

A project funded by the United Nations Development Programme/Global Environment Facility (UNDP/GEF) and executed by the United Nations Office for Project Services (UNOPS)

**Special Study on Sediment Discharge  
and Its Consequences (SedSS)**

**Technical Report Number 9**

**IMPACTS OF SEDIMENTATION ON BIOTA**

by  
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2000

**Pollution Control and Other Measures to Protect Biodiversity in Lake  
Tanganyika (RAF/92/G32)**  
**Lutte contre la pollution et autres mesures visant à protéger la biodiversité du  
Lac Tanganyika (RAF/92/G32)**

Le Projet sur la diversité biologique du lac Tanganyika a été formulé pour aider les quatre États riverains (Burundi, Congo, Tanzanie et Zambie) à élaborer un système efficace et durable pour gérer et conserver la diversité biologique du lac Tanganyika dans un avenir prévisible. Il est financé par le GEF (Fonds pour l'environnement mondial) par le biais du Programme des Nations Unies pour le développement (PNUD)''

The Lake Tanganyika Biodiversity Project has been formulated to help the four riparian states (Burundi, Congo, Tanzania and Zambia) produce an effective and sustainable system for managing and conserving the biodiversity of Lake Tanganyika into the foreseeable future. It is funded by the Global Environmental Facility through the United Nations Development Programme.

**Burundi: Institut National pour Environnement et Conservation de la Nature**  
**D R Congo: Ministrie Environnement et Conservation de la Nature**  
**Tanzania: Vice President's Office, Division of Environment**  
**Zambia: Environmental Council of Zambia**

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## Executive Summary

1. An investigation into the relationship between the benthic fauna and patterns of sediment deposition was conducted between January 1999 and March 2000 at the southern end of Lake Tanganyika. The programme had three main components. The first was to monitor the distribution of invertebrates within the mouths of the Kalambo and Lunzua Rivers, with subsidiary data collected from the mouth of the Lufubu River. The second was a field experiment to quantify the impact of sediment deposition on an area of rocky substratum and, particularly, the impact that had on the existing fish fauna and rates of recolonisation. The third objective was the establishment of aquarium facilities to enable the measurement of invertebrate life history traits when subjected to varying sediment loads.
2. The study was done through a consultancy with the Zoology Department of Trinity College, Dublin University, Ireland in collaboration with the Royal Belgium Institute of Natural Sciences, Brussels. The work was part of the Special Studies on 'Sediment Discharge and its Consequences' which formed part of the Lake Tanganyika Biodiversity Project. The work was coordinated by Trinity College and the contract was for a period of 110 days.
3. Monthly monitoring of the mouths of the Kalambo and Lunzua, and twice-yearly (wet and dry seasons) monitoring indicated that lower abundance and taxa richness were associated with periods of greatest turbidity. Lowest numbers of both parameters were found nearest to the discharge areas of the Kalambo and Lunzua both rivers. No distinct spatial pattern was evident from the Lufubu samples. Overall, the larger invertebrates (i.e those retained in a 2000  $\mu$ m mesh sieve) showed a more distinct decline associated with high turbidity than the smaller organisms. The results obtained from the monitoring of the river mouths imply but do not prove an impact of sediment *per se* as other factors such as water flow regime and sediment structure may be implicated.
4. The field experiments showed quite clearly that increased sediment load to rocky substrata affects the composition and abundance of fish and invertebrates. Within a short time of sediment addition, sites were colonised by a number of typical sand dwelling species. Rock dwelling species appear to remain on impacted sites for several days. This may be a consequence of their territoriality that prevents moving readily

to adjacent, and probably already occupied, territories. Recolonisation rates by molluscs was slower among the sediment impacted treatments than the control sites where no sediment was added. Some quadrats retained sediment even after six months of it been laid down whereas in others and more sloping areas sediment cleared after a short period of time.

5. The contract was done through close working relationships with personnel of Zambian Fisheries laboratory at Mpulungu, Zambia. Training to conduct the type of field monitoring that comprised a main part of the field work of this contract was provided for personnel from Zambian Fisheries who formed part of the sediments and Biodiversity Special Studies. The tools for basic monitoring should therefore be in place, but we recommend that serious consideration is given to the means for establishing further basic training and for maintenance of skills that have been developed within the Fisheries laboratory.

## **Acknowledgements**

The authors would like to acknowledge the support provided by NRI (University of Greenwich), the department of Fisheries, Zambia and those individuals who have helped with all aspects of the logistics and scientific operations of the work. In particular this includes the sediments facilitator Olivier Drieu and the project administrator Clement Mwelwa. The programme was greatly helped by the support of Leonard Mwape (Chief Fisheries Officer) and collaboration of Robert Sinyinza and the sediments team of Zambian Fisheries. Rueben Shapola provided important diving skills and assistance for the field experiment. We would also thank Greame Patterson, Kelly West, Andy Menz and Ritesh Bhandari of the LTBP for their advice and support.

Further technical assistance was provided by Peter Stafford of the Department of Zoology, Trinity College.

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## **Introduction & background to the project**

Accelerating sediment input into Lake Tanganyika has been identified as a serious threat to the lake's unique and species rich ecosystem (Cohen *et al.*, 1993). In response to that threat one of the main branches of the Lake Tanganyika Biodiversity Project (LTBP) was the establishment of a Special Study on the impact of sediment. This has itself comprised a number of different activities. These have included the assessment of sediment loss within the catchment, coring of the sediment to trace historical changes in the extent and pattern of sediment deposition, the monitoring of biological communities in relation to sediment deposition and experimental work on the effect of changes in sediment load on biotic communities. The work reported here forms part of these last two areas of investigation.

Lake Tanganyika, estimated to have existed for between 9-20 Myr, contains one of the most diverse array of species of any freshwater system in the world. It is well known not only for its largely endemic fish communities but also for extensive adaptive radiation among other groups, notably the molluscs and crustaceans. The recognition of its importance as a centre for biodiversity prompted the extensive collation of information by Coulter (1991). It is also recognised that that biodiversity is under increasing threat from a range of catchment and lake activities. Probably the major threat from catchment use is an acceleration of sediment load that has arisen from increasing catchment use, particularly non-sustainable agriculture, including deforestation.

The part of the Special Study reported here included participation of personnel from the Zambian Fisheries laboratory at Mpulungu. This was part of the project's ethos to actively involve national institutions in the monitoring and research. This formed part of the wider aspirations of the project for capacity building among local institutions and personnel. The goal of this would be to enable local institutions to continue a sustainable monitoring and investigative process of the main environmental threats to the lake. Our project did not, however, include any component of formal training but was designed to develop a working relationship with Zambian Fisheries.

The contract was for a total of 110 days. It was coordinated by Dr. Kenneth Irvine of Dublin University, Zoology Department and included a collaboration with Dr. Erik Verheyen of the Royal Belgium Institute of Natural Science (RBINS). Significant assistance to the work was provided by Mr Ian Donohue of Dublin University and Dr. Martin Taylor of the RBINS. It also involved active participation with members of the Special study

team of Zambian Fisheries, supervised by Robert Sinyinza through liaison with the European scientists and with the Sediments Study Facilitator, Olivier Drieu.

## **Objectives of the project**

The project was designed to be within the general goals and Workplan of the Special Study and was divided into three distinct components. These dealt, respectively with 1) *In situ* monitoring of the biota in relation to impact of sediment characteristics and deposition 2) Investigation of increased sediment load on key taxa in a field experiment 3) Aquarium laboratory studies on increased sediment loads on survival, growth and fecundity of selected taxa.

### **Objective 1: The monitoring of invertebrates within the Lunzua, Kalambo and other (e.g. Lufubu) river mouths in relation to patterns of sediment distribution.**

This built upon work initiated by a visit to the Region by Dr. K.Irvine (Dublin University, Ireland) in September 1997 and by Dr P. Tierney in April/May 1998 under separate contracts of NRI. These visits, respectively, identified suitable study sites and initiated protocols for the monitoring of benthic invertebrates, to be implemented by Zambian Fisheries staff. This objective was to include a review of current taxonomic literature and expertise for the benthic inshore fauna of Lake Tanganyika, submitted as a separate deliverable.

### **Objective 2: Field experiment to establish recolonisation of rocky substrata following disturbance by sediment**

Possible sites and the logistics for this work were identified by K. Irvine and P. Tierney in their respective visits in September 1997 and April 1998. This work was designed to use Zambian divers, trained by the LTBP Biodiversity Special Study, and to establish experimental underwater quadrats that were either disturbed by sediment addition (treatments) or left intact (controls). The programme was designed to monitor mainly fish recolonisation rates, but also included the measurement of recolonisation by molluscs. *Eretmodus cyanostictus* collected from the sites were to be fin-clipped to provide material for molecular genetic work to investigate whether or not there is a specificity of genotypes of fish which are early recolonisers.

**Objective 3: Establishment of aquarium facilities and measurement of invertebrate life history traits when subjected to varying sediment loads.**

The work was designed to improve facilities within the Mpulungu laboratory by upgrading the aquaria facilities and provide a means for the investigation of increased sediment load on some “model”organisms.

# ZAMBIAN FIELD PROGRAMME

## Methodologies

**The monitoring of invertebrates within the Lunzua, Kalambo and Lufubu river mouths in relation to patterns of sediment distribution.**

### *Monthly monitoring of the Kalambo and Lunzua river mouths*

A monthly monitoring programme of sediment off the mouths of the Kalambo and Lunzua Rivers commenced in January 1999 and has been ongoing until March 2000. Sediment was collected using a Petite PONAR grab deployed with the winch of the *Silver Shoal*. Zooplankton were sampled by vertical hauls from 1-2m from the bottom, with a 30 cm diameter 65  $\mu$ m mesh-size net. Off the mouth of the Kalambo river, sampling locations were situated at 5, 10 and 15 m depth perpendicular to the river mouth, and at *ca.* 10 m depth approximately 0.8 km to the southeast of the river mouth. Off the mouth of the Lunzua River, sampling locations were at 5 and 10 m depth perpendicular to the river mouth (the presence of large numbers of gastropod shells precluded sample collection from 15 m depth), and at *ca.* 20 m depth about 0.5 km to the northwest of the river mouth. The later sites at each river were selected to act as control sites, where impact from sediment discharge would be likely reduced compared with the sites perpendicular to the river mouths. The control site at the mouth of the Lunzua was discontinued in August 1999 because snagging among rocks at the site caused the loss of the benthic grab, and it was considered too high a risk to continue sampling there with a replacement grab. Sampling occurred approximately at the same location on each sampling trip. The coordinates of each sampling location were verified and recorded on each sampling trip using a Garmin\_ GPS 45. Nominal positions are shown in Table 1.

**Table 1.** GPS locations for sampling stations off the mouths of the Kalambo and Lunzua Rivers.

Site	GPS location
Kalambo_ 5 m	8° 36.19' S, 31° 11.00' E
Kalambo_10 m	8° 36.40' S, 31° 11.00' E
Kalambo_15 m	8° 36.45' S, 31° 11.16' E
Kalambo_Control (10 m)	8° 36.24' S, 31° 11.36' E
Lunzua_5 m	8° 44.40' S, 31° 10.30' E
Lunzua_10 m	8° 44.20' S, 31° 10.20' E
Lunzua_Control (20 m)	8° 44.00' S, 31° 09.50' E

At each sampling location, separate samples were taken for sediment description and invertebrate enumeration. Secchi disc depth was recorded. Volume of sediment collected from each site was measured using plastic measuring cylinders in order to provide a means of estimating invertebrate densities  $\text{cm}^{-3}$ , which owing to the variation in amount of sediment collected with each grab was considered a better means of quantification than areal abundance. Sediment was separated using Endecott\_ sieves into three sediment size fraction (212-355  $\mu\text{m}$ , 355-2000  $\mu\text{m}$  and  $>2000 \mu\text{m}$ ). Fractionation occurred either on the boat or within 24 hours back in the laboratory. Depending on volume of sediment collected samples were sub-sampled a number of times using a sample splitter. Animals in subsamples were counted under a stereo dissecting microscope and placed in small collection vials containing 90% ethanol. The 212 – 355  $\mu\text{m}$  fraction was sorted live as preserved animals were difficult to locate. Animals were identified as far as possible, with further identification occurring at a later date at Dublin University. Zooplankton were preserved in excess 70% ethanol and counted in the laboratory under an inverted microscope.

On return to the laboratory, samples collected for sediment description were firstly dried by placing them in a Raven\_ scientific oven for 2 to 3 hours (depending on the sediment type) at 300°C. Sediment was then examined using a x10 magnification hand-lens, and physical characteristics such as sorting, colour and dominant mineral type noted. The sediment was then pounded prior to sieving through 2 mm and 63  $\mu\text{m}$  Endecott\_ sieves, and the mass of sediment retained in each sieve noted. Fractions were then recombined

and 20 ml 3.66% hydrochloric acid added to about a 10g subsample. Percentage calcium carbonate of the sediment was calculated according to

$$\% \text{CaCO}_3 = (W_1 - W_2)/W_1 * 100$$

where  $W_1$  is the mass of sediment prior to addition of hydrochloric acid and  $W_2$  is the mass of sediment after to acid addition. Approximating 20 g of sediment was then heated at 105°C for 2 hours, and reweighed. Percentage organic matter of the sediment was calculated by

$$\% \text{ organic matter} = (W_3 - W_4)/W_3 * 100$$

where  $W_3$  and  $W_4$  refer to the mass of sediment prior to and after reheating, respectively.

### ***Intensive sampling of Kalambo, Lunzua and Lufubu river mouths***

In addition to the routine monthly monitoring of the Kalambo and Lunzua River mouths, more intensive sampling was done in March and September 1999 in the river mouths of the Kalambo, Lunzua and Lufubu Rivers. This was designed to coincide with maximum influence of dry and wet seasons. A random stratified approach was taken to the sampling of these river mouths. Four zones of difference were identified within each river mouth for the Lunzua and Kalambo Rivers, and three for the mouth of the Lufubu River. Zones 1 and 2 were situated perpendicular to the river mouth as it entered the lake, but differed in depth. Zones 3 and 4 were present on either side of the river mouth, if topography permitted, and at depths intermediate of those of zones 1 and 2. Zone boundaries were defined using lines of longitude or latitude, depending on the orientation of the river mouth, and depth measurements. Sampling locations within each zone were chosen using random number tables, and located using a Garmin\_ GPS 45. Samples were collected with a Petite PONAR grab, and the total volume of sediment recorded after settling. Samples were then passed through a 2000  $\mu\text{m}$  and 355  $\mu\text{m}$  sieve, and the sediment retained in the sieves was then preserved for later analysis, as described above. In practice the 2000  $\mu\text{m}$  sieve retained little inorganic sediment and any animals retained could be easily extracted with a pair of forceps. Sediment less than 355  $\mu\text{m}$  in size was not retained because it was not possible for analysis of the 212 – 355  $\mu\text{m}$  fraction to be done within three days.

#### ***Kalambo River***

Intensive sampling took place on 9 March 1999 (wet season sampling) and 26 September 1999 (dry season sampling). Sampling zone boundaries and numbers of replicates collected are shown in Table 2.

**Table 2.** Boundaries of the sampling zones and number of replicate samples collected off the mouth of the Kalambo River.

<b>Zone</b>	<b>Longitudinal Boundaries (S)</b>	<b>Depth (m)</b>	<b>Number of Replicates</b>
1	31° 10.9' – 31° 11.1'	3 – 6	5
2	31° 10.9' – 31° 11.1'	8 – 11	5
3	31° 10.6' – 31° 10.8'	5 – 8	5
4	31° 11.2' – 31° 11.4'	5 - 8	5

## 2.2 Lunzua River

Intensive sampling of the Lunzua River took place on 1 March 1999 (wet season sampling) and 27 September 1999 (dry season sampling). The area of Chituta bay into which the Lunzua enters is largely homogenous according to water depth. Sampling zone boundaries and numbers of replicates collected are shown in Table 3.

**Table 3.** Boundaries of the sampling zones and number of replicate samples collected off the mouth of the Lunzua River.

<b>Zone</b>	<b>Longitudinal Boundaries (E)</b>	<b>Depth (m)</b>	<b>Number of Replicates</b>
1	31° 10.1' – 31° 10.3'	3 – 6	5
2	31° 10.1' – 31° 10.3'	8 – 11	5
3	31° 09.8' – 31° 10.0'	5 – 8	5
4	31° 10.4' – 31° 10.6'	5 - 8	5

## Lufubu River

Owing to the nature of Kasololo Bay in the area that the Lufubu River enters, sampling of the mouth of the Lufubu River took place within three sampling zones instead of four. Intensive sampling took place on 23 February 1999 (wet season sampling) and 29 September 1999 (dry season sampling). Sampling zone boundaries and number of replicates are shown in Table 4.

**Table 4.** Boundaries of the sampling zones and number of replicate samples collected off the mouth of the Lufubu River.

<b>Zone</b>	<b>Latitudinal Boundaries (S)</b>	<b>Depth (m)</b>	<b>Number of Replicates</b>
1	8° 33.41' - 8° 33.63'	1 - 4	6
2	8° 33.41' - 8° 33.63'	4 - 8	6
3	8° 33.64' - 8° 33.74'	3 - 6	6

The river enters the lake in Kasololo Bay, where a zone of high turbidity occurred in the wet season, extending to approximately 800 m from the river mouth owing to high volumes of suspended sediment from the river entering the bay. Water depth increased only gradually with increasing distance from the river mouth, hence the shallow nature of the sampling zones, relative to zones of the Kalambo and Lunzua intensive sampling. The Lufubu River itself is the largest river entering Zambian waters of the lake, and it meanders considerably before it enters the bay. The bed of the bay is extremely variable in both depth and substrate type, resulting in the collection of very differing sediment types within the zones themselves.

