# STREAM FISH ASSEMBLAGES ALONG THE LONGITUDINAL GRADIENT OF THE NYAGUI RIVER.

By

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## ABSTRACT

This study investigated the influence of longitudinal and environmental gradients on fish biodiversity in a central African context. The Nyagui River was used as a study site. Fish and microhabitat data were collected at fourteen stations in three periods of different flow. A total of twenty-four species were collected including *Mesobola brevianalis* that was not previously documented in the lower Zambezi system. A number of species that were expected to occur at low altitude were not collected during this sampling period. Species richness, diversity, and relative abundance increased from upstream to downstream in all sampling months and this was related to increasing catchment area. The number of species and their relative abundance was also correlated to habitat diversity that was calculated using the Shannon Diversity index and this relationship was explained by a power curve and was significant in October and November. Altitudinal difference in species composition was also exhibited. The most abundant species, accounting for >50% of the total catch, at altitude >1 400m were *Barbus paludinosus*, *Micropterus salmoides* and *Clarias gariepinus* while at lower altitude (<1 400m) *Chiloglanis neumanni*, *Labeobarbus marequensis, Labeo cylindricus* and *Barbus trimaculatus* were more abundant reflecting a response of fish to the physical constraints imposed by stream size and gradient. Based on Canonical Correspondence Analysis, the species at the upstream stations were associated with slow and shallow habitats with abundant aquatic vegetation that probably provided cover from predators. Species at the downstream stations were on the other hand associated with fast flowing riffles on coarse substrates, shallow pools and deep pools with rocks. The construction of Kunzvi Dam is likely to lead to the decline in species that are associated with flowing water both in the dam and downstream and an increase in the lacustrine adapted cichlids. It was concluded from this study that catchment area is a good predictor of species richness and their abundance and the number of species and their abundance is correlated to habitat heterogeneity at each station and this relationship is weak during the time of flooding. Species were also associated with specific habitats and any alteration in flow is likely to lead to change in species composition and abundance

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## INTRODUCTION

The central theme in stream fish community ecology is an understanding of the factors responsible for structuring fish assemblages in these aquatic ecosystems (Godinho *et al*, 2000; Wootton *et al*., 2000; Koel and Peterka, 2003). This is because the ichthyofauna in most rivers is increasingly threatened by human activities that place a heavy demand on freshwater resources (Collares-Pereira and Cowx, 2004). Freshwater fishes are ranked as the most threatened among all classes of vertebrates worldwide (Collares-Pereira and Cowx, 2004) with about twenty-four species now considered to be rare or endangered in southern Africa (Skelton, 1993) and one species possibly being extinct in Zimbabwe (Marshall and Gratwicke, 1998-99).

In Zimbabwe, very little work has been done on the ecology of rivers despite the fact that they support a diverse assemblage of fish. Many aquatic habitats in Zimbabwe are being degraded by pollution, siltation, the introduction of alien species and other human activities (Minshull, 1993) but only a few studies have considered their fish assemblages (Gratwicke and Marshall, 2001; Gratwicke *et al*., 2003). There is therefore a paucity of information on stream fish in Zimbabwe and more comprehensive studies in these systems are urgently needed.

This study determined the relative importance of abiotic factors (water flow, water quality and habitat) to the distribution of fish along a longitudinal gradient in the Nyagui River. This river is a major tributary of the Mazowe River and was selected for this study because there are no major physical barriers including dams along its entire length, and none in the Mazowe River below the Nyagui/Mazowe confluence. Since the Mazowe River enters the Zambezi River downstream of the Cabora Bassa dam, the Nyagui River is therefore one of the few rivers in Zimbabwe that still has a direct link to Indian Ocean. This meant that there were no barriers to fish migration along the river and potamodromous and diadromous species were expected to occur in the system. This study will also document the fish species found in this river prior to the construction of the proposed Kunzvi dam, which is planned as another source for water to the city of Harare. Finally, the continuous nature of the river provided an opportunity to study the relative importance of abiotic factors, both on the spatial and temporal scale, in influencing stream fish assemblages. The understanding, definition, and measurement of relevant habitat characteristics are the basis for understanding patterns of community diversity among stream fish (Gorman and Karr, 1978).

The main aims of this study were to provide data on the fish species found in the Nyagui River and to address the following questions: (1) what fish species are found in the Nyagui River basin and what is their longitudinal pattern of abundance and diversity, (2) how do these fish assemblages vary spatially and temporally and (3) what environmental variables determine patterns of fish abundance and microhabitat use?

## LITERATURE REVIEW

### The ecology of stream fishes

A major question in fish community ecology is whether the collection of a fish species at a site is merely by chance or governed by certain mechanisms that allows for its coexistence with other species and a suite of environmental variables (Lévêque, 1997). The structure of fish assemblages may be a result of stochastic factors such as disturbance or deterministic interactions such as competition and predation (Grossman and Freeman, 1987; Lowe-McConnell, 1987) Contemporary abiotic factors such as the physical and chemical environment may also be important determinants (Vila-Gispert *et al*., 2002). Several authors have argued that abiotic factors become increasingly important as determinants of fish community structure from downstream to upstream because environmental fluctuations, especially in flow, are much greater (Horwitz, 1978; Closs and Lake, 1996; Taylor and Warren, 2001). Biotic factors in the form of competition and predation on the other hand tend to be more influential in downstream sections that are environmentally benign (Gilliam *et al.*, 1993).

It has also been suggested that streams, both tropical and temperate, are always subjected to high environmental variability, and the composition of a fish assemblage is a consequence of its stability which is itself determined by environmental variability (Grossman and Freeman, 1987; Oberdorff *et al.*, 2001a). The overall goal in community ecology is therefore to determine the causal processes underlying the observed patterns in a manner that allows for prediction and forecasting on the nature of assemblage in the response to the changing environment (Wootton *et al*., 2000; Jackson *et al*., 2001).

**Longitudinal distribution of stream fishes**

A stream environment is characterised by a unidirectional flow of water and the existence of a gradient in flow volume from source to mouth (Lévêque, 1997). This physical gradient is linked to changes in community structure and function. Vannote *et al*. (1980) argue that the predictable change in the physical aspects of a stream from headwaters to large rivers is matched by a consistent pattern of stream biota. A general gradient of increasing species diversity and richness from upstream to downstream has been noted in stream fishes (Moyle and Cech, 1982; 2004; Gilliam *et al*., 1993; Jackson *et al*., 2001; Bistoni and Hued, 2002; Ostrand and Wilde, 2002;

Vilella *et al*., 2004). This change has been linked to the physical nature of a stream with most headwater streams being highly variable environments with fluctuating flow and depth. These are therefore harsh environments inhabited by a few species that can either withstand the extreme conditions or recolonise areas following a disturbance (Magoulick, 2000). In contrast, the downstream sections are relatively stable allowing more fish species to coexist (Jackson *et al*., 2001).

The increase in diversity from upstream to downstream has been related to increasing stream order since stream order is usually positively correlated with stream width and negatively correlated with stream velocity (Udoidiong and King, 2000; Moyle and Cech, 2004). Differences in flow variability between upstream and downstream sections explain because it was correlated with increased constancy in flow in the downstream sections (Horwitz, 1978). In both temperate and tropical streams fishes tend to occur in specific habitats and habitat complexity, especially horizontal heterogeneity, which is greater in high order streams, is important in determining the characteristics of a fish community (Gorman and Karr, 1978). Schlosser (1982) related an increase in species richness from upstream to downstream with an increase in the number of pools, which contributed to habitat complexity.

Species richness and diversity have also been explained in terms of the species-area relationship and Angermeier and Schlosser (1989) emphasised the importance of habitat area, habitat volume, and habitat heterogeneity in determining species richness. They argued that these attributes, which increase along the longitudinal profile, are important in determining the number of habitats and refugia for many species. Bistoni and Hued (2002) argue that deep waters are associated with increasing stability which allows the vertical separation of microhabitats for sympatric species and in this way an increase in water volume leads to an increase in living space and enhances the survival of bigger fish. In a study of West African Rivers Hugueny (1989) found a positive species-area relationship and Welcomme (1985) made the same conclusions using data from rivers worldwide. This has been explained by the greater number of ecological niches in larger rivers compared to smaller ones (Welcomme, 1985).

Stream fishes exhibit many adaptations in response to changing conditions brought about by the morphology of the stream. The highly eroding upper sections of many streams may be inhabited by species adapted to fast and turbulent waters through the possession of stiffened pectoral spines (e.g. *Amphilus*), buccal suckers (e.g. *Chiloglanis, Garra, Labeo* and *Synodontis*), pectoral fin suckers (e.g. *Glossogobius*) and elongated forms (e.g. *Aethiomastacembelus*, *Mormyrops*) (Lévêque, 1997). In the Bandama River basin (Ivory Coast), the middle zones were occupied by riffle specialists in turbulent waters while pools were occupied by larger species and predators such as *Hydrocynu*s, which also persisted in the low zones (Lévêque, 1997). Clear zonation of fish species is usually exhibited in the upstream sections, but in many tropical streams this zonation is usually less pronounced downstream because of the smooth transition of habitats and environmental conditions (Bistoni and Hued, 2002). River morphology can also alter the predictable change or zonation of species. In the Luongo River (Zambia) for example, the upper and lower sections have steep gradients that are separated by a long floodplain and low gradient middle zone and species that inhabit fast flowing waters occupy the headwaters and lower sections (Balon and Stewart, 1983).

**Temporal variability in stream fishes**

Lotic systems, especially in seasonal tropical and temperate environments, are characterised by environmental fluctuations dictated by hydrology and temperature

(Allan, 1995). Species abundances and species composition respond to these environmental factors to produce a temporal pattern in assemblage composition that, like spatial variability, changes according to the severity of the disturbances. Temporal variability in species diversity and abundance can mask the role of microhabitat and the availability of habitats and resources if hydrological variability is severe enough to inhibit any interspecific interactions and habitat preferences (Grossman *et al*., 1998). A similar conclusion was reached by Magoulick (2000) who suggested that, while local abiotic factors were important in structuring fish assemblages, temporal variations were more important determinants of species richness and abundances in harsh and variable environments.

Temporal variability of the environment mostly affects the rates of mortality, recruitment, immigration and extinction of fish communities (Taylor and Warren, 2001) and mortality rates are usually high during periods of drought and low flow (Closs and Lake, 1996), while flooding and increased flow may enhance recruitment and the recolonisation of previously uninhabited areas (Godinho *et al*., 2000). Grossman *et al*., (1990) found in a number of streams that a high coefficient of variation in the flow, which is a measure of hydrological variability, was associated with extensive fluctuations in assemblage composition. The diversity and species richness of fish in an intermittent stream was high during the wet season but population variance was also high leading to low stability (Medeiros and Maltchik, 2001). During the dry periods restricted pools favoured the dominance of a few species adapted to the harsh conditions and the community remained fairly stable in this discontinuous environment until disrupted by flooding (Medeiros and Maltchik 2001).

Temporal variations in fish assemblages have also been explained by their situation in different sections of a stream, which again is determined by differences in environmental stability (Horwitz, 1978; Godinho *et al*., 2000). Assemblages in small and highly variable streams tend to exhibit high extinction and mortality rates (Taylor and Warren, 2001). In more stable sections of the stream where the environment fluctuates less extensively, normally associated with downstream sections, the rates of mortality tend to be lower. Seasonal changes reflected by a contraction of stream habitats may also induce variability in species richness and abundance. This was noted in fish communities of Neotropical streams, rivers and lagoons where species richness was higher during the wet season (rising water levels) in streams while abundance and diversity were high during the dry season (falling water levels) in rivers and lagoons (Galacatos *et al*., 2004).

**Microhabitat: the physical template**

The microhabitat is a patch in a pool or riffle having a homogeneous substrate, depth and velocity of water, and where a fish spends most of its time (Lévêque, 1997). Its conditions are linked to the overall aspects of the macrohabitat, such as temperature and water quality, slope and elevation, and water supply which not only determine the nature and morphology of streams but also the fish species that might be able to inhabit them.

Different habitat types attract different fish species and this has led to the concept of the habitat-guild in the study of the dynamics of stream fish communities (Schlosser, 1982; Grossman and Freeman, 1987; Taylor, 2000; Vadas and Orth, 2000). This concept is based on the fact that strong species-habitat associations are a consequence of both individual adaptation and the interaction of all taxa in an assemblage or community (Taylor, 2000). The different habitats in a stream provide shelter, attachment sites, foraging grounds and refugia for stream fish (Angermeier and Schlosser, 1989; Pyron and Lauer, 2004). These associations are strengthened by morphological, physiological and ecological adaptations that include specialised body forms such as the cyprinids and specialised catfishes found in high gradient headwaters (Moyle and Vondracek, 1985; Moyle and Cech, 2004).

The most important characteristics of a microhabitat are current velocity, water depth, substrate and cover (Gorman and Karr, 1978; Schlosser, 1982; Angermeier and Schlosser, 1989; Vadas and Orth, 2000; Ostrand and Wilde, 2002). The interaction between these features and fish assemblages can explain how habitat and fish species diversity are related (Gorman and Karr, 1978; Schlosser, 1982) so that the presence of a fish species in a particular section of a stream is explained by its physical and chemical attributes (Pyron and Lauer, 2004). Grossman and Freeman (1987) reported that species did not randomly occupy microhabitats, but exhibited statistically distinct patterns of microhabitat use and assemblages could be assigned to feeding guilds in either the water column or the stream bed. Differences in the selection of habitats between juvenile and adult bull trout (*Salvelinus confluentus*) and cutthroat trout (*Oncorhynchus clarki*) were related to velocity, substrate and seasonality with juveniles being associated with shallow and slow flowing waters that offered more protection from aquatic predators, reduced the chances of displacement and also were less energetically demanding while seasonal differences among adults were related to spawning (Spangler and Scarnecchia, 2001).

**Effect of flow variability on stream fish**

Stream flow is a function of the hydrology and geomorphology of an area and it controls important characteristics such as width, depth, current velocity and substrate composition and thus plays a central role in stream ecology (Koel and Peterka, 2003). The effect of stream flow on fish communities has been studied on both spatial (Horwitz, 1978; Schlosser, 1982) and temporal scales (Grossman *et al*., 1990; Godinho *et al*., 2000; Medeiros and Maltchik, 2001). Increased stream flow brings about an expansion of stream habitats and refugia, and increases the food available to stream fishes (Medeiros and Maltchik, 2001) although it may lead to the displacement of some species from their microhabitats and force them to increase their energy expenditure by living in sub-optimal environments (Grossman *et al*., 1998).

Species richness of fish in 15 prairie streams in Illinois and Ohio (USA) was correlated with flow variability with the highest species richness being found in headwater streams with a more constant flow while the downstream addition of species was greatest in streams with a relatively high constancy (Horwitz, 1978). Using the coefficient of variation as a measure of assemblage stability and persistence, Oberdorff *et al*. (2001a) reported that flow variability had a negative influence on species richness by increasing assemblage variability. Environmental variability also had strong effects on recruitment and mortality (Horwitz, 1978; Oberdorff *et al*., 2001a), which led to local extinctions, and immigration and emigration of individual fish (Taylor and Warren, 2001).

In many streams fluctuations in the abundance of fish and their species composition depends on the severity of hydrological variability. While local physical and chemical factors often act as templates on which fish assemblages are structured, these factors can be overridden by the stochastic variation in flow (Magoulick, 2000). Grossman *et al*. (1998) concluded that habitat specialisations were not important determinants of community structure when fluctuations in flow regime were sufficiently severe to control the populations in an assemblage.

Water level fluctuations related to flow variability are important cues for many tropical fish species and the onset of the rains induces flow in intermittent and seasonal streams leading to continuity of streams, inundation of floodplains and the flushing of terrestrial nutrients into the rivers thus expanding the food resources available to fish (Moyle and Cech, 2004). Many tropical fishes make extensive upstream spawning migrations at this time, or move into floodplains to spawn (Bowmaker, 1973; Welcomme, 1985; Lowe-McConnell, 1987; Lévêque, 1997).

**Role of turbidity on stream fish**

Many rivers carry high levels of suspensoids (suspended solids and colloidal particles) brought to them through soil erosion (Minshull, 1993; Lévêque, 1997). In aquatic ecosystems, sediment is transported either as suspended matter or as bed load, with the former reducing water clarity and increasing turbidity (Richardson and Jowett, 2002) and the latter transforming course stream beds into fine beds, which favour cosmopolitan species over endemic taxa (Walters *et al*., 2003). Turbidity can affect fish directly by causing death through clogging their gill rakers and gill filaments, reducing egg survival, affecting migrations (Lévêque, 1997; Richardson and Jowett, 2002) or indirectly by affecting their ability to feed, depth distribution and abundance (Rowe *et al*., 2003).

In a study of turbid streams in East Cape region of New Zealand, Richardson and Jowett (2002) found that fish abundance and diversity decreased with increased sediment concentrations and turbidity. Streams with high sediment loads had shallower and swifter stream habitats, finer substrates, and less cover for fish. Benthic invertebrates, an important food source for many fishes, also decreased when sediment loads were high (Walters *et al*., 2003). Using a piscivory-transparency-morphometry model in Neotropical streams, Galacatos *et al*. (2004) reported that the relative abundance of diurnal, vision-oriented feeders like characiforms decreased compared to that of nocturnal or low light fishes when the transparency of the water was low. The reactive distance for predaceous species like the smallmouth bass, *Micropterus dolomieu*, decreased with increasing turbidity, with the greatest decrease rate being recorded from 0 to 25 NTU (Sweka and Hartman (2003). Decreased prey availability and consumption and the subsequent growth of fish are generally associated with elevated turbidity but there are exceptions. Juveniles Chinook salmon, *Oncorhynchus tshawytscha*, and walleye, *Stizostedion vitreum*, were found to increase their food consumption when turbidity was high, possibly because the risk of predation was lower and they could spend more time feeding (Gregory, 1993). Turbidity has also been found to increase the survival of photophobic species such as *Cyprinus carpio* and *Clarias gariepinus* while the feeding of *Oreochromis mossambicus* was enhanced under turbid conditions due to increased cover from terrestrial predators (Bruton, 1985).

## STUDY AREA

The Nyagui River is a major tributary of the Mazowe River. It originates on the central plateau of Zimbabwe at an altitude of above 1 600m near the town of Marondera, flowing north to join the Mazowe River at an altitude of about 840m near

Shamva town. Its catchment is largely rural with about 95% comprising of communal farming area while the rest is in the formerly commercial farming area. The river is joined by several tributaries that include The Nyagambi and Shavanhohwe on the east and the Nyambuya, Nora, Chinyika and Umwindsi on the west with the last having its source in the northern suburbs of Harare. Apart from the agricultural activities that contribute to silt loads to the river and its tributaries, it remains generally unmodified by other human activities such as discharge of sewage effluent.

The only notable dams at the time of the study were Longlands and Rufaro on Nyambuya River that supply Marondera town with water and a few other farm dams, most of which fill during the rainy season. These dams help to regulate the streams and provide suitable habitats for exotic predators such as *Micropterus salmoides* and *Serranochromis robustus* (Gratwicke *et al*., 2003). The proposed Kunzvi dam near the Nyagui/Nora confluence, which is intended to supply water to the city of Harare, will have a major impact on the river by regulating its flow and blocking the migration routes of fish. At present, the Nyagui is almost unique in Zimbabwe in that there are no major dams along its course, from its source to the sea, and fish movements should therefore be unimpeded.

The flow of the river and its tributaries is seasonal, with strong flow during the rainy season (November-April), diminishing during the course of the dry season to reach its lowest level in October-November. By this time the upstream section and most of the smaller tributaries have ceased to flow.

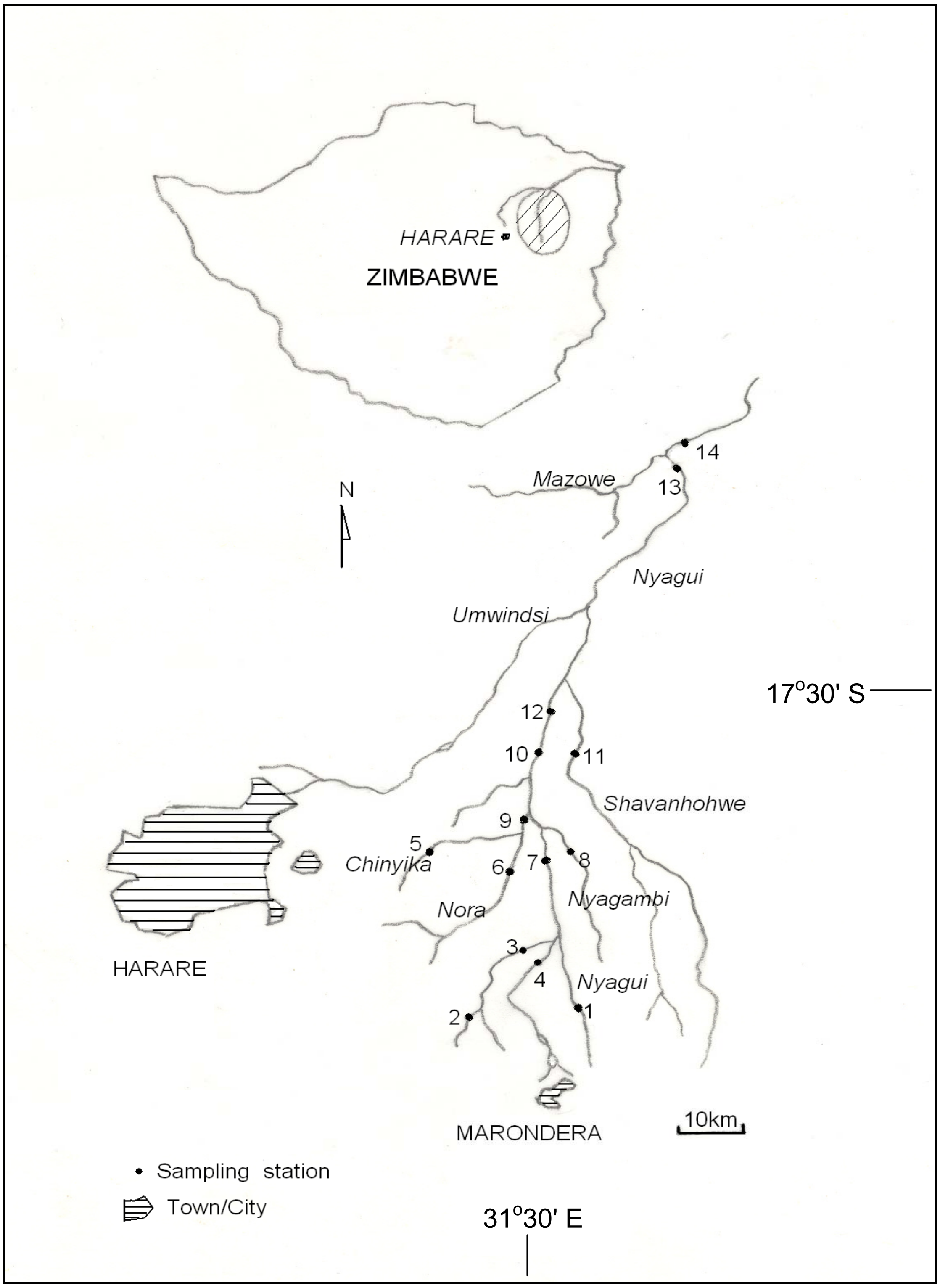


Figure 1: The Nyagui River in Zimbabwe with its major tributaries and the location of sampling stations 1-14.

# METHODS

## Data collection

Fourteen sampling stations were located along the length of the Nyagui River from near its source to the confluence of the Mazowe (Figure 1). Each sampling station was chosen to include all the available habitats including pools and riffles. They varied in length from 30m at the upstream stations and 100m in the downstream ones. Each station was sampled three times: first in October 2004 before the rains began, then in November 2004 after the first rains, and finally in January 2005 when the river was in flood. An exception to this was station 14 on The Mazowe River, which was only sampled twice (in November 2004 and January 2005).

The methods for collecting microhabitat and total habitat data followed those developed by Gorman and Karr (1978), Schlosser (1982) and Peres-Neto (2004). At each station transects were set up at 5m intervals perpendicular to the stream flow. Starting from the wetted edge the water depth and velocity was measured every 50 cm across the transect. At these points the dominant substrates were visually characterised, within a radius of 25 cm, and categorised into five physical categories based on the size of alluvial material. A further two categories included biotic factors (aquatic vegetation and tree trunks) and the stream habitats were finally categorised according to depth, as follows: 0-5 cm (riffles and margins), 5-20 cm (riffles and shallow pools), 20-50 cm (pools) and > 50 cm (deep pools) (Table 1). The velocity of the water was measured with an FP201 electronic flow meter and five current categories were recognised, ranging from <0.05 to >5 m $s^{-1}$. The number of points assessed at each habitat sampled varied from 38 at upstream stations to 320 in downstream ones. The habitat categories identified at each site were combined and used to calculate habitat diversity using Shannon-Weiner diversity index.

Table 1: The classification of stream habitats in the Nyagui River according to criteria in Gorman and Karr (1978) and Schlosser (1982).

| Category | Depth (cm) | Current (m $s^{-1}$) | Substrate (mm) |
|---|---|---|---|
| 1 | 0-5 (very shallow) | <0.05 (very slow) | <0.05 (silt) |
| 2 | 5-20 (shallow) | 0.05-0.2 (slow) | 0.5-2 (sand) |
| 3 | 20-50 (moderate) | 0.2-0.4 (moderate) | 2-10 (gravel) |
| 4 | >50 (deep) | 0.4-1 (fast) | 10-30 (pebble) |
| 5 | | >1 (torrent) | >30 (rock) |
| 6 | | | Aquatic vegetation (vascular plants or algae) |
| 7 | | | Other (e.g. tree trunks) |

The following variables were measured at each station with a Horiba UU 23 multiprobe meter: temperature (ºC), dissolved oxygen (mg $l^{-1}$), turbidity (NTU), conductivity (µS$cm^{-1}$), and pH. Fish were collected at each station with a Smith-Root VI-A electrofisher powered by a Honda EZ 4500 generator producing a 750V DC current, although it varied according to the conductivity of the water, which ranged from 2-39 µS $cm^{-1}$. Sampling was done at sites where physical barriers prevented fish from escaping upstream while a blocking net with 8-mm mesh was used to prevent them from escaping downstream. Electrofishing lasted for 10 minutes at each site and was done by moving upstream from the blocking net. All the fish that were collected were identified, counted, weighed and measured to standard length.

**Data analysis**

The environmental variables measured at each station were based on the habitat characteristics of substrate, current and depth and expressed as a proportion (percentage) of the total habitat. Catch per unit effort (CPUE) was determined for each species and was interpreted as a measure for relative abundance. At each station, each habitat type was identified as a combination of substrate, current and depth. The Shannon diversity was used to calculate habitat diversity based on the number of categories of each habitat type measured at each station as follows:

$$H' = -\sum p_i \ln p_i$$

where $p_i$ is the proportion of each habitat type (Gorman and Karr, 1978; Schlosser, 1982) and fish species diversity based on the number and abundance of species. The catchment area for each station was determined from the 1:500 000 map. Habitat diversity was then regressed against catchment area to determine whether habitat complexity increased with increase in the size of the area being drained. A similar plot was used to determine whether species richness and relative abundance (using CPUE) increased with increase in catchment size. A scatter plot was used to determine the relationship between habitat diversity and number of species and relative abundance.

Detrended correspondence analysis was used to determine the spatial pattern of species distribution. The longitudinal distribution of species was also summarised by determining the proportional abundance of species at altitude >1400m, 1000-1400m and <1000m. To summarise the relationship between species and habitat environmental variables, a canonical correspondence analysis (CCA) was performed using CANOCO 4.0 (ter Braak and Smilauer, 1998). CCA is an ordination technique that extracts axes based on a linear combination of environmental variables that maximally separates species scores (Quinn and Keough, 2002).

# RESULTS

## Physical and chemical variables

Stations 1 to 5 were characterised by substrates with a high proportion of sand and silt, extensive aquatic vegetation (*Phragmites* and *Nymphea*), and were in the very shallow and shallow depth categories, while flow was categorised as very slow and slow (Table 2). Station 4 differed, however, in having a higher proportion of gravel, pebble and rock substrates. These were the most upstream stations, situated at an altitude > 1400 m, and consisted of shallow pools that were isolated during the dry season and only became connected at the onset of the rains. No riffles were associated with these stations.

Stations 6 to 12 were further downstream and in the 'middle' section of the river, situated at altitudes ranging from 1152-1328 m, and they were characterised by a combination of all substrate types with a high proportion of gravel and pebble. Exceptions to this were stations 8 and 11 on the Nyagambi and Shavanhohwe rivers respectively, which were dominated by sand and silt (Table 2). All the downstream stations had relatively little aquatic vegetation cover, while the water was moderately deep to deep and a combination of all flow categories with torrent flow increasing from October to January.

Temperature and dissolved oxygen generally increased from upstream to downstream with temperature reflecting changes in altitude while oxygen concentrations reflected the increase in river flow and water movement. Temperature also changed seasonally increasing a mean of 20.2ºC in October to 26.9 and 26.1ºC in November and January respectively (Table 3). There was little fluctuation in pH although the water was slightly alkaline in October (mean pH = 7.9) but this decreased with river flow with the river becoming slightly acidic (mean pH = 7.4 in

November and 6.7 in January). The conductivity of the water was always very low because most of the catchment consists of granitic rocks but there was some seasonal variation. In October, when there was low flow at most stations, the mean conductivity was 11.4 μS $cm^{-1}$ and it rose to 16.7 μS $cm^{-1}$ in November after the first rains but then fell to 9.6 μS $cm^{-1}$ in January when the river was flowing strongly (Table 3).

Turbidity was generally low although there was a general trend of higher turbidity at the upstream stations. Turbidity was related to flow and the mean was lowest in October (13.4 NTU) when there was little flow, rising to 24.1 and 30.7 NTU in November and January respectively as the flow increased (Table 3).

Table 2: The mean habitat composition (%) at the 14 sampling stations in the Nyagui River, October-January 2004. (Data for each month are in Appendix A).

| | Stations | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| Altitude (m) | 1562 | 1558 | 1552 | 1529 | 1402 | 1328 | 1222 | 1273 | 1192 | 1156 | 1191 | 1152 | 844 | 822 |
| Substrate: silt | 60 | 57 | 43 | 8 | 47 | 10 | 5 | 20 | 2 | 3 | 27 | 10 | 0 | 10 |
| sand | 40 | 43 | 57 | 30 | 52 | 10 | 13 | 68 | 8 | 8 | 47 | 17 | 13 | 10 |
| gravel | 0 | 0 | 0 | 17 | 0 | 40 | 33 | 10 | 40 | 40 | 2 | 17 | 47 | 40 |
| pebble | 0 | 0 | 0 | 20 | 0 | 30 | 30 | 2 | 42 | 38 | 0 | 17 | 30 | 10 |
| rock | 0 | 0 | 0 | 25 | 2 | 10 | 18 | 0 | 8 | 10 | 35 | 40 | 13 | 30 |
| Plants: aquatic | 53 | 50 | 10 | 10 | 33 | 12 | 20 | 8 | 8 | 12 | 27 | 27 | 13 | 10 |
| riparian cover | 7 | 5 | 0 | 7 | 10 | 5 | 10 | 7 | 5 | 8 | 5 | 10 | 20 | 15 |
| Depth: very shallow | 57 | 43 | 47 | 20 | 53 | 13 | 17 | 27 | 20 | 13 | 23 | 10 | 13 | 15 |
| shallow | 27 | 33 | 32 | 45 | 40 | 40 | 30 | 33 | 43 | 42 | 30 | 20 | 27 | 30 |
| moderate | 13 | 20 | 18 | 30 | 7 | 23 | 33 | 25 | 27 | 28 | 33 | 40 | 40 | 35 |
| deep | 3 | 4 | 3 | 5 | 0 | 16 | 20 | 15 | 10 | 17 | 14 | 30 | 20 | 20 |
| Flow: very slow | 70 | 33 | 53 | 53 | 38 | 5 | 8 | 23 | 8 | 3 | 40 | 13 | 5 | 5 |
| slow | 20 | 27 | 23 | 30 | 45 | 17 | 13 | 23 | 7 | 10 | 22 | 27 | 7 | 10 |
| moderate | 10 | 23 | 17 | 13 | 14 | 27 | 27 | 23 | 27 | 23 | 20 | 27 | 23 | 20 |
| fast | 0 | 15 | 7 | 4 | 3 | 33 | 30 | 20 | 40 | 45 | 16 | 23 | 43 | 35 |
| torrent | 0 | 2 | 0 | 0 | 0 | 18 | 22 | 11 | 18 | 19 | 2 | 10 | 22 | 30 |

Table 3: The water quality at all stations for the three sampling periods.

| | Stations | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| Temperature ($^{o}$C): (Oct) | 17.0 | 16.7 | 17.5 | 19.1 | 16.9 | 20.9 | 22.0 | 20.9 | 20.4 | 20.0 | 22.4 | 24.0 | 25.0 | |
| (Nov) | 19.4 | 25.6 | 26.1 | 26.2 | 21.8 | 25.8 | 29.6 | 28.7 | 28.1 | 27.4 | 29.2 | 30.7 | 27.4 | 31.0 |
| (Jan) | 21.6 | 26.9 | 26.3 | 25.4 | 22.4 | 25.6 | 26.0 | 26.0 | 27.3 | 27.5 | 26.9 | 26.4 | 29.3 | 28.3 |
| pH: (Oct) | 7.8 | 8.0 | 7.6 | 7.9 | 7.6 | 7.6 | 7.9 | 8.2 | 7.8 | 8.0 | 7.9 | 8.3 | 8.1 | |
| (Nov) | 6.8 | 6.9 | 6.7 | 7.1 | 7.8 | 7.2 | 7.8 | 7.3 | 7.4 | 7.7 | 7.4 | 7.5 | 7.8 | 7.9 |
| (Jan) | 7.0 | 6.4 | 6.4 | 6.4 | 7.1 | 6.2 | 6.9 | 6.4 | 6.6 | 7.1 | 6.9 | 6.7 | 7.3 | 7.12 |
| Conductivity ($\mu Scm^{-1}$):(Oct) | 39.0 | 2.0 | 3.0 | 3.0 | 3.0 | 3.0 | 4.0 | 5.0 | 3.0 | 12.0 | 2.0 | 36.4 | 33.1 | |
| (Nov) | 17.0 | 12.9 | 10.1 | 15.0 | 12.6 | 16.8 | 22.8 | 29.8 | 16.6 | 16.4 | 11.2 | 14.8 | 17.3 | 20.3 |
| (Jan) | 14.7 | 6.8 | 5.7 | 6.2 | 9.3 | 11.1 | 10.7 | 9.6 | 10.9 | 11.1 | 7.2 | 11.0 | 9.1 | 11.4 |
| Dissolved oxygen ($mgI^{-1}$):(Oct) | 6.81 | 6.49 | 5.83 | 6.02 | 5.24 | 7.60 | 8.98 | 8.98 | 8.32 | 9.94 | 6.70 | 9.06 | 9.80 | |
| (Nov) | 5.50 | 8.20 | 6.50 | 8.00 | 6.10 | 7.90 | 8.70 | 8.60 | 8.40 | 8.40 | 8.80 | 9.40 | 8.20 | 7.90 |
| (Jan) | 5.01 | 6.52 | 6.78 | 6.66 | 5.90 | 7.91 | 8.32 | 7.42 | 7.70 | 7.51 | 7.93 | 7.01 | 8.52 | 7.63 |
| Turbidity (NTU): (Oct) | 30.2 | 16.0 | 13.1 | 7.2 | 9.4 | 16.0 | 7.6 | 12.3 | 4.5 | 2.4 | 7.3 | 31.6 | 16.3 | |
| (Nov) | 28.4 | 19.4 | 40.1 | 15.3 | 21.9 | 46.5 | 16.1 | 15.9 | 20.3 | 22.3 | 18.3 | 20.3 | 21.6 | 31.4 |
| (Jan) | 44.6 | 40.4 | 39.4 | 42.1 | 33.8 | 33.9 | 23.7 | 41.1 | 20.3 | 22.9 | 19.5 | 20.7 | 22.1 | 24.9 |

**Population patterns**

A total of 4 155 individual fishes representing twenty-four species in eight families were collected during the whole sampling period. The most widespread species (collected at ≥50% of all stations) were *Chiloglanis neumanni*, *Clarias gariepinus*, *Labeo cylindricus*, *Labeobarbus marequensis*, *Micropterus salmoides* and *Tilapia rendalli*. The most numerous species (each constituting >10% of the total) were *C. neumanni* and *L. marequensis*. Other relatively numerous species were *Barbus trimaculatus*, *Tilapia rendalli* and *Labeo cylindricus*, each of which made up 8% of the total each (Table 4).

The number of species increased from the upstream stations to the downstream ones in all the sampling periods (Table 5). The highest stations (1 and 5) had four and three species respectively, while the lowest stations (13 and 14) had 15 and 18 species respectively. The greatest number of species (N) was recorded in November at the onset of the rainy season while the lowest (N) was in January when the river was flowing strongly. This probably reflects the difficulty of catching fish during periods of high flow.

The mean species diversity, measured with the Shannon index, was <2.0 at the upper stations (1-9 except for stations 6 and 7) and >2.0 at the lower ones (9-14 except for station 8), a trend similar to that of species richness (Table 5). The same trend was evident with relative abundance, measured as catch per unit effort (CPUE), which was lowest at station 5 (mean = 0.9 fish $min^{-1}$) and highest at station 14 (mean = 26.2 fish $min^{-1}$). The relative abundance at the five upstream stations was highest in October (dry season) and decreased in November and January with rising water. At the downstream stations (6-14) the relative abundance was highest in November and lowest in January during the time of flooding (Table 5).

Table 4: The total number of fish collected in the Nyagui River, and the proportion (%) of each in the total

| Family | Species | October | November | January | Total | % |
|---|---|---|---|---|---|---|
| Mormyridae | *Cyphomyrus discorhynchus* | | 3 | 1 | 4 | 0.1 |
| | *Mormyrus longirostris* | | 1 | 1 | 2 | 0.0 |
| Cyprinidae | *Mesobola brevianalis* | | 12 | 45 | 57 | 1.4 |
| | *Opsaridium zambezense* | 34 | 58 | 40 | 132 | 3.2 |
| | *Barbus lineomaculatus* | 9 | 21 | 2 | 32 | 0.8 |
| | *Barbus radiatus* | 10 | 15 | 5 | 30 | 0.7 |
| | *Barbus trimaculatus* | 126 | 193 | 18 | 337 | 8.1 |
| | *Barbus paludinosus* | 69 | 23 | 27 | 119 | 2.9 |
| | *Barbus unitaeniatus* | | 17 | | 17 | 0.4 |
| | *Labeobarbus marequensis* | 224 | 374 | 114 | 712 | 17.1 |
| | *Labeo cylindricus* | 122 | 173 | 27 | 322 | 7.7 |
| Alestiidae | *Brycinus imberi* | | 2 | 5 | 7 | 0.2 |
| | *Micralestes acutidens* | 4 | 17 | 3 | 24 | 0.6 |
| Amphiliidae | *Zaireichthys rotundiceps* | 9 | 10 | | 19 | 0.5 |
| Clariidae | *Clarias gariepinus* | 105 | 78 | 45 | 228 | 5.5 |
| Mochokidae | *Chiloglanis neumanni* | 687 | 417 | 86 | 1190 | 28.6 |
| Centrachidae | *Micropterus salmoides* | 87 | 116 | 36 | 239 | 5.8 |
| Cichlidae | *Pseudocranilabrus philander* | 58 | 62 | 52 | 172 | 4.1 |
| | *Pharyngochromis acuticeps* | | 45 | 24 | 69 | 1.7 |
| | *Tilapia sparmanii* | 18 | 5 | 5 | 28 | 0.7 |
| | *Tilapia rendalli* | 54 | 159 | 133 | 346 | 8.3 |
| | *Oreochromis mossambicus* | 12 | 25 | 9 | 46 | 1.1 |
| | *Oreochromis niloticus* | | 3 | 1 | 4 | 0.1 |
| | *Serranochromis robustus* | 10 | 5 | 4 | 19 | 0.5 |
| Total | | 1638 | 1834 | 683 | 4155 | 100.0 |

Table 5: Mean values of physical and species data from all stations for the three sampling periods, October 2004-January 2005.

| | Station | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| Altitude (m) | 1562 | 1558 | 1552 | 1529 | 1402 | 1328 | 1222 | 1273 | 1192 | 1156 | 1191 | 1152 | 844 | 822 |
| Catch. area ($km^2$) | 11.3 | 26.8 | 19.3 | 14.8 | 3.8 | 31.3 | 64 | 14 | 43.5 | 138 | 63.8 | 141 | 264 | 825 |
| Mean number of species | 3.3 | 4.0 | 5.3 | 4.3 | 2.7 | 7.7 | 8.3 | 6.0 | 6.0 | 10.0 | 7.0 | 11.0 | 12.7 | 17.5 |
| Mean sp.diversity(Shannon) | 1.2 | 1.4 | 1.6 | 1.3 | 1.0 | 1.9 | 2.1 | 1.7 | 1.7 | 2.2 | 1.9 | 2.3 | 2.4 | 2.7 |
| Mean CPUE (num $min^{-1}$) | 3.5 | 2.3 | 2.6 | 2.8 | 0.9 | 10.1 | 12.1 | 7.0 | 8.7 | 25.8 | 5.8 | 18.2 | 24.9 | 26.2 |

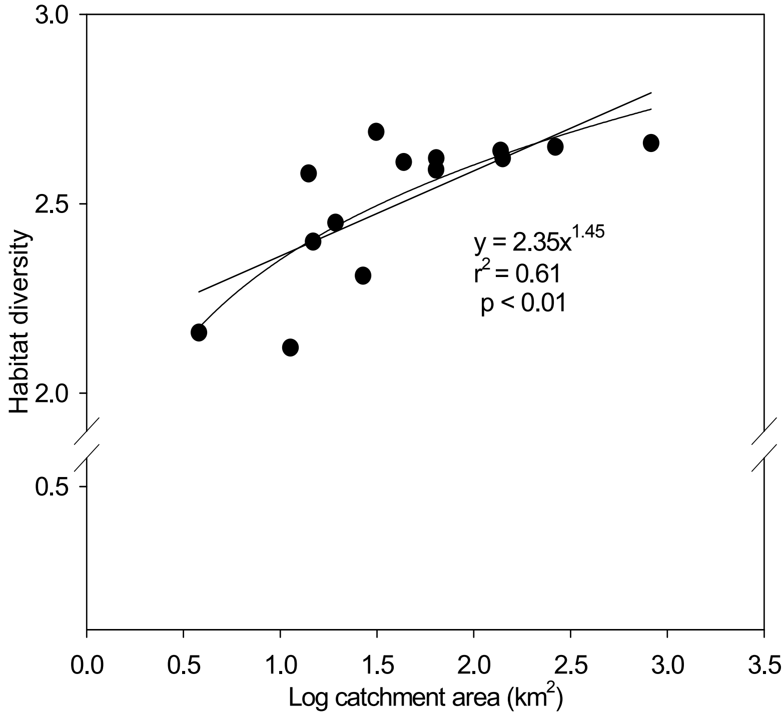


Figure 2: The relationship between habitat diversity and catchment area at each sampling station.

It is likely that species richness and abundance will be determined, to some extent, by the size of a river with larger rivers having greater diversity and numbers than small ones, partly because of their volume but also because they might offer a greater variety of habitats. The size of the catchment should determine the size of a river and so a relationship between catchment and habitat diversity is likely to occur. In the Nyagui system there was a significant correlation between the catchment area of each sampling station and its habitat diversity (Figure 2). The extent to which these variables control species richness and relative abundance were therefore examined by plotting them against each other.

Catchment area is a strong predictor of species richness because these two variables were strongly correlated in each month (Figure 3). There was also a strong correlation between relative abundance (CPUE) and catchment area (Figure 4). In

October and November the slopes of the regressions were nearly the same (18.4 and 17.6 respectively) but in January the slope was much less (7.1) suggesting that fish were not so easily caught when the river was flowing strongly. Therefore catchment area could be used to predict relative abundance with some allowance being made for seasonal variation.

At a local scale it is assumed that the number of species and their relative abundance is related to habitat diversity with greater habitat heterogeneity offering more refuge, breeding and foraging sites for fish. This relationship was shown by a positive correlation between species richness and CPUE on habitat diversity that was explained by a power curve (Figure 5 and 6). This relationship was, nevertheless, only significant in October and November and not significant in January when the river was in flood suggesting that species and habitat associations were strong during the dry and early rain period and weak when the river was in flood. The results also reflected the close relationship between species richness and their relative abundance. A few species that were collected at stations with low habitat diversity were found in low abundance while a high abundance was associated with more species at stations with high habitat diversity.

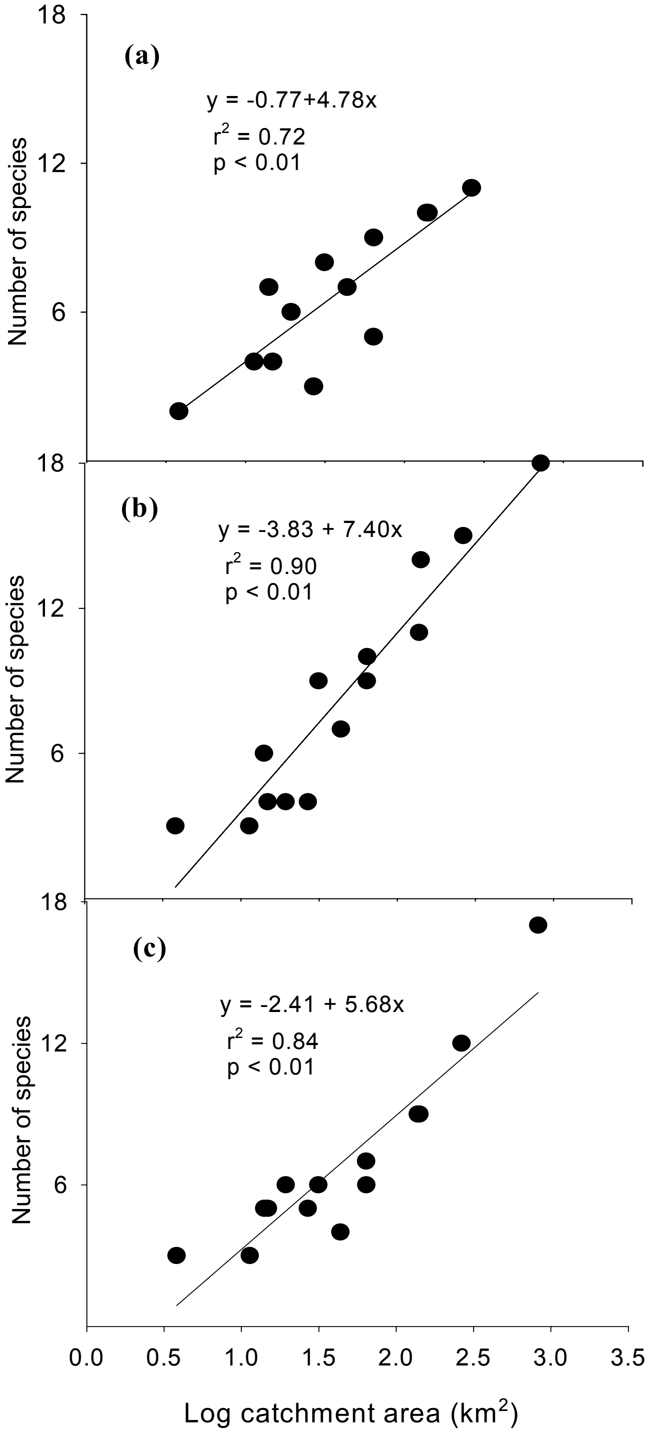


Figure 3: The relationship between the number of species and the catchment area at each station in (a) October, (b) November and (c) January.

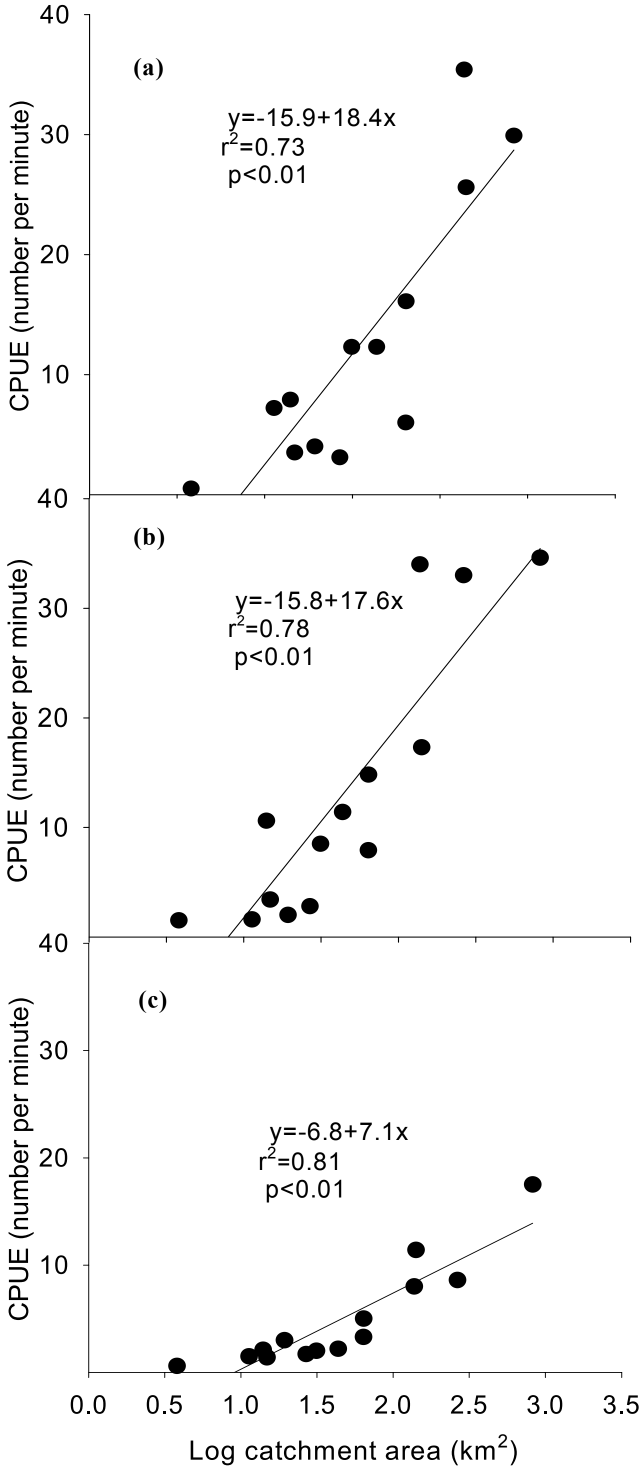


Figure 4: The relationship between relative abundance (CPUE) and the catchment area at each station in (a) October, (b) November and (c) January.

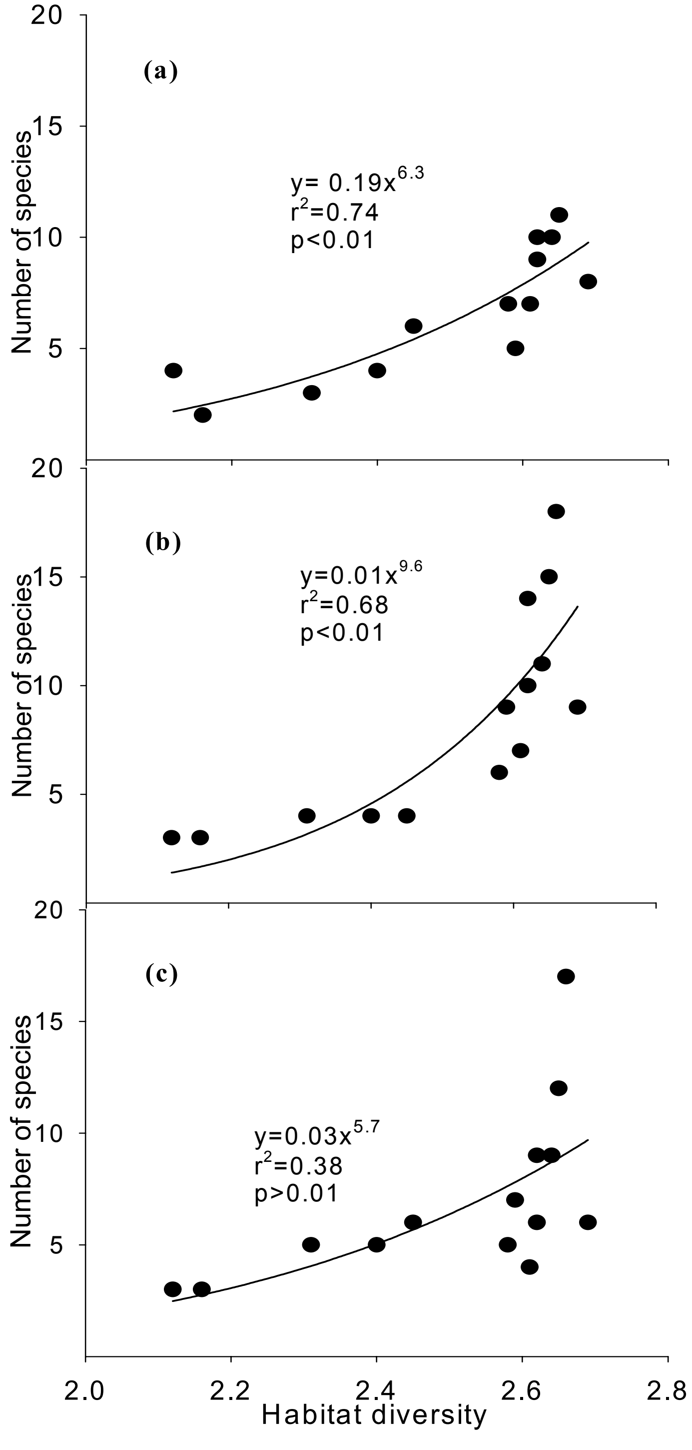


Figure 5: The relationship between species richness and habitat diversity in (a) October, (b) November, (c) January and (d) all months combined.

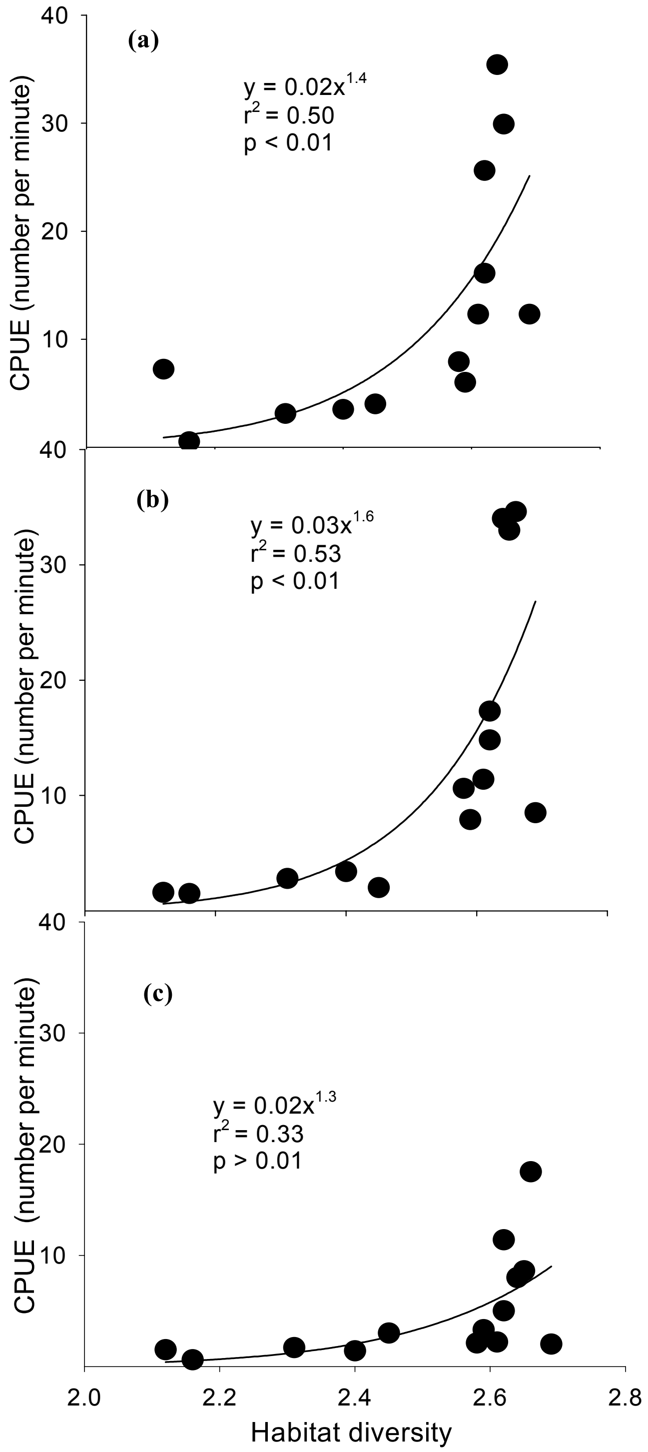


Figure 6: The relationship between relative abundance (CPUE) and habitat diversity in (a) October, (b) November, (c) January and (d) all months combined.

The longitudinal distribution of fish species in the Nyagui River was apparently determined by altitude. A Detrended correspondence analysis was used to explain this distribution. Four axes were extracted that all explained 49.9% o the total variance (Table 6). The first two axes contributed 32.2% and 11.4% with eigenvalues of 0.581 and 0.202 respectively and were used in this analysis. Three species grouping were produced in this analysis (Figure 7). The first group consisted of species found at the five upstream stations, at an altitude > 1400m and were dominated by *B. paludinosus,* which made up 30% of the catch at these stations. Other important species (>10% of the sample) were *C. gariepinus*, *M. salmoides* and *T. rendalli* (Table 7). The second group had species at altitudes of 1000-1400 m (stations 6-12) and the most numerous species was *C. neumanni* (36%) followed by *L. marequensis* (16%) and *B. trimaculatus* (13%). The last group had species at altitudes < 1000 m (stations 13 and 14) and the three most abundant species were *L. marequensis* (25%), *C. neumanni* (22%) and *L. cylindricus* (16%). There was an overlap on the DCA axis with some species, including *C. neumanni, L. marequensis, L. cylindricus, T. rendalli and O. zambezense* being found in the last two groups (Figure 7).

Table 6: DCA summary statistics for species data

| | Axis 1 | Axis 2 | Axis 3 | Axis 4 |
|---|---|---|---|---|
| Eigen values | 0.581 | 0.202 | 0.072 | 0.042 |
| Length of gradient | 3.293 | 1.453 | 1.633 | 1.375 |
| Cummulative % variance of species data | 32.2 | 43.6 | 47.6 | 49.9 |

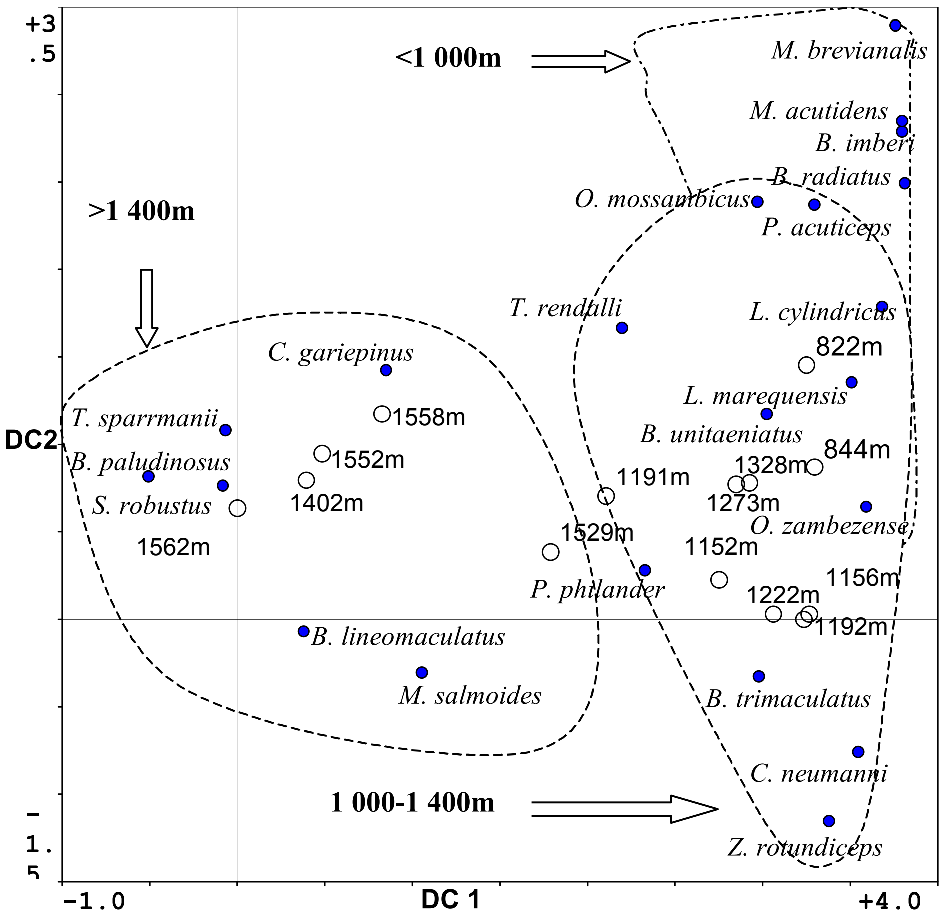


Figure 7: Detrended correspondence analysis on (•) species distribution and (○) altitude.

Table 7: A schematic longitudinal pattern of fish for all stations. Only the species that together account for > 50% of the total catch are listed.

| Altitude | Habitat characteristics | Mean habitat diversity | Species |
|---|---|---|---|
| > 1 400 m (Stations 1-5) | Shallow pools, slow flow, aquatic vegetation | 1.6 | *B. paludinosus*<br>*C. gariepinus*<br>*M. salmoides* |
| 1 000-1 400 m (Stations 6-12) | Shallow, moderate, deep pools, slow flow, moderate and fast flow. Riffles with gravel and pebble substrate | 2.4 | *C. neumanni*<br>*L. marequensis*<br>*B. trimaculatus* |
| < 1 000m (Stations 13-14) | Shallow, moderate, deep pools, slow, moderate, fast and torrent flow. Boulders in deep pools. Riffles with gravel and pebble substrate | 2.7 | *L. marequensis*<br>*C. neumanni*<br>*L. cylindricus* |

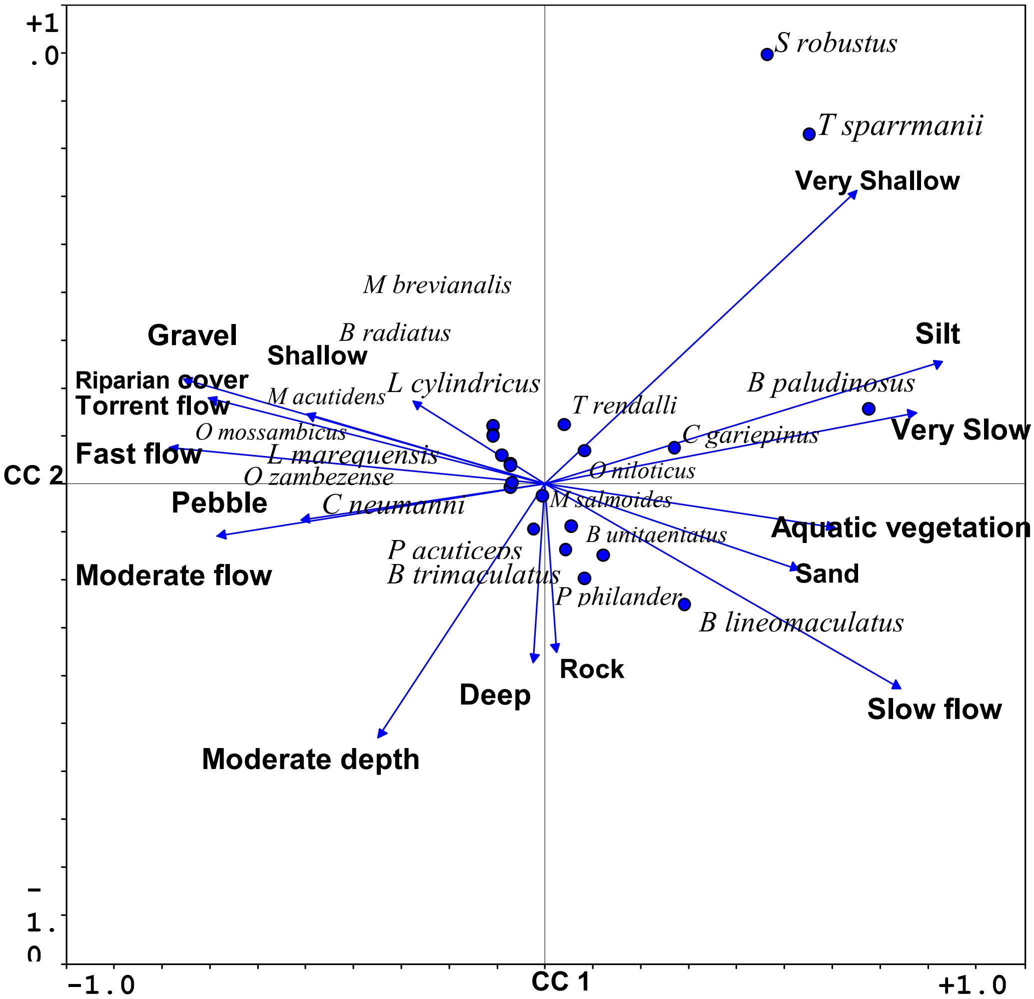


Figure 8: Canonical correspondence analysis of (•) species and habitat variables shown by arrows for all months

Table 8: CCA summary statistics for all site environmental variables and species

| | **Axis 1** | **Axis 2** | **Axis 3** | **Axis 4** |
|---|---|---|---|---|
| Eigenvalues | 0.455 | 0.355 | 0.275 | 0.225 |
| Cumulative % variance of species-environment relation | 23.3 | 41.4 | 55.5 | 67.0 |
| Inter-set correlations with axes | | | | |
| Silt | **0.829** | 0.255 | -0.241 | 0.136 |
| Sand | **0.529** | -0.180 | -0.074 | -0.158 |
| Gravel | **-0.754** | 0.219 | 0.268 | -0.019 |
| Pebble | **-0.510** | -0.075 | 0.217 | 0.434 |
| Rock | 0.023 | -0.352 | -0.301 | -0.473 |
| Aquatic vegetation | **0.606** | -0.090 | -0.311 | 0.479 |
| Riparian vegetation | -0.496 | 0.145 | 0.130 | -0.347 |
| Very Shallow | **0.649** | **0.610** | 0.026 | -0.070 |
| Shallow | -0.276 | 0.172 | 0.280 | 0.506 |
| Moderate depth | -0.348 | **-0.531** | -0.222 | -0.404 |
| Deep | -0.023 | -0.373 | -0.235 | 0.117 |
| Very slow flow | **0.774** | 0.147 | -0.201 | -0.336 |
| Slow flow | **0.742** | -0.427 | -0.185 | 0.047 |
| Moderate flow | **-0.684** | -0.109 | 0.047 | 0.359 |
| Fast flow | **-0.783** | 0.077 | 0.192 | 0.293 |
| Torrent flow | **-0.702** | 0.180 | 0.199 | -0.136 |
| **Total inertia = 1.955** | | | | |

**Canonical Correspondence Analysis of species and habitat relationships.**

Four axes, which altogether explained 67% of the total variance, were extracted by the CCA of the combined samples. The first and second axes explained 23.3% and 18.1% with eigenvalues of 0.455 and 0.355 respectively (Table 8) and were used in the interpretation of the results. Figure 8 shows the ordination of environment and species variables. The arrows indicate the relative importance of the correlations of environmental variables on the ordination axes. The degree to which the environmental variables are correlated to the CCA axis is determined by examining their length and their intraset correlations (Table 8). Significant correlations are also highlighted in Table 8. Two main gradients were observed on the first axis of species scores plot. The first gradient was associated with the variables silt, very slow, slow flow, very shallow depth, aquatic vegetation and sand, which were all positively correlated to the first axis. *Barbus paludinosus* on stations 1 and 5 was positioned in relation to these variables. These stations had a high proportion of silt and aquatic vegetation, and had a very slow flow. Other species associated with this gradient were *S. robustus* and *T. sparrmanii* in very shallow habitats and *B. lineomaculatus* in slow flowing habitats (Figure 8).

The second gradient was characterised by habitat variables gravel, pebble, moderate, fast and torrent flow, which were negatively correlated to the first axis (Table 8). The species associated with this gradient were *O. zambezense*, *L. marequensis*, *C. neumanni* and *L. cylindricus*, which were mostly found at downstream stations from station 7 (Figure 8). Also associated with these habitat variables were species sampled on the Mazowe River (station 14), which included *M. brevianalis*, *C. discorhynchus*, *M. longirostris*, and *B. imberi*. Moderate depth and deep habitats, and boulders (defined as rock in the analysis) were negatively correlated to the second axis. These habitat variables were mainly found at stations 4, 11, 12, 13 and 14 where *P. acuticeps, P. philander*, and *B. trimaculatus* were relatively abundant, the former being found on all except station 4. Other species such as *T. rendalli*, *M. salmoides* and *C. gariepinus* generally had a wide distribution and were not easily defined by the habitat variables.

## DISCUSSION

Prior to this study there was no record of the fish species found in the Nyagui River, which is part of the lower Zambezi system. Of the twenty-four species collected, four were exotics including *Mesobola brevianalis* that has not been recorded in the lower Zambezi but is known to have been introduced into a tributary, the Inyangombe River near Nyanga (north-eastern Zimbabwe) (Marshall, personal communication). The results also suggest that *Oreochromis niloticus*, another exotic and potentially invasive species, is not yet well established in the system even though it is widespread in many other systems into which it has been introduced. Of particular interest was the occurrence of *Opsaridium zambezense* at most downstream stations of the Nyagui River and the Nora River and also at lower altitude (<1 000m). The genus *Opsaridium* has two species in Zimbabwe, *O. zambezense* and *O. peringueyi*, whose status is a cause for concern with the latter probably now extinct (Marshall and Gratwicke, 1998/99). *Opsaridium zambezense* is a rheophilous species with a wide distribution in the Zambezi River but has disappeared from Lake Kariba and in many tributaries of the lake (Marshall and Gratwicke, 1998/99). The construction of Kunzvi dam could therefore lead to a reduction in the range of this species.

Species that are part of the lower Zambezi fauna but were not collected fall into two groups. The first consists of species likely to be found at low altitude (<1000m), such as *Petrocephalus catastoma, Labeo altivelis, L. congoro, L. molybdinus, Hydrocynus vittatus* and *Schilbe intermedius.* The distribution of most of these species is likely to be limited to larger rivers and decreasing in the tributaries. The second group consist of migratory species such as *Anguilla bengalensis* and *A. mossambica* and also *Awaous aeneofuscus* and *Glossogobius giuris*. Although there are no dams in the Nyagui River or after its confluence with the Mazowe River these species were not collected possibly because they are uncommon and were therefore unlikely to be encountered.

The patterns of species richness and abundance were explained in relation to catchment area and habitat diversity with the former being a good predictor of both number of species and their relative abundance. The relationship between number of species inhabiting a river system and the size of the river as represented by its basin area has been demonstrated in large systems (Welcomme, 1985) and this study has shown that it can be applied to smaller ones as well. The reason is that a larger catchment will have a greater diversity of habitats (Hugueny, 1989). This study showed that habitat diversity increased with catchment area because the river became bigger and wider with more habitat types being represented.

Species richness and relative abundance were also correlated to habitat diversity in this study. As habitat diversity increased from upstream to downstream, both species richness and their abundance also increased and this was more apparent in October and November although this relationship was not linear. These results support the view that at a local scale a there is a correlation between habitat complexity and number of species (Gorman and Karr, 1978; Schlosser, 1982). A weak relationship between habitat complexity and species richness and their abundance was observed in January when the river was in flood. Similar results were obtained in some tropical and temperate streams in the USA and this was related to environmental variability in flow that induced an imbalance between fish assemblages and their habitats (Angermeier and Schlosser, 1989). Although seasonal variation in stream flow was not determined in this study, it probably played a role in determining species composition at the different stations. Nevertheless, the spatial variation in species richness and abundance were greater than the temporal patterns in the Nyagui River, suggesting that spatial heterogeneity in environmental conditions have greater influence on species composition and abundance. In addition the presence of *M. salmoides,* an exotic predator, probably had an impact on species richness and abundance especially at the upstream stations where its abundance was greater than 10% of the total.

The longitudinal pattern of species composition that was explained by altitude on DCA axes is a reflection of the response of fish to the physical constrains imposed by stream size and gradient. The abundance of smaller species, which included *B. paludinosus* and *T. sparrmanii* was related to the shallow, slow flowing and low gradients on the central plateau. The increase in both the number of species and larger species further downstream reflected the greater variety of habitats in these stations. A similar pattern of species zonation was observed on the Kalomo River (Zambia) which was described as having a reverse longitudinal gradient as its headwaters originate on a plateau with a gentle slope while the downstream section has a steeper gradient and a variety of habitats (Balon, 1974). Payne (1986) also observed an increase in species richness from headwaters downstream on stream of the Freetown peninsula (Sierra Leone) and related this to the availability of resources including food and refugia.

Canonical correspondence analysis reflected differences in the upstream and downstream fish-habitat associations. Cover in the form of aquatic vegetation, shallow and slow flowing habitats were important variables associated with species at the upstream stations where the abundances of *M. salmoides* was > 10%. This is consistent with the results of other studies where cover has been found to be an important determinant of fish distribution for predator avoidance (Bond and Lake, 2003). Species distribution on the downstream stations, aided by morphological and physiological adaptations, was associated with preferred substrate, depth and velocity suggesting that the latter were important variables determining species composition in this section. Such species and habitat associations have important implications on the management and conservation of stream fishes and an alteration in the flow requirements of a given species is likely to lead to its decrease in abundance or even disappearance from the system.

The construction of Kunzvi Dam is likely change the species composition in the river, as it has on other African rivers. The construction of Lake Kariba, for instance, was associated with a transition in time of riverine-type fish to lacustrine cichlids and also a species cline from the eastern to the western part of the lake (Kenmuir, 1984). The species present in the Nyagui River and likely to increase in abundance in the dam are cichlids such as *T. rendalli, O. niloticus*, *O. mossambicus*, *P. acuticeps* and *P. philander* that are able to utilise a variety of habitats and food types. Other species that are likely to increase include *S. robustus* and *M. salmoides*. Species that prefer flowing water such as *C. neumanni*, *L. marequensis* and *O. zambezense* are likely to disappear in the dam. These species were among the first to disappear in Lake Kariba (Kenmuir, 1984). Regulated flow is also likely to reduce the abundance and distribution of these species immediately below the dam. Another change is likely to be associated with species such as *L. cylindricus* and eels that make upstream spawning migrations, as the dam will be an effective barrier to such movements. Construction of fish ladders in modern dam designs has often been recommended to cater for such movements.

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**APPENDICES: TABLES OF RAW DATA**

Table A1: Percentage composition of habitat data at all stations in October 2004

| | Stations | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| Substrate | | | | | | | | | | | | | |
| % silt | 70 | 60 | 50 | 15 | 60 | 10 | 5 | 20 | 5 | 5 | 20 | 10 | 0 |
| % sand | 30 | 40 | 50 | 30 | 40 | 10 | 10 | 70 | 5 | 10 | 40 | 10 | 10 |
| % gravel | 0 | 0 | 0 | 15 | 0 | 40 | 40 | 10 | 40 | 45 | 0 | 20 | 50 |
| % pebble | 0 | 0 | 0 | 20 | 0 | 30 | 30 | 0 | 45 | 35 | 0 | 20 | 30 |
| % rock | 0 | 0 | 0 | 20 | 0 | 10 | 15 | 0 | 5 | 5 | 40 | 40 | 10 |
| Vegetation | | | | | | | | | | | | | |
| %aquatic vegetation | 50 | 50 | 10 | 10 | 50 | 15 | 20 | 5 | 5 | 5 | 20 | 25 | 10 |
| % riparian cover | 5 | 5 | 0 | 5 | 10 | 5 | 10 | 5 | 5 | 5 | 5 | 10 | 20 |
| Depth | | | | | | | | | | | | | |
| % very shallow | 70 | 60 | 55 | 30 | 60 | 20 | 30 | 40 | 30 | 20 | 30 | 10 | 30 |
| % shallow | 20 | 30 | 35 | 50 | 40 | 40 | 30 | 30 | 50 | 50 | 30 | 20 | 30 |
| % moderate depth | 10 | 10 | 10 | 20 | 0 | 20 | 30 | 20 | 10 | 20 | 30 | 40 | 30 |
| % deep | 0 | 0 | 0 | 0 | 0 | 20 | 10 | 10 | 10 | 10 | 10 | 20 | 10 |
| Flow | | | | | | | | | | | | | |
| % very slow flow | 90 | 50 | 60 | 70 | 50 | 5 | 15 | 50 | 15 | 5 | 70 | 30 | 10 |
| % slow flow | 10 | 30 | 30 | 30 | 50 | 20 | 20 | 30 | 10 | 10 | 20 | 50 | 15 |
| % moderate flow | 0 | 20 | 10 | 0 | 0 | 40 | 30 | 20 | 30 | 30 | 10 | 20 | 30 |
| % fast flow | 0 | 0 | 0 | 0 | 0 | 30 | 30 | 0 | 40 | 50 | 0 | 10 | 40 |
| % torrent flow | 0 | 0 | 0 | 0 | 0 | 5 | 5 | 0 | 5 | 5 | 0 | 0 | 5 |

Table A2: Percentage composition of habitat data at all stations in November 2004

| | Stations | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| Substrate | | | | | | | | | | | | | | |
| % silt | 60 | 70 | 40 | 5 | 40 | 10 | 5 | 20 | 0 | 5 | 20 | 10 | 0 | 10 |
| % sand | 40 | 30 | 60 | 30 | 60 | 10 | 20 | 65 | 10 | 10 | 40 | 20 | 10 | 10 |
| % gravel | 0 | 0 | 0 | 20 | 0 | 40 | 30 | 10 | 40 | 45 | 5 | 20 | 50 | 40 |
| % pebble | 0 | 0 | 0 | 20 | 0 | 30 | 30 | 5 | 40 | 30 | 0 | 10 | 30 | 10 |
| % rock | 0 | 0 | 0 | 25 | 0 | 10 | 15 | 0 | 10 | 10 | 35 | 40 | 10 | 30 |
| Vegetation | | | | | | | | | | | | | | |
| %aquatic vegetation | 40 | 50 | 10 | 10 | 30 | 10 | 20 | 10 | 10 | 20 | 20 | 25 | 10 | 10 |
| % riparian cover | 5 | 5 | 0 | 5 | 10 | 5 | 10 | 5 | 5 | 10 | 5 | 10 | 20 | 15 |
| Depth | | | | | | | | | | | | | | |
| % very shallow | 60 | 60 | 55 | 20 | 50 | 20 | 10 | 30 | 20 | 10 | 20 | 10 | 10 | 20 |
| % shallow | 30 | 30 | 30 | 45 | 40 | 40 | 40 | 30 | 40 | 45 | 30 | 20 | 30 | 30 |
| % moderate depth | 10 | 10 | 15 | 30 | 10 | 20 | 30 | 25 | 30 | 25 | 40 | 40 | 40 | 30 |
| % deep | 0 | 10 | 10 | 5 | 0 | 20 | 20 | 15 | 10 | 10 | 10 | 30 | 10 | 20 |
| Flow | | | | | | | | | | | | | | |
| %very slow flow | 60 | 45 | 50 | 60 | 45 | 10 | 10 | 20 | 10 | 5 | 40 | 10 | 5 | 10 |
| % slow flow | 30 | 20 | 20 | 30 | 45 | 20 | 10 | 20 | 10 | 10 | 20 | 30 | 5 | 10 |
| % moderate flow | 10 | 20 | 20 | 10 | 10 | 30 | 30 | 20 | 30 | 30 | 20 | 30 | 30 | 30 |
| % fast flow | 0 | 15 | 10 | 0 | 0 | 30 | 30 | 30 | 40 | 45 | 20 | 20 | 40 | 30 |
| Torrent flow | 0 | 0 | 0 | 0 | 0 | 10 | 20 | 10 | 10 | 10 | 0 | 10 | 20 | 20 |

Table A3: Percentage composition of habitat data for all stations in January 2005.

| | Stations | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| Substrate | | | | | | | | | | | | | | |
| % silt | 50 | 40 | 40 | 5 | 40 | 10 | 5 | 20 | 0 | 0 | 40 | 10 | 0 | 10 |
| % sand | 50 | 60 | 60 | 30 | 55 | 10 | 10 | 70 | 10 | 5 | 60 | 20 | 20 | 10 |
| % gravel | 0 | 0 | 0 | 15 | 0 | 40 | 30 | 10 | 40 | 30 | 0 | 10 | 40 | 40 |
| % pebble | 0 | 0 | 0 | 20 | 0 | 30 | 30 | 0 | 40 | 50 | 0 | 20 | 30 | 10 |
| % rock | 0 | 0 | 0 | 30 | 5 | 10 | 25 | 0 | 10 | 15 | 30 | 40 | 20 | 30 |
| Vegetation | | | | | | | | | | | | | | |
| %aquatic vegetation | 70 | 50 | 10 | 10 | 20 | 10 | 20 | 10 | 10 | 10 | 40 | 30 | 20 | 10 |
| % riparian cover | 10 | 5 | 0 | 10 | 10 | 5 | 10 | 10 | 5 | 10 | 5 | 10 | 20 | 15 |
| Depth | | | | | | | | | | | | | | |
| %very shallow depth | 40 | 10 | 30 | 10 | 50 | 0 | 10 | 10 | 10 | 10 | 20 | 10 | 0 | 10 |
| % shallow depth | 30 | 40 | 30 | 40 | 40 | 40 | 20 | 40 | 40 | 30 | 30 | 20 | 20 | 30 |
| % moderate depth | 20 | 40 | 30 | 40 | 10 | 30 | 40 | 30 | 40 | 40 | 30 | 40 | 50 | 40 |
| % deep | 10 | 10 | 10 | 10 | 0 | 30 | 30 | 20 | 10 | 20 | 20 | 30 | 30 | 20 |
| Flow | | | | | | | | | | | | | | |
| % very slow flow | 60 | 5 | 50 | 30 | 20 | 0 | 0 | 0 | 0 | 0 | 10 | 0 | 0 | 0 |
| % slow flow | 20 | 30 | 20 | 30 | 40 | 10 | 10 | 20 | 0 | 10 | 30 | 0 | 0 | 10 |
| % moderate flow | 20 | 30 | 20 | 30 | 30 | 10 | 20 | 30 | 20 | 10 | 30 | 30 | 10 | 10 |
| % fast flow | 0 | 30 | 10 | 10 | 10 | 40 | 30 | 30 | 40 | 40 | 30 | 40 | 50 | 40 |
| % torrent flow | 0 | 5 | 0 | 0 | 0 | 40 | 40 | 20 | 40 | 40 | 10 | 30 | 40 | 40 |

Table A4: The catch per unit effort (no $min^{-1}$) of all species at all stations in October 2004.

| | | Stations | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Family | Species | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | Total |
| Mormyridae | *Cyphomyrus discorhynchus* | | | | | | | | | | | | | | |
| | *Mormyrus longirostris* | | | | | | | | | | | | | | |
| Cyprinidae | *Mesobola brevianalis* | | | | | | | | | | | | | | |
| | *Opsaridium zambezense* | | | | | | | 1.0 | | 0.4 | 0.5 | | 0.6 | 1.1 | 34 |
| | *Barbus lineomaculatus* | 0.4 | | 0.2 | | 0.3 | | | | | | | | | 9 |
| | *Barbus radiatus* | | | | | | | | | | | | | 1.0 | 10 |
| | *Barbus trimaculatus* | | | | | | | 1.0 | 4.0 | 0.4 | 4.3 | 1.4 | 2.0 | | 126 |
| | *Barbus paludinosus* | 5.0 | | 2.0 | | | | | | | | | | | 69 |
| | *Barbus unitaeniatus* | | | | | | | | | | | | | | |
| | *Labeobarbus marequensis* | | | | | | 6.0 | 2.0 | 1.0 | 2.0 | 5.3 | | 2.0 | 4.0 | 224 |
| | *Labeo cylindricus* | | | | | | 0.7 | 0.3 | 0.2 | 0.7 | 2.8 | | 1.5 | 6.0 | 122 |
| Alestiidae | *Brycinus imberi* | | | | | | | | | | | | | | |
| | *Micralestes acutidens* | | | | | | | | | | | | | 4.0 | 4 |
| Amphiliidae | *Zaireichthys rotundiceps* | | | | | | 0.2 | 0.3 | 0.1 | | 0.2 | | | 0.1 | 9 |
| Clariidae | *Clarias gariepinus* | 0.6 | | 0.5 | 0.4 | 0.2 | 0.4 | | 2.0 | 1.3 | 0.2 | 2.0 | 2.2 | 0.5 | 105 |
| Mochokidae | *Chiloglanis neumanni* | | | | | | 3.0 | 9.0 | 1.0 | 7.2 | 21.0 | | 14.0 | 14.0 | 687 |
| Centrachidae | *Micropterus salmoides* | 1.3 | | 0.6 | 0.3 | | 0.3 | 2.4 | | 0.5 | 0.3 | 0.4 | 2.0 | 0.7 | 87 |
| Cichlidae | *Pseudocranilabrus philander* | | | | 2.6 | | | 0.5 | | | 0.3 | 2 | 0.7 | | 58 |
| | *Pharyngochromis acuticeps* | | | | | | | | | | | | | | |
| | *Tilapia sparrmanii* | | 1.2 | 0.4 | | | 0.1 | 0 | 0.1 | | | | | | 18 |
| | *Tilapia rendalli* | | 1 | 0.3 | 0.2 | | 1.7 | 0.3 | | | 0.4 | 0.5 | 0.5 | 0.6 | 54 |
| | *Oreochromis mossambicus* | | | | | | | | | | | | 0.3 | 1.0 | 12 |
| | *Oreochromis niloticus* | | | | | | | | | | | | | | |
| | *Serranochromis robustus* | | 0.1 | | | | | | | | | | | | 10 |

Table A5: The catch per unit effort (no $min^{-1}$) of all species at all stations in November 2004.

| | | Stations | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Family | Species | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | Total |
| Mormyridae | *Cyphomyrus discorhynchus* | | | | | | | | | | | | | | 0.3 | 3 |
| | *Mormyrus longirostris* | | | | | | | | | | | | | | 0.1 | 1 |
| Cyprinidae | *Mesobola brevianalis* | | | | | | | | | | | | | | 1.2 | 12 |
| | *Opsaridium zambezense* | | | | | | | 3.5 | | | 0.2 | | | 1.1 | 1.0 | 58 |
| | *Barbus lineomaculatus* | | | | | 0.4 | | 0.3 | | | | | 1.4 | | | 21 |
| | *Barbus radiatus* | | | | | | | | | | | | | 0.6 | 0.9 | 15 |
| | *Barbus trimaculatus* | | | | | | 8.0 | 1.0 | 1.5 | 0.8 | 3.2 | 1.4 | 9.3 | 0.8 | 0.5 | 193 |
| | *Barbus paludinosus* | 0.8 | | 0.4 | | 0.5 | 0.4 | | | | | | 0.2 | | | 23 |
| | *Barbus unitaeniatus* | | | | | | | | | | 0.3 | 0.2 | 0.6 | 0.4 | 0.2 | 17 |
| | *Labeobarbus marequensis* | | | | | | 1.6 | 1.0 | 6.3 | 2.5 | 4.6 | 0.1 | 0.8 | 14.1 | 6.3 | 374 |
| | *Labeo cylindricus* | | | | | | 0.3 | 0.6 | 0.4 | 0.2 | 3.1 | 0.1 | 0.2 | 4.6 | 8.0 | 173 |
| Alestiidae | *Brycinus imberi* | | | | | | | | | | | | | | 0.2 | 2 |
| | *Micralestes acutidens* | | | | | | | | | | | | | 0.6 | 1.1 | 17 |
| Amphiliidae | *Zaireichthys rotundiceps* | | | | | | | 0.4 | | 0.3 | | | 0.2 | 0.1 | | 10 |
| Clariidae | *Clarias gariepinus* | 0.5 | 0.5 | 0.1 | 0.3 | 0.6 | 0.5 | | 1.0 | 0.4 | 0.5 | 1.3 | 0.5 | 0.3 | 0.6 | 78 |
| Mochokidae | *Chiloglanis neumanni* | | | | | | 2.0 | 4.2 | 0.5 | 7.0 | 17.1 | | 0.7 | 4.2 | 6.0 | 417 |
| Centrachidae | *Micropterus salmoides* | 0.3 | | | 1.7 | | 0.7 | 1.7 | | 0.2 | 3.0 | 0.7 | 1.6 | 1.4 | 0.5 | 116 |
| Cichlidae | *Pseudocranilabrus philander* | | | | 1.0 | | | 0.4 | | | 0.6 | 2.7 | 0.5 | 0.6 | 0.4 | 62 |
| | *Pharyngochromis acuticeps* | | | | | | | | | | 0.2 | 0.9 | 0.5 | 1.2 | 1.7 | 45 |
| | *Tilapia sparrmanii* | | 0.3 | 0.3 | | | | | | | | | | | | 5 |
| | *Tilapia rendalli* | | 1.5 | 0.1 | 0.4 | | 2.0 | 1.6 | 0.9 | | 1.4 | 0.5 | 0.5 | 2.1 | 4.5 | 159 |
| | *Oreochromis mossambicus* | | | | | | | | | | | | 0.3 | 0.9 | 1.3 | 25 |
| | *Oreochromis niloticus* | | | | | | 0.3 | | | | | | | | | 3 |
| | *Serranochromis robustus* | | 0.5 | | | | | | | | | | | | | 5 |

Table A6: The catch per unit effort (no $min^{-1}$) of all species at all stations in January 2005.

| | | Stations | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Family | species | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | Total |
| Mormyridae | *Cyphomyrus discorhynchus* | | | | | | | | | | | | | | 0.1 | 1 |
| | *Mormyrus longirostris* | | | | | | | | | | | | | | 0.1 | 1 |
| Cyprinidae | *Mesobola brevianalis* | | | | | | | | | | | | | | 4.5 | 45 |
| | *Opsaridium zambezense* | | | | | | | 0.5 | | | 0.9 | | 0.2 | 1.2 | 1.2 | 40 |
| | *Barbus lineomaculatus* | | | | | 0.2 | | | | | | | | | | 2 |
| | *Barbus radiatus* | | | | | | | | | | | | | 0.2 | 0.3 | 5 |
| | *Barbus trimaculatus* | | | | | | 0.4 | | 0.3 | | 0.7 | 0.2 | 0.2 | | | 18 |
| | *Barbus paludinosus* | 0.9 | 0.5 | 1.2 | | 0.1 | | | | | | | | | | 27 |
| | *Barbus unitaeniatus* | | | | | | | | | | | | | | | |
| | *Labeobarbus marequensis* | | | | | | 0.4 | 1.0 | 0.8 | 0.7 | 1.7 | 0.1 | 1.5 | 2.0 | 3.3 | 114 |
| | *Labeo cylindricus* | | | | | | 0.1 | 0.3 | 0.2 | 0.4 | 0.5 | | 0.2 | 0.8 | 0.2 | 27 |
| Alestiidae | *Brycinus imberi* | | | | | | | | | | | | | 0.3 | 0.3 | 5 |
| | *Micralestes acutidens* | | | | | | | | | | | | | | 0.3 | 3 |
| Amphilidae | *Zaireichthys rotundiceps* | | | | | | | | | | | | | | | |
| Clariidae | *Clarias gariepinus* | 0.2 | 0.4 | 0.5 | 0.2 | 0.3 | 0.2 | | | 0.3 | | 0.2 | 0.4 | 0.3 | 1.5 | 45 |
| Mochokidae | *Chiloglanis neumanni* | | | | | | | 2.0 | 0.6 | 0.8 | 1.1 | | 1.2 | 0.4 | 2.4 | 86 |
| Centrachidae | *Micropterus salmoides* | 0.4 | 0.2 | 0.5 | 0.3 | | 0.1 | | | | 0.6 | 0.6 | 0.3 | 0.5 | 0.1 | 36 |
| Cichlidae | *Pseudocranilabrus philander* | | | | 0.5 | | | 0.7 | | | 0.8 | 0.9 | 1.6 | 0.3 | 0.4 | 52 |
| | *Pharyngochromis acuticeps* | | | | | | | | | | 0.2 | 0.5 | | 0.6 | 1.1 | 24 |
| | *Tilapia sparmanii* | | | 0.2 | 0.1 | | | | 0.2 | | | | | | | 5 |
| | *Tilapia rendalli* | | 0.2 | 0.3 | 0.3 | | 0.8 | 0.4 | | | 1.5 | 0.8 | 6.0 | 2.0 | 1.3 | 133 |
| | *Oreochromis mossambicus* | | | 0.3 | | | | | | | | | | 0.2 | 0.4 | 9 |
| | *Oreochromis niloticus* | | | | | | | | | | | | | | 0.1 | 1 |
| | *Serranochromis robustus* | | 0.4 | | | | | | | | | | | | | 4 |

Table A7: Mean values for all stations for the three sampling periods.

| | Station | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| Altitude (m) | 1562 | 1558 | 1552 | 1529 | 1402 | 1328 | 1222 | 1273 | 1192 | 1156 | 1191 | 1152 | 844 | 822 |
| Catchment area ($km^2$) | 11.3 | 26.8 | 19.3 | 14.8 | 3.8 | 31.3 | 64 | 14 | 43.5 | 138 | 63.8 | 141 | 264 | 825 |
| N (October) | 4 | 3 | 6 | 4 | 2 | 8 | 9 | 7 | 7 | 10 | 5 | 10 | 11 | |
| N (November) | 3 | 4 | 4 | 4 | 3 | 9 | 10 | 6 | 7 | 11 | 9 | 14 | 15 | 18 |
| N (January) | 3 | 5 | 6 | 5 | 3 | 6 | 6 | 5 | 4 | 9 | 7 | 9 | 12 | 17 |
| Species diversity (Oct) | 1.3 | 1.1 | 1.7 | 1.3 | 0.7 | 1.9 | 2.1 | 1.8 | 1.9 | 2.2 | 1.6 | 2.2 | 2.3 | |
| Species diversity (Nov) | 1.1 | 1.4 | 1.4 | 1.3 | 1.1 | 2.2 | 2.3 | 1.7 | 1.8 | 2.3 | 2.1 | 2.6 | 2.6 | 2.7 |
| Species diversity (Jan) | 1.1 | 1.6 | 1.8 | 1.2 | 1.1 | 1.7 | 1.8 | 1.6 | 1.4 | 2.2 | 1.9 | 2.1 | 2.4 | 2.7 |
| Habitat diversity (Oct) | 1.1 | 1.4 | 1.4 | 1.3 | 1.1 | 2.2 | 2.3 | 1.7 | 1.8 | 2.3 | 2.1 | 2.6 | 2.6 | |
| Habitat diversity (Nov) | 1.9 | 2.2 | 1.9 | 2.3 | 2.1 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | 2.4 | 2.6 | 2.6 | 2.8 |
| Habitat diversity (Jan) | 1.5 | 1.5 | 1.3 | 1.6 | 1.4 | 2.5 | 2.5 | 2.5 | 2.5 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 |
| CPUE (October) | 7.3 | 2.3 | 4.0 | 3.5 | 0.5 | 12.4 | 16.8 | 8.4 | 12.3 | 35.3 | 6.3 | 25.8 | 33.0 | |
| CPUE (November) | 1.6 | 2.8 | 0.9 | 3.4 | 1.5 | 15.8 | 14.7 | 10.6 | 11.7 | 34.2 | 7.9 | 17.3 | 33.0 | 34.8 |
| CPUE (January) | 1.5 | 1.7 | 3.0 | 1.4 | 0.6 | 2.0 | 4.9 | 2.1 | 2.2 | 8.0 | 3.3 | 11.6 | 8.8 | 17.6 |

N is the number of species, Oct is October, Nov is November and Jan is January.

# APPENDIX 2

# THE USE OF A FISH ASSEMBLAGE INTEGRITY INDEX IN THE NYAGUI RIVER

## INTRODUCTION

As rivers continue to be degraded worldwide, the use of biotic indices to assess the integrity of aquatic ecosystems has increased (Ganasan and Hughes, 1998). This is because many countries, especially the less developed ones, find it difficult to consistently monitor their aquatic systems using physical and chemical variables because of a lack of funds (Bozzetti and Schulz, 2004). Since fish are an integral component of the aquatic ecosystems, they are now being widely used in biomonitoring exercises.

Karr pioneered the use of fish for biomonitoring of streams and rivers in 1981 when he developed the Index of Biotic Integrity (IBI) (Fausch *et al*., 1984). A typical IBI would include a total of 12 community attributes (metrics) that are compared to the values expected from a relatively undisturbed stream. The IBI has thus gained popularity in the last 20 years and has been used in North America (Osborne *et al*., 1992), Europe (Belliard *et al*., 1999; Belpaire *et al*., 2000; Oberdorff *et al*., 2001b; Briene *et al*., 2004), India (Ganasan and Hughes, 1998) and New Zealand (Joy and Death, 2004).

Their applicability and usefulness in assessing tropical and subtropical regions have also been studied. Hugueny *et al*. (1996) applied the IBI to assess the state of a fish assemblage in the Konkouré River, Guinea while Toham and Teugels (1999) used it to evaluate the impact of deforestation on the Ntem River (Cameroon). The IBI was also used to the different levels of human disturbances on fish in Brazilian streams despite the lack of reliable historical data that could be used as a reference condition (Bozzetti and Schulz, 2004).

The IBI has a sound ecological basis but its applicability in southern Africa has been beset by the following problems: (1) most of the metrics of IBI require detailed historical and ecological information which is not always available, (2) from a technical perspective, IBI requires specialist equipment for sampling that is expensive and unavailable to most developing countries, (3) sampling in most African rivers can be dangerous and is sometimes hampered by accessibility that makes it impossible to do intensive sampling and (4) most fish species are hardy and resistant to natural disturbances such as floods and drought which are frequently mimicked by human disturbances (Kleynhans, 1999).

One of the first attempts to use fish in biomonitoring was in the Okavango River (Namibia) when metrics for developing an index that approximated the North American IBI were selected (Hocutt *et al*., 1994). It was concluded that it was difficult to use fish for biomonitoring purposes because of the scarcity of information. It was suggested that the Jaccard similarity index (based on observed and expected number of species) could be used and Ramm (1988) had earlier developed a community degradation index (CDI) based on the principles of the Jaccard index. It lacked some biological rationale since it did not include ecological aspects such as trophic specialisation, habitat specialisation and species intolerance (Kleynhans, 1999).

It was against this background that Kleynhans (1999) developed the Fish Assemblage Integrity Index (FAII), which included the biological aspects lacking in the Jaccard similarity index. The FAII is also based on the concept of a biological segment, defined as “a portion of a stream in which the fish community remains generally homogenous due to the relative uniformity of the physical habitat” (Kleynhans, 1999). These segments are defined for the purposes of specifying the expected reference condition of the fish assemblage and portrays a reasonable reconstruction of the natural pattern of fish distribution

Most biotic indices have been used to assess rivers that are affected by pollution but very few studies have considered the impact of other factors such as excessive siltation, which is a major problem in many Zimbabwean rivers where it by threatens aquatic habitats (Minshull, 1993). The objective of this study was therefore to determine whether or not the FAII could be applied to the Nyagui River and whether it would reveal the effect of human impacts such as the introduction of alien species or dam-building. This is also the first time anyone has attempted to use this index in Zimbabwe.

## STUDY AREA

The Nyagui River is a major tributary of the Mazowe River, which drains north-eastern Zimbabwe, and its catchment is largely rural. It is a seasonal river with most of its flow occurring during the rainy season (November-April). The river rises on the central plateau of Zimbabwe where the gradient is gentle and descends from an altitude of 1600m to join the Mazowe River at an altitude of about 840m. The river and its tributaries were divided into segments based on the dominant substrate and it was assumed the fish community was relatively homogenous in each (see Kleynhans, 1999). Segment 1 was in the headwaters and characterised by shallow pools with sand and silt as substrates. In segment 2, the middle section, the substrates were typically gravel and pebbles and a combination of deep and shallow pools and riffles. Segment 3 comprised of stations at altitude <1 000m.

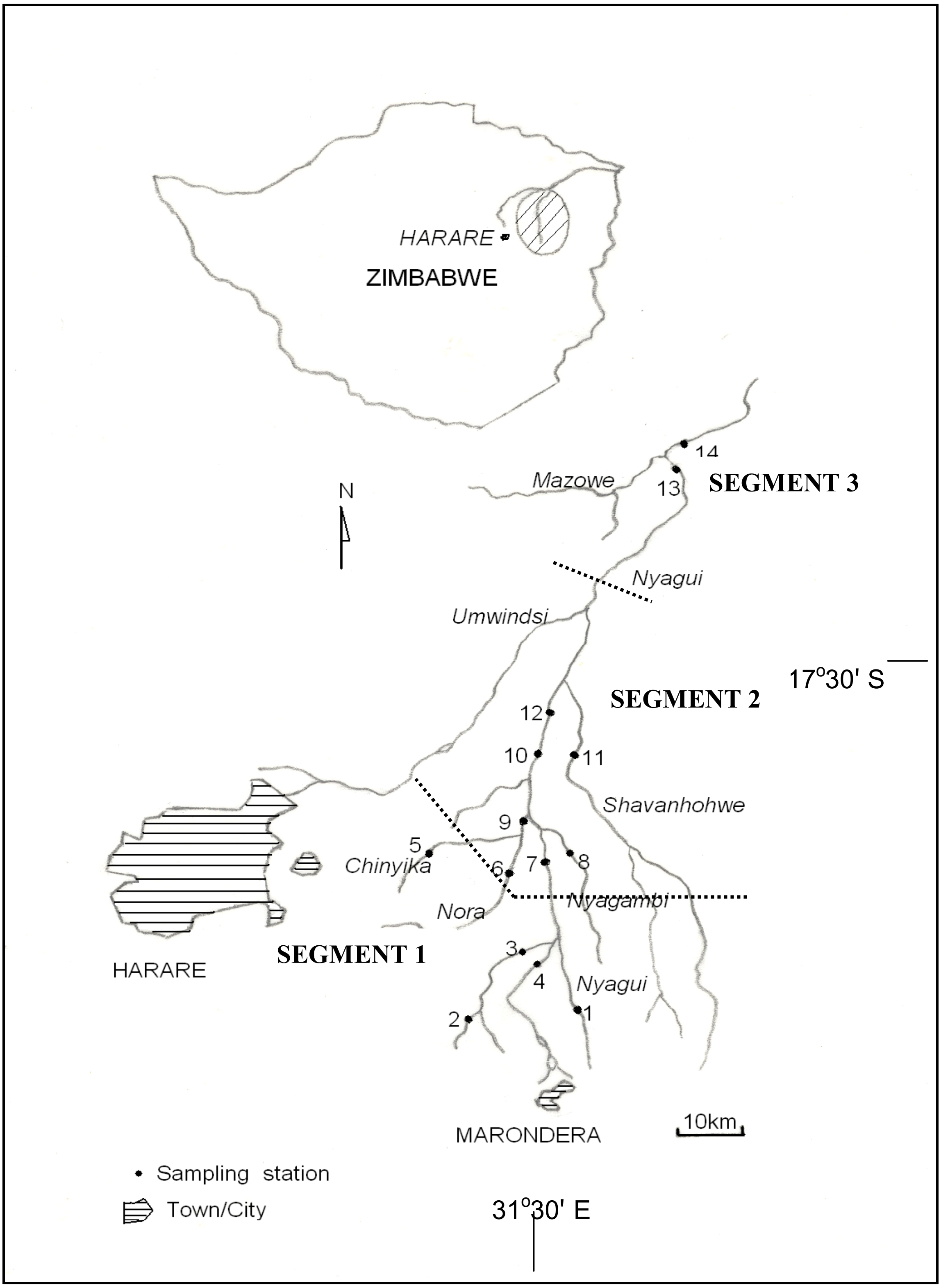


Figure 1: The segments and sampling stations on the Nyagui River, its tributaries and Mazowe River.

## METHODS

The initial step in calculating the FAII is to determine the biological segments, which was done with 1: 500000 and 1:100000 maps and personal knowledge gained during the sampling programme. Information on the distribution of fish in the catchment was obtained from Bell-Cross and Minshull (1988) and Skelton (1993). The FAII measures is based on the native fishes found a river with alien species being noted and interpreted as possible causes for the fall in FAII scores. Three aspects of fish assemblages are taken into consideration (Kleynhans, 1999).

1) The relative intolerance of fish species. Intolerance is defined as the degree to which a species can withstand changes to its environment. The change can be physical (e.g. flow velocity, marginal vegetation, change in depth, bottom and substrate) or chemical (water quality). Four components that must be taken into account are (a) habitat preference and specialisation, (b) food preference and specialisation, (c) requirements for flowing water during different stages of growth and (d) association of the fish with unmodified waters. A fish with low specialisation is given a score of 1, moderate specialisation a score of 3 and high specialisation a score of 5. The mean of the ratings are calculated to obtain an intolerance score ranging from 1 (tolerant species) and 5 (intolerant species).
2) The frequency of occurrence of a species is a surrogate for abundance. Since the expected frequency of occurrence is estimated from other sources the highest possible score expected for each species under natural conditions was used (Bozzetti & Schulz, 2004). Frequency of occurrence was determined as the number of sampling stations in a segment at which a species was recorded divided by the total number of stations sampled in that segment. A frequency of

occurrence below 34% was considered infrequent and given a score of 1, while 34-67% given a score of 3 and 67-100% was considered to be a widespread species and given a score of 5.

3) The health rating was the percentage of fish with evident disease or other anomalies and a frequency of >5% affected fish >5% was given a score of 1, 2-5% given a score of 3 and <2% a score of 5.

Habitat variables were also considered according to the categories given in Table 1.

Table 1: The classification of stream habitats in the Nyagui River. After Gorman and Karr (1978) and Schlosser (1982).

| Category | Depth (cm) | Current (m $s^{-1}$) | Substrate (mm) |
|---|---|---|---|
| 1 | <50 (shallow) | <0. 4 (slow) | <0.05 (silt) |
| 2 | >50 (deep) | >0.4 (fast) | 0.5-2 (sand) |
| 3 | | | 2-10 (gravel) |
| 4 | | | 10-30 (pebble) |
| 5 | | | >30 (rock) |
| 6 | | | Aquatic vegetation (vascular plants or algae) |
| 7 | | | Other (e.g. tree trunks) |

The FAII is calculated from observed and expected values, with the latter serving as a baseline or reference, according to:

$$\text{FAII (obs)} = \Sigma\ IT \times ((F+H)/2)$$

where FAII (obs) = observed fish assemblage integrity index, IT = intolerance rating, F = observed frequency of occurrence and H = observed health rating for each species in a segment

The expected FAII score is calculated as:

$$FAII\ (exp) = \Sigma\ IT \times ((F+H)/2)$$

where F and H are expected values from the reference condition. The habitat type based on substrate, current and depth were used in determining the expected values at each station in a segment. The relative (or final) FAII score is calculated as a percentage, i.e. observed value divided by expected value times 100.

**Interpretation of the FAII score**

The interpretation of FAII scores is purely descriptive as shown in Table 2.

Table 2: The interpretation of the FAII according to the categories set out in Kleynhans (1999).

| **Class rating** | **Expected conditions for integrity classes** | **Relative FAII score (% of expected)** |
|---|---|---|
| A | Unmodified, or approximately natural conditions | 90 to 100 |
| B | Largely natural with few modifications. Species richness and presence of intolerant species indicate little modifications. | 80 to 89 |
| C | Moderately modified. A lower than expected species richness and presence of most intolerant species. Health impairment may be evident at the lower limit of this class. | 60 to 79 |
| D | Largely modified. A lower than expected species richness and absence or much lowered presence of intolerant species and moderately intolerant species. Health impairment may become more evident at the lower limit of this class. | 40 to 59 |
| E | Seriously modified. A very lower than expected species richness and general absence of intolerant species and moderately intolerant species. Health impairment may become very evident. | 20 to 39 |
| F | Critically modified. Extremely lowered species richness and an absence of intolerant and moderately tolerant species. Only tolerant species may be present. Health impairment very evident. | 0 to 19 |

Linear regression was used to compare the relationship between the expected and observed number of species in each segment. The factors considered important in determining the number of species and the final FAII score were the proportion of *Micropterus salmoides*, habitat diversity and catchment area. Separate regressions were made to determine the impact of each of these factors on species richness. The relative importance of these three factors on species richness for the whole system was analysed using multiple linear regression. The variables used in the analysis are presented in Table 3.

Table 3: The variables used in multiple linear regression analysis. N is the number of species at each station, % bass is the proportion of *Micropterus salmoides,* Area is given as log transformed and D is the mean habitat diversity for each station

| Station | N | % bass | Area($km^2$) | D |
|---|---|---|---|---|
| 1 | 3 | 21.0 | 1.05 | 1.50 |
| 2 | 4 | 28.3 | 1.42 | 1.70 |
| 3 | 6 | 15.3 | 1.28 | 1.53 |
| 4 | 3 | 29.7 | 1.17 | 1.73 |
| 5 | 3 | 0 | 0.57 | 1.53 |
| 6 | 8 | 5.4 | 1.49 | 2.43 |
| 7 | 9 | 12.8 | 1.81 | 2.46 |
| 8 | 8 | 0 | 1.15 | 2.26 |
| 9 | 7 | 1.9 | 1.64 | 2.30 |
| 10 | 12 | 7.8 | 2.14 | 2.50 |
| 11 | 9 | 5.8 | 1.80 | 2.37 |
| 12 | 14 | 6.2 | 2.15 | 2.60 |
| 13 | 16 | 3.6 | 2.42 | 2.60 |
| 14 | 16 | 0.5 | 2.92 | 2.70 |

## RESULTS

A total of 31 indigenous species were expected to occur in the system but nine of them typically occur at low altitudes in the system and would not be expected to occur in segment 1 or possibly some stations in segment 2. A total of seven species was collected in segment 1 and sixteen indigenous species were collected in segments, two and three each. Table 4 described the habitat types sampled in each segment. The distribution of species in the segment was summarised in Table 5. The FAII score was calculated and summarised in Table 6. Since there was no observed source of disturbance in the catchment other than that of siltation, all fish were considered to be in good health, hence the health rating metric was omitted in the analysis.

Table 4: The habitat types sampled at each station for the three segments. S/S-sand and silt, G/P-gravel and pebble, R-rocks and boulders, Av-aquatic vegetation

| | | Habitats | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Slow deep | | | | Slow shallow | | | | Fast deep | | | | Fast shallow | | | |
| Segment | Station | S/S | G/P | R | Av | S/S | G/P | R | Av | S/S | G/P | R | Av | S/S | G/P | R | Av |
| 1 | 1 | | | | | + | | | + | | | | | | | | |
| | 2 | + | | | | + | | | + | | | | | + | | | |
| | 3 | + | | | | + | | | + | + | | | | + | | | |
| | 4 | | + | | | | + | | | | | | | | | | |
| | 5 | | | | | + | | | + | | | | | | | | |
| 2 | 6 | + | + | | | + | | | + | + | | | | | + | | |
| | 7 | + | + | + | + | + | + | | + | + | + | + | | + | + | | |
| | 8 | + | | | | + | + | | + | + | | | | + | + | | |
| | 9 | | + | | | + | + | | + | + | + | + | | | + | | |
| | 10 | + | + | + | | + | + | | + | + | + | + | | | + | + | + |
| | 11 | + | | + | + | + | | + | + | + | | + | | + | | | |
| | 12 | + | + | + | + | + | + | + | + | | + | + | + | | + | | + |
| 3 | 13 | + | + | + | + | | + | + | + | | + | + | | | + | + | |
| | 14 | + | + | + | + | + | + | + | + | | + | + | | | + | + | + |

Table 5: The fishes expected to occur in the Mazowe system (based on Bell-Cross & Minshull, 1988, Skelton, 2003 and BE Marshall, personal communication) and those recorded at the 14 sampling stations the Nyagui system. The symbol ● denotes those species likely only to occur at an altitude of <1000 m, the symbol ★ denotes an exotic species and the symbol + denotes the expected occurrence of a species at a station and symbol in parenthesis indicates + presence and - absence.

| | | Segment 1 | | | | | Segment 2 | | | | | | | Segment 3 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Family | Species | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| Mormyridae | *M. longirostris* ● | | | | | | | | | | | | | | +(+) |
| | *Cyphomyrus discorhynchus* | | | | | | | | | | | | | | +(+) |
| | *Marcusenius macrolepidotus* | | | | | | | | | | | | | | + |
| | *Petrocephalus catostoma* ● | | | | | | | | | | | | | | +(-) |
| Anguillidae | *Anguilla bengalensis* | | | | | | | | | | | | | | + |
| | *A. mossambica* | | | | | | | | | | | | | | + |
| Cyprinidae | *Mesobola brevianalis* ★ | | | | | | | | | | | | | | |
| | *Opsaridium zambezense* | | | | | | | +(+) | | +(+) | +(+) | | +(+) | +(+) | +(+) |
| | *Barbus annectens* | | | | | | | | | | | | | | |
| | *B. lineomaculatus* | +(+) | +(-) | +(+) | +(-) | +(+) | +(-) | +(+) | | | +(+) | | +(+) | | + |
| | *B. radiatus* | | | | | | | | | | | | +(-) | +(+) | +(+) |
| | *B. trimaculatus* | +(-) | +(-) | +(-) | +(-) | +(-) | +(+) | +(+) | +(+) | +(+) | +(+) | +(+) | +(+) | +(+) | +(+) |
| | *B. paludinosus* | +(+) | +(+) | +(+) | +(-) | +(+) | +(+) | +(-) | +(-) | +(-) | +(-) | +(-) | +(+) | +(-) | +(-) |
| | *B. unitaeniatus* | | | | | | | | | | +(+) | +(+) | +(+) | +(+) | +(+) |
| | *Labeobarbus marequensis* | | | | +(-) | | +(+) | +(+) | +(+) | +(+) | +(+) | +(+) | +(+) | +(+) | +(+) |
| | *Labeo altivelis* ● | | | | | | | | | | | | | | +(-) |
| | *L. congoro* ● | | | | | | | | | | | | | | +(-) |
| | *L. cylindricus* | | | | +(-) | | +(+) | +(+) | +(+) | +(+) | +(+) | +(+) | +(+) | +(+) | +(+) |
| | *L. molybdinus* | | | | | | | | | | | | | +(-) | +(-) |
| Alestiidae | *Brycinus imberi* ● | | | | | | | | | | | | | +(+) | +(+) |
| | *Micralestes acutidens* | | | | | | | | | | | | | +(+) | +(+) |
| | *Hydrocynus vittatus* ● | | | | | | | | | | | | | | +(-) |
| Amphiliidae | *Zaireichthys rotundiceps* | | | | | | +(+) | +(+) | +(+) | +(+) | +(+) | +(+) | +(+) | +(+) | |
| Schilbeidae | *Schilbe intermedius* ● | | | | | | | | | | | | | | +(-) |
| Clariidae | *Clarias gariepinus* | +(+) | +(+) | +(+) | +(+) | +(+) | +(+) | +(-) | +(+) | +(+) | +(+) | +(+) | +(+) | +(+) | +(+) |
| Mochokidae | *Chiloglanis neumanni* | | | | | | +(+) | +(+) | +(+) | +(+) | +(+) | | +(+) | +(+) | +(+) |
| Centrarchidae | *Micropterus salmoides* ★ | | | | | | | | | | | | | | |
| Cichlidae | *Pseudocrenilabrus philander* | | | | +(+) | | | +(+) | | | +(+) | +(+) | +(+) | +(+) | +(+) |
| | *Pharyngochromis acuticeps* | | | | | | | | | | +(+) | +(+) | +(+) | +(+) | +(+) |
| | *Tilapia sparrmanii* | | +(+) | +(+) | +(-) | | | +(-) | +(+) | | +(-) | +(-) | +(-) | +(-) | +(-) |
| | *T. rendalli* | | +(+) | +(+) | +(+) | | +(+) | +(+) | +(+) | | +(+) | +(+) | +(+) | +(+) | +(+) |
| | *Oreochromis mossambicus* | | | (+) | | | | | | | | | +(+) | +(+) | +(+) |
| | *O. niloticus* ★ | | | | | | | | | | | | | | |
| | *Serranochromis robustus* ★ | | | | | | | | | | | | | | |
| Gobiidae | *Awaous aeneofuscus* ● | | | | | | | | | | | | | | +(-) |
| | *Glossogobius giuris* ● | | | | | | | | | | | | | | +(-) |
| Total number of species | | | | 7 | | | | | 16 | | | | | 16 | |

Table 6: The FAII score based on the expected and observed fish species (indicated in brackets). The symbol * indicates there is insufficient information available to estimate the frequency of occurrence.

| | | Frequency of occurrence | | |
|---|---|---|---|---|
| Species | Intolerance rating | Segment 1 | Segment 2 | Segment 3 |
| *Mormyrus longirostris* | 2.5 | | | 1 (1) |
| *Cyphomyrus discorhynchus* | 3.5 | | | 1 (1) |
| *Marcusenius macrolepidotus* | 2.5 | | *(0) | 1 (0) |
| *Petrocephalus catastoma* | 3 | | | * (0) |
| *Anguilla mossambica* | 3 | | * (0) | * (0) |
| *A. bengalensis* | 3 | | * (0) | * (0) |
| *Opsaridium zambezense* | 4.5 | | 5 (5) | 2 (2) |
| *Barbus lineomaculatus* | 2 | 5 (3) | 4(3) | 1 (0) |
| *B. unitaeniatus* | 2.5 | | 3 (3) | 2 (2) |
| *B. radiatus* | 2 | | 2 (1) | 2 (2) |
| *B. trimaculatus* | 2 | 3 (0) | 5 (5) | 2 (2) |
| *B. paludinosus* | 2 | 5 (4) | 5 (2) | 2 (0) |
| *Labeobarbus marequensis* | 1.5 | | 5 (5) | 2 (2) |
| *Labeo cylindricus* | 3.5 | | 5 (5) | 2 (2) |
| *L. molybdinus* | 3.5 | | *(0) | 1 (0) |
| *Brycinus imberi* | 3 | | | 2 (2) |
| *Micralestes acutidens* | 2 | | | 2 (2) |
| *Hydrocynus vittatus* | 4 | | | * (0) |
| *Zaireichthys rotundiceps* | 4.5 | | 5 (5) | 1 (0) |
| *Clarias gariepinus* | 1 | 5 (5) | 5 (5) | 2 (2) |
| *Chiloglanis neumanni* | 5 | | 4.5 (4.5) | 2 (2) |
| *Pharyngochromis acuticeps* | 1 | | 2.5 (2.5) | 2 (2) |
| *Pseudocrenilabrus philander* | 1 | 1 (1) | 3 (3) | 2 (2) |
| *Tilapia sparrmanii* | 1 | 3 (2) | 3 (1) | 1 (0) |
| *T. rendalli* | 1 | 3 (3) | 5 (4.5) | 2 (2) |
| *Oreochromis mossambicus* | 1 | 1 (1) | 2 (1) | 2 (2) |
| Species richness | | 10 (7) | 20 (16) | 26 (16) |
| Stations sampled | | 5 | 7 | 2 |
| Relative FAII score (%) | | 67 | 91.6 | 82 |
| Integrity class rating | | C | A | B |

***Segment 1***: Five stations were sampled in this segment and these comprised mainly of the upstream stations. Of the expected ten species, seven were collected depicting a lower than expected species richness. This segment was therefore classified as moderately modified (class C) and had a relative score of 67% (Table 6). The habitats for all stations were generally dominated by sand and silt with aquatic vegetation. Also present in this segment were two exotic species, *Micropterus salmoides* and *Serranochromis robustus*, the latter being found at station 2 only.

***Segment 2***: Seven stations were sampled in this segment and sixteen of the expected nineteen species were collected during the sampling period. The segment was classified as unmodified (class A) with a relative score of 91.6% (Table 6). Intolerant species that included *O. zambezense*, *C. neumanni* and *L. rotundiceps* were collected in this segment. Two exotics were collected with *M. salmoides* being found at all stations except stations 8 and 9 and its abundance was <10% at all stations except at station 7 while only one specimen of *Oreochromis niloticus* was collected at station 6. All stations comprised of both pools and riffles that encompassed most of the habitat categories except stations 8 and 11 that had only pools. Station 8 was on Nyagambi River and station 11 was on Shavanhohwe River, both tributaries of Nyagui River.

***Segment 3***: This segment had two stations and was classified as largely natural with a relative FAII score of 82%. The number of species collected was sixteen and was lower than the expected twenty-six. The intolerant species collected in this segment were *O. zambezense* and *C. neumanni*. Both *M. salmoides* and one specimen of *O. niloticus* were collected in this segment. Another species collected was *Mesobola brevianalis* that had not been previously documented in this system. Most of the habitat categories were found in this segment.

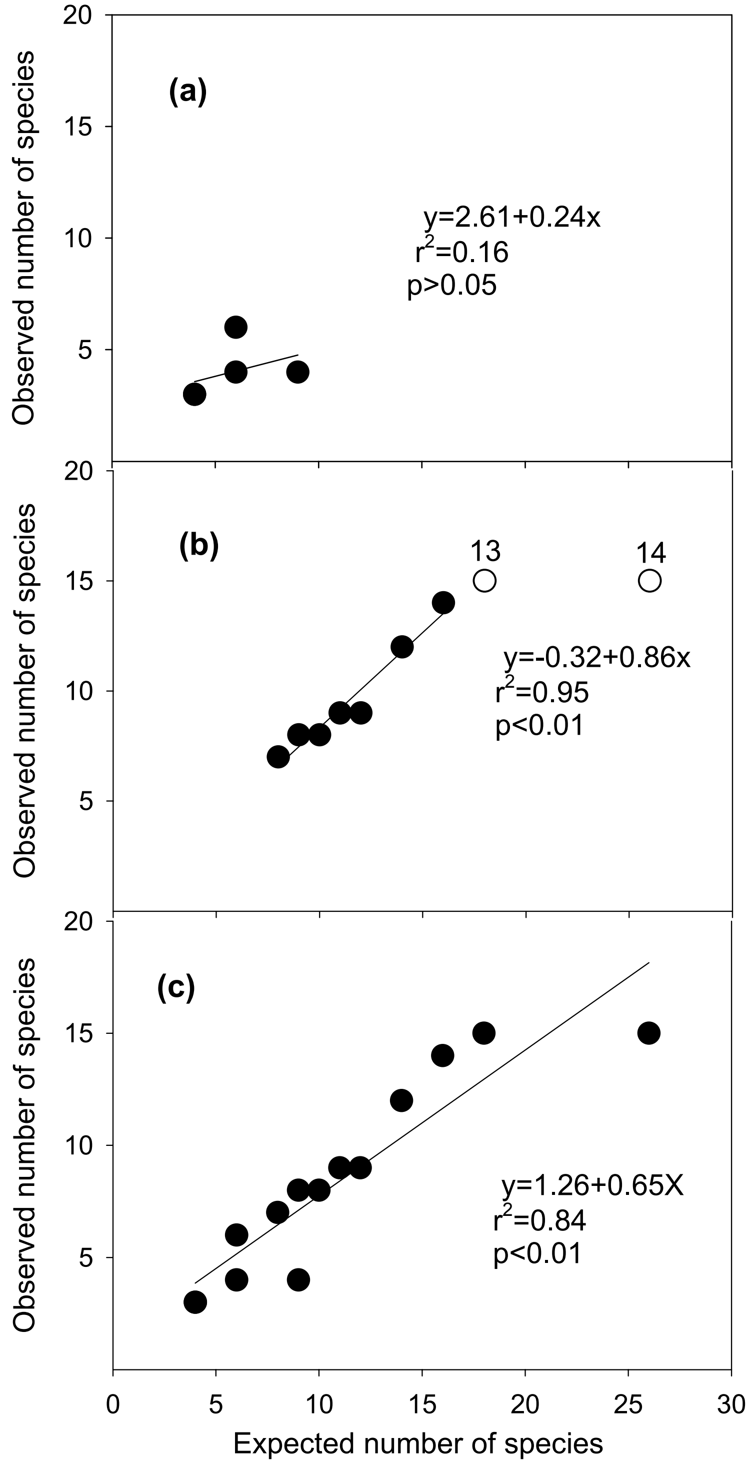


Figure 2: The relationship between the observed and expected number of species in (a) segment 1 (b) segment 2 and 3, and (c) the three segments, the symbol (○) denotes the two stations in segment 3

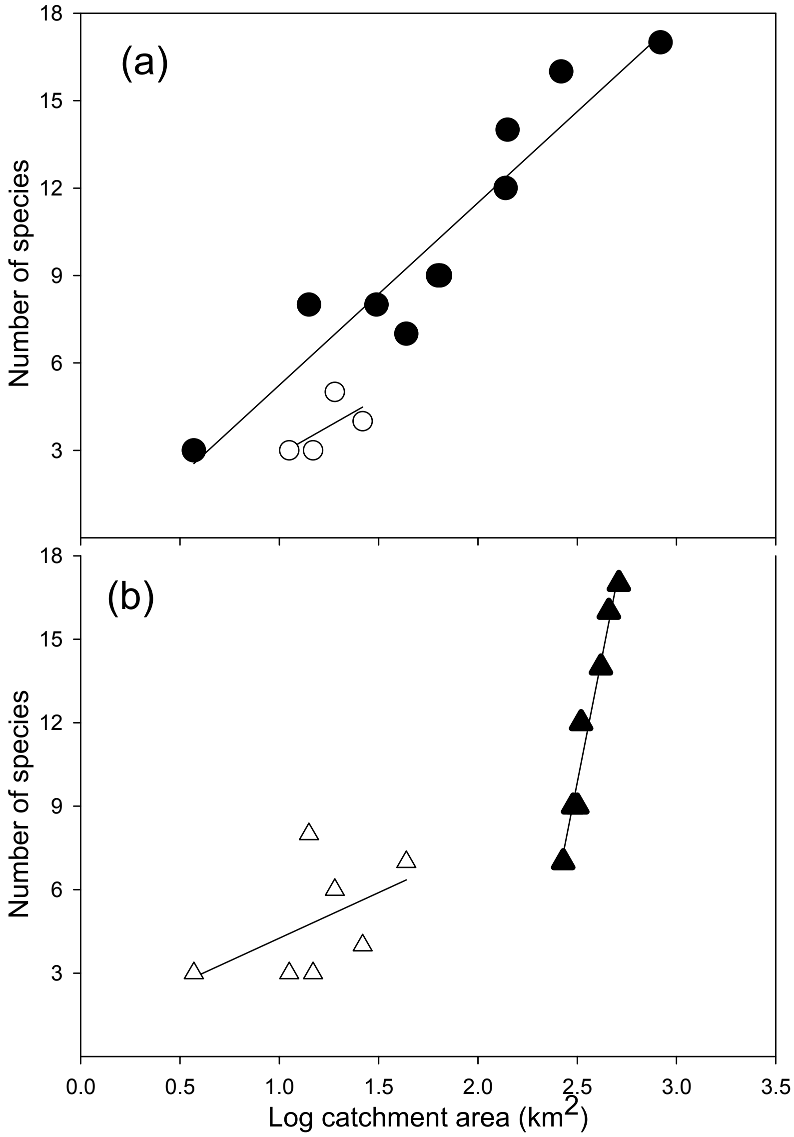


Figure 3: (a) Relationship between catchment area and species richness at stations with <10% (●) and > 10% (○) *Micropterus salmoides.* Regressions were fitted by $y = -1.08 + 6.25x$, $r^2=0.89$, $p<0.01$and $y = -1.03 + 3.89x$, $r^2 = 0.41$, $p > 0.01$, respectively.
(b) Relationship between catchment area and species richness at stations with habitat diversity >2.5 (▲) and < 2.5 (△). Regressions were fitted by $y = -74.9 + 33.9x$, $r^2 = 0.94$, $p < 0.01$ and $y = 0.98 + 3.27x$, $r^2 = 0.27$, $p > 0.05$).

A multiple linear regression of variables on species richness was calculated as:

$$N = -4.89 - 0.119B + 5.06\log A + 2.53D,\ r^2 = 0.93,\ p < 0.001$$

where $N$ = number of species, $B$ = % bass, $A$ = area (km$^2$), $D$ = habitat diversity. The significance of the parameters was tested by an analysis of variance which gave the following results:

ANOVA

| SOURCE | DF | SS | MS | F | p |
|---|---|---|---|---|---|
| Regression | 3 | 214.9 | 71.6 | 41.8 | <0.01 |
| Error | 9 | 15.4 | 1.7 | | |
| Total | 12 | 230.3 | | | |

| | Coefficients | SE | Stand coeff | t | p |
|---|---|---|---|---|---|
| Constant | -4.896 | 5.56 | | -0.88 | 0.402 |
| % bass | -0.119 | 0.05 | -0.262 | -2.23 | 0.053 |
| Area (km$^2$) | 5.065 | 1.16 | 0.644 | 4.37 | 0.002 |
| D | 2.532 | 2.61 | 0.161 | 0.97 | 0.309 |

Under unmodified environmental conditions a positive relationship would be expected between the observed and expected number of species. There was no relationship between the observed and expected number of species in segment 1 suggesting a lower than expected species richness (Figure 2a). There were only two stations in segment 3 and the data was combined with that of segment 2 since the relative FAII scores for these segments were high and positive correlation was observed between the expected and observed number of species (Figure 2b). The same relationship was also obtained when data for the three segments was combined (Figure 2c). There was a positive correlation between species richness and catchment area at stations with <10% *M. salmoides* and habitat diversity >2.5 while no such relationship was observed at stations with >10% *M. salmoides* and habitat diversity <2.5 (Figure 3). The latter situation was mainly related to stations in segment 1 suggesting that both bass and low habitat diversity (due to high proportion of sand and silt) were probably important in determining species richness hence the relative FAII score.

The impact of bass was high at stations with low habitat diversity (segment 1) and decreased downstream with increase in habitat diversity. In multiple regression analysis, a combination of proportion of bass, catchment area and habitat diversity explained the number of species at each station when all stations were combined in multiple regressions ($p<0.01$, $r^2=0.93$). Only catchment area had a significant partial regression slope for the number of species ($p<0.01$) suggesting that this variable explained much of the variation in the number of species for all the segments.

## DISCUSSION

The relative FAII scores in this study were based on the combined samples of the three sampling months since Hocutt *et al*. (1994) cautioned against the use of single samples in systems where the history of ichthyofauna under study is poorly known. Also, the scores of many biotic indices have been found to be unaffected by changes in seasons and flow (Karr, 1981 in Bozzetti and Schulz, 2004). Segment 1 with five upstream stations, was classified as moderately modified and this result was also supported by a lack of correlation between the expected and observed species. Bozzetti and Schulz (2004) reported low IBI score in catchments impacted by diffuse agricultural activities due to loss of the physical habitat diversity and the fragmentation of river systems by small dams. The upstream stations under study were dominated by sand and silt that had presumably been washed into the riverbed and there were also a few farm dams. The impact of *M. salmoides* whose abundance was >10% of the population was high at stations with low habitat diversity. A few species, mainly *B. paludinosus*, were present at habitats with shallow depth and aquatic vegetation that provided cover from the predator.

The impact of exotic species on indigenous species has been documented. Exotic predators have been found to eliminate native species and reducing their distribution (Closs and Lake, 1996; Gratwicke and Marshall, 2001). The presence of introduced species can be one of the most resistant forms of human impact since their elimination and reduction in rivers is difficult because they cannot be controlled by simple technology or engineering technique, or modification in land use. The largemouth bass, *M. salmoides*, and *S. robustus* are predators and were reported to be the cause for the decline in the distribution and abundance of minnows in the upper Manyame catchment (Zimbabwe) (Gratwicke and Marshall, 2001). Although a few specimens of *O. niloticus* were collected, this is another exotic species that has the potential of competitively eliminating indigenous cichlid species. When it was introduced into Lake Victoria it led to the decline of *Oreochromis variabilis* and *O. esculentus* (Lowe-McConnell, 2000; Balirwa *et al*., 2003) while in Lake Kariba it was linked to the possible decline of *O. mortimeri* (Chifamba, 1998).

Of the twenty species expected in segment 2, sixteen were collected while the frequency of occurrence of the remaining four species could not be determined. The relative FAII class rating of A (unmodified) was also supported by a linear relationship between the expected and the observed species and also by the presence of intolerant species such as *O. zambezense*, *C. neumanni* and *Z. rotundiceps*. These species are habitat specialists and the loss of a preferred habitat is usually reflected by their absence. In the upper Manyame catchment, the distribution of these species has been limited due to fragmentation of the system by small dams, pollution and the impact of exotic predators (Gratwicke *et al*., 2003).

The class rating of segment 3 as largely natural (B) was largely obscured by the fact that some species expected in this segment were not collected. These included species that were either rare and less frequent (*P. catastoma, L. altivelis, L. congoro, L. molybdinus H. vittatus, S. intermedius*, *M. macrolepidotus*) or migratory (*A. bengalensis, A. mossambica, Awaous aeneofuscus* and *Glossogobius giuris*) and would otherwise need an extensive sampling period and other sampling techniques not used in this study. Nevertheless, the presence of intolerant species such as *O. zambezense* and *C. neumanni* was a reflection of a system that has not been modified. When the catchment area, proportion of bass and habitat diversity were all considered in multiple regression analysis, only catchment area was found to have a significant impact on the number of species for the three segments. This result suggests that the impact of bass and low habitat diversity (presumably due to siltation) was not high when all segments were combined in the analysis.

The FAII is based on sound ecological principles that provide an insight on the status of an assemblage in a given aquatic system as was shown in this study. Nevertheless, challenges remain in the provision of a reliable reference condition that is the basis for comparison since it is based on historical data that may not be easily available for some system. The traditional approach was the use of least impacted sections of the river mostly the upstream section. The problem with this approach is that most upstream sections may also be impacted as was observed in this study. In addition to this, most upstream sections may not reflect the assemblage composition of the whole river since species richness naturally increase from upstream to downstream and these are factors that need to be taken into consideration. In the cases where historical information on the distribution of fish species, recommendations have been made to come up with a hypothetical reference condition that usually is built on repeated sampling to produce a cumulative data set (Bozzetti and Schulz, 2004).

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