
	L1C	L1D	L3	L5	L7	L8A	L8B	L9	L10	L12	L13	L14
B. afrohamiltoni												
B. annectens										2		
B. eutaenia						0.7				1	0.7	
B. marequensis						0.3						
B. paludinosus												
B. radiatus												
B. toppini												
B. trimaculatus	6.9	11.2	1			0.3					0.3	
B.trimaculatus (fry)				6.1			2.4					1.2
B. unitaeniatus												
B. viviparus			1			3.9	0.8			1	2.6	6
C. gariepinus				0.9	1.5							
C. paratus						0.7						
G. callidus			2.1			0.3					0.3	
L. molybdinus				0.9		0.3					2.3	1.2
L. rosae												
M. acutidens											1.6	
M. brevianalis												
M. macrolepidotus												
O. mossambicus	5.7	17.2	0.5	7.8		3.9					1.3	
P. catostoma												
P. philander												
S. meridianus											0.3	
S. zambezensis												
T. rendalli						3.3					0.3	
No. species	2	2	4	4	1	9	2	0	0	3	9	3
CPUE	12.6	28.4	4.6	15.7	1.5	13.7	3.2	0	0	4	9.7	8.4

Table 2: LONDOLOZI MARGINALLY OFFSTREAM POOLS

CPUE per species for each trip.

A) POOL- L1A series.

SPECIES	TRIP		
	JUN	JLY	
		L1A1	L1A2
O.mossambicus	2.8	11.3	11.3
T.rendalli	0.8	1.3	5
G.callidus	2.8	2.6	6.3
B.annectens	0.4		2.5
B.viviparus	+		0.6
Number of species	5	3	5
CPUE	6.8	16.3	25.6

\+ Presumed present due to subsequent capture

B) Pool- L1B series.

SPECIES	TRIP					
	JUN	JLY			SEP	
		L1B1	L1B2	L1B3	L1B1	L1B2
B.annectens	0.4	0.4	+	1.1		0.9
B.trimaculatus	0.2	0.4	1.3	1.1		1.7
B.unitaeniatus	0.2		+			2.6
B.viviparus	+		+	1.1		2.6
B.radiatus	+		+			0.9
G.callidus	0.8	10.3	9.5	5.8	1	0.9
M.brevianalis	0.2					
O.mossambicus	1.2	27.7	4.1	5.8	4	4.3
T.rendalli	+	1.5				
Number of species	9	5	7	5	2	7
CPUE	3	40.3	15	14.7	5	13.7

\+ Presumed present due to subsequent capture

Table 3: LONDOLOZI OFFSTREAM POOLS

CPUE per species for each trip.

A) L2A

SPECIES	TRIP
	JUN
B.toppini	1
B.paludinosus	10
T.rendalli	1
O.mossambicus	6
No. of species	4
CPUE	18

B) Pool L2b.

SPECIES	TRIP				
	JUN	JLY	AUG	SEP	OCT
A. mossambica				0.3	
B.afrohamiltoni	+	0.1			
B.annectens	3.3	7	5.6		
B.paludinosus	1.2	2.2	2.6	0.3	
B.radiatus	0.2				
B.toppini	2.1	6.9	12	0.3	1
B.trimaculatus	1.4	1.6	1		
B.unitaeniatus	1	0.9	0.3		
C.gariepinus		0.1	0.3	0.8	1
G.callidus	1.4	0.3	0.5		
L.molybdinus	+	0.3	0.3		
M.acutidens	0.4	0.3	0.3		
M.brevianalis	6.7	2.5	1.4		
O.mossambicus	9	3.9	4.8	1	
T.rendalli	+	0.3			
S.zambezensis	+	+	0.3		
Number of species	14	14	12	5	2
CPUE	26.7	26.4	29	2.6	2

\+ Presumed present due to subsequent capture

Table 4: LONDOLOZI INSTREAM POOLS

CPUE per species for each trip.

A) POOL L6A

SPECIES	TRIP			
	JUN	JLY		AUG
		L6A1	L6A2	L6A1
B.annectens	1.3	2.2		0.7
B.eutaenia	+	0.2		
B.marequensis	1.6	0.7		
B.radiatus	1	2.6		
B.trimaculatus	0.5	2	1.6	0.7
B.unitaeniatus	+	0.4		
B.viviparus	3.1	3.9		0.7
C.paratus	+	0.2	0.5	
G.callidus	0.8	1.5	1.1	
L.molybdinus	1.3	1.7		1.3
M.acutidens	0.5			
M.brevianalis	0.3			
M.macrolepidotus	0.3			
O.mossambicus	4.4	2.2		6.5
P.catostoma	0.3			
T.rendalli	1.3	2.6		2
S.meridianus	+	0.4		
Number of species	17	13	3	6
CPUE	16.7	20.7	3.2	11.7

+ Presumed present due to subsequent capture

B) POOL L6B

SPECIES	TRIP				
	JUN	JYL	AUG	SEP	OCT
A.bengalensis			0.3		
B.annectens	3.4	2.9	1.3	4.7	2.6
B.marequensis	0.4	0.9	0.3	0.6	0.3
B.radiatus	1.5	3.3	2.9	5	2.3
B.trimaculatus	0.4	0.5	0.5	2.5	2
B.viviparus	0.4	2.1	0.8	4.7	1.4
C.paratus	0.2	+	+	1	0.6
G.callidus	0.6	0.5	0.8	2.8	2.6
L.molybdinus	0.2	1.2	1.1	3.8	2.3
L.rosae	+	+	0.3	0.3	
M.acutidens	1.3	1.2	+	0.6	0.3
M.brevianalis	0.8	0.5	+	0.3	
M.macrolepidotus	0.2	0.2	+	2.2	
O.mossambicus	2.5	1.2	5.3	5.7	8.4
P.catostoma	0.4	0.2	0.5	0.6	0.3
S.meridianus	0.2	0.2	0.3	0.3	0.3
T.rendalli	0.4	0.6	0.6	0.3	
Number of species	16	16	17	16	12
CPUE	13	15.3	14.9	35.4	23.4

+ Presumed present due to subsequent capture

C) POOL- L11.

SPECIES	TRIP		
	JUN	JLY	AUG
B.annectens	1.8		
B.marequensis	1	0.6	
B.radiatus	1.2		
B.trimaculatus	0.4	5.6	
B.unitaeniatus	0.2	0.2	
B.viviparus	1.6		
C.gariepinus	+	0.2	0.5
G.callidus	0.2		
L.molybdinus	0.8	0.6	
L.rosae	0.1		
M.acutidens	3		
O.mossambicus	0.1		
S.meridianus	0.2		
T.rendalli	+	0.2	0.5
Number of species	14	6	2
CPUE	10.7	7.5	1.1

+ Presumed present due to subsequent capture

D) POOL- L15 series.

SPECIES	TRIP				
	JUN	JLY		AUG	
		15A	15B	15A	15B
B.annectens	3.4	0.3			
B.marequensis	1.2	2.9			
B.radiatus	0.3				
B.trimaculatus	0.6	1.9			
B.viviparus	5.9	0.3	70		2.3
G.callidus	+		2		
L.molybdinus	0.6		1		
M.acutidens	2.5				
M.brevianalis	0.3				
O.mossambicus	1.2	1.6	1		0.8
S.meridianus	1				
T.rendalli	2.2		3		
Number of species	12	5	5	0	2
CPUE	19.2	6.9	77	0	3.1

+ Presumed present due to subsequent capture

E) POOL L16 series

SPECIES	TRIP								
	JUN	JLY	AUG	SEP		OCT			
				16A	16B	16A 1	16A 2	16A 3	16B
A.bengalensis				0.2			2.7	1.5	
A. mossambica									0.3
B.annectens	0.7	0.3	1	1.7	8.5				
B.eutaenia	+	+	+		0.4				
B.marequensis	+	0.1							
B.radiatus	0.4	0.1	0.6	0.7	4.7				
B.trimaculatus	1.1	0.8	0.3	0.9	7.4				
B.viviparus	3.4	2.8	5.9	3.8	6.2	7	1.8	0.8	0.7
C.gariepinus				0.2			1.8		0.3
G.callidus	1	1.6	1.7	1.4	5.4		0.9		0.3
L.molybdinus	1.8	1.3	1.1		4.3				
L.rosae	+	0.2							
M.acutidens	+	+	+	0.2					
M.brevianalis	+		+		+				0.3
M.macrolepidotus	+	+	+	0.5					
O.mossambicus	2.3	1.1	2.1	5.7	10	30.2	2.2	11.5	20.7
P.catostoma	0.3	0.1	0.3						
P.philander	+	+	+		0.4				
S.meridianus	0.1	0.2	0.3						
T.rendalli	0.3	0.2	0.4	1.2	+				0.3
Number of species	17	17	15	11	11	2	5	3	7
CPUE	13.6	8.6	13.7	16.6	47.3	37	9.4	13.8	23

+ Presumed present due to subsequent capture

F) Pool L17

SPECIES	TRIP		
	JUN	JLY	SEP
B.annectens		1.3	
B.trimaculatus		1.7	
B.viviparus		14	
C.gariepinus		0.4	
S.meridianus		1.7	
T.rendalli		2.5	
Total no. species	?	6	0
CPUE	?	21.6	0

G) Pool L4

SPECIES	TRIP	
	JUN	JLY
B. annectens	2.4	
B. radiatus	0.4	
B. trimaculatus	3.2	
B. viviparus	1.6	
C. gariepinus	0.4	
G. callidus	0.4	
L. molybdinus	1.2	
M. brevianalis	0.4	
O. mossambicus	13.2	
T. rendalli	5.6	
No. species	10	0
CPUE	28.8	0

Table 5: Species composition and abundance (CPUE) of Mlondozi pools that persisted for June, 1992 only.

SPECIES	POOL							
	M1B	M1C	M1D	M1E	M2	M3	M5	M8
A.mossambica	0.1			0.1				
B.afrohamiltoni				0.4				
B.annectens				0.1				
B.imberi				0.3				
B.paludinosus				0.2				
B.radiatus				0.1				
B.toppini								
B.viviparus		0.4		0.1				2.2
C.gariepinus		0.9		0.8				
G.callidus								
G.giurus		0.9	35.3	1.6				
H.vittatus				0.1				
L.rosae				0.4				
M.acutidens				0.1				
M.macrolepidotus								1.1
P.catostoma								
O.mossambicus		15.8	16.6	0.1		0.9	9.4	8.6
P.philander			2.7			0.9		
S.meridianus								
T.rendalli		1.3	4.6	0.2		3.5	1.2	2.1
No. of species	1	5	4	14	0	3	2	4
CPUE	0.1	19.3	59.2	4.63	0	5.3	10.6	14

Table 6: MLONDOZI

CPUE per species for each trip.

A) M1a series. Pools from an ephemeral tributary

SPECIES	TRIP			
	JUN	JLY	AUG	SEP
	M1A	M1A	M1A1	M1A1
B.annectens		0.2		
B.radiatus		0.1		
B.toppini		0.3	0.0	
B.viviparus		0.1	0.1	
M.macrolepidotus		1.7		
O.mossambicus		0.8	0.1	
P.catastoma		0.1		
C.gariepinus			1.4	0.04
Total no. species	[illegible]	8	[illegible]	1
CPUE	[illegible]	3.3	1.5	0.04

APPENDIX III

TABLE I. CONDENSED SPECIES LIST AFTER WELLS 1991 OF THE MACRO- INVERTEBRATE FAUNA OF THE SABIE SAND RIVER SYSTEM (JUNE 92 TO OCTOBER 92). TAXA NOT PRESENT ARE NOT SHOWN.

HABITAT	SANDY SUBSTRATUM							WATER COLUMN						
SITE	14	20	14	20	14	20	14	14	20	14	20	14	20	14
DATE	JUNE		JULY		SEPT		OCT	JUNE		JULY		SEPT		OCT
EPHEMEROPTERA														
BAETIDAE														
Demoulina complex		1												
Baetidae juv.			1											
Centroptilum sp.		3												
CAENIDAE			1											
Afrocaenis		1												
Caenodes	4													
DIPTERA														
CHIRONOMIDAE	120	126	615	11	775	3	404	1	2		1	1	1	11
TIPULIDAE		3												
CERATOPOGONIDAE		1	4		4	2	22							1
DIXIDAE		1		1										
CULICIDAE		3	6		1		5							
STRATIOMYDAE														
PSYCHODIDAE					21									
TABANIDAE														
COLEOPTERA														
ELMIDAE	1	2			1		1							
DYTISCIDAE larvae											1			
HEMIPTERA														
NAUCORIDAE	10													
GERRIDAE										1		2		
NOTONECTIDAE	1			1			1	4			2	1	8	19
CORIXIDAE	5	7	158		10		38				3	3	2	2
ODONATA														
ZYGOPTERA												1		
ANISOPTERA														
GOMPHIDAE				2										
LIBELLULIDAE				2										
MOLLUSCA														
PULMONATA														
Helisoma				1										
BIVALVA														
SPHAERIDAE														
Pisidium sp.	2		1	4	1	50								
UNIONIDAE														
Unio caffer				1	1		2							
CRUSTACEA														
MACRURA														
Caridina nilotica				1										
OSTRACODA	1					19								
CLADOCERA	1					1								
COPEPODA				1		1	17			200	739	451	300	2203
OLIGOCHAETA	9													
ANNELIDA														
UNKNOWN FAM					22									
LUMBRICULIDAE	32		1			2	507							
HIRUDINEA	1	11		12		3	28							
TUBIFICIDAE						2								
ARACHNIDA														
HYDRACARINA	9						8		1					81
TOTAL	193	158	786	38	835	82	1002	5	3	201	746	459	311	2317
NUMBER OF TAXA	13	11	8	11	9	9	11	3	2	2	5	5	4	6

Site 14 = Sand River (Londolozi)
Site 20 = Sabie River (Molondozi)

TABLE 2. CONDENSED SPECIES LIST AFTER WELLS 1991 OF THE MACRO- INVERTEBRATE FAUNA OF THE SABIE SAND RIVER SYSTEM (JUNE 92 TO OCTOBER 92). TAXA NOT PRESENT ARE NOT SHOWN.

HABITAT	VEGETATION					RIFFLE			BEDROCK GULLIES					
SITE	14	20	14	20	20	14	20	14	14	20	14	20	14	20
DATE	JUNE		JULY		SEPT	JUNE		JULY	JUNE		JULY		SEPT	
EPHEMEROPTERA														
BAETIDAE														
Demoulina complex	32					4								
Cloeon complex	667	5	46		70	2						1		
Centroptiloides sp.		3						1		3	2			
Baetidae juv.	77	3	166			4		4	5	3	1			
B. monticula						1								
Potamocloeon complex			37			1								
Centroptilum sp.			977		20	8			2		1	1		4
LEPTOPHLEBIIDAE		1												
HEPTAGENIIDAE														
Compsoneuriella sp.	2		2	1										
TRICORYTHIDAE														
Neurocaenis						2								
Trichorythus													1	
POLYMITARCIDAE														
Povilla sp.		1						6						
CAENIDAE											1	1		
Afrocaenis				6				1						
Caenis	19					10								
Caenodes		33	65		1	13		2	1			1		
Caenospella				6										
Caenidae juveniles	15	1				1			1	1				
TRICHOPTERA														
HYDROPSYCHIDAE														
Cheumatopsyche afra									1					
ECNOMIDAE														
Ecnomus sp.												1		
LEPTOCERIDAE				4										
Leptocerus		3												
HYDROPTILIDAE														
Orthotrichia barnardii		4												
DIPTERA		5		1				3		1		4		
SIMULIIDAE						817			3			1		
CHIRONOMIDAE	28	21	63		62	237		121	52	29	9	359	41	110
CERATOPOGONIDAE		1			54	6								
DIXIDAE				1										
CULICIDAE	69	4	131		55	1		1				2		1
STRATIOMYDAE										1				
TABANIDAE							1							
COLEOPTERA														
PSEPHENIDAE			1											
ELMIDAE	1	2			1									
ELMIDAE larvae					2									
HELODIDAE								1						
DRYOPIDAE	1					1								
HYDRAENIDAE						1								
HYDROPHILIDAE					1									
NOTERIDAE			6		8							1		2
DYTISCIDAE					14					3		1		
Laccophilus		47												
DYTISCIDAE larvae			15		12	1			1					3
COLEOPTERA larvae			60				1							

TABLE 2. (CONT)														
HABITAT	VEGETATION					RIFFLE			BEDROCK GULLIES					
SITE	14	20	14	20	20	14	20	14	14	20	14	20	14	20
DATE	JUNE		JULY		SEPT	JUNE		JULY	JUNE		JULY		SEPT	
EPHYDRIDAE							3							
HALIPLIDAE										1		1		
CIRCULIONIDAE					3									
HEMIPTERA														
NAUCORIDAE	1			1	2	2								
BELOSTOMATIDAE		1	1											
NOTONECTIDAE			1		17								4	2
PLEIDAE		3	1		38									
CORIXIDAE		3	2	2		1			3		160	33	117	98
MESOVELIDAE			4											
VELIIDAE	1													
ODONATA														
ZYGOPTERA		3	6				1							
LESTIDAE			7											
PROTONEURIDAE	1													
ANISOPTERA			4											
GOMPHIDAE			2	2	1									
AESHNIDAE				1										
CODULIDAE				1	1							3		
LIBELLULIDAE				1						1				
MOLLUSCA														
PULMONATA					1									
Burnupia sp.					3	1	1							
Corbicula	2	1			2	17								
Lymnaea					43	1								
Helisoma	5	11	10		51									
Planorbis				62	2									
Lymnaea		1			20									
Physa	1				3									
Ferissia					12									
BIVALVA														
SPHAERIDAE														
Pisidium sp.		2			27	28								10
CRUSTACEA														
MACRURA														
Caridina nilotica	1	2	1	39	9									
OSTRACODA	2				214								13	168
CLADOCERA	22	4	230	663	716						122			
COPEPODA		37		945	538				1		13	234	3	
TURBELLARIA					7									
NEMATODA						1								
OLIGOCHAETA							1							
LEPIDOPTERA					2									
ANNELIDA														
LUMBRICULIDAE	14	1			29			7		1				6
HIRUDINEA				7	28	1		2	1	2				26
ARACHNIDA														
FAM UNKNOWN		4			2									
HYDRACARINA		7			4						5	1		
TOTAL	959	214	1838	1743	2075	1162	8	149	71	46	314	645	179	430
NUMBER OF TAXA	20	29	24	17	38	25	6	11	11	11	9	16	6	11

Site 14 = Sand River (Londolozi)
Site 20 = Sabie River (Mlondozi)

TABLE 3. INVERTEBRATE SPECIES COMPOSITION OF FIVE HABITAT TYPES IN POOL L6A AT LONDOLOZI (JUNE 1992 TO OCTOBER 1992).

DATE	JUNE	JULY	SEPT	OCT	JUNE	JULY	SEPT	OCT	JUNE	JULY	SEPT	OCT	JUNE	JULY	SEPT	OCT	JUNE	JULY	SEPT	OCT	JUNE	JULY	SEPT	OCT
HABITAT	RIFFLE				VEGETATION				BEDROCK GULLIES				SANDY SUBSTRATUM				WATER COLUMN				TOTAL			
EPHEMEROPTERA																								
BAETIDAE																								
Demoulina complex	13				87																100			
Baetidae juv.					194					1											194	1		
Centroptilum sp.		1							23	2											23	3		
HEPTAGENIIDAE																								
Compsoneuriella sp.					4																4			
TRICORYTHIDAE																								
Neurocaenis																								
Machadorythus									1												1			
POLYMITARCIDAE																								
Povilla sp.		2																				2		
CAENIDAE		1												1				1				3		
Afrocaenis		2																				2		
Caenis	30				56				2												88			
Caenodes		2								1			8								8	3		
Caenidae juveniles					37																37			
TRICHOPTERA																								
ECNOMIDAE		1																				1		
DIPTERA																								
SIMULIIDAE	1730								5												1735			
CHIRONOMIDAE	307	43			27				42	13			182	179							558	235		
CULICIDAE	2	1			128																130	1		
COLEOPTERA																								
ELMIDAE					2				1				1								4			
HELODIDAE		2			1																1	2		
DRYOPIDAE	1				1																2			
HEMIPTERA																								
NAUCORIDAE	5				2																7			
NOTONECTIDAE													1								1			
CORIXIDAE									11	6			10	21							21	27		
VELIIDAE					3																3			
ODONATA																								
ZYGOPTERA																								
PROTONEURIDAE					3																3			
ANISOPTERA																								
LIBELLULIDAE														1								1		
MOLLUSCA																								
Corbicula					5																5			
BIVALVA																								
SPHAERIDAE																								
Pisidium sp.													3								3			
TURBELLARIA									32												32			
HYDRACARINA									1				18								19			

TABLE 3. (CONT.)																								
DATE	JUNE	JULY	SEPT	OCT	JUNE	JULY	SEPT	OCT	JUNE	JULY	SEPT	OCT	JUNE	JULY	SEPT	OCT	JUNE	JULY	SEPT	OCT	JUNE	JULY	SEPT	OCT
HABITAT	RIFFLE				VEGETATION				BEDROCK GULLIES				SANDY SUBSTRATUM				WATER COLUMN				TOTAL			
NEMATODA																								
LUMBRICULIDAE													64	3							64	3		
TUBIFICIDAE													15								15			
CRUSTACEA																								
OSTRACODA					6																6			
CLADOCERA					65																65			
ANNELIDA																								
HIRUDINEA		6								1			1								1	7		
TOTAL	2088	61	0	0	621	0	0	0	118	24	0	0	303	205	0	0	0	1	0	0	3130	291	0	0
NUMBER OF TAXA	7	10	0	0	16	0	0	0	9	6	0	0	10	5	0	0	0	1	0	0	28	14	0	0

TABLE 4. INVERTEBRATE SPECIES COMPOSITION OF FIVE HABITAT TYPES IN POOL L6B AT LONDOLOZI (JUNE 1992 TO OCTOBER 1992).

DATE	JUNE	JULY	SEPT	OCT	JUNE	JULY	SEPT	OCT	JUNE	JULY	SEPT	OCT	JUNE	JULY	SEPT	OCT	JUNE	JULY	SEPT	OCT	JUNE	JULY	SEPT	OCT
HABITAT	RIFFLE				VEGETATION				BEDROCK GULLIES				SANDY SUBSTRATUM				WATER COLUMN				TOTAL			
EPHEMEROPTERA																								
BAETIDAE																								
Cloeon complex					2000	46				1											2000	47		
Centroptiloides sp.		4																				4		
Baetidae *juv.*	11	11				166			9												20	177		
B. monticula	2																				2			
Potamacloeon complex	2					37															2	37		
Centroptilum sp.	2					977			3												5	977		
LEPTOPHLEBIIDAE																								
Choroterpes complex											1												1	
Leptophlebid juv.											1												1	
HEPTAGENIIDAE																								
Compsoneuriella sp.					1	2															1	2		
Heptageniid juv.											1												1	
TRICORYTHIDAE																								
Neurocaenis	6																				6			
Trichorythus											2												2	
Trichorythid juveniles											1												1	
POLYMITARCIDAE																								
Povilla sp.		4																				4		
CAENIDAE										2												2		
Caenodes	4	3				65			1												5	68		
Caenidae juveniles					6				1												7			
TRICHOPTERA																								
HYDROPSYCHIDAE																								
Cheumatopsyche afra									2												2			
HYDROPTILIDAE		1																				1		
DIPTERA		8																				8		
SIMULIIDAE	675								4												679			
CHIRONOMIDAE	342	49			22	63			98	14	1		58	718	1716	1101	1		2	28	521	844	1719	1129
CERATOPOGONIDAE	17													11	3	64				3	17	11	3	67
CULICIDAE					79	131								1		15					79	132		15
PSYCHODIDAE															63								63	
COLEOPTERA																								
PSEPHENIDAE						1																1		
ELMIDAE														1		2						1		2
DRYOPIDAE					1																1			
HYDRAENIDAE	3																				3			
HYDROPHILIDAE																1								1
NOTERIDAE	1					6										1					1	6		1
DYTISCIDAE					1																1			
DYTISCIDAE larvae	1				1	15			1												3	15		
COLEOPTERA larvae						60																60		

TABLE 4. (CONT.)																								
DATE	JUNE	JULY	SEPT	OCT	JUNE	JULY	SEPT	OCT	JUNE	JULY	SEPT	OCT	JUNE	JULY	SEPT	OCT	JUNE	JULY	SEPT	OCT	JUNE	JULY	SEPT	OCT
HABITAT	RIFFLE				VEGETATION				BEDROCK GULLIES				SANDY SUBSTRATUM				WATER COLUMN				TOTAL			
HEMIPTERA																								
NAUCORIDAE													20								20			
BELOSTOMATIDAE						1																1		
GERRIDAE																		2				2		
NOTONECTIDAE					1	1											8				9	1		
PLEIDAE						1				1												2		
CORIXIDAE	3					2			5											2	8	2		2
MESOVELIDAE						4																4		
ODONATA																								
ZYGOPTERA						6				1									2			7	2	
LESTIDAE						7																7		
ANISOPTERA						4																4		
GOMPHIDAE						2																2		
MOLLUSCA																								
Helisoma					14	10															14	10		
Lymnaea					1																1			
Physa					2																2			
Ferissia					1																1			
Bulinus															1								1	
BIVALVA																								
SPHAERIDAE																								
Pisidium sp.		1												2	1	1						3	1	1
UNIONIDAE																								
Unio cafer															1	3							1	3
NEMATODA	4																				4			
LUMBRICULIDAE		20														1511						20		1511
CRUSTACEA																								
MACRURA																								
Caridina nilotica					1	1															1	1		
OSTRACODA											3		1								1		3	
CLADOCERA						230							1								1	230		
COPEPODA									1	40	8					51				312	1	40	8	363
OLIGOCHAETA													18								18			
ANNELIDA																								
HIRUDINEA	3								1							6					4			6
TOTAL	1076	101	0	0	2131	1838	0	0	126	59	18	0	98	733	1785	2756	9	2	4	345	3440	2733	1807	3101
NUMBER OF TAXA	15	9	0	0	14	23	0	0	11	6	8	0	5	5	6	11	2	1	2	4	33	35	14	12

TABLE 5. INVERTEBRATE SPECIES COMPOSITION OF FIVE HABITATS IN POOL L16A AT LONDOLOZI (JUNE 92 TO OCTOBER 92).

DATE	JUNE	JULY	SEPT	OCT	JUNE	JULY	SEPT	OCT	JUNE	JULY	SEPT	OCT	JUNE	JULY	SEPT	OCT	JUNE	JULY	SEPT	OCT	JUNE	JULY	SEPT	OCT
HABITAT	RIFFLE				VEGETATION				BEDROCK GULLIES				SANDY SUBSTRATUM				WATER COLUMN				TOTAL			
EPHEMEROPTERA																								
BAETIDAE																								
Demoulina complex					10																10			
Cloeon complex	5																				5			
Centroptiloides sp.										5												5		
Baetidae juv.	1	1			36					1				2							37	4		
B. latus	1																				1			
B. quantus	1																				1			
Centroptilum sp.	21													1							21	1		
HEPTAGENIIDAE																								
Composoneuriella sp.					2																2			
TRICORYTHIDAE																								
Machadorythus													4								4			
POLYMITARCIDAE																								
Povilla sp.		11																				11		
CAENIDAE										2				2								4		
Afrocaenis														1								1		
Caenis					1								12								13			
Caenodes	36	1							1					1							37	2		
Caenidae juveniles	3				3																6			
TRICHOPTERA																								
HYDROPSYCHIDAE																								
Cheumatopsyche afra	1																				1			
DIPSEUDOPSIDAE																								
Dipseudopsis sp.													1								1			
DIPTERA																								
SIMULIIDAE	44								4												48			
CHIRONOMIDAE	61	270			35				5		109		614	948	42	107				4	715	1218	151	111
CERATOPOGONIDAE													5		4	1					5		4	1
CULICIDAE		1									1			17	1							18	2	
TABANIDAE													2								2			
COLEOPTERA													1								1			
ELMIDAE													2			1					2			1
DRYOPIDAE	2																				2			
HYDROPHILIDAE		1																				1		
DYTISCIDAE larvae	1	1																			1	1		
HALIPLIDAE															1								1	
LIMNEBIDAE																				1				1
HEMIPTERA																								
NAUCORIDAE													96								96			
BELOSTOMATIDAE					1									1							1	1		
GERRIDAE																				1				1
NOTONECTIDAE									1	1			27		1			1		21	28	2	1	21
CORIXIDAE	1	1								475	56			453	2	73			5	3	1	929	63	76

TABLE 5. (CONT.)																								
DATE	JUNE	JULY	SEPT	OCT	JUNE	JULY	SEPT	OCT	JUNE	JULY	SEPT	OCT	JUNE	JULY	SEPT	OCT	JUNE	JULY	SEPT	OCT	JUNE	JULY	SEPT	OCT
HABITAT	RIFFLE				VEGETATION				BEDROCK GULLIES				SANDY SUBSTRATUM				WATER COLUMN				TOTAL			
NEPIDAE					1																1			
ODONATA																								
ZYGOPTERA																								
PROTONEURIDAE					1																1			
ANISOPTERA					1																1			
GOMPHIDAE																1								1
LIBELLULIDAE													1								1			
MOLLUSCA																								
Burnupia sp.	4																				4			
Corbicula	52												3								55			
Lymnaea	3																				3			
Melanoides													8								8			
BIVALVA																								
SPHAERIDAE																								
Pisidium sp.	83														1						83		1	
UNIONIDAE																								
Unio cafer														1	1	4						1	1	4
HYDRACARINA										15			3			24				231	3	15		255
NEMATODA																								
LUMBRICULIDAE																9								9
CRUSTACEA																								
MACRURA																								
Caridina nilotica					1																1			
CLADOCERA										365												365		
COPEPODA																		600	300	291		600	300	291
OLIGOCHAETA					42								57								99			
ANNELIDA																								
UNKNOWN FAM															1								1	
HIRUDINEA	3												7		1	79					10		1	79
CNIDARIA																								
HYDROZOA																								
Hydra sp.	1																				1			
TOTAL	324	287	0	0	134	0	0	0	11	864	166	0	843	1427	55	299	0	601	305	552	1312	3179	526	851
NUMBER OF TAXA	19	8	0	0	12	0	0	0	4	7	3	0	16	10	10	9	0	2	1	7	39	18	11	13

TABLE 8. INVERTEBRATE SPECIES COMPOSITION OF FIVE HABITAT TYPES IN POOL L16B AT LONDOLOZI (JUNE 82 TO OCT 82).

DATE	JUNE	JULY	SEPT	OCT	JUNE	JULY	SEPT	OCT	JUNE	JULY	SEPT	OCT	JUNE	JULY	SEPT	OCT	JUNE	JULY	SEPT	OCT	JUNE	JULY	SEPT	OCT
HABITAT	RIFFLE				VEGETATION				BEDROCK GULLIES				SANDY SUBSTRATUM				WATER COLUMN				TOTAL			
EPHEMEROPTERA																								
BAETIDAE																								
Demoulina complex					10																10			
Cloeon complex	6																				6			
Centroptiloides sp.										6												6		
Baetidae juv.	1	1			36					1				2							37	4		
B. latus	1																				1			
B. quennus	1																				1			
Centroptilum sp.	21													1							21	1		
HEPTAGENIIDAE																								
Compsoneuriella sp.					2																2			
TRICORYTHIDAE																								
Machadorythus													4								4			
POLYMITARCIDAE																								
Povilla sp.		11																				11		
CAENIDAE										2				2								4		
Afrocaenis														1								1		
Caenis					1								12								13			
Caenodes	36	1							1					1							37	2		
Caenidae juveniles	3				3																6			
TRICHOPTERA																								
HYDROPSYCHIDAE																								
Cheumatopsyche afra	1																				1			
DIPSEUDOPSIDAE																								
Dipseudopsis sp.													1								1			
DIPTERA																								
SIMULIIDAE	46								4												48			
CHIRONOMIDAE	61	271			36				5		12		614	940	567	4				1	716	1219	579	5
CERATOPOGONIDAE													6		5						6		6	
CULICIDAE		1												17	3							18	3	
TABANIDAE													2								2			
COLEOPTERA													1								1			
ELMIDAE													2		2						2		2	
DRYOPIDAE	2																				2			
HYDROPHILIDAE		1																				1		
DYTISCIDAE larvae	1	1																			1	1		
HEMIPTERA																								
NAUCORIDAE													88								88			
BELOSTOMATIDAE					1									1							1	1		
GERRIDAE																			6				6	
NOTONECTIDAE									1	1	11		27			2		1	3	36	28	2	14	38
CORIXIDAE	1	1								476	296			463	28	41			4		1	940	327	41
NEPIDAE					1																1			

TABLE 8. (CONT.)																								
DATE	JUNE	JULY	SEPT	OCT	JUNE	JULY	SEPT	OCT	JUNE	JULY	SEPT	OCT	JUNE	JULY	SEPT	OCT	JUNE	JULY	SEPT	OCT	JUNE	JULY	SEPT	OCT
HABITAT	RIFFLE				VEGETATION				BEDROCK GULLIES				SANDY SUBSTRATUM				WATER COLUMN				TOTAL			
ODONATA																								
ZYGOPTERA																								
PROTONEURIDAE					1																1			
ANISOPTERA					1																1			
GOMPHIDAE															1								1	
LIBELLULIDAE													1								1			
MOLLUSCA																								
Burnupia sp.	4																				4			
Corbicula	62												3								66			
Lymnaea	3																				3			
Physa															1								1	
Melanoides													8								8			
PULMONATA																								
BIVALVA																								
SPHAERIDAE																								
Pisidium sp.	83														1						83		1	
UNIONIDAE																								
Unio cafer														1								1		
HYDRACARINA										16			3							1	3	16		1
CRUSTACEA																								
MACRURA																								
Caridina nilotica					1																1			
OSTRACODA											38												38	
CLADOCERA										365												365		
COPEPODA																		800	1364	8004		800	1364	8008
OLIGOCHAETA					42								67								89			
ANNELIDA																								
UNKNOWN FAM															86								86	
HIRUDINEA	3												7								10			
CNIDARIA																								
HYDROZOA																								
Hydra sp.	1																				1			
TOTAL	326	288	0	0	134	0	0	0	11	884	364	0	843	1427	873	47	0	801	1367	8044	1313	3180	2394	8091
NUMBER OF TAXA	19	8	0	0	12	0	0	0	4	7	4	0	18	9	9	3	0	2	4	4	30	18	13	6

TABLE 7. INVERTEBRATE SPECIES COMPOSITION OF FIVE HABITAT TYPES IN POOL M7A AT MOLONDOZI (JUNE 92 TO SEPTEMBER 92).

DATE	JUNE	JULY	SEPT	JUNE	JULY	SEPT	JUNE	JULY	SEPT	JUNE	JULY	SEPT	JUNE	JULY	SEPT	JUNE	JULY	SEPT
HABITAT	RIFFLE			VEGETATION			BEDROCK GULL.			SANDY SUBSTR.			WATER COLUMN			TOTAL		
EPHEMEROPTERA																		
BAETIDAE																		
Cloeon complex						43												43
Baetidae juv.							2								1	2		1
Centroptilum sp.							1				1		1			2	1	
CAENIDAE																		
Caenodes											1						1	
TRICHOPTERA																		
GLOSSOSOMATIDAE							1									1		
DIPTERA							2									2		
CHIRONOMIDAE							74		176	1	22	2	5			80	22	178
CERATOPOGONIDAE									1			3						4
DIXIDAE											4						4	
CULICIDAE									1		1						1	1
TABANIDAE	1															1		
COLEOPTERA																		
ELMIDAE												1						1
ELMIDAE larvae						1												1
NOTERIDAE									1		1						1	1
DYTISCIDAE						38					1						1	38
DYTISCIDAE larvae							1						1			2		
COLEOPTERA larvae	1															1		
EPHYDRIDAE	3															3		
HEMIPTERA																		
NAUCORIDAE						7												7
BELOSTOMATIDAE				1												1		
NOTONECTIDAE						1			1		1				11		1	13
PLEIDAE						26												26
CORIXIDAE									6									6
ODONATA																		
ZYGOPTERA	1			1												2		
COENAGRIONIDAE						1												1
ANISOPTERA																		
GOMPHIDAE						1					6						6	1
AESHNIDAE											1						1	
LIBELLULIDAE						1	3				4					3	4	1
MOLLUSCA																		
Burnupia sp.	1					1										1		1
Corbicula						5												5
Helisoma						7					3						3	7
Planorbis						5												5
Physa						1												1
PULMONATA						4												4

TABLE 7. (CONT.)																		
DATE	JUNE	JULY	SEPT	JUNE	JULY	SEPT	JUNE	JULY	SEPT	JUNE	JULY	SEPT	JUNE	JULY	SEPT	JUNE	JULY	SEPT
HABITAT	RIFFLE			VEGETATION			BEDROCK GULLIES			SANDY SUBSTRATUM			WATER COLUMN			TOTAL		
BIVALVA																		
SPHAERIDAE																		
Pisidium sp.												1						1
UNIONIDAE																		
Unio caffer											2						2	
TURBELLARIA						22												22
HYDRACARINA						13							3			3		13
NEMATODA																		
LUMBRICULIDAE									19									19
CRUSTACEA																		
MACRURA																		
Caridina nilotica											3						3	
OSTRACODA						128												128
COPEPODA						40												40
CONCHOSTRACA															1			1
OLIGOCHAETA	1															1		
ANNELIDA																		
HIRUDINEA						52			78		31	9			1		31	140
TUBIFICIDAE												6						6
TOTAL	8	0	0	2	0	397	84	0	283	1	82	22	10	0	14	105	82	716
NUMBER OF TAXA	6	0	0	2	0	20	7	0	8	1	15	6	4	0	4	15	15	32

TABLE 8. INVERTEBRATE SPECIES COMPOSITION OF FIVE HABITAT TYPES IN POOL M7B AT MOLONDOZI (JUNE 92 TO SEPTEMBER 92).

DATE	JUNE	JULY	SEPT	JUNE	JULY	SEPT	JUNE	JULY	SEPT	JUNE	JULY	SEPT	JUNE	JULY	SEPT
HABITAT	VEGETATION			BEDROCK GULL.			SANDY SUBSTR.			WATER COLUMN			TOTAL		
EPHEMEROPTERA															
BAETIDAE															
Cloeon complex			43	1									1		43
Centroptiloides sp.				9									9		
Baetidae juv.				6								1	6		1
Centroptilum sp.					2		10						10	2	
HEPTAGENIIDAE															
Compsoneuriella sp.		1												1	
Heptageniid juv.															
CAENIDAE	11												11		
Afrocaenis		6												6	
Caenis	14												14		
Caenodes					2									2	
Caenospella		6												6	
Caenidae juveniles				3									3		
TRICHOPTERA															
ECNOMIDAE															
Ecnomus sp.					1									1	
LEPTOCERIDAE		4												4	
HYDROPTILIDAE	1			1									2		
DIPSEUDOPSIDAE															
Dipseudopsis sp.							1						1		
DIPTERA		1												1	
SIMULIIDAE					1									1	
CHIRONOMIDAE	6				113	176	376	4	2				382	117	178
TIPULIDAE							8						8		
CERATOPOGONIDAE						1	2		3				2		4
DIXIDAE		1					3						3	1	
CULICIDAE	1			1	3	1	9						11	3	1
STRATIOMYDAE				2									2		
COLEOPTERA	2												2		
ELMIDAE	4						5		1				9		1
ELMIDAE larvae			1												1
DRYOPIDAE	1												1		
NOTERIDAE					1	1								1	1
DYTISCIDAE			38	10									10		38
DYTISCIDAE larvae											2			2	
HALIPLIDAE				4									4		
HEMIPTERA															
NAUCORIDAE		1	7											1	7
NOTONECTIDAE			1			1						11			13
PLEIDAE	1		26										1		26
CORIXIDAE		2		1	1	6					4		1	7	6

TABLE 8. (CONT.)															
DATE	JUNE	JULY	SEPT	JUNE	JULY	SEPT	JUNE	JULY	SEPT	JUNE	JULY	SEPT	JUNE	JULY	SEPT
HABITAT	VEGETATION			BEDROCK GULL.			SANDY SUBSTR.			WATER COLUMN			TOTAL		
ODONATA															
ZYGOPTERA															
COENAGRIONIDAE			1												1
ANISOPTERA	1												1		
GOMPHIDAE		2	1											2	1
AESHNIDAE		1												1	
CODULIDAE		1			6									7	
LIBELLULIDAE		1	1					1						2	1
MOLLUSCA															
Burnupia sp.	1		1										1		1
Corbicula	3		5										3		5
Helisoma			7												7
Planorbis		62	5											62	5
Physa			1												1
PULMONATA			4												4
BIVALVA															
SPHAERIDAE															
Pisidium sp.							1		1				1		1
TURBELLARIA			22												22
HYDRACARINA			13		2									2	13
NEMATODA															
LUMBRICULIDAE				3		19							3		19
CRUSTACEA															
MACRURA															
Caridina nilotica		39												39	
OSTRACODA			128												128
CLADOCERA		663												663	
COPEPODA		945	40	1	468			4			1		1	1418	40
CONCHOSTRACA												1			1
OLIGOCHAETA	19												19		
ANNELIDA															
HIRUDINEA	1	7	52	6		78	2	6	9			1	9	13	140
TUBIFICIDAE									6						6
TOTAL	66	1743	397	48	600	283	417	15	22	0	7	14	531	2365	716
NUMBER OF TAXA	14	17	20	13	11	8	10	4	6	0	3	4	30	26	31

TABLE 9. INVERTEBRATE SPECIES COMPOSITION OF FIVE HABITAT TYPES IN POOL M9D AT MOLONDOZI (JUNE 92 TO SEPTEMBER 92).

DATE	JUNE	JULY	SEPT	JUNE	JULY	SEPT	JUNE	JULY	SEPT	JUNE	JULY	SEPT	JUNE	JULY	SEPT	JUNE	JULY	SEPT
HABITAT	RIFFLE			VEGETATION			BEDROCK GULLIES			SANDY SUBSTRATUM			WATER COLUMN			TOTAL		
EPHEMEROPTERA																		
BAETIDAE																		
Demoulina complex										4						4		
Cloeon complex				14	3	161		1							1	14	4	162
Centroptiloides sp.				8												8		
Baetidae juv.				10			1		1							11		1
Centroptilum sp.					34	54			2								34	56
LEPTOPHLEBIIDAE				3												3		
HEPTAGENIIDAE																		
Compsoneuriella sp.				1												1		
TRICORYTHIDAE																		
Machadorythus										1						1		
POLYMITARCIDAE																		
Povilla sp.				3												3		
CAENIDAE								1									1	
Afrocaenis										2						2		
Caenodes				100	35	2										100	35	2
Caenidae juveniles				4												4		
TRICHOPTERA																		
LEPTOCERIDAE																		
Leptocerus				9												9		
HYDROPTILIDAE																		
Orthotrichia barnardi				11												11		
DIPTERA				16	3			7								16	10	
CHIRONOMIDAE				64	73	146	13	605	8		8	3		1	4	77	687	161
CERATOPOGONIDAE				2		162										2		162
CULICIDAE				13	32	156						1				13	32	157
COLEOPTERA																		
PSEPHENIDAE												1						1
ELMIDAE	3			5		2					1					8	1	2
HELODIDAE larvae				1												1		
DRYOPIDAE	1															1		
HYDROPHILIDAE						2												2
NOTERIDAE						1			4									5
DYTISCIDAE					5	5		2									7	5
Laccophilus				141												141		
DYTISCIDAE larvae						26.					1						1	26
COLEOPTERA larvae				1												1		
HALIPLIDAE					16			2									18	
CIRCULIONIDAE						8												8
HEMIPTERA																		
BELOSTOMATIDAE				1												1		
NOTONECTIDAE				1	23	3					2			3	12	1	28	15
PLEIDAE				9	8	38										9	8	38

TABLE 9. (CONT.)																		
DATE	JUNE	JULY	SEPT	JUNE	JULY	SEPT	JUNE	JULY	SEPT	JUNE	JULY	SEPT	JUNE	JULY	SEPT	JUNE	JULY	SEPT
HABITAT	RIFFLE			VEGETATION			BEDROCK GULLIES			SANDY SUBSTRATUM			WATER COLUMN			TOTAL		
CORIXIDAE				10	35			64	283	21		1		2		31	101	284
ODONATA																		
ZYGOPTERA				9												9		
ANISOPTERA						1												1
MOLLUSCA																		
Burnupia sp.										1						1		
Corbicula	1															1		
Lymnaea						129												129
Helisoma				34	23	33						1				34	23	34
Lymnaea				2												2		
Physa					1	8											1	8
Tamichia												1						1
BIVALVA																		
SPHAERIDAE																		
Pisidium sp.				7	18	81			31		12	147				7	30	259
HYDRACARINA				20	4											20	4	
NEMATODA												29						29
LUMBRICULIDAE				2		48										2		48
CRUSTACEA																		
MACRURA																		
Caridina nilotica				7	7	21						1				7	7	22
OSTRACODA					70	366			505			56					70	927
CLADOCERA				12	186	1395						4				12	186	1399
COPEPODA				111	598	785						2		1476		111	2074	787
LEPIDOPTERA						5												5
ANNELIDA																		
HIRUDINEA	5			1						31						37		
ARACHNIDA																		
FAM UNKNOWN				11		5										11		5
CNIDARIA																		
Hydra sp.						1												1
TOTAL	10	0	0	643	1174	3644	14	682	834	60	24	247	0	1482	17	727	3362	4742
NUMBER OF TAXA	4	0	0	33	19	27	2	7	7	6	5	12	0	4	3	39	22	32

APPENDIX IV

Table 1: Identification to genus of algae from selected pools in July, 1992. An estimate of quantity is included.

GENUS	POOL NUMBER							
	L1B	L2B	L2b surface scum	L6B	L11	L11 surface scum	L15A	L16
Oscillatoria	filaments +	filament		filaments	filaments		filament	filaments
Spirogyra	filaments	filaments		filaments + +	filaments		filaments	filaments
Nitzschia	cells + +	cells + +		cells + +	cells		cells + +	cell
Synedra	cells	cells	cells	cell	cell			cell
Cyclotella	cells + +		cells			cells		
Staurastrum	cells	cells					cells	cells + +
Micrasterias	cells		cells			cells	cell	cells
Melosira	filament			cells				
Stigeoclonium		filaments			filament			
Diatoma		cell						
Botryococcus			colonies +			colonies		
Chlorella			cells			cells		
Chrysococcus			cells + +			cells + +		
Cladophora				filaments + +			filaments	
Navicula				cells				
Anacystis					colony			
Fragilaria					cells			
Euglena							cells	
Cocconeis							cells	
Aphanothece(cf)								cells + +

APPENDIX V

LIST OF MAPS DEPICTING CHANGES IN PHYSICAL AND CHEMICAL CONDITIONS IN ALL POOLS OVER THE DROUGHT PERIOD

Maps are housed at the Institute for Water Research at Rhodes University, Grahamstown and are available upon request.

APPENDIX VI

CHANGES IN NUMBER AND DISTRIBUTION OF HIPPOPOTAMI IN THE SABIE RIVER, KRUGER NATIONAL PARK, DURING THE 1992 DROUGHT

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Kruger National Park

January 1992

INTRODUCTION

Hippopotami are counted annually in the Kruger National Park (KNP) as part of an extensive monitoring programme (Joubert 1983). The six major rivers, the Crocodile, Sabie, Olifants, Letaba, Shingwedzi and Luvuvhu/Limpopo rivers, are included in this census.

More than 700 hippopotami, the highest density in the KNP rivers (6,9 animals/km) during the 1991 census, were recorded in the Sabie River (Viljoen 1992). The decrease in the Sabie River's flow during 1992 as a result of the severe drought in southern Africa was expected to cause significant changes in hippopotamus numbers and distribution. Hippopotamus mortalities were reported in several regions during previous droughts in southern Africa (Smuts & Whyte 1981, Walker *et al.* 1987, Whyte & Viljoen 1989).

Two additional hippopotamus censuses were conducted to complement the annual census to study the expected spatial changes in the Sabie River hippopotamus population. This document is partly an extract of the annual KNP hippopotamus census report (Viljoen 1993).

METHODS

A standardized aerial census technique has been in use since 1984 for a mid-dry season hippopotamus census in KNP rivers during June-August (Joubert 1983). The two additional 1992 Sabie River censuses were conducted at the beginning (13 May) and the end of the dry season (15 October) while the regular, annual census was completed on 4 August.

A Bell 206 Jetranger helicopter was used for the census flights. The crew consisted of the pilot (front right seat), two observers (front left seat and rear right seat) and a data recorder (left rear seat) who assisted as an additional observer. All hippopotamus sightings were recorded directly onto 1:10000 topographical data maps noting the locality, group size and number of calves (i.e. animals younger than one year). Hippopotami counted in and out of the water were recorded separately. Warm, sunny days were selected for the censuses and flights were conducted between late morning and early afternoon (10:00 - 14:00) when the majority of hippopotami are usually outside the water and therefore easier to count. The duration of the censuses were 01:37h, 01:51h and 01:44h for the May, August and October censuses respectively. The flight path was 20-55m above ground and air speed of about 25-35 knots was maintained. A criss-cross flight path was followed in sections where the river is wide or braided. Although the full length of the Sabie River was censused during the August and October censuses, the May census included only the section downstream of Kruger Gate (Fig. 1). Hippopotami counted in dams in the near vicinity of the Sabie River were also included in the river total.

All recorded observations on the data maps were transferred to a computerized grid system with a digitizer tablet and computer. The data were extracted and analyzed using a commercial statistical software (SAS Institute 1991). Hippopotamus densities were calculated according to five different river sections adapted from a classification proposed by Venter (1991).

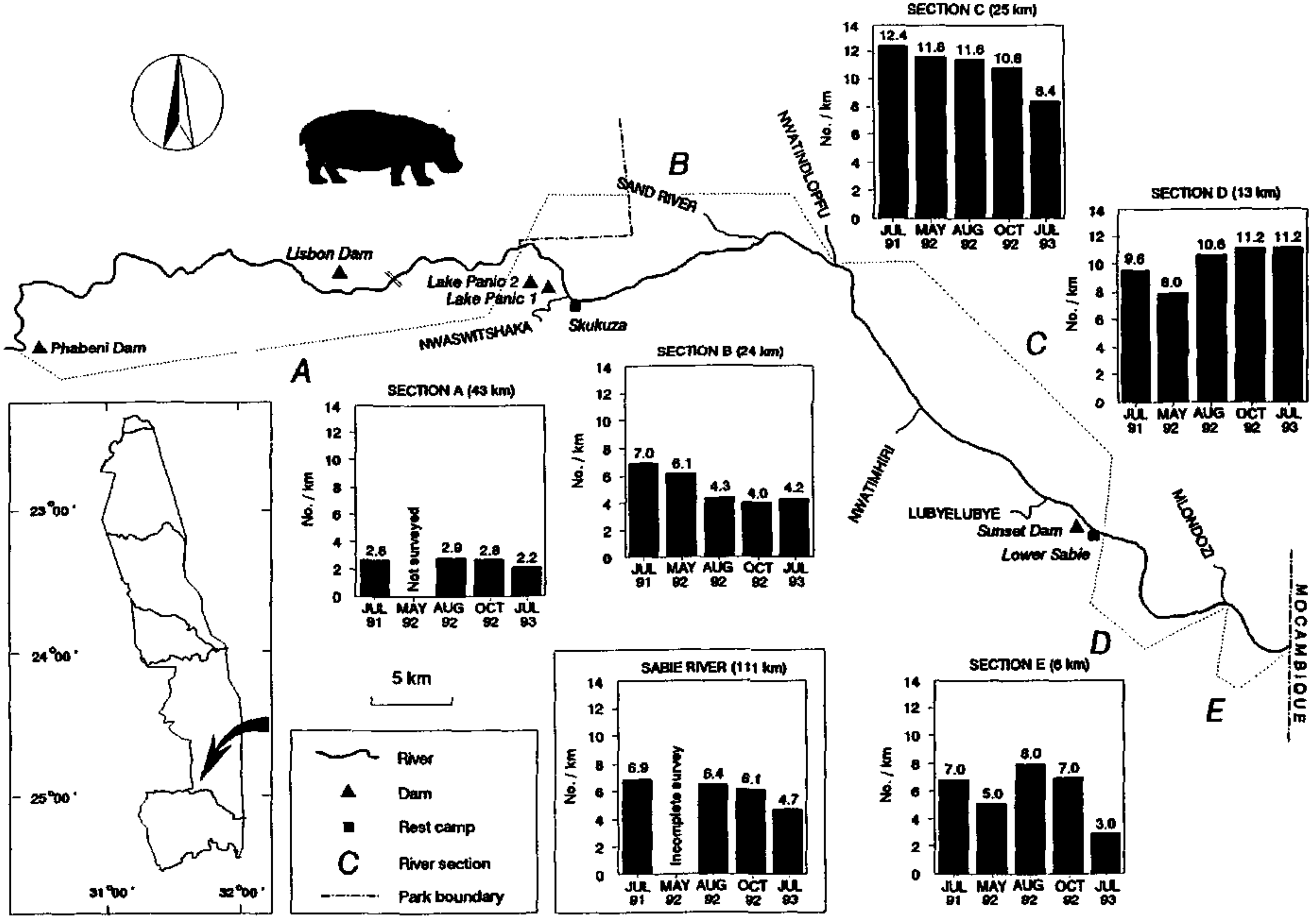

Fig. 1. Changes in the density of hippopotami in different sections of the Sabie River (July 1991 - October 1992).

RESULTS AND DISCUSSION

The August census was the first complete census of the Sabie River in 1992 and provides the best comparison with the previous annual census. A population decrease of 7,9% from July 1991 (Viljoen 1992) to 708 hippopotami in August 1992 was recorded (Table 1). Hippopotami in five dams near the Sabie River were included in the river totals (Table 2). The overall population density was 6,4 animals/km. Population densities in the five river sections varied from 2,9 animals/km upstream from Skukuza to 11,6 animals between Nwatindlopfu and Lower Sabie (Fig. 1). A population decrease of 38,5% occurred from July 1991 to August 1992 between Skukuza and Nwatindlopfu (Section B). Hippopotami increased in the two sections downstream of Lower Sabie (12,8% and 14,3% respectively) while remaining relatively unchanged upstream of Skukuza (Section A).

TABLE 1. Census totals for hippopotami in the Sabie River as obtained during the 1991 annual census and three 1992 censuses (May, August and October).

CENSUS PERIOD	RIVER	
	SECTIONS B-E	TOTAL *
July 1991	647	769
May 1992 *	574	601
August 1992	582	708
October 1992	553	672

* River Section A was excluded in the May 1992 census (see Fig. 1).

TABLE 2. Number of hippopotami in dams near the Sabie River during three 1992 hippopotamus censuses (May, August and October).

DAM	DIST. FROM RIVER (km)	MAY		AUGUST		OCTOBER	
		TOTAL	CALVES	TOTAL	CALVES	TOTAL	CALVES
Phabeni	1.0	*		26	6	30	
Lisbon	1.0	*		12	1	11	
Lake Panic 1	0.6	1		3			
Lake Panic 2	1.2	19	1	8		8	
Sunset	0.3			1		2	

* River section A was excluded in the May 1992 census (see Fig. 1).

The annual census in August and the two additional censuses in the Sabie River during 1992 indicated that changes in both the hippopotamus total and distribution occurred (Fig. 1). The population density remained relatively unchanged upstream of Skukuza (Section A) during the last two censuses. With the exception of the section between Nwatindlopfu and Lower Sabie (Section C) where the density remained relatively stable, hippopotamus densities varied in the other sections. The most important changes occurred between Skukuza and Nwatindlopfu (Section B) where the hippopotamus density decreased between the censuses, and downstream of Lower Sabie where density increased. However, these changes in population density are not significant (Two-way analysis of variance; F-ratio=0,475; P>0,05). The only hippopotamus mortalities (12) from the air were recorded during the October census.

Several hippopotami were present in dams near the Sabie River during the censuses (Table 2), 7,1% and 7,6% of the total during the August and October censuses respectively. Phabeni Dam near the western boundary of the KNP and Lisbon Dam north-west of Kruger Gate had an average of 5,7% of the Sabie River hippopotamus total in August and October.

The number of calves observed varied between four in October (0,6% of the population) and 62 in August (8,6% of the population). The majority of hippopotami (92,5%) were on land during the August census but only 39,4% and 9,7% were outside the water during the May and October censuses respectively (Table 3). Hippopotamus calves are very difficult to count in the water and the high percentages of hippopotami in the water during the May and October censuses possibly resulted in an undercount of calves. An earlier experimental count in the Olifants River revealed that significantly fewer hippopotamus calves are counted when the majority of hippopotami are in the water although the total number of animals does not differ significantly (Viljoen, unpublished data). Only seven calves were counted in dams during the August census and none during the October census (Table 2).

Hippopotamus births have been reported to be correlated with rainfall (Laws & Clough 1966, Smuts & Whyte 1981). Smuts & Whyte (1981) found that hippopotamus conception rates in the KNP differed significantly between droughts and years with above average rainfall. The percentage calves recorded during the August census differs by only 3,3% from the nine-year average for the Sabie River (Viljoen 1993).

TABLE 3. Hippopotami recorded on land and in the water during three 1992 censuses (May, August and October).

PERIOD	HIPPOPOTAMI				CALVES ** SEEN		TOTAL *
	ON LAND		IN WATER				
	TOTAL	%	TOTAL	%	TOTAL	%	
May *	226	39.4	348	60.6	35	6.1	574
August	655	92.5	53	7.5	62	8.6	708
October	65	9.7	607	90.3	4	0.6	672

* River section A was excluded in the May 1992 census (see Fig. 1).

** Animals aged younger than one year (both on land in in the water).

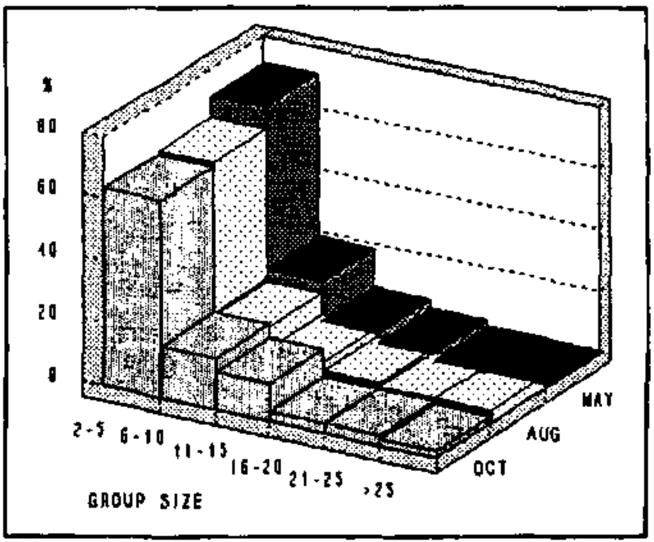

FIG. 2. Hippopotamus group sizes recorded during *three censuses in the Sable River (May,* August and October 1992).

The majority of hippopotamus herds (66,3%) consisted of 2-5 individuals during all three censuses (Fig. 2). Only 5,1% of the herds numbered more than 20 individuals. Although overall group sizes remained largely unchanged between the three surveys (Fig. 2), the percentage of single individuals recorded (Table 4) varied significantly between the three surveys ($\chi^2=41,89$; $P<0,01$; df=2). The highest percentage of single animals occurred in October (44,6% and 7,6% on land in the water respectively) and the lowest in May (11,9% and 8.0% on land in the water respectively). Average group sizes did not differ significantly between hippopotami on land and in the water during the three censuses ($\chi^2=3{,}11$; $P>0{,}05$; df=2).

Hippopotamus groups are variable in size and composition and changes may even occur during one day (Klingel 1991). Group size is not a sociological parameter but depends on density and habitat conditions such as the availability of suitable pools and sandy banks (Klingel 1991). The relatively unchanged group sizes in the Sabie River are probably the result of pool sizes and sandy banks which remained suitable in spite of the low-flow conditions.

TABLE 4. Group sizes of hippopotami recorded both on land and in the water during three 1992 censuses (May, August and October).

PERIOD	ON LAND			IN WATER		
	NO. OF INDIVID. ***	NO. OF GROUPS **	AVG. GROUP SIZE *	NO. OF INDIVID. ***	NO. OF GROUPS **	AVG. GROUP SIZE *
May	27	45	4.4	28	52	6.2
(%)	11.9			8.0		
August	45	78	7.8	17	11	3.3
(%)	6.9			32.1		
October	29	10	3.6	46	82	6.8
(%)	44.6			7.6		
AVERAGE	33.7	44.3	6.4	30.3	48.3	6.3

* Average group size of groups consisting of ≥ 2 individuals.
** Number of groups consisting of ≥ 2 individuals.
*** Total number of single individuals.

River section A was excluded in the May 1992 census (see *Fig. 1*).

CONCLUSIONS

Although the Sabie River hippopotamus population total decreased during the drought, densities in the different river sections remained largely unchanged. The drought resulted only in a few mortalities towards the end of the dry season, unlike the Letaba and Luvuvhu rivers where large numbers of hippopotami died during the 1992 dry season (Viljoen 1993). During drought conditions the availability of pools often becomes a severe limiting factor (Smuts & Whyte 1981). Hippopotamus group sizes did not change significantly, nor was the percentage calves recorded significantly lower than during previous years, indicating that pool conditions in the Sabie River remained adequate to sustain the present hippopotamus population during the study period.

ACKNOWLEDGEMENTS

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