## Field experiment on impact of sediment on biotic communities

The first experiment was set up in April 1999 off Cholera Bay, Mbita island. The site had suitable rocky substratum for this work and was 4-10 m deep. It was considered to be less prone to disturbance from storms compared with the original suggested location off *Tanganyika Lodge*. The experiment on the effect of increased sediment load on the fish and invertebrate communities of the rocky shore *in situ* involved eight quadrats of dimensions 5m x 5m. Sediment was added to four of the quadrats and the other four were used as 'control' sites. Ninety bags of sediment (mean weight 22.5 +/- 2.0 kg) were dropped from the *R/V Silver Shoal* onto each quadrat to which sediment was to be added. This resulted in 2028.9 +/- 178.8 kg being placed onto each quadrat, which is

approximately equal to 80 kg sediment m<sup>-2</sup>. The sediment was later emptied onto the quadrat using SCUBA. Physical characteristics of each quadrat (prior to any sediment addition) are shown in Table 5.

**Table 5.** Characteristics of Quadrats used in the Field Experiment.

Quadrat	Median depth (m)	Gradient	Rugosity <sup>1</sup>
1	4	0.04	1.24
2	3	0.09	1.28
3	4.3	0.12	1.08
4	3	0.32	1.15
5	2.7	0.34	1.22
6	2.7	0.16	1.22
7	2.8	0.24	1.2
8	3.0	0.35	1.2

The monitoring of the experiment included work on fish and invertebrates (mainly molluscs). Fish were monitored by direct recording by divers prior to deposition of sediment and, subsequently, on day 2, 4, 7, 14, 21, 28 afterwards and at approximately monthly intervals thereafter for six months. Molluscs were removed from each quadrat on day 0, prior to sediment application, and again 7 days after the addition of sediment in order to compare numbers of molluscs that had returned to treated compared with control sites. In a continuation of this experiment, set up in September, two new experimental sites (7& 8) were set up as in some of the original experimental sites the sand was not spread out evenly and had shifted to lower end of the quadrat. The second experiment comprised the three original control sites plus the two new experimental sites. Sampling protocol was as for the first experiment.

<sup>1</sup> Rugosity is a measure of 'rockiness' or 'unevenness' of the lake bed. It is defined as the ratio of substratum surface length to actual straight level line length. It is measured by measuring out a straight level line of known length (*e.g.* 4 m), and then measuring the surface length of the substratum by following the orientation of the straight level line but placing the measuring tape against the substratum, following the 'unevenness' of the surface.

## **Establishment of aquaria facilities and measurement of invertebrate life history traits when subjected to varying sediment loads.**

Progress on the establishment of an aquaria facility occurred at a much slower rate than had been anticipated. The original location, that of the former aquaria in Mpulungu, was considered to be unsuitable as it was a) originally designed for large fish-keeping tanks and b) was the office of the sediment facilitator. It was decided in January 1999 that the aquaria facilities were to be set up in one of the stores at the Fisheries laboratory. This required the connection of pipe work from the lake, some minor building works and the establishment of an electrical supply. There were also delays in dispatch from Europe of a submersible pump and other equipment that hindered progress in January 1999. In January 1999 pipework was bought and old oil drums modified to be suitable as water holding tanks, No further significant progress was made with making the store suitable for an aquaria facility until the end of the year and the subsequent visit by Irvine in January 2000.

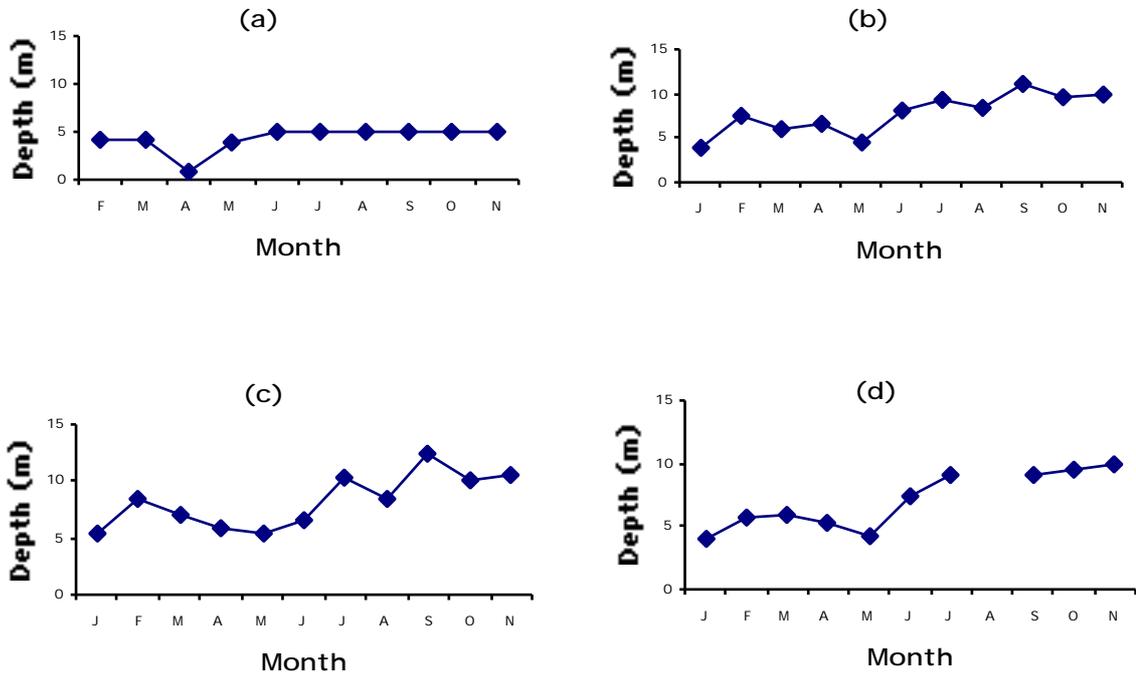
In January 2000, facilities for aquaria work in the lower storage room were installed. The system comprises a submersible pump positioned off the sediment, and housed in a metal cylinder, in about 2 m of water. The pump supplies water through plastic and then metal piping, two filters and into a header tank (converted oil drum) in the storage room. A second tank is supplied by the first tank. This provides water for aquaria work. A sturdy concrete table on which to work has been constructed and there is a supply of electricity and fluorescent lighting. A number of glass aquaria of different sizes have been made. Aeration is provided by an air pump with six outlets. The main concern with the facility is the possibility that the room can heat up during the day, which may be detrimental to live animals. The wooden door hinges have been reversed so that the doors can now open inwardly in order to allow some ventilation, while still retaining security with the outer metal grid. Some simple experiments were set up after the completion of the building work in the aquaria.

# Results

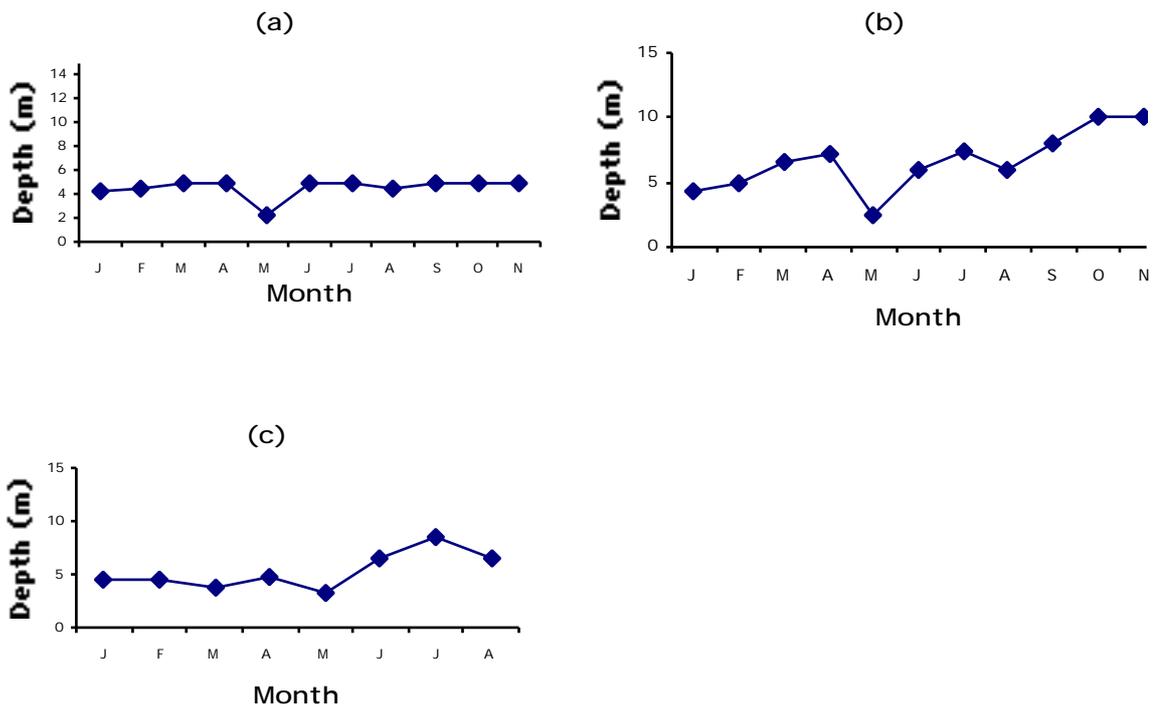
## Monthly monitoring of the Kalambo and Lunzua river mouths

### *Water transparency*

Water transparency off the mouths of both the Kalambo and Lunzua varied seasonally (Figures 1 and 2) with maximum visibility recorded during the later months of the dry season (July-September). Minimum transparency was recorded around May, not long after the end of the wet season. The time lag between the ‘peak’ of the rains (March/April) and the turbidity maxima in May reflects time for mobilisation of runoff and sediment from the catchment. The pattern of transparency among the sites were similar within each river mouth, although the transition of transparency on successive dates at the control site of the Kalambo was much smoother than those sites nearer the source of sediment deposition. Transparency was no longer recorded at the control site of the Lunzua following the loss of the first grab in August. Overall, transparency of water off the Kalambo River appeared a little greater than off the Lunzua. For most of the year depth of water transparency exceeded the maximum depth of the shallowest station.



**Figure 1.** Secchi depths recorded from (a) 5 m, (b) 10 m, (c) 15 m and (d) the ‘control’ site (10 m depth) at the Kalambo River Mouth for the period January – November 1999.

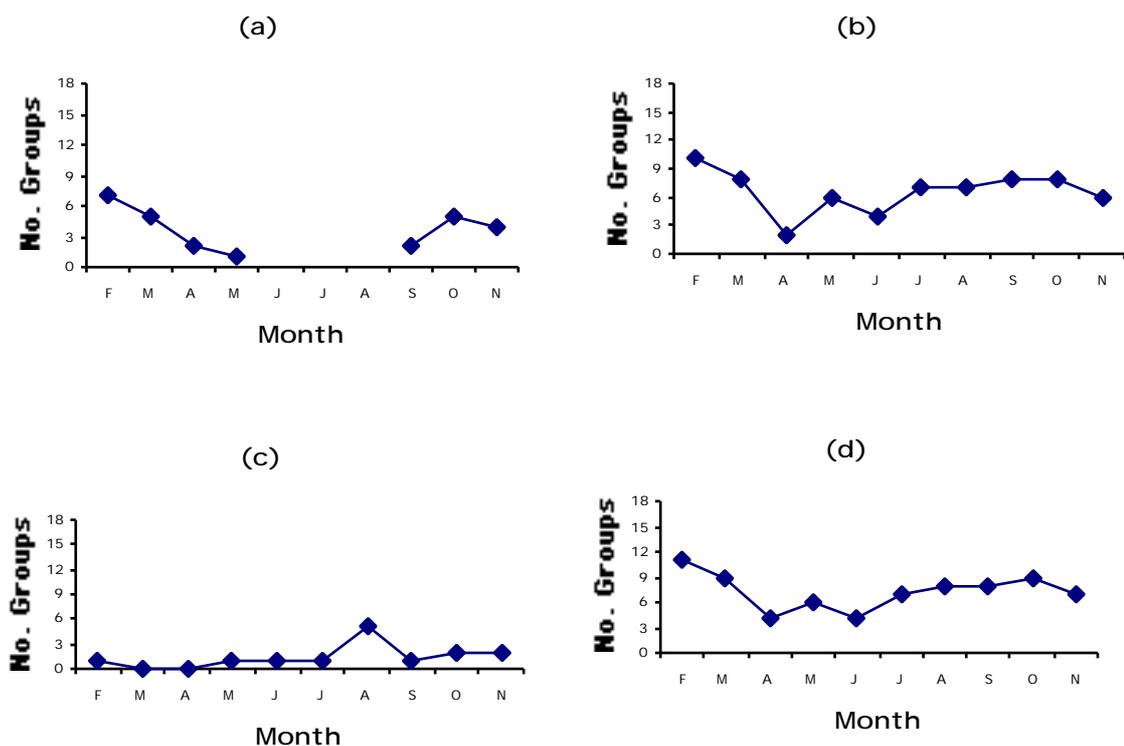


**Figure 2.** Secchi depths recorded from (a) 5 m, (b) 10 m and (c) the ‘control’ site (22 m depth) at the Lunzua River Mouth for the period January – November 1999 (January – August for the ‘control’ site).

## *Pattern of invertebrate distributions*

### *Taxa richness*

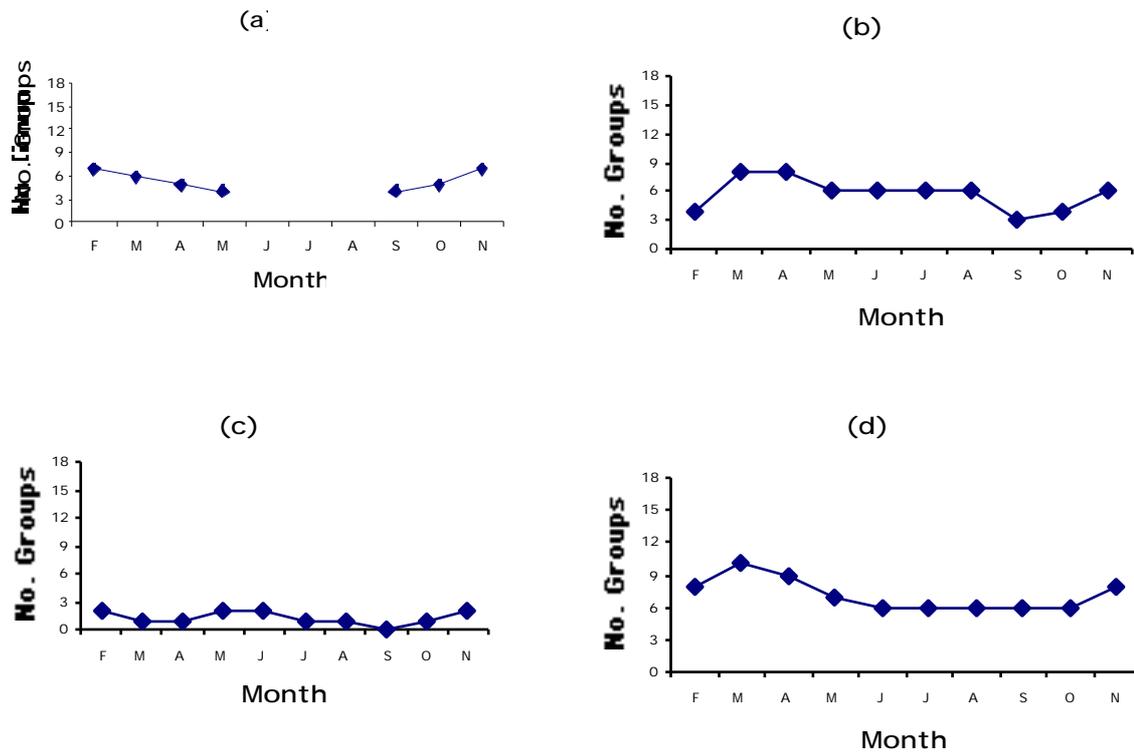
The seasonal pattern of readily identified invertebrate taxonomic groups<sup>2</sup> found within different size fractions of sediment at the routine sampling stations off the Kalambo Rivers are shown in Figures 3-6.



**Figure 3.** The number of taxonomic groups recorded from the 5 m deep station off the Kalambo River between February-November 1999 from sediment fractions of (a) 212-355  $\mu$ m, (b) 355-2000  $\mu$ m and (c) >2000  $\mu$ m. Total number of groups identified are shown in (d).

A large decrease in the number of taxonomic groups found at 5 m in April-May (Figure 3) coincided with the turbidity maxima. Overall, the lowest number of groups were found from April to June, just after the peak of the rainy season, with a notable increase again over the dry season.

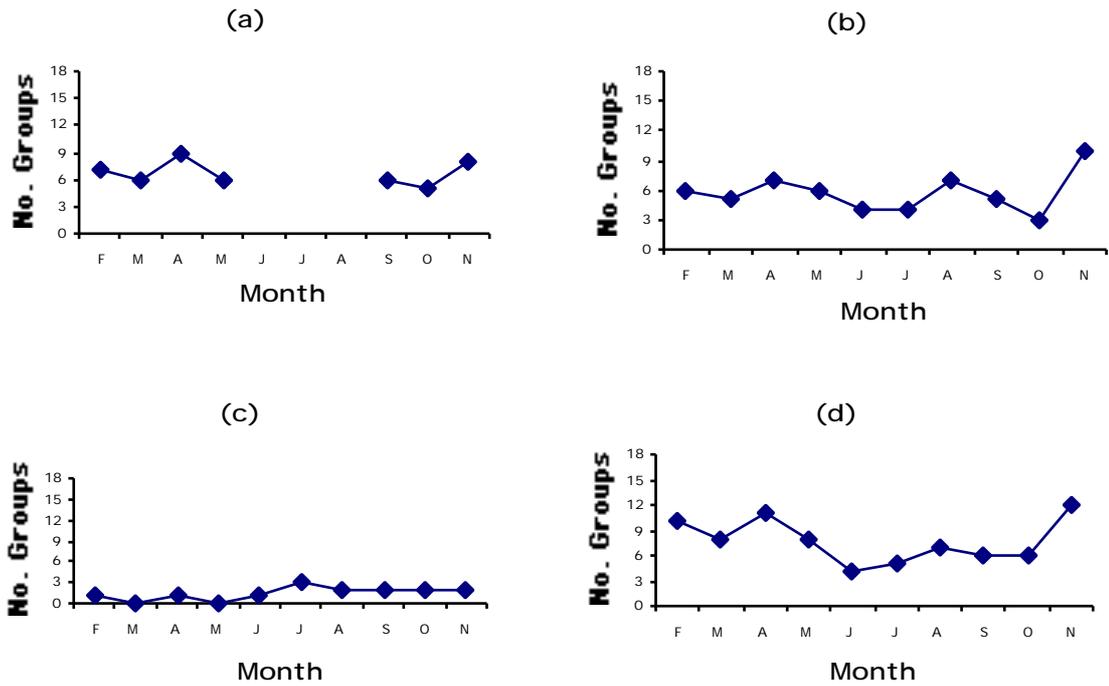
<sup>2</sup> 'Groups' are defined as higher-level taxa (the taxonomic level varies from group to group). The following groups were used: Acari, Bivalvia, Brachiura, Branchiura, Caridea, Chironomidae, Cladocera, Cnidaria, Ephemeroptera, Gastropoda, Harpactacoidae, Hemiptera, Hirudinea, Nematoda, Oligochaetae, Ostracoda, Trichoptera, Turbellaria.



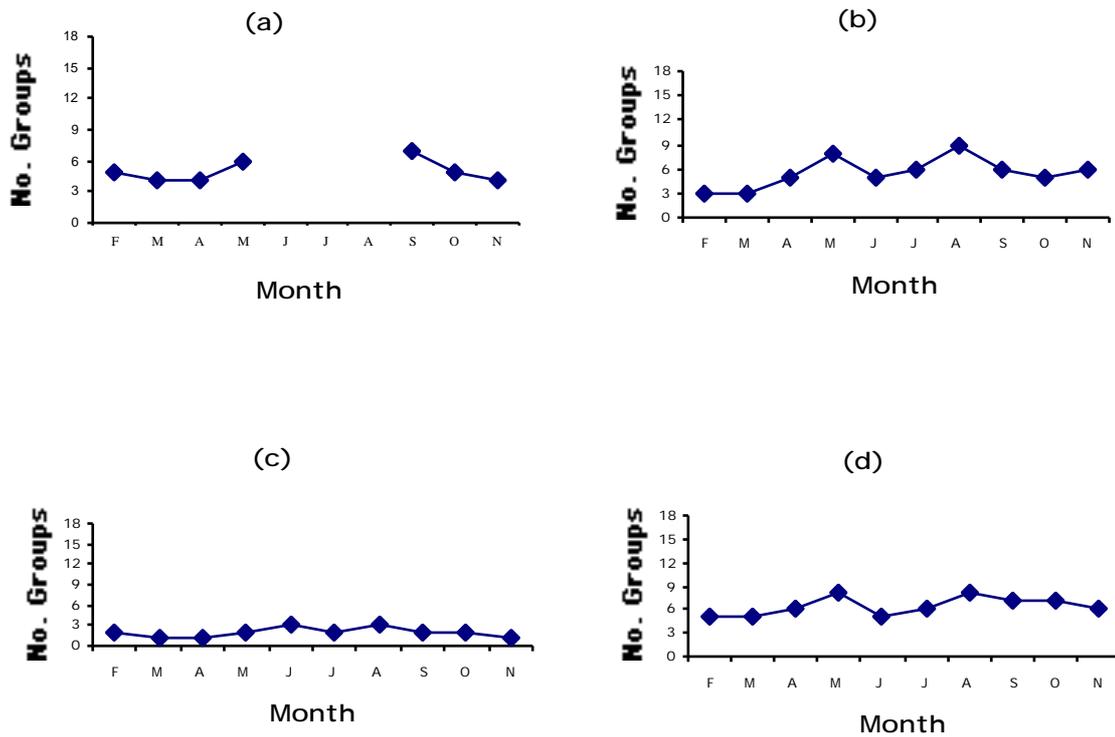
**Figure 4.** The number of taxonomic groups recorded from the 10 m deep station off the Kalambo River between February-November 1999 from sediment fractions of (a) 212-355  $\mu$ m, (b) 355-2000  $\mu$ m and (c) >2000  $\mu$ m range. Total number of groups identified are shown in (d).

In contrast to the situation at 5 m, the number of groups found off the Kalambo at 10 m depth (Figure 4) increased during the wet season and decreased over the dry season. This suggests that, compared with 5 m depth, the benthos at 10 m is less affected by the increasing sediment load that enters with water flow from the catchment. Similar trends occurred at 15 m station (Figure 5) although not as marked as at 10 m depth.

At the control site (Figure 6) maximum number of taxonomic groups were found in May and August, with quite a variable month-to-month pattern of taxa richness. There was no marked difference between the dry and the wet season. Overall, the total number of taxa groups found at the 5, 10 and 15 m sites did not differ much from that of the control site, but there was a greater extent of variability among dates, particularly at the 5 and 15 m sites.

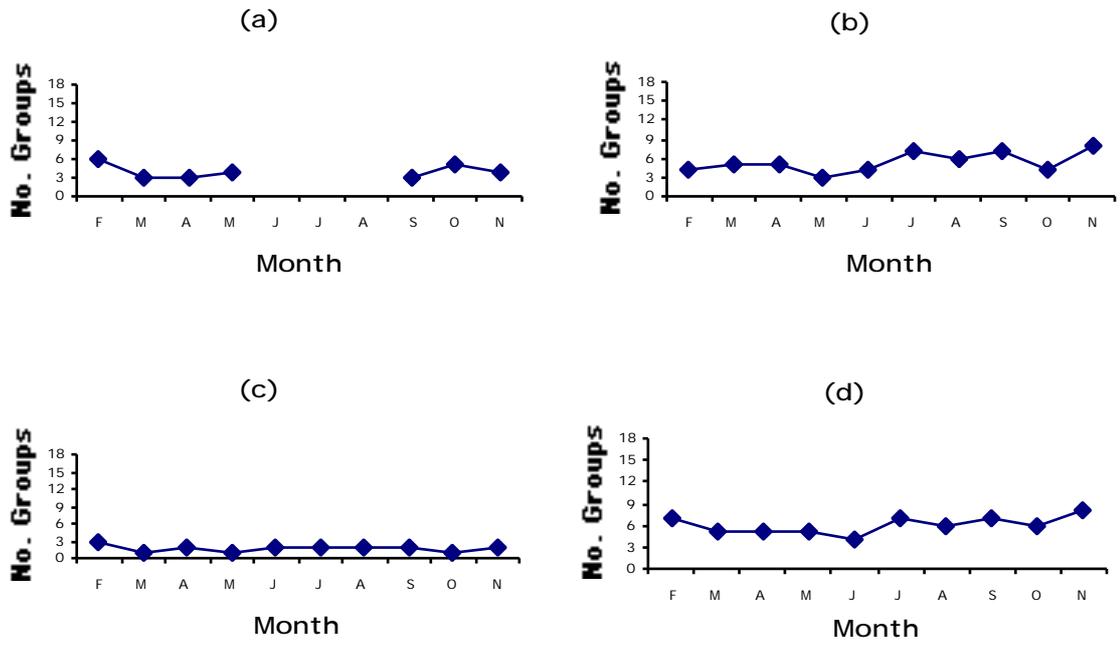


**Figure 5.** The number of taxonomic groups recorded from the 15 m deep station off the Kalambo River between February-November 1999 from sediment fractions of (a) 212-355  $\mu$ m, (b) 355-2000  $\mu$ m and (c) >2000  $\mu$ m. Total number of groups identified are shown in (d).

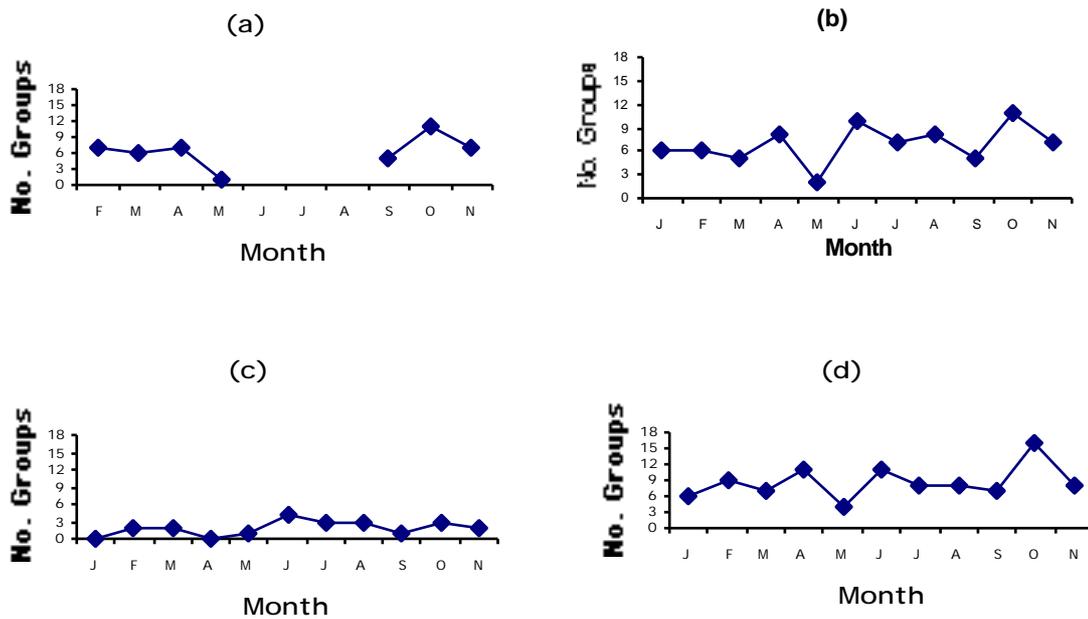


**Figure 6.** The number of taxonomic groups recorded from the control (10m deep) station off the Kalambo River between February-November 1999 from sediment fractions of (a) 212-355 m, (b) 355-2000 m and (c) >2000 m. Total number of groups identified are shown in (d).

Off the mouth of the Lunzua River the seasonal pattern of taxa richness was somewhat different from that of the Kalambo. While the pattern at the 5m deep station (Figure 7) was not as clear as the equivalent site off the Kalambo, the minimum number of groups was also found during the maximum period of turbidity, which was in May and June at this site. The lowest number of taxonomic groups at the 10 m deep station off the Lunzua also occurred during May (Figure 8), and was also concurrent with maximum turbidity. Other than the May record and the taxa maximum recorded in October, seasonal changes in the total number of groups at this site was not marked. Turbidity was high at the 10 m deep Lunzua station during most of the dry season, and it may be significant that the October maxima occurred following a decrease in turbidity. The control site off the Lunzua was only sampled from January to August, and owing to the incomplete seasonal records, the data is not shown. No discernible patterns were, however, apparent.



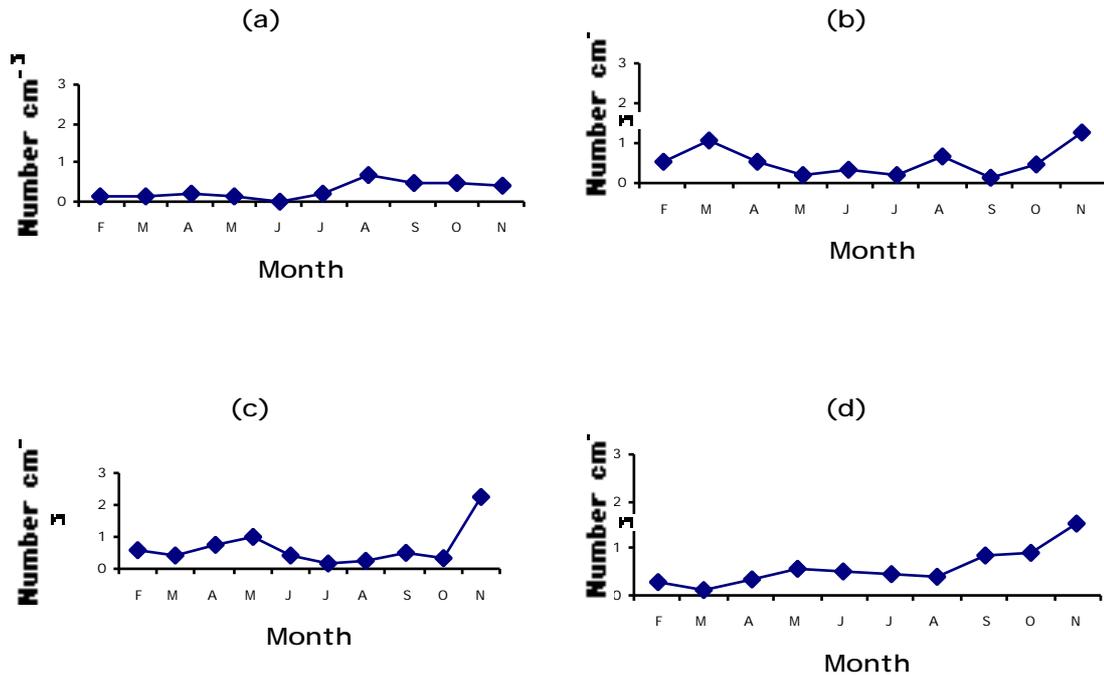
**Figure 7.** The number of taxonomic groups recorded from the 5 m deep station off the Lunzua River between February-November 1999 from sediment fractions of (a) 212-355  $\mu\text{m}$ , (b) 355-2000  $\mu\text{m}$  and (c)  $>2000 \mu\text{m}$ . Total number of groups identified are shown in (d).



**Figure 8.** The number of taxonomic groups recorded from the 10 m deep station off the Lunzua River between February-November 1999 from sediment fractions of (a) 212-355  $\mu\text{m}$ , (b) 355-2000  $\mu\text{m}$  and (c) >2000  $\mu\text{m}$ . Total number of groups identified are shown in (d).

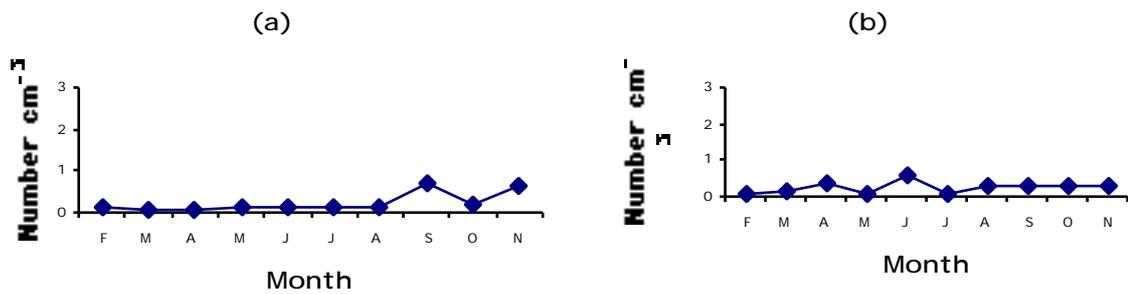
### *Abundance*

Comparisons of the abundance of invertebrates found at the different sites are presented as number of animals found in sediment fractions > 353  $\mu\text{m}$ , owing to uncertainties of accurate counts of animals from the smaller size fraction. The total number of organisms found off the Kalambo River (Figure 9) showed a similar trend to that of the number of groups. Small differences like minimum density of organisms occurring in June at the 5m deep station, whereas the period of maximum turbidity and minimum taxa richness was in May, may reflect a lag phase for the effect of turbidity or may be owing to natural variation within the data. The greater time for number of organisms to increase during the dry season at the 5m site compared with the rapid increase in number of groups likely reflects natural time delays in population increases relative to organism recolonisation. Maximum densities found at the 10 m and 15 m site coincided quite well with peaks of taxa richness found during March and November, respectively. This was not the case for the control site, where a steady increase in abundance between September and November was recorded. This coincided with a small but steady decline in taxa richness.



**Figure 9.** Mean ( $n = 2$ ) number of organisms found in sediment fraction  $>355 \mu\text{m}$  at (a) 5 m, (b) 10 m, (c) 15 m (c) and (d) at a control site (10 m depth) off the Kalambo River Mouth, February-November 1999.

Densities of benthic invertebrates off the Lunzua are shown in Figure 10. Overall, abundance was both markedly less than at the Kalambo and showed reduced seasonal variation. Maxima numbers at 5 m depth, found in September, coincided with maximum taxa richness. Maximum abundance at the 10m station was found in June at 10 m depth during a period of increasing water transparency following the May minimum. Sampling at the control site at 22 m was discontinued in August. Until that time densities were consistently enumerated at  $<0.25 \text{ cm}^{-3}$ .



**Figures 10.** Mean ( $n = 2$ ) number of organisms found in sediment fraction  $>355 \mu\text{m}$  at (a) 5 m, and (b) 10 m (b) at the Lunzua River Mouth, February-November 1999.

In general, in both the Kalambo and Lunzua River Mouths annual minima of abundance and taxa richness were associated with the wet season or periods of high turbidity or both. This was most marked with the shallower sites, although at the 10 m site at the Kalambo the maximum number of groups were found in the early part of the year, with a steady decline between February and June. The Kalambo control site showed a steady increase in abundance throughout the year. Abundance was generally lower at that site in the dry season compared with the wet. At the Lunzua, abundance was generally lower than at the Kalambo throughout all sites although the number of groups recorded throughout the year was similar off both river mouths. Overall, the results from the monthly monitoring suggests a decline in taxa richness and abundance of benthic invertebrates associated with periods of high turbidity. The results can be quite variable and, clearly the nature of the sediment of the two river mouths affect the overall abundance and species composition of invertebrates found there.

## Intensive sampling of the Kalambo, Lunzua and Lufubu River mouths

### *Kalambo*

In zone 1, that which was nearest to the river mouth, the total density of organisms found in sediment fractions  $> 355 \text{ }\mu\text{m}$  in size (Table 6), showed a significant increase in the dry season compared with the wet season (*t*-test;  $P < 0.05$ ; *d.f.* = 4). A total number of 11 tax groups were identified in the wet season and 8 in the dry. There was no significant difference (*t*-test,  $P > 0.05$ ; *d.f.* = 4) in mean total taxa richness between the two dates, although more taxa groups were found in the  $>2000 \text{ }\mu\text{m}$  sediment fraction in the dry season compared with the wet (*t*-test,  $P < 0.05$ ; *d.f.* = 4).

In Zone 2 off the Kalambo no significant differences in abundance were found between the wet (total:  $0.6 \pm 0.14 \text{ cm}^{-3}$ ;  $n = 6$ ) and the dry (total:  $0.9 \pm 0.28 \text{ cm}^{-3}$ ;  $n = 8$ ) season. Nine taxonomic groups were identified in March and 10 in September. Mean number of taxa groups per sample was  $4.4 \pm 0.93$  ( $n = 6$ ) and  $5.0 \pm 0.84$  in the wet and dry season sampling, respectively.

**Table 6.** Abundance of benthic invertebrates and number of taxa groups found in Zone 1 off the Kalambo River in March (wet) and September (dry) 1999. Only means with significant ( $P < 0.05$ ) differences between wet and dry season samples are shown.

Category	Season	Mean $\pm$ <i>s.e.</i> ( $n = 5$ )
Mean number of organisms (355 $\mu\text{m}$ – 2000 $\mu\text{m}$ ) $\text{cm}^{-3}$	Wet	$0.4 \pm 0.10$
	Dry	$0.8 \pm 0.16$
Mean number of organisms ( $>355 \text{ }\mu\text{m}$ ) $\text{cm}^{-3}$	Wet	$0.4 \pm 0.10$
	Dry	$0.9 \pm 0.17$
Mean number of groups ( $>2000 \text{ }\mu\text{m}$ ) $\text{sample}^{-1}$	Wet	$1.0 \pm 0.32$
	Dry	$2.2 \pm 0.37$

In zone 3 of the Kalambo (Table 7) there was a significant increase in the dry season compared with the wet season of density of organisms found in >355  $\mu$ m sediment (*t-test*,  $P < 0.05$ ;  $d.f. = 4$ ). The mean number density of animals found in the 355 – 2000  $\mu$ m sediment fraction was greater in the dry compared with the wet season, but at significant (*t-test*) values of  $P < 0.1 > 0.05$ . A total of 8 and 12 taxa groups were found during the intensive sampling in the wet and dry season, respectively.

**Table 7.** Abundance of benthic invertebrates and number of taxa groups found in Zone 3 off the Kalambo River in March (wet) and September (dry) 1999. Only first category is significant at  $P < 0.05$  (others  $P < 0.05 > 0.1$ ) between wet and dry season samples.

Category	Season	Mean $\pm$ s.e (n =5)
Mean number of organisms (355 $\mu$ m – 2000 $\mu$ m) cm <sup>-3</sup>	Wet	0.6 $\pm$ 0.18
	Dry	1.6 $\pm$ 0.42
Mean number of organisms (>355 $\mu$ m) cm <sup>-3</sup>	Wet	0.6 $\pm$ 0.18
	Dry	1.7 $\pm$ 0.41
Mean number groups (355 $\mu$ m – 2000 $\mu$ m) sample <sup>-1</sup>	Wet	4.6 $\pm$ 0.51
	Dry	6.2 $\pm$ 0.58

Increased differences between wet and dry season of taxa richness and invertebrate densities in the different sediment size fractions was found in Zone 4 (Table 9) compared with the other zones. Both the density of organisms found in the 355  $\mu$ m – 2000  $\mu$ m and >2000  $\mu$ m sediment fractions showed significant increases in the dry compared with the wet season (*t-tests*,  $P < 0.05$  and  $P < 0.01$ , respectively). Overall differences in densities from the two size fractions combined were significant at  $P < 0.001$ . A total of 9 taxonomic groups were found in Zone 4 during the wet season sampling and 11 groups during the dry season. Mean number of taxa groups per station was not significantly different (*t-test*;  $P > 0.05$ ;  $d.f. = 4$ ) between the two sampling dates.

**Table 8.** Abundance of benthic invertebrates and number of taxa groups found in Zone 4 off the Kalambo River in March (wet) and September (dry) 1999. Only means with significant ( $P < 0.05$ ) differences between wet and dry season samples are shown.

Category	Season	Mean $\pm$ s.e (n =5)
Mean number of organisms (355 $\mu$ m – 2000 $\mu$ m) cm <sup>-3</sup>	Wet	0.3 $\pm$ 0.06
	Dry	0.8 $\pm$ 0.08
Mean number of organisms (>2000 $\mu$ m) cm <sup>-3</sup>	Wet	0.04 $\pm$ 0.01
	Dry	0.1 $\pm$ 0.02
Mean number of organisms (>355 $\mu$ m) cm <sup>-3</sup>	Wet	0.4 $\pm$ 0.06
	Dry	0.9 $\pm$ 0.07
Mean number of groups (>2000 $\mu$ m) sample <sup>-1</sup>	Wet	1.0 $\pm$ 0.0
	Dry	2.0 $\pm$ 0.0

While higher densities were found in all four zones off the Kalambo in September compared with March, there were no marked differences in overall abundance within each zone within each sampling period. In the March samples mean abundance in all four zones from the complete sample (i.e > 353  $\mu$ m size-fraction) in all zones were very similar ranging from only 0.4-0.6 cm<sup>-3</sup>. Ranges of mean ( $\pm$  s.e; n = 5) abundance of the larger invertebrates (those retained on the 2000  $\mu$ m sieve) was 0.012  $\pm$  0.004 cm<sup>-3</sup> (zone 1) to 0.04  $\pm$  0.01 cm<sup>-3</sup> (zone 4) during March and 0.03  $\pm$  0.01 cm<sup>-3</sup> (zones 1 & 3) to 0.14  $\pm$  0.02 cm<sup>-3</sup> (zone 4) during September.

### **Lunzua**

In Zone 1 off the Lunzua River no significant differences in invertebrate abundance or taxa number were found between the intensive sampling done in March compared with September. Total mean ( $\pm$  s.e; n = 6) abundance during the wet season sampling was 0.2  $\pm$  0.07 cm<sup>-3</sup> and during the dry sampling, 0.4  $\pm$  0.45 cm<sup>-3</sup>. Mean ( $\pm$  s.e; n = 6) number of taxa groups found per sample was 5.6  $\pm$  0.4 and 5.6  $\pm$  0.8 in the wet and dry sampling, respectively. Eleven taxa groups were identified from the samples in March and 8 in September.

In Zone 2 (Table 9) the only variable that showed a statistically significant difference between the sample dates was a greater (*t-test*;  $P < 0.05$ ; *d.f.* = 4) number of taxa groups found in the > 2000  $\mu$ m sediment fraction found in March compared with September. The density of organisms in this size fraction were also higher in March compared with September, but only at a significance of  $P > 0.05 < 0.1$ . In contrast to trends noticed elsewhere from the results of the intensive sampling, overall mean density of organisms

was less in the dry compared with the wet season, although only at a significance of  $P > 0.05 < 0.1$  (*t-test*; *d.f* = 4).

**Table 9.** Abundance of benthic invertebrates and number of taxa groups found in Zone 2 off the Lunzua River in March (wet) and September (dry) 1999. Difference in mean abundance are not significant, but almost so (see text).

Category	Season	Mean $\pm$ s.e (n =5)
Mean number of organisms (355 – 2000 $\mu$ m) $\text{cm}^{-3}$	Wet	1.1 $\pm$ 0.28
	Dry	0.4 $\pm$ 0.11
Mean number of organisms (>2000 $\mu$ m) $\text{cm}^{-3}$	Wet	0.01 $\pm$ 0.01
	Dry	0.03 $\pm$ 0.01
Mean number of groups (355 – 2000 $\mu$ m) $\text{sample}^{-1}$	Wet	6.0 $\pm$ 0.55
	Dry	4.4 $\pm$ 0.51
Mean number of groups (>2000 $\mu$ m) $\text{sample}^{-1}$	Wet	0.8 $\pm$ 0.37
	Dry	1.8 $\pm$ 0.02

In zone 3 (table 10), both mean density of invertebrates and mean number of taxa found in the samples increased in the dry season relative to the wet season (*t-test*;  $P < 0.05$ ; *d.f* = 4). Nine taxa groups were identified in March and 8 in September.

**Table 10.** Abundance of benthic invertebrates and number of taxa groups found in Zone 3 off the Lunzua River in March (wet) and September (dry) 1999. Only means with significant ( $P < 0.05$ ) differences between wet and dry season samples are shown.

Category	Season	Mean $\pm$ s.e (n =5)
Mean number of organisms (355 – 2000 $\mu$ m) $\text{cm}^{-3}$	Wet	0.7 $\pm$ 0.22
	Dry	1.5 $\pm$ 0.24
Mean number of organisms (>355 $\mu$ m) $\text{cm}^{-3}$	Wet	0.7 $\pm$ 0.22
	Dry	1.5 $\pm$ 0.26
Mean number of groups (>2000 $\mu$ m) $\text{sample}^{-1}$	Wet	6.6 $\pm$ 0.68
	Dry	4.4 $\pm$ 0.24

In Zone 4 of the Lunzua there was again an increase (*t-test*;  $P < 0.05$ ; *d.f* =4) in mean density of invertebrates found in September compared with March (Table 11). Overall number of taxa groups was 7 and 12 in the March and September, respectively. Overall mean number of groups per sample (March: 5.2  $\pm$  0.58; September: 8.8  $\pm$  1.66) was significant at  $P < 0.05 > 0.1$ , although a more significant change ( $P < 0.01$ ) was observed among mean taxa groups found in the larger sediment fraction.

**Table 11.** Abundance of benthic invertebrates and number of taxa groups found in Zone 4 off the Lunzua River in March (wet season) and September (dry season) 1999. Only means with significant ( $P < 0.05$ ) differences between wet and dry season samples are shown.

Category	Season	Mean ( $\pm$ s.e; $n = 5$ )
Mean number of organisms (355 _m – 2000 _m) cm <sup>-3</sup>	Wet	0.8 $\pm$ 0.19
	Dry	2.6 $\pm$ 0.65
Mean number of organisms (>355 _m) cm <sup>-3</sup>	Wet	0.7 $\pm$ 0.19
	Dry	2.7 $\pm$ 0.66
Mean number of groups (>2 mm) sample <sup>-1</sup>	Wet	0.4 $\pm$ 0.25
	Dry	2.0 $\pm$ 0.32

Differences in abundance of invertebrates found among the four sampling zones off the Lunzua were more marked than the Kalambo. During March mean ( $\pm$  s.e;  $n = 5$ ) abundance ranged from  $0.23 \pm 0.01$  cm<sup>-3</sup> (zone 1) to  $1.1 \pm 0.29$  cm<sup>-3</sup> (zone 2). Respective mean abundance in zones 3 and 4 was  $0.7 \pm 0.22$  cm<sup>-3</sup> and  $0.7 \pm 0.19$  cm<sup>-3</sup>. In September this range had increased to  $0.39 \pm 0.45$  cm<sup>-3</sup> (zone 1) to  $2.7 \pm 0.66$  cm<sup>-3</sup> (zone 4), with zones 2 and 4 having respective means of  $0.43 \pm 0.11$  cm<sup>-3</sup> and  $1.5 \pm 0.26$  cm<sup>-3</sup>. Lower numbers were, therefore, associated with the shallower station close to the river mouth both during the wet and the dry season sampling.

## Lufubu

There were few significant differences in mean density or number of taxa groups found between the March and September samples taken off the mouth of the Lufubu River and differences among zones within both sampling periods were slight. Mean densities of animals, mean number of groups per sample and total number of groups per zone are shown in Tables 12-14 for Zone 1-3, respectively. Overall densities were greater in September compared with March. They were also lower at both times than those found off the Kalambo and generally lower than those found in Zones 2, 3 and 4 of the Lunzua.

**Table 12.** Abundance of benthic invertebrates and number of taxa groups found in Zone 1 off the Lufubu River in March (wet season) and September (dry season) 1999.

Category	Season	Mean ( $\pm$ s,e; $n = 6$ )
Mean number of organisms ( $>355 \text{ } \mu\text{m}$ ) $\text{cm}^{-3}$	Wet	$0.4 \pm 0.17^*$
	Dry	$0.6 \pm 0.20$
Mean number of Groups ( $>355 \text{ mm}$ ) $\text{sample}^{-1}$	Wet	$3.8 \pm 0.40$
	Dry	$4.5 \pm 1.38$
Total number groups	Wet	9
	Dry	12

\*  $n = 5$

**Table 13.** Abundance of benthic invertebrates and number of taxa groups found in Zone 2 off the Lufubu River in March (wet season) and September (dry season) 1999.

Category	Season	Mean ( $\pm$ s,e; $n = 6$ )
Mean number of organisms ( $>355 \text{ } \mu\text{m}$ ) $\text{cm}^{-3}$	Wet	$0.2 \pm 0.07$
	Dry	$0.5 \pm 0.22$
Mean number of Groups ( $>355 \text{ mm}$ ) $\text{sample}^{-1}$	Wet	$3.3 \pm 0.21$
	Dry	$4.2 \pm 0.79$
Total number groups	Wet	4
	Dry	10

The only statistically significant changes (*t-test*;  $P < 0.05$ ) between wet and dry seasons in the Lufubu samples related to invertebrates found in sediment  $> 2000 \text{ } \mu\text{m}$  in zone 2 and zone 3. Mean ( $\pm$  s,e;  $n = 6$ ) numbers found, respectively in zone 2 and 3, in the wet

season samples were  $0.01 \pm 0.004 \text{ cm}^{-3}$  and  $0.003 \pm 0.002 \text{ cm}^{-3}$  and in the dry season,  $0.031 \pm 0.01 \text{ cm}^{-3}$  and  $0.08 \pm 0.02 \text{ cm}^{-3}$ . In both cases, however, overall densities were small. The mean number of taxa groups increased (*t-test*;  $P < 0.01$ ) in the coarse sediment fraction in Zone 3 from  $0.7 \pm 0.33$  in the wet season samples to  $2 \pm 0.26$  in the dry season.

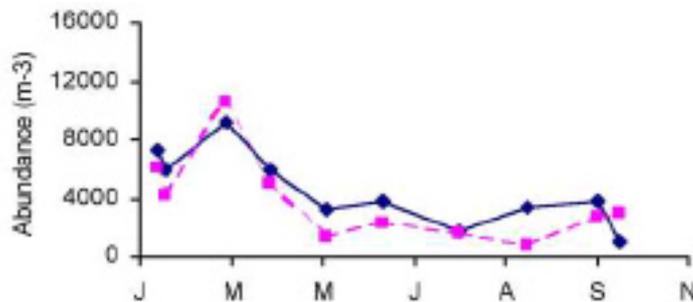
**Table 14.** Abundance of benthic invertebrates and number of taxa groups found in Zone 3 off the Lufubu River in March (wet season) and September (dry season) 1999.

Category	Season	Mean ( $\pm$ s,e; $n = 6$ )
Mean number of organisms (>355 $\mu$ m) $\text{cm}^{-3}$	Wet	$0.3 \pm 0.07$
	Dry	$0.5 \pm 0.15$
Mean number of Groups (>355 $\mu$ m) $\text{sample}^{-1}$	Wet	$3.8 \pm 0.31$
	Dry	$4.2 \pm 0.70$
Total number groups	Wet	5
	Dry	7

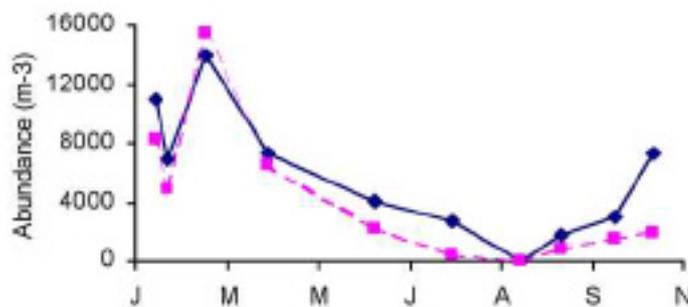
The results from the intensive monitoring of the mouths of Kalambo and Lunzua Rivers were in good agreement with those of monthly monitoring. A lower density of animals and number of taxa groups were found in March compared with September in all zones, with the exception of zone 2 of the Lunzua. The differences among different zones within any one time and river mouth were not so clear, but overall there was evidence of reduced taxa richness and animals abundance in the zone closest to river discharge in the Kalambo and Lunzua.

## Zooplankton

Zooplankton abundance found during 1999, and coinciding with sample dates for benthic invertebrates, off the Kalambo and Lunzua Rivers are shown in Figure 10 and 11, respectively. Sample numbers varied from one to three and have been pooled together to provide an assessment of seasonal variability rather than differences among sampling stations. An examination of the data, however, did not reveal any notable trends among sampling points within dates. Samples were collected from stations, 5-20 m deep.



**Figure 10.** Abundance of calanoid (continuous line) and cyclopoid (dashed line) copepods found during sampling off the mouth of the Kalambo River in 1999.



**Figure 11.** Abundance of calanoid (continuous line) and cyclopoid (dashed line) copepods found during sampling off the mouth of the Lunzua River in 1999.

Maximum abundance off both rivers was found in the early part of the year. Trends in numbers of both calanoids (*Tropodiatomus simplex*) and cyclopoid were similar, with calanoids usually the slightly more numerous of the two groups.

Off the Lufubu samples were taken much more infrequently, and usually results were available from only one sample on each sampling occasion (Table 15).

**Table 15.** Abundance (m<sup>-3</sup>) of zooplankton found off the Lufubu River during 1999.

Date	Calanoids	Cyclopoids	<i>n</i>
20/03/99	3609	2855	3
18/06/99	1206	1269	1
22/07/99	3629	1281	1
19/08/99	1122	2943	1
23/09/99	5887	2433	2
29/09/99	1384	813	2

### ***Granulometry\_Lunzua, Kalambo and Lufubu.***

While samples for sediment analysis were collected on each sampling trip from each station, the final data set represented less than this. Some data was also discarded because of difficulties with knowing from which stations they were collected. Seasonal data for the Kalambo River Mouth are shown in Tables 16-18 for the 5m, 10m, 15 m and 10m control site, respectively. The data for the Kalambo was more extensive than that of the Lunzua owing to greater number of stations sampled over the year there. In the Kalambo samples there was no overall and readily determined trend in the description and size distribution of the sediment. In all cases the sediment mainly comprised particles within the 63-2000  $\mu$ m fraction with low percentage calcium carbonate. To date no data has been provided for evaluation of organic content of the samples.

Sediment samples collected off the Lunzua River mouth (Tables 20-21), indicated a greater distribution of sediment sizes at 10 m depth than found either at the shallower station (5 m) or at all the stations sampled off the Kalambo.

**Table 16.** Granulometry data collected from the Kalambo River Mouth at 5 m depth during 1999. Sizes and CaCO<sub>3</sub> contents are expressed as %. Sorting abbreviations refer to well sorted (WS), moderately sorted (MS) and poorly sorted (PS). Shapes refer to angular (A), subrounded (SR) and rounded (R).

Date	>2mm	>63_ m <2mm	<63um	Sorting	Shape	CaCO <sub>3</sub>	Description
4 Feb	0.4	98.9	0.7	PS	A	0.2	Fine sand
9 Mar	0.1	94.4	5.4	MS	A	0	Grey gravelly sand, plant and gastropods
6 Apr	13.7	85.9	0.5	PS	A	0.2	Brown gravelly sand
3 Jun	0.5	97.1	2.3	MS	SR	1	Light brown slightly gravelly sand
15 Jul	0.2	97.3	2.5	MS	SR	0.2	Grey slightly gravelly sand
15 Jul	3.5	94.1	2.4	MS	SR	0.1	Grey slightly gravelly sand
21 Aug	1.2	98.5	0.4	MS	SR	0.1	Grey gravelly muddy sand with debris
28 Sep	0.6	98.3	1.1	MS	R	0.3	Light brown gravelly sand, gravelly with plants.
11 Oct	1.7	84.3	14.0	MS	A	0.3	Grey gravelly sand with plant debris
2 Dec	11.8	88.0	0.2	PS	A	0.2	Light brown slightly gravelly with plant debris
<b>Mean</b>	3.4	93.7	3.0			0.3	
<i>s.e.</i>	1.60	1.76	1.32			0.09	

**Table 17.** Granulometry data collected from the Kalambo River Mouth at 10 m depth during 1999. Sizes and CaCO<sub>3</sub> contents are expressed as %. Sorting abbreviations refer to well sorted (WS) and moderately sorted (MS). Shapes refer to angular (A), subangular (SA) well rounded (WR) and rounded (R).

Date	>2mm	>63_μm <2mm	<63μm	Sorting	Shape	CaCO <sub>3</sub>	Description
18 Jan	2.2	87.7	10.1	WS	A	0.1	Light Brown Gravelly muddy sand
18 Jan	0.2	85.3	13.6	MS	R	1.7	Light grey gravelly muddy sand with broken shells
4 Feb	0.3	79.0	20.7	MS	SA	0.1	Grey gravelly muddy sand with plant debris
9 Mar	3.4	90.3	6.3	MS	R	0.4	Grey gravelly sand with plant debris
6 Apr	6.8	90.7	2.5	MS	R	0.1	Grey gravelly sand
3 Jun	7.3	89.9	2.8	WS	WR	2.2	Light brown gravelly muddy sand with a few shells
21 Aug	0.9	86.7	12.47	WS	R	0.1	Grey gravelly muddy sand
11 Oct	0.8	93.0	6.17	WS	R	0.2	Grey gravelly sand with plant debris
2 Dec	4.2	92.9	2.90	MS	R	0.1	Brown pebble and gravelly
<b>Mean</b>	2.22	87.7	10.1			0.10	
<i>s.e</i>	0.83	1.58	1.97			0.24	

**Table 18.** Granulometry data collected from the Kalambo River Mouth at 15 m depth during 1999. Sizes and CaCO<sub>3</sub> contents are expressed as %. Sorting abbreviations refer to poorly sorted (PS) and moderately sorted (MS). Shapes refer to angular (A), subangular (SA), very angular (VA) and subrounded (SR).

Date	>2mm	>63_ m <2mm	<63um	Sorting	Shape	CaCO <sub>3</sub>	Description
4 Feb	6.5	74.2	19.4	MS	SA	1.2	Grey gravelly muddy sand with broken shells
9 Mar	4.8	92.6	2.7	MS	SA	1.1	Grey slightly gravelly sand with gastropods
15 Jul	1.5	96.3	2.1	MS	A	0.1	Grey slightly gravelly sand
21 Aug	8.6	84.3	7.2	MS	SA	0.05	Grey gravelly and shelly muddy sand
28 Sep	15.0	80.4	4.6	WS	VA	0.01	Light brown sand, gravelly with plant debris.
11 Oct	9.3	86.7	4.0	PS	SR	0.6	Light brown slightly gravelly with a few shells
02 Dec	5.2	89.9	5.0	MS	SR	0.2	Light brown slightly gravelly with a few shells
<b>Mean</b>	7.3	86.3	6.4			0.5	
<i>s.e</i>	1.61	2.84	2.25			0.19	

**Table 19.** Granulometry data collected from the Kalambo River Mouth at the 10 m deep Control site during 1999. Sizes and CaCO<sub>3</sub> contents are expressed as %. Sorting abbreviations refer to well sorted (WS) and moderately sorted (MS). Shapes refer to angular (A), subangular (SA) and rounded (R).

Date	>2mm	>63_ m <2mm	<63um	Sorting	Shape	CaCO <sub>3</sub>	Description
4 Feb	0.2	94.3	5.50	MS	SA	1.6	Grey gravelly sand with broken shells
9 Mar	0.4	92.3	7.3	WS	R	0.01	Grey gravelly sand with plant debris sand
6 Apr	0.1	88.4	11.6	MS	R	0.1	Grey slightly gravelly,sand.
3 Jun	0.2	97.6	2.3	WS	R	1.8	Light brown slightly gravelly sand with some plant debris
21 Aug	0.2	99.2	0.6	WS	A	0.1	Sand; grey charcoal present.
11 Oct	7.1	82.7	10.2	WS	R	0.4	Light grey slightly gravelly sand
2 Dec	1.4	97.2	1.4	MS	R	0.3	Light brown slightly gravelly sand; charcoal plants and a few shells
<b>Mean</b>	1.4	93.1	5.5			0.6	
<i>s.e</i>	0.97	2.21	1.64			0.29	

**Table 20.** Granulometry data collected from the Lunzua River Mouth at 5 m depth during 1999. Sizes and CaCO<sub>3</sub> contents are expressed as %. Sorting abbreviations refer to poorly sorted (PS), moderately sorted (MS) and well sorted (WS). Shapes refer to angular (A), rounded (R) and subrounded (SR).

Date	>2mm	>63_μm <2mm	<63μm	Sorting	Shape	CaCO <sub>3</sub>	Description
20 Jan	0.0	94.3	5.7	PS	A	0.3	Brown gravelly sand
1 Feb	0.01	91.9	8.0	MS	SR	0.21	Grey slightly gravelly sand with plant debris
8 Feb	11.1	82.9	6.0	WS	A	0.1	Grey slightly gravelly muddy sand with broken shells
1 Mar	5.0	89.2	5.8	WS	R	0.58	Grey fine gravelly muddy sand and plant debris
12 Apr	0.1	96.5	3.4	PS	A	0.2	Grey slightly gravelly, sand.
1 Jun	4.1	92.9	3.1	WS	R	0.9	Brown slightly gravelly sand
14 Jul	9.2	82.3	8.5	MS	SR	1.5	Light brown clay
20 Aug	0.7	93.6	5.7	PS	A	0.08	Brown gravelly muddy sand
27 Sep	4.9	92.4	2.7	WS	SA	0.35	Brown slightly gravelly, sand.
11 Oct	8.3	76.7	14.9	WS	SR	0.2	Brown gravelly, muddy sand.
02 Dec	1.7	94.2	4.1	MS	SR	0.2	Light brown slightly gravelly sand with few shells and plant debris.
<b>Mean</b>	4.1	89.7	6.2			0.42	
<i>s.e</i>	1.25	1.80	0.99			0.12	

**Table 21.** Granulometry data collected from the Lunzua River Mouth at 10 m depth during 1999. Sizes and CaCO<sub>3</sub> contents are expressed as %. Sorting abbreviations refer to poorly sorted (PS), moderately sorted (MS) and well sorted (WS). Shapes refer to angular (A), rounded (R) and subrounded (SR).

Date	>2mm	>63_μm <2mm	<63μm	Sorting	Shape	CaCO <sub>3</sub>	Description
8 Feb	30.6	59.3	10.2	PS	A	0.3	Grey fine sand and slightly gravelly sand
1 Mar	1.9	76.8	21.3	WS	R	0.3	Grey slightly, gravelly, muddy sand with shells
12 Apr	20.2	63.6	16.3	WS	R	1.3	Brown gravelly, muddy, sand.
1 June	50.7	47.1	2.1	MS	SR	0.9	Light brown muddy, gravelly and shells
14 Jul	0.6	99.0	0.41	MS	SR	0.1	Grey clay
20 Aug	23.3	63.0	13.66	PS	SR	0.1	Grey gravelly muddy and shelly sand
11 Oct	26.1	63.0	10.92	MS	R	0.1	Light brown/grey gravelly with few shells
2 Dec	8.0	88.6	3.42	MS	R	0.1	Light brown/grey slightly gravelly sand with few shells.
<b>Mean</b>	20.16	70.06	9.78			0.39	
<i>s.e.</i>	5.90	5.99	2.59			0.16	

## **Field experiment on impact of sediment on biotic communities**

### *Fish*

The sites from the first field experiment, numbered 1A, 1B, 2 and 3 and the control sites, numbered 4, 5 and 6 were monitored on a regular basis (Tables 22-28). Before monitoring began, the skill was established of each of the divers of the BIOSS team (Rueben Shapola, Isaac Zulu, Robert Sinyinza, Charles Lukwesa, Maybin Mwenda) to identify and count the fish species that were found on these sites. Preliminary tests showed that the observations of the divers were significantly different, both in the species observed as in the number of specimens that were counted for each species (data not shown). Therefore, the fieldwork was planned in such a way that Rueben Shapola - whose observation were deemed the most reliable – would always be one of the (for safety reasons minimum) two divers that would gather the data for the field experiment. The observations of each diver were recorded separately and combined in the final data sets. In principle the data shown are based on the observations of Rueben Shapola, only supplemented with data of his co-diver(s) in cases of rare (low numbers of particular fish species) that could be assumed not been seen by him. The purpose of this exercise was to gather reliable data and at the same time leave the other divers the time to learn how to identify and reliably count all species occurring in the study area. In practice this model varied.

During the second experiment, two new sites (numbered 7 & 8) were set up with the same amount of sediment as in the previous experiments and it was decided to continue using sites 4, 5 and 6 as controls. To evaluate the improvement of the reliability of the observations of the members of the BIOSS team, their observations were compared (data not shown). The discrepancy between the observations of Rueben Shapola and his colleagues was as different as during the initial phase of the project (see above). Therefore, we decided to continue to combine the data of the divers – with emphasis on the data set collected by Rueben Shapola. Results from these sites are shown in Tables 29-33. During the course of the two experiments 45 fish species were identified (Table 34), 42 of which belonged to the family Cichlidae

The amount of sediment applied to the experimental sites was chosen to be high enough to cover the whole 25 m<sup>2</sup> area of each site with at least 2-3 cm of sand. This approach

was taken because there was insufficient time to make trial experiments to evaluate how much sediment was actually required to perform the proposed experiment optimally. Probably as a result of our approach the amount of sand appears to have been too high to be washed away during the three-six months the experiment lasted. Indeed, it appears that rocky substrates at depths > 2.5 m will remain covered with sediment for several months. Therefore, the supposed impact of such phenomenon, if it were to occur on a grander scale, can be expected to have long-lasting consequences for local taxa adapted to rocky substrates.

The number of species on the different control sites did not vary much if one considers the important variation of the species and specimen numbers on each site. Unfortunately the data on the record sheets seem to suggest that the observations, planned to be carried out under the guidelines described above, were not always carried out as planned. Therefore it is impossible to say whether the observed variation (particularly in specimen numbers) is true or artefactual. Consequently, no statistical evaluation of the obtained results was attempted. At any rate, the control sites were usually dominated by three taxa: *Tropheus moorii*, *Lamprologus moorii* and to a lesser extent *Eretmodus cyanostictus*. Other taxa were occasionally present in high numbers and are observed to be swarms of *Ophthalmotilapia ventralis* and other Ectodini that are often seen to move around the habitats of these shallow shores.

The intensive monitoring of the species composition on the sites within the first week after the site was impacted with sediment reveals two things. First, it appears that the typical rock-dwellers do not immediately disappear from their territories. Our observations suggest that conspecifics from neighboring, unimpacted territories may have prevented or delayed them from shifting their territories. Generally, it appears that several weeks after their natural habitat was destroyed by sediment, the most typical rock-dwelling cichlids were greatly reduced in numbers, or had disappeared altogether. In contrast, it is clear that within two to 7 days after a site was covered with sediment, some sand-dwelling taxa, particularly *Lamprologus callipterus*, *Lamprologus tetracanthus*, *Telmatochromis vittatus* and *Ophthalmotilapia* species moved into the newly created sandy area, where on several occasions they were seen to start making nests and initiate breeding activities.

**Table 22.** Fish recorded at site 1\_A from first field experiment (see text for details)

Species	Day	Day	Day	Day <sup>3</sup>	Day	Day	Day	Mont	Mont	mont		
	0	+2	+4	+7	+14	+21	+28	h	h3	sand	rock	
<i>C. furcifer</i>	6	8	15	1	7	4	26	6	10	12	4	0
<i>C. horei</i>	0	2	2	0	2	0	0	0	0	0	0	0
<i>E. cyanostictus</i>	4	1	2	1	2	3	2	0	3	0	0	3
<i>E. descampsi</i>	0	4	0	0	13	0	0	0	0	0	0	0
<i>G. pfefferi</i>	1	0	0	0	0	0	1	0	0	0	0	0
<i>J. ornatus</i>	2	0	1	1	2	2	2	2	0	3	0	2
<i>J. regani</i>	0	0	0	1	0	0	3	0	0	0	0	0
<i>L. tanganycae</i>	0	0	0	0	0	0	9	0	0	0	0	0
<i>L. attenuatus</i>	0	1	0	0	0	1	0	0	0	0	0	1
<i>L. callipterus</i>	1	6	2	1	9	0	0	0	0	3	0	0
<i>L. caudopunctatus</i>	1	2	0	1	9	0	6	4	30	4	0	0
<i>L. dardenii</i>	1	0	2	1	6	4	5	2	70	11	4	0
<i>L. elongatus</i>	2	2	0	1	0	2	2	0	3	3	0	2
<i>L. labiatus</i>	1	2	2	0	1	3	3	0	0	0	0	3
<i>L. lemairi</i>	0	0	0	0	0	1	0	0	0	0	0	1
<i>L. modestus</i>	0	0	0	1	0	0	0	0	0	0	0	0
<i>L. moori</i>	10	10	0	1	1	10	0	2	0	2	0	10
<i>L. tetracanthus</i>	12	20	10	1	17	3	21	16	15	15	0	3
<i>Mastacembelus</i> <i>sp.</i>	1	0	1	1	0	0	1	0	1	0	0	0
<i>N. sexfasciatus</i>	0	0	0	0	0	2	0	0	0	0	0	2
<i>N. fasciatus</i>	0	0	0	0	0	1	0	0	0	0	0	1
<i>N. mondabu</i>	0	2	0	0	0	0	0	0	0	0	0	0
<i>N. mustax</i>	0	0	0	0	0	4	0	0	3	0	0	4
<i>O. nasuta</i>	0	0	0	1	0	0	100	0	9	7	0	0
<i>O. ventralis</i>	100	20	20	1	0	16	0	2	3	0	16	0
<i>P. microlepis</i>	5	3	2	0	0	0	4	0	6	0	0	0
<i>P. plecodus</i>	0	0	1	0	0	0	0	0	0	0	0	0
<i>P. orthognatus</i>	2	0	0	1	0	0	0	0	0	0	0	0
<i>T. dhont</i>	0	0	0	0	0	0	0	0	0	4	0	0
<i>T. bifrenatus</i>	6	2	0	1	4	2	0	0	5	0	0	2
<i>T. moorii</i>	8	0	4	1	0	6	2	0	0	0	0	6
<i>T. temporalis</i>	6	1	1	1	0	0	0	0	0	0	0	0
<i>T. vittatus</i>	1	1	0	0	0	0	0	0	0	0	0	0
<i>X. boulengeri</i>	0	1	0	0	0	0	0	0	0	0	0	0
<i>X. flavipinnis</i>	0	0	2	1	4	0	2	2	11	5	0	0
<i>X. sima</i>	3	6	2	0	0	0	0	0	0	0	0	0
<i>X. spilopterus</i>	3	15	2	1	0	10	8	0	9	5	10	0
<b>Species</b>	<b>21</b>	<b>20</b>	<b>17</b>	<b>20</b>	<b>13</b>	<b>17</b>	<b>17</b>	<b>8</b>	<b>14</b>	<b>12</b>	<b>4</b>	<b>13</b>
<b>Specimens</b>	<b>176</b>	<b>109</b>	<b>71</b>	<b>20</b>	<b>77</b>	<b>74</b>	<b>197</b>	<b>36</b>	<b>178</b>	<b>74</b>	<b>34</b>	<b>40</b>
<b>Visibility</b>	<b>ok</b>	<b>ok</b>	<b>ok</b>	<b>ok</b>	<b>very</b>	<b>mode</b>	<b>poor</b>	<b>ok</b>	<b>ok</b>		<b>fair</b>	
					<b>poor</b>	<b>rate</b>						

<sup>3</sup> Indicates that only species number and not abundance recorded.

**Table 23.** Fish recorded at site 1\_B from first field experiment (see text for details)

<b>Species</b>	<b>Day +2</b>	<b>Day +4</b>	<b>Day<sup>4</sup> +7</b>	<b>Day +14</b>	<b>Day +21</b>	<b>Day +28</b>	<b>mont h2</b>	<b>mont h3</b>	<b>mont h4</b>	<b>mont h6</b>
<i>A. calvus</i>	0	0	0	0	0	0	0	0	1	0
<i>C. melanostigma</i>	0	0	0	0	0	0	0	0	1	0
<i>C. furcifer</i>	1	20	18	10	11	12	14	10	4	6
<i>C. horei</i>	0	10	7	4	0	0	0	0	2	0
<i>E. cyanostictus</i>	1	0	11	6	13	11	7	12	18	13
<i>E. descampsi</i>	0	0	3	0	0	0	0	0	0	0
<i>G. pfefferi</i>	1	1	0	0	3	0	0	1	0	0
<i>J. ornatus</i>	1	0	1	1	1	1	0	0	4	6
<i>J. regani</i>	1	2	0	4	0	0	0	0	0	0
<i>L. attenuatus</i>	0	0	0	0	0	0	1	0	0	0
<i>L. tanganicus</i>	0	0	0	2	1	5	0	0	1	0
<i>L. callipterus</i>	1	4	0	0	0	1	0	0	0	0
<i>L. caudopunctatus</i>	1	5	5	6	10	4	16	6	0	19
<i>L. dardenii</i>	1	0	0	0	2	5	0	2	2	1
<i>L. elongatus</i>	0	1	0	0	0	0	0	0	0	0
<i>L. labiatus</i>	1	6	2	1	4	2	0	0	2	0
<i>L. lemairi</i>	1	0	0	0	1	0	0	0	0	0
<i>L. mondabu</i>	0	1	0	0	0	1	0	0	0	0
<i>L. modestus</i>	1	5	3	2	1	2	4	0	0	0
<i>L. moori</i>	1	20	25	12	20	14	13	12	14	17
<i>L. multipunctatus</i>	1	0	0	0	0	0	0	0	0	0
<i>L. tetracanthus</i>	1	18	10	9	15	9	11	10	4	11
<i>Mastacembelus</i>	0	0	0	0	0	1	0	0	1	0
<i>N. sexfasciatus</i>	0	0	0	0	0	0	0	0	1	0
<i>N. leleupi</i>	1	0	0	0	0	0	0	0	1	0
<i>N. mondabu</i>	1	0	0	0	0	0	0	0	0	0
<i>O. nasuta</i>	0	21	21	6	5	0	4	0	0	0
<i>N. fasciatus</i>	0	0	0	1	0	1	0	0	1	0
<i>N. mustax</i>	1	7	10	13	14	4	0	0	0	1
<i>O. ventralis</i>	1	15	17	2	3	100	4	2	15	2
<i>P. straleni</i>	0	0	0	2	0	0	0	0	1	0
<i>P. microlepis</i>	0	3	0	0	0	1	0	0	4	0
<i>P. orthognathus</i>	0	0	0	1	0	0	0	0	2	0
<i>P. polyodon</i>	1	0	1	1	0	0	0	0	0	0
<i>S. babauti</i>	0	0	0	0	0	0	0	0	1	0
<i>S. diagramma</i>	1	1	1	0	2	0	2	0	0	0
<i>T. vittatus</i>	0	0	0	0	0	0	0	0	0	4
<i>T. bifrenatus</i>	1	0	9	5	8	3	8	0	0	0
<i>T. dhonti</i>	0	0	1	0	0	0	0	0	0	0
<i>T. moorii</i>	1	14	11	11	9	12	8	8	10	15
<i>T. temporalis</i>	1	0	0	4	0	0	0	8	0	0
<i>X. longipinnis</i>	0	0	0	0	0	0	0	0	1	0
<i>X. flavipinnis</i>	0	0	0	0	0	0	0	0	2	0
<i>X. spilopterus</i>	1	15	4	0	2	3	0	2	1	5
<b>Species</b>	24	19	19	21	19	20	12	11	24	12
<b>Specimens</b>	24	169	160	103	125	192	92	73	94	100
<b>Visibility</b>	ok	poor	poor	poor	poor	ok	ok	ok	fair	fair

<sup>4</sup> Indicates that only species number and not abundance recorded.

**Table 24.** Fish recorded at site 2 from first field experiment; r = rock and s = sand

Species	Day	Day	Day	Day	Day	Day	Day	Day	Day	Month	Month	Month	Month	Month	Month
	-1	+2	+4	+7	+14	+21	+21	+28	+28	2	2	3	3	4	4
						r	s	r	s	r	s	r	s	r	s
<i>C. furcifer</i>	10	5	4	17	24	9	0	4	0	0	3	0	0	0	7
<i>E. cyanostictus</i>	10	8	5	7	12	0	4	8	0	8	0	8	0	2	0
<i>A. compressiceps</i>	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
<i>G. pfefferi</i>	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0
<i>J. ornatus</i>	2	2	0	0	1	0	0	0	2	0	0	1	0	2	0
<i>J. regani</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>L. tanganicae</i>	0	0	0	0	6	6	0	0	0	0	0	0	0	2	0
<i>L. callipterus</i>	0	30	3	0	0	0	1	0	0	0	0	0	0	0	0
<i>L. caudopunctatus</i>	10	10	0	0	3	0	2	6	0	0	5	6	0	0	6
<i>L. elongatus</i>	1	2	0	0	5	0	0	0	0	0	0	0	0	0	0
<i>L. fasciatus</i>	1	0	0	0	0	0	0	1	0	1	0	1	0	0	0
<i>L. Labiatus</i>	4	0	4	0	4	0	2	0	0	0	0	0	0	0	0
<i>L. lemairi</i>	2	1	2	0	2	0	0	0	0	2	0	1	0	0	0
<i>L. moori</i>	20	12	18	32	34	16	0	10	2	10	0	4	0	7	0
<i>L. multipunctatus</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>L. attenuatus</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
<i>L. tetracanthus</i>	2	2	2	19	8	0	12	0	8	0	7	0	2	0	2
<i>Mastacembelus</i>	0	0	0	0	0	1	1	0	0	0	1	0	0	0	0
<i>N. mustax</i>	0	0	6	13	13	0	8	0	0	4	0	0	0	6	0
<i>O. ventralis</i>	20	24	10	26	12	105	0	30	0	0	0	0	0	0	60
<i>O. nasuta</i>	0	0	0	22	24	30	0	0	0	20	0	0	0	0	0
<i>P. microlepis</i>	0	2	0	3	2	0	0	0	0	0	0	0	0	2	0
<i>P. orthognatus</i>	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
<i>P. straeleni</i>	1	0	0	0	0	0	3	1	0	0	0	0	0	0	0
<i>S. diagramma</i>	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
<i>S. sp</i>	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>T. bifrenatus</i>	4	4	0	7	3	0	4	2	0	0	0	0	0	0	0
<i>T. dhondti</i>	1	0	0	0	2	0	2	0	0	0	0	0	0	0	0
<i>T. moorii</i>	24	12	6	32	23	17	0	10	0	7	0	6	0	6	0
<i>T. temporalis</i>	6	0	0	7	0	0	0	0	0	0	0	0	0	0	0
<i>T. vittatus</i>	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0
<i>X. sima</i>	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
<b>Species</b>	18	15	12	12	19	6	10	10	3	8	3	8	1	9	4
<b>Specimens</b>	120	117	62	187	181	183	39	73	12	53	15	28	2	29	75
<b>Visibility</b>	ok	ok	ok	poor	fair	poor		poor		ok		ok		fair	

**Table 25.** Fish recorded at site 3 from first field experiment; r = rock and s = sand; na:

Species	Day -1	Day +2	Day +4	Day +7	Day +14 r	Day +14 s	Day +21 r	Day +21 s	Day +28 r	Day +28 s	Mon 2 r	Mon 2 s	Mon 3 r	Mon 3 s	Mon 4 r	Mon 4 s
<i>C. furcifer</i>	0	4	5	7	9	0	2	0	0	4	0	0	0	0	0	4
<i>C. horei</i>	0	1	0	1	1	0	0	0	0	0	3	0	4	0	2	0
<i>E. cyanostictus</i>	20	5	9	15	15	5	5	3	8	0	10	0	6	0	21	0
<i>G. pfefferi</i>	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>J. ornatus</i>	2	4	0	3	0	0	0	0	0	0	0	0	2	0	4	0
<i>J. regani</i>	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>L. callipterus</i>	4	2	12	11	2	0	0	1	0	0	7	0	0	0	0	4
<i>L. attenuatus</i>	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0
<i>A. calvus</i>	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
<i>L. caudopunctatus</i>	14	27	8	18	24	0	0	15	10	0	0	0	0	3	0	1
<i>L. dardenii</i>	1	0	0	7	0	0	0	0	0	2	0	0	0	0	2	0
<i>L. elongatus</i>	2	2	0	1	0	0	0	0	0	1	0	0	0	0	0	0
<i>L. fasciatus</i>	3	2	7	4	2	0	0	0	0	2	0	0	0	0	1	0
<i>L. labiatus</i>	3	4	2	4	2	0	0	0	1	0	8	0	4	0	4	0
<i>L. lemairi</i>	4	1	0	0	0	0	2	0	0	1	0	0	0	0	0	0
<i>L. moori</i>	20	8	0	15	11	0	26	4	16	0	0	11	6	0	8	0
<i>L. multipunctatus</i>	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>L. niger</i>	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>L. sexfasciatus</i>	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>L. tanganicæ</i>	0	0	0	0	3	13	0	0	0	0	3	0	0	0	0	0
<i>L. tetracanthus</i>	6	7	0	9	11	0	0	8	0	8	0	9	0	6	0	4
<i>Mastacembelus</i>	1	1	1	0	2	0	0	0	0	0	0	0	2	0	0	0
<i>N. fasciatus</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
<i>N. mustax</i>	6	0	0	18	26	0	15	4	0	0	5	0	0	0	0	0
<i>O. nasuta</i>	0	0	50	16	26	0	0	0	0	0	0	0	0	0	0	0
<i>O. ventralis</i>	22	40	3	0	41	0	50	0	8	0	0	0	0	200	0	20
<i>P. microlepis</i>	2	2	3	2	2	0	0	0	0	0	0	0	0	0	6	0
<i>P. orthognatus</i>	1	0	4	0	0	0	0	0	0	0	0	7	1	0	0	0
<i>P. sp</i>	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>P. straeleni</i>	1	0	0	4	1	0	2	0	0	0	0	0	0	0	0	0
<i>S. babauti</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
<i>S. diagramma</i>	0	0	0	1	2	0	1	0	0	0	11	0	2	0	0	0
<i>S. sp</i>	10	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>T. bifrenatus</i>	0	4	7	7	1	1	4	2	1	0	0	0	4	0	2	0
<i>T. dhondti</i>	0	0	0	2	0	0	0	0	0	0	0	0	0	0	1	0
<i>T. moorii</i>	10	13	7	18	23	0	16	3	16	0	12	0	10	0	20	0
<i>T. temporalis</i>	6	1	0	5	1	1	0	0	0	0	0	0	1	0	1	0
<i>T. vittatus</i>	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>X. spilopterus</i>	3	0	12	0	0	0	0	0	0	0	0	0	0	0	0	0
<b>Species</b>	24	20	18	21	21	4	10	8	7	6	8	4	11	3	15	5
<b>Specimens</b>	144	127	154	161	197	20	121	40	60	14	59	28	42	209	75	29
<b>Visibility</b>	ok	ok	ok	poor	fair		very poor		poor		ok		ok		fair	

**Table 26.** Fish recorded at site 4 (Control) from first field experiment.

	Day +1	Day +2	Day +7	Day +14	Day +21	Day +28	Mon 2	Mon 3	Mon 4
<i>C. furcifer</i>	1	28	17	0	25	2	0	2	0
<i>C. horei</i>	0	0	0	0	0	0	0	0	4
<i>E. cyanostictus</i>	1	9	15	13	8	4	7	0	4
<i>G. pfefferi</i>	1	2	0	0	2	0	0	0	0
<i>J. ornatus</i>	1	7	6	2	2	0	0	0	2
<i>J. regani</i>	1	0	0	4	0	0	0	0	0
<i>L. tanganicus</i>	0	0	0	0	6	2	0	0	0
<i>L. callipterus</i>	0	0	2	0	0	0	0	0	0
<i>L. caudopunctatus</i>	0	0	0	0	0	14	0	6	0
<i>L. dardenii</i>	0	0	0	0	0	20	0	0	7
<i>L. elongatus</i>	0	1	0	0	0	0	0	0	0
<i>L. fasciatus</i>	1	3	1	0	2	1	2	0	2
<i>L. labiatus</i>	1	4	5	4	2	2	2	0	3
<i>L. moori</i>	1	23	28	22	18	12	9	6	16
<i>L. multipunctatus</i>	0	0	1	0	0	0	0	0	0
<i>Mastacembelus</i>	0	0	0	0	1	0	0	0	0
<i>N. mondabu</i>	0	0	0	0	0	0	0	0	0
<i>N. mustax</i>	1	19	22	25	11	0	5	0	0
<i>O. nasuta</i>	1	25	22	2	12	0	0	0	0
<i>O. ventralis</i>	1	12	15	2	23	6	6	1	13
<i>P. microlepis</i>	0	4	2	0	2	0	1	0	0
<i>P. orthognatus</i>	1	0	0	0	0	6	3	0	0
<i>P. polyodon</i>	1	3	1	0	0	0	2	0	0
<i>P. straeleni</i>	0	1	0	0	0	1	0	1	0
<i>S. diagramma</i>	1	4	3	0	2	0	0	0	0
<i>S. sp</i>	1	0	0	0	0	0	0	0	0
<i>T. bifrenatus</i>	1	0	3	9	3	6	0	8	0
<i>T. dhondti</i>	0	3	2	0	0	0	0	0	0
<i>T. irsacae</i>	1	0	0	0	0	0	0	0	0
<i>T. moorii</i>	1	22	35	22	12	6	19	4	12
<i>T. temporalis</i>	1	7	8	0	0	0	0	0	0
<b>Species</b>	19	18	18	10	16	13	10	7	9
<b>Specimens</b>	19	177	188	105	131	82	56	28	63
<b>Visibility</b>	ok	ok	very poor	very poor	poor	fairly good	ok	ok	fair

**Table 27.** Fish recorded at site 5 (Control) from first field experiment

	Day +1	Day +2	Day +4	Day +7	Day +14	Day +21	Day +28	Mon 2	Mon 3	Mon 4
<i>A. calvus</i>	0	0	0	1	1	1	1	0	0	0
<i>C. furcifer</i>	20	12	5	2	19	6	6	5	1	5
<i>C. horei</i>	0	0	2	1	0	0	0	0	2	0
<i>E. cyanostictus</i>	9	13	6	10	18	0	2	11	12	11
<i>G. pfefferi</i>	6	0	0	0	0	1	1	1	0	3
<i>J. ornatus</i>	4	2	2	5	2	4	1	3	3	5
<i>J. regani</i>	8	0	2	0	1	0	0	0	0	0
<i>L. faoe</i>	0	0	0	0	0	1	0	0	0	0
<i>L. mariae</i>	0	0	0	0	0	0	1	1	0	0
<i>L. tanganicus</i>	0	0	0	0	18	0	2	4	0	0
<i>L. callipterus</i>	16	11	7	4	0	0	0	0	0	0
<i>L. caudopunctatus</i>	15	8	16	1	6	10	0	0	11	0
<i>L. dardenii</i>	0	11	0	0	0	0	7	0	0	0
<i>L. elongatus</i>	0	6	0	0	1	0	0	0	0	0
<i>L. fasciatus</i>	6	5	4	0	2	2	0	4	2	2
<i>L. labiatus</i>	7	3	2	0	0	1	2	2	0	8
<i>L. lemairi</i>	5	3	0	0	0	0	2	0	0	0
<i>L. modestus</i>	0	0	2	2	0	0	0	0	0	0
<i>L. moori</i>	20	30	21	26	18	16	14	17	12	14
<i>L. tetracanthus</i>	24	0	10	4	8	12	4	9	5	13
<i>Mastacembelus</i>	0	0	0	2	0	0	0	0	0	1
<i>N. mustax</i>	21	10	20	24	20	0	6	14	11	11
<i>O. nasuta</i>	14	12	10	0	0	0	0	7	5	7
<i>O. ventralis</i>	12	10	9	0	0	0	4	6	2	12
<i>P. paradoxus</i>	0	0	0	0	0	0	1	0	0	0
<i>P. microlepis</i>	0	6	6	0	1	0	0	4	0	0
<i>P. orthognatus</i>	8	2	0	0	0	4	2	0	3	4
<i>P. plecodus</i>	2	0	0	0	0	0	0	0	0	0
<i>P. straeleni</i>	0	0	2	0	1	1	0	0	0	0
<i>P. polyodon</i>	0	0	0	2	0	0	0	1	0	0
<i>S. diagramma</i>	3	3	2	0	2	0	0	3	2	5
<i>T. bifrenatus</i>	7	3	2	3	0	2	1	7	0	0
<i>T. dhonti</i>	0	2	3	0	0	0	0	0	0	0
<i>T. irsacae</i>	0	0	0	0	0	0	3	0	0	0
<i>T. moorii</i>	6	17	17	17	12	6	7	15	14	19
<i>T. temporalis</i>	15	0	2	0	0	0	0	0	0	0
<i>T. vittatus</i>	0	0	0	0	0	0	0	0	3	0
<i>X. spilopterus</i>	0	0	0	0	0	0	0	1	0	0
<b>Species</b>	21	20	22	15	16	13	20	19	15	15
<b>Specimens</b>	228	169	152	103	129	65	67	115	88	120
<b>Visibility</b>	ok	ok	very poor	very poor	fair	poor	good	ok	ok	fair

**Table 28.** Fish recorded at site 6 (Control) from first field experiment

<b>Species</b>	<b>Day +1</b>	<b>Day +4</b>	<b>Day +7</b>	<b>Day +14</b>	<b>Day +21</b>	<b>Day +28</b>	<b>Mon 2</b>	<b>Mon 3</b>	<b>Mon 4</b>	<b>Mon 6</b>
<i>C. furcifer</i>	13	8	19	7	0	15	8	0	3	1
<i>C. horei</i>	0	2	0	0	0	3	2	0	0	0
<i>E. cyanostictus</i>	10	14	14	19	4	12	13	7	23	10
<i>H. microlepis</i>	40	0	0	0	0	0	0	0	0	0
<i>E. descampsi</i>	3	0	0	0	0	0	0	0	0	0
<i>G. pfefferi</i>	0	0	0	0	0	2	0	0	0	1
<i>J. ornatus</i>	0	3	4	5	2	2	0	2	0	1
<i>J. regani</i>	2	0	0	0	0	0	0	0	0	0
<i>L. tanganicus</i>	0	0	0	6	0	5	3	1	2	0
<i>L. attenuatus</i>	0	0	0	0	0	0	0	0	0	0
<i>L. callipterus</i>	14	5	3	0	0	0	0	0	0	0
<i>L. caudopunctatus</i>	0	2	2	4	8	0	0	0	2	5
<i>L. dardenii</i>	0	0	3	0	0	10	11	1	0	8
<i>L. elongatus</i>	3	3	5	1	1	0	2	2	0	0
<i>L. fasciatus</i>	9	4	5	0	4	1	2	0	5	41
<i>L. labiatus</i>	5	3	4	0	0	2	2	0	7	3
<i>L. lemairi</i>	0	0	0	1	0	3	3	0	0	0
<i>L. modestus</i>	0	0	0	0	0	2	0	0	0	0
<i>L. moori</i>	25	32	20	8	12	25	31	17	26	11
<i>L. multipunctatus</i>	0	0	0	0	1	0	0	0	0	0
<i>L. tetracanthus</i>	2	2	9	9	4	4	6	9	9	9
<i>Mastacembelus</i>	0	0	0	0	1	0	0	0	0	0
<i>N. tretocephalus</i>	0	1	1	1	0	0	0	0	0	0
<i>L. mustax</i>	15	17	21	16	0	17	15	9	17	5
<i>O. nasuta</i>	17	14	31	17	0	0	0	8	0	0
<i>O. ventralis</i>	14	17	32	1	4	20	2	1	10	4
<i>P. paradoxus</i>	0	0	0	0	0	0	0	0	0	1
<i>P. microlepis</i>	0	0	2	3	0	0	5	0	0	0
<i>P. orthognatus</i>	3	0	1	0	0	5	0	5	4	0
<i>P. straeleni</i>	1	0	0	0	0	5	0	0	0	0
<i>P. polyodon</i>	5	1	3	0	0	0	4	0	0	0
<i>S. diagramma</i>	4	3	4	1	0	3	2	2	4	0
<i>T. dhonti</i>	0	0	0	0	0	0	0	0	1	0
<i>T. bifrenatus</i>	5	2	8	2	2	3	3	0	0	0
<i>T. moorii</i>	25	17	27	9	10	13	19	24	26	30
<i>T. irsacae</i>	0	0	0	0	0	0	0	0	0	1
<i>T. temporalis</i>	3	0	0	0	0	0	0	0	0	0
<i>X. vittatus</i>	0	0	0	0	0	0	0	3	2	0
<i>X. spilopterus</i>	2	0	3	0	0	0	3	0	2	4
<b>Species</b>	22	19	22	17	12	20	19	14	16	16
<b>Specimens</b>	220	150	221	110	53	152	136	91	143	135
<b>Visibility</b>	ok	poor	fair	poor	poor	good	ok	ok	fair	fair

**Table 29.** Fish recorded at site 4 (Control) from second field experiment

<b>Species</b>	<b>Day 0</b>	<b>Day +2</b>	<b>Day +5</b>	<b>Day +12</b>	<b>Day +18</b>	<b>Day +25</b>	<b>Month +2</b>	<b>Month +3</b>
<i>C. furcifer</i>	4	0	0	1	0	0	0	2
<i>C. horei</i>	0	0	1	0	0	4	1	0
<i>E. cyanostictus</i>	17	6	12	16	20	14	6	6
<i>E. descampsi</i>	0	0	0	0	0	0	0	0
<i>G. pfefferi</i>	0	0	0	0	0	2	0	0
<i>J. ornatus</i>	4	12	2	3	2	4	0	2
<i>J. regani</i>	0	0	0	0	0	0	0	0
<i>L. tanganycae</i>	6	0	2	1	6	10	2	0
<i>L. attenuatus</i>	0	0	0	0	0	0	0	6
<i>L. callipterus</i>	0	2	0	0	2	0	0	2
<i>L. caudopunctatus</i>	2	3	4	0	4	4	2	0
<i>L. dardenii</i>	0	0	1	0	0	0	0	0
<i>L. elongatus</i>	0	0	2	0	0	0	0	2
<i>L. labiatus</i>	4	5	4	1	2	4	3	2
<i>L. modestus</i>	0	0	1	0	2	2	0	0
<i>L. moori</i>	23	22	18	27	20	22	0	18
<i>L. multipunctatus</i>	1	0	1	0	0	2	16	0
<i>L. tetracanthus</i>	0	2	2	0	0	0	0	0
<i>Mastacembelus</i>	0	0	1	0	2	0	0	1
<i>N. sexfasciatus</i>	0	0	1	0	0	0	0	0
<i>N. fasciatus</i>	1	1	3	3	2	2	3	2
<i>N. mustax</i>	6	0	0	4	0	0	0	0
<i>C. nasuta</i>	0	0	0	0	0	0	0	0
<i>C. ventralis</i>	5	5	20	0	4	10	0	6
<i>F. microlepis</i>	2	2	0	0	1	2	1	2
<i>F. straeleni</i>	2	0	1	2	0	0	0	0
<i>F. orthognatus</i>	2	2	0	0	2	0	0	0
<i>F. fumula</i>	0	0	1	0	0	0	0	0
<i>F. polyodon</i>	0	0	4	0	0	0	0	0
<i>S. diagramma</i>	2	0	0	1	0	0	0	2
<i>T. bifrenatus</i>	6	0	0	1	0	0	0	0
<i>T. moorii</i>	23	23	20	19	18	14	16	8
<i>T. temporalis</i>	0	2	1	0	0	0	0	2
<i>T. vittatus</i>	4	4	1	0	6	4	3	2
<i>X. spilopterus</i>	0	2	0	0	0	0	0	0
<i>A.compressiceps</i>	1	0	1	0	0	2	0	0
<i>Clarias spp</i>	0	0	0	0	0	1	0	0
<b>Species</b>	19	15	23	12	15	17	10	16
<b>Specimens</b>	115	93	104	79	93	103	53	65
<b>Visibility</b>	fair	fair	good	fair	fair	good	very poor	good

**Table 30.** Fish recorded at site 5 (Control) from second field experiment

<b>Species</b>	<b>Day 0</b>	<b>Day +2</b>	<b>Day +5</b>	<b>Day +12</b>	<b>Day +19</b>	<b>Day +26</b>	<b>Mont h 2</b>	<b>Mont h 3</b>
<i>C. furcifer</i>	1	4	4	1	3	0	0	0
<i>C. horei</i>	2	0	2	3	1	0	0	0
<i>E. cyanostictus</i>	21	23	25	16	18	12	12	6
<i>J. ornatus</i>	4	3	2	2	1	3	4	2
<i>L. tanganicae</i>	4	2	6	1	2	4	0	0
<i>L. attenuatus</i>	0	0	0	0	0	0	0	4
<i>L. callipterus</i>	0	0	0	0	1	4	0	0
<i>L. caudopunctatus</i>	1	1	0	0	2	2	4	24
<i>L. dardenii</i>	7	4	3	0	1	16	0	0
<i>L. elongatus</i>	0	0	1	0	3	4	2	6
<i>L. labiatus</i>	6	3	3	2	3	4	7	1
<i>L. lemairi</i>	0	0	1	1	1	0	0	0
<i>L. moori</i>	38	34	32	23	31	24	26	40
<i>L. multipunctatus</i>	0	0	0	0	0	2	0	0
<i>L. tetracanthus</i>	3	0	2	0	4	6	5	6
<i>Mastacembelus</i>	0	0	0	0	0	0	0	2
<i>N. sexfasciatus</i>	0	1	0	0	0	0	0	0
<i>N. fasciatus</i>	0	3	3	0	1	3	6	4
<i>N. mondabu</i>	2	0	0	0	0	0	0	0
<i>N. mustax</i>	4	5	3	3	2	0	0	0
<i>C. ventralis</i>	2	2	6	0	5	6	52	10
<i>P. straeleni</i>	1	0	1	0	0	0	0	1
<i>P. microlepis</i>	0	2	2	0	1	2	3	0
<i>P. orthognatus</i>	1	3	3	4	0	0	6	2
<i>S. diagramma</i>	0	2	4	2	2	0	1	0
<i>T. bifrenatus</i>	2	0	3	0	3	0	0	0
<i>T. moorii</i>	17	18	23	22	23	18	7	10
<i>T. temporalis</i>	0	0	0	0	0	0	0	0
<i>T. vittatus</i>	2	0	0	2	0	4	8	0
<i>X. spilopterus</i>	0	2	1	0	0	0	2	2
<i>A. compressiceps</i>	0	0	0	0	0	0	0	1
<b>Species</b>	18	17	21	13	20	16	15	16
<b>Specimens</b>	118	112	130	82	108	114	145	121
<b>Visability</b>	poor	fair	good	fair	fair	good	very poor	good

**Table 31.** Fish recorded at site 6 (Control) from second field experiment

<b>Species</b>	<b>Day +2</b>	<b>Day +4</b>	<b>Day +7</b>	<b>Day +14</b>	<b>Day +21</b>	<b>Mon 1</b>	<b>Mon 2</b>	<b>Mon 3</b>
<i>C. furcifer</i>	2	0	1	3	11	0	0	2
<i>C. horei</i>	3	2	1	0	3	0	2	2
<i>E. cyanostictus</i>	20	22	20	20	21	10	13	4
<i>G. pfefferi</i>	0	1	0	0	0	0	1	0
<i>J. ornatus</i>	2	2	1	0	4	0	0	2
<i>L. tanganyicae</i>	100	2	30	3	6	6	0	0
<i>L. attenuatus</i>	0	0	0	0	0	0	0	2
<i>L. callipterus</i>	0	0	0	0	0	2	0	0
<i>L. caudopunctatus</i>	3	0	3	0	5	11	2	2
<i>L. dardenii</i>	1	0	0	0	1	2	0	0
<i>L. elongatus</i>	2	0	1	3	4	4	2	2
<i>L. labiatus</i>	4	2	8	1	5	1	4	1
<i>L. lemairi</i>	0	0	0	0	0	2	1	0
<i>L. modestus</i>	0	0	1	0	1	2	1	0
<i>L. moorii</i>	33	35	33	34	32	20	25	30
<i>L. multipunctatus</i>	0	0	0	0	0	4	0	0
<i>L. tetracanthus</i>	10	7	4	4	7	10	3	0
<i>Mastacembelus</i>	1	0	0	0	0	1	2	0
<i>N. sexfasciatus</i>	1	1	2	0	2	2	1	0
<i>N. fasciatus</i>	0	2	2	0	6	2	1	0
<i>N. mondabu</i>	0	0	0	0	0	1	2	1
<i>N. mustax</i>	5	5	6	6	4	0	0	0
<i>C. ventralis</i>	1	4	7	0	4	4	0	20
<i>P. straeleni</i>	0	1	0	0	4	0	2	1
<i>P. microlepis</i>	1	0	3	0	2	0	2	2
<i>P. orthognatus</i>	3	2	4	0	2	0	4	4
<i>P. polyodon</i>	0	0	0	1	4	0	0	1
<i>S. diagramma</i>	1	2	2	2	4	0	2	0
<i>T. dhont</i>	1	0	0	0	0	0	0	0
<i>T. bifrenatus</i>	0	0	4	0	5	0	0	0
<i>T. moorii</i>	20	23	24	21	21	15	12	8
<i>T. temporalis</i>	0	0	0	0	0	0	1	1
<i>T. vittatus</i>	2	3	6	2	3	2	6	4
<i>X. spilopterus</i>	2	2	2	0	0	2	0	0
<i>P. famula</i>	1	0	0	0	0	0	0	0
<b>Species</b>	23	18	22	12	24	20	21	18
<b>Specimens</b>	219	118	165	100	161	103	89	89
<b>Visibility</b>	poor	fair	good	fair	fair	fair	very poor	good

**Table 32.** Fish recorded at site 7 (Treatment) from second field experiment

<b>Species</b>	<b>Day -1</b>	<b>Day +2</b>	<b>Day +4</b>	<b>Day +7</b>	<b>Day +14</b>	<b>Day +21</b>	<b>Day +28</b>	<b>Mont h 1</b>	<b>Month 2</b>	<b>Month 3</b>
<i>C. furcifer</i>	1	0	0	0	0	0	0	1	1	0
<i>C. horei</i>	5	3	3	12	8	6	5	4	5	2
<i>E. cyanostictus</i>	39	2	7	10	3	8	13	6	9	2
<i>J. ornatus</i>	4	4	5	6	3	4	4	4	5	2
<i>L. tanganycae</i>	0	0	0	60	0	0	0	0	0	0
<i>L. attenuatus</i>	1	4	0	0	0	0	7	0	3	0
<i>L. callipterus</i>	2	4	2	5	0	2	6	0	1	0
<i>L. caudopunctatus</i>	3	1	2	3	0	4	0	0	22	0
<i>L. dardenii</i>	0	2	0	5	6	2	3	1	4	2
<i>L. elongatus</i>	0	0	0	0	0	0	1	1	0	0
<i>L. labiatus</i>	6	2	3	0	3	1	2	3	0	0
<i>L. lemairi</i>	0	0	0	0	0	3	0	2	1	0
<i>L. modestus</i>	5	10	2	2	3	8	2	2	4	0
<i>L. moori</i>	20	6	5	1	4	5	10	4	5	2
<i>L. multipunctatus</i>	0	0	0	0	0	7	0	0	0	0
<i>L. tetracanthus</i>	13	37	17	38	26	28	20	12	22	10
<i>Mastacembelus</i>	1	0	0	1	0	1	0	0	0	0
<i>N. fasciatus</i>	0	1	0	0	0	0	0	0	0	0
<i>N. mondabu</i>	4	0	2	0	2	6	1	0	2	2
<i>N. mustax</i>	4	4	3	0	1	1	0	0	0	0
<i>N. ventralis</i>	10	3	9	12	8	20	6	11	7	0
<i>P. straeleni</i>	1	0	0	0	0	0	0	0	0	1
<i>P. microlepis</i>	2	1	2	4	3	3	1	0	2	0
<i>S. babauti</i>	2	0	2	1	1	0	1	0	1	0
<i>S. diagramma</i>	7	0	1	0	0	2	0	0	0	0
<i>T. dhont</i>	4	3	2	1	1	3	0	0	2	0
<i>T. bifrenatus</i>	9	2	6	0	0	0	0	3	4	0
<i>T. moorii</i>	15	0	0	2	2	2	10	2	2	0
<i>T. temporalis</i>	8	0	4	2	1	4	5	0	2	3
<i>T. vittatus</i>	0	0	3	2	0	4	9	0	0	1
<i>P. amula</i>	2	0	0	0	1	0	0	0	0	0
<i>S. maginatum</i>	2	0	3	0	0	0	0	0	0	0
<b>Species</b>	25	17	20	18	17	22	18	14	20	10
<b>Specimens</b>	170	89	83	167	76	124	106	56	104	27
<b>Visibility</b>	fair	fair	fair	fair	fair	good	poor	good	very poor	good

**Table 33.** Fish recorded at site 8 (Treatment) from second field experiment

<b>Species</b>	<b>contro 1</b>	<b>Day +2</b>	<b>Day +4</b>	<b>Day +7</b>	<b>Day +14</b>	<b>Day +21</b>	<b>Day +28</b>	<b>Month 2</b>	<b>Month 3</b>
<i>C. horei</i>	5	9	10	4	4	6	3	4	2
<i>E. cyanostictus</i>	9	2	8	12	4	10	3	6	0
<i>G. pfefferi</i>	0	0	1	0	0	0	0	0	0
<i>J. ornatus</i>	4	2	2	4	2	4	0	0	0
<i>L. attenuatus</i>	0	10	2	0	0	0	0	6	6
<i>L. callipterus</i>	9	2	0	1	1	10	8	6	6
<i>L. caudopunctatus</i>	0	1	0	2	0	0	2	20	0
<i>L. dardenii</i>	2	13	2	12	32	4	4	2	6
<i>L. elongatus</i>	1	1	0	1	0	0	1	1	2
<i>L. labiatus</i>	8	2	4	2	1	2	4	2	0
<i>L. modestus</i>	2	5	5	1	3	2	5	5	0
<i>L. moori</i>	0	1	2	6	1	6	0	0	0
<i>L. multipunctatus</i>	0	0	0	1	0	0	0	0	0
<i>L. tetracanthus</i>	25	100	43	23	35	20	20	27	20
<i>N. sexfasciatus</i>	0	0	1	0	0	0	0	0	0
<i>N. fasciatus</i>	1	1	2	1	0	0	0	0	0
<i>N. mondabu</i>	6	3	4	2	3	2	3	1	1
<i>N. mustax</i>	4	0	0	0	0	0	0	0	0
<i>C. ventralis</i>	6	10	10	12	9	2	0	16	0
<i>P. microlepis</i>	0	2	10	3	0	1	0	1	0
<i>S. diagramma</i>	6	0	0	0	0	0	0	0	0
<i>T. dhont</i>	3	0	0	1	4	0	2	4	0
<i>T. bifrenatus</i>	20	4	0	0	3	0	6	7	0
<i>T. moorii</i>	0	0	6	0	1	4	1	3	0
<i>T. temporalis</i>	15	3	4	2	2	4	4	2	0
<i>T. vittatus</i>	0	6	10	0	0	7	0	0	3
<i>X. flavipinnis</i>	0	0	0	0	0	0	0	0	2
<i>P. famula</i>	5	0	0	0	0	0	0	0	0
<i>S. babauti</i>	5	2	2	1	1	1	1	5	0
<i>P. straeleni</i>	0	0	0	0	0	0	0	0	2
<b>Species</b>	19	20	19	19	16	16	15	18	10
<b>Specimens</b>	136	179	128	91	106	85	67	118	50
<b>Visibility</b>	fair	fair	fair	good	fair	fair	good	very poor	good

**Table 34.** Total taxa of fish identified and habitat preference on the experimental and control sites from both field experiments.

Genus	species	cichlid	non cichlid	rocks	sand & intermediate
<i>Altolamprologus</i>	<i>compressiceps</i>	X		X	
<i>Clarias</i>	<i>species</i>		X		X
<i>Ctenochromis</i>	<i>horei</i>	X			X
<i>Cyathopharynx</i>	<i>furcifer</i>	X			X
<i>Ectodus</i>	<i>descampsi</i>	X			X
<i>Eretmodus</i>	<i>cyanostictus</i>	X		X	
<i>Gnatochromis</i>	<i>pfefferi</i>	X			X
<i>Julidochromis</i>	<i>ornatus</i>	X		X	
<i>Julidochromis</i>	<i>regani</i>	X		X	
<i>Lamprologus</i>	<i>attenuatus</i>	X			X
<i>Lamprologus</i>	<i>callipterus</i>	X			X
<i>Lamprologus</i>	<i>caudopunctatus</i>	X			X
<i>Lamprologus</i>	<i>elongatus</i>	X			X
<i>Lamprologus</i>	<i>lemairi</i>	X			X
<i>Lamprologus</i>	<i>modestus</i>	X			X
<i>Lamprologus</i>	<i>moori</i>	X		X	
<i>Lamprologus</i>	<i>multipunctatus</i>	X			X
<i>Lamprologus</i>	<i>tetracanthus</i>	X			X
<i>Limnothrissa</i>	<i>tanganicae</i>		X		X
<i>Limnotilapia</i>	<i>dardenii</i>	X			X
<i>Lobochilotes</i>	<i>labiatus</i>	X			X
<i>Mastacembelus</i>	<i>species</i>		X		
<i>Neolamprologus</i>	<i>fasciatus</i>	X		X	
<i>Neolamprologus</i>	<i>mondabu</i>	X			X
<i>Neolamprologus</i>	<i>mustax</i>	X			X
<i>Neolamprologus</i>	<i>sexfasciatus</i>	X		X	
<i>Ophthalmotilapia</i>	<i>nasuta</i>	X			X
<i>Ophthalmotilapia</i>	<i>ventralis</i>	X			X
<i>Perissodus</i>	<i>microlepis</i>	X			X
<i>Petrochromis</i>	<i>famula</i>	X		X	
<i>Petrochromis</i>	<i>orthognatus</i>	X		X	
<i>Petrochromis</i>	<i>polyodon</i>	X		X	
<i>Plecodus</i>	<i>straeleni</i>	X			X
<i>Simochromis</i>	<i>babaulti</i>	X		X	
<i>Simochromis</i>	<i>diagramma</i>	X		X	
<i>Simochromis</i>	<i>marginatum</i>	X		X	
<i>Telmatochromis</i>	<i>bifrenatus</i>	X			X
<i>Telmatochromis</i>	<i>dhont</i>	X			X
<i>Telmatochromis</i>	<i>moorii</i>	X			X
<i>Telmatochromis</i>	<i>temporalis</i>	X			X
<i>Telmatochromis</i>	<i>vittatus</i>	X			X
<i>Xenotilapia</i>	<i>boulengeri</i>	X			X
<i>Xenotilapia</i>	<i>flavipinnis</i>	X			X
<i>Xenotilapia</i>	<i>sima</i>	X			X
<i>Xenotilapia</i>	<i>spilopterus</i>	X			X

### ***Gastropods***

Owing to difficulties with taxonomy, the macrogastropods of the genus *Lavigeria* recorded from the experiment have not yet been identified to species level. The number of living molluscs present on quadrats to which sediment was added was significantly different (*paired t-test*,  $P < 0.05$ ) seven days after the addition of sediment compared with prior to the start of the experiment (Table 35). Although a significant difference was also found for the control unimpacted sites (*paired t-test*,  $P_3 < 0.05$ ), the percentage decrease in gastropod number at the termination of the experiment was significantly greater in the sediment impacted quadrats compared with the control quadrats (*pooled t-test*,  $P < 0.05$ ). This suggests that gastropod recolonisation occurs at a lesser rate in the sediment impacted plots owing to the presence of large quantities of sandy sediment. Average size of gastropod, measured by shell weight, found in most of the quadrats was smaller among the treatment sites at the end of the experiment (day 7) compared with the control sites (Table 36).

**Table 35.** Field experiment 1: Total number of gastropods present on each quadrat before the beginning (day 0) and at the end (day 7) of the experiment, and percentage decrease in gastropod number after the experiment. Sediment was added to quadrats 1 – 4, and quadrats 5 – 8 are the ‘control’ sites.

Quadrat	Day No.	Total Number of Gastropods	Percentage Decrease in Gastropod Number
1	0	435	--
1	7	43	90.1
2	0	442	--
2	7	46	89.6
3	0	311	--
3	7	198	36.3
4	0	362	--
4	7	85	76.5
5	0	811	--
5	7	723	10.9
6	0	429	--
6	7	201	53.2
7	0	341	--
7	7	294	13.8
8	0	614	--
8	7	453	26.2

**Table 36.** Field Experiment 1: Average individual shell weight for each quadrat at the beginning (day 0) and end (day 7) of the experiment for both sediment impacted plots (quadrats 1 – 4) and ‘control’ sites (quadrats 5 – 8).

Quadrat Number	Day 0	Day 7
1	1.3	0.1
2	1.6	0.2
3	0.3	0.3
4	0.9	0.1
5	1.2	1.2
6	1.5	1.5
7	0.4	0.7
8	1.5	0.5

There was a significant relationship ( $r^2 = 0.59$ ). between rugosity (pre-sediment addition) and percentage decrease in gastropod number at the end of the experiment. The percentage number decrease for all of the sediment impacted quadrats was, for a given rugosity, proportionally less than the control sites (Figure 12). This implies that a greater than expected decrease in gastropod numbers occurred owing to the presence of large volumes of sediment. It is probable that the rugosity of the sediment impacted quadrats, and therefore the available habitat suitable for gastropods, was substantially decreased after sediment addition owing to the ‘filling-in’ of interstices between rocks and boulders decreasing the surface area of rocks available.



**Figure 12.** Relationship of rugosity and percentage number decrease of gastropds for both sediment impacted and 'control' quadrats of Field Experiment 1. Circles: sediment impacted plots; crosses: controls.

In field experiment two, after 10 days from the start, the density of organisms on the surface of rocks in both treatment and control quadrats had decreased significantly (*paired t-test*, treatment,  $P < 0.05$ ;  $d.f. = 3$ ; control,  $P < 0.01$ ;  $d.f. = 3$ ). While cumulative algal cover and number of identifiable taxa groups showed significant decreases (*paired t-test*,  $P < 0.05$ ) in the experimental quadrats from day 0 to day 10, no significant differences were recorded among the control sites (Tables 37 and 38).

**Table 37.** Quadrat number, day number, algal cover index, total number of organisms per cm<sup>2</sup>, and number taxa groups per quadrat for treatment quadrats of Field Experiment 2 on before sediment addition (day 0) and 10 days after sediment addition, including *P*-values (*paired t-tests*) for differences between days.

Quadrat Number	Day Number	Algal Cover Index	Total Number Organisms per cm <sup>2</sup>	Number Groups (per quadrat)
1	0	12	3.1	14
2	0	12	6.99	16
3	0	12	5.37	14
4	0	11	3.72	15
1	10	10	0.52	10
2	10	6	0.65	13
3	10	8	0.31	10
4	10	7	0.26	11
		<i>P</i> = 0.016	<i>P</i> = 0.014	<i>P</i> < 0.001

**Table 38.** Quadrat number, day number, algal cover index, total number of organisms per cm<sup>2</sup>, and number of taxa groups per quadrat for the control quadrats of Field Experiment 2 on day 0 and day 10, including *P*-values (*paired t-tests*) for differences between days.

Quadrat Number	Day Number	Algal Cover Index	Total Number Organisms per cm <sup>2</sup>	Number Groups (per quadrat)
5	0	12	3.99	14
6	0	13	3.15	12
7	0	12	5.19	13
8	0	12	3.92	13
5	10	14	0.78	11
6	10	12	0.86	14
7	10	13	0.61	13
8	10	10	1.04	15
		<i>P</i> = 1.00	<i>P</i> = 0.0069	<i>P</i> = 0.846

Table 39 shows the percentage change of the abundance of the invertebrate taxa groups between day 0 and day 10 of the experiment. It appears that chironomids were the least affected by the effects of settled sediment, with no significant difference between experimental and control quadrats. Densities of Acari, gastropods, harpactacoids, nematodes, shrimps and Trichoptera decreased significantly in sediment impacted areas.

The shrimps and gastropods were the most impacted groups. The range of percentage decreases in gastropod number from this experiment was between 51.4% and 100%.

**Table 39.** Mean percentage decrease and P-values (*t*-test of individuals,  $H_0$ : mean = 0,  $H_A$ : mean  $\neq$  0) for each higher level taxonomic group 10 days after sediment addition relative to pre-sediment addition values for experimental and control quadrats. *P*-values (pooled t-test) for differences between treatments are shown.

Taxa	Experimental Quadrats		Control Quadrats		Difference Between Treatments
	Mean % Decrease	P	Mean % Decrease	P	P
Acari	94.28	<0.001	73.5	0.003	0.043
Branchiura	100	<0.001	-33.03	0.533	0.060
Chironomids	64.82	0.001	43.78	0.043	0.179
Cyclopoids	97.97	<0.001	84.67	0.002	0.148
Ephemeroptera	78.3	0.001	-9.66	0.814	0.061
Gastropods	86.86	0.001	5.09	0.536	<0.001
Harpactacoids	98.91	<0.001	90.92	<0.001	0.005
Hemiptera	91.68	0.002	-59.15	0.466	0.080
Hirudinea	98.68	<0.001	43.14	0.436	0.293
Nematoda	92.38	<0.001	39.5	0.035	0.003
Oligochaetes	-91.03	0.618	-100		
Ostracods	90.77	<0.001	85.41	0.001	0.294
Shrimp	97.69	<0.001	-71.02	0.172	0.006
Trichoptera	87.83	<0.001	25.42	0.160	0.004
Turbellaria	89.33	<0.001	86.74	0.002	0.764

### Discussion of field results

The monitoring of the River mouths indicated that lower abundance and taxa richness were associated with the periods of greatest turbidity. Lowest numbers of both parameters were found nearest to the discharge areas of both rivers. Results from the 10 m stations were, however, not in agreement between the two river mouths. Overall, the larger invertebrates (i.e those retained in a 2000  $\mu$ m mesh sieve) showed a more distinct decline associated with high turbidity than the smaller organisms. The results obtained from the monitoring of the river mouths imply but do not prove an impact of sediment *per se* as other factors such as water flow regime and sediment structure may be implicated. There

was, however, no obvious changes between sediment description among the sites at the Kalambo, although differences were apparent between the two sites at the Lunzua. No data was collected or analysed for water in the mouths of the rivers. The results from the intensive monitoring confirmed those of the monthly monitoring results in that, generally lower abundance and tax richness were associated with the period of higher turbidity present during the wet compared with the dry season. There is a possibility that areas that are further from the source of sediment input act as 'refugia' for benthic invertebrates. It is not known whether or not this involves active migration, although that is somewhat difficult to envisage.

It is apparent since this work was planned that the maximum period of turbidity is related to maximum catchment water discharge and occurs sometime towards the end of the rainy period. In retrospect, therefore, a better timing for the intensive sampling to detect maximum impact of sediment discharge may have been April or May. This was further suggested by the values in Secchi depth readings. Maximum water visibility was generally away from the river mouths. In the control site of the Kalambo there was a steady increase in Secchi depth from May to November.

The field experiments showed quite clearly that increased sediment load to rocky substrata affects the composition and abundance of fish and invertebrates. Within a short time of sediment addition, sites were colonised by a number of typical sand dwelling species. Rock dwelling species appear to remain on impacted sites for several days. This may be a consequence of their territoriality that prevents moving readily to adjacent, and probably already occupied, territories. Recolonisation rates by molluscs was slower among the sediment impacted treatments than the control sites where no sediment was added. Some quadrats retained sediment even after six months of it been laid down whereas in others and more sloping areas sediment cleared after a short period of time.

# GENETIC VARIABILITY OF A ROCK DWELLING CICHLID FISH

## A Study of *Eretmodus cyanostictus*

### Summary

287 specimens of *Eretmodus cyanostictus* were screened for genetic variability at 4 microsatellite loci. High levels of genetic substructuring was observed even in the absence of sedimented/sandy stretches of shoreline. The overall  $F_{ST} = 0.098$ ,  $P > 0.001$ . Average  $F_{ST}$  between populations separated by barriers was almost double that of populations not separated by such barriers. However, a Mantel test revealed that this difference was not statistically significant ( $P = 0.0784$ ). The presence of genetic substructuring in populations inhabiting continuous stretches of rocky shore suggests that population sizes are very small in this species. The significant relationship between  $\log_{10}M$  and  $\log_{10}$  separation distance suggests that the populations are at, or near equilibrium with respect to genetic variation. We observed significantly reduced genetic variation in Zambian populations relative to the DRC populations ( $P = 0.0086$ ). This supports the hypothesis that Zambian populations are affected by environmental changes (sedimentation) that are absent in the DRC populations. However, there are alternative natural causes which may explain the observed pattern. These results suggest that the probable small population sizes and low levels of migration in this species means individual populations are extremely vulnerable to localised sedimentation. Localised sedimentation is unlikely to endanger the species as a whole. However, sedimentation over the entire range of the species may present a serious threat to the species. It is unlikely that all rock dwelling species are as stenotopic as *E. cyanostictus*. Therefore, further rock-dwelling species, which differ in their breeding system and depth ranges, need to be investigated. This will provide vital information for planning conservation strategies for these unique species.

## **Introduction**

We investigated the fine scale dispersal capabilities of *Eretmodus cyanostictus*, the small goby-like cichlid of the Eretmodini tribe, selected for this project, because it inhabits the shallow rocky 'surge zone' of Lake Tanganyika (Ruber *et al.* 1999). Microsatellite DNA markers were used to investigate the affects of geographic scale and environmental characteristics on population substructuring in *E. cyanostictus*. Knowledge of the dispersal capabilities of rock-dwelling species is essential if we are to fully understand the processes behind population divergence and speciation, but will also provide essential data for conservation efforts. We will investigate dispersal capacities over rocky and sandy (sedimented) habitats by comparing genetic differentiation between populations separated by such substrates. These analyses will also allow us to estimate effective population sizes in this species, which will indicate the vulnerability of populations of this rock-dwelling species, in cases where sedimentation is localised or generalised over the study area. Finally, this approach will quantify the level of genetic differentiation over the study area, which can then be compared with populations inhabiting the pristine Democratic Republic of Congo shoreline investigated in a previous study (Ruber *et al.* submitted).

## **Methods**

### ***DNA preparation and amplification***

A total of 287 specimens of *Eretmodus cyanostictus* were collected from 9 localities in Zambia (Figure 13) during two collecting trips in April and October 1999. Fin clips were taken from freshly caught specimens and immediately preserved in 70% ethanol.

Total DNA was extracted from ethanol preserved fin clips using Proteinase K digestion and salt precipitation, using a technique modified from Aljanabi & Martinez (1997). Extracted DNA was resuspended in 200µl of autoclaved MQ H<sub>2</sub>O. All samples were screened for variation at each of 4 SSR loci: Pzeb1, Pzeb3 (van Oppen *et al.* 1997), TmoM11 and TmoM5 (Zardoya *et al.* 1996). PCR amplifications were performed under the following conditions: 94°C 120s, followed by 5 cycles of 94°C 45s; (A)°C 45s; 72°C 45s, followed by 30 cycles of 91°C 30s; (A)°C 30s; 72°C 30s, followed by 72°C 10mins. The annealing temperature (A) was 55°C for Pzeb1, Pzeb3 and TmoM5, and 50°C for TmoM11. 10µl reaction mixes consisted of 2µl (20ng) template DNA, 0.5 µM of each primer, 200µM of each dNTP, 0.26 units Taq polymerase (Pharmacia Biotech),

1µl 10x reaction buffer (Pharmacia Biotech). The mixture was overlaid with 10µl of mineral oil. Amplified products were resolved on 6% denaturing polyacrylamide gels (short) on an Alf Express DNA sequencer. Product sizes were determined by comparison with M13mp8 DNA sequence standards. Allelelinks software (Pharmacia Biotech) was used to size the fragments. Alleles were binned into 1 bp (Pzeb1) or 2 bp categories (Pzeb3, TmoM5 and TmoM11) and compared with a suite of standard alleles run on each gel.

### ***Data analysis***

Genotypes at all pairs of loci were tested for linkage disequilibrium and deviations from Hardy Weinburg equilibrium using the exact test of Genepop (Genepop version 3.1d; Raymond & Rousset 1995). Significance levels were determined using the Markov chain method (dememorisation number=5000, 100 batches, 2000 iterations). Bottleneck (Cornuet & Luikart 1996) was used to test for recent changes in effective population size, which can bias estimates of genetic structure. Infinite allele based measures (Kimura & Crow 1964) were used in preference to stepwise mutation models for all statistics. In recently isolated populations, IAM methods are likely to give more accurate estimates of population structure (Slatkin 1995). Pairwise  $F_{ST}$  was estimated following Weir & Cockerham (1984) using Arlequin 1.1 (Schneider et al. 1997). Overall  $F_{ST}$  was calculated using FSTAT (Goudet 1995). Differences in allele frequencies between populations were calculated using Fisher's exact test (Genepop 3.1d, Raymond & Rousset 1995). Fisher's (1954) method was used to combine single locus probabilities to give a multilocus estimate. The values from the two statistics were tested for significant departures from zero using permutation tests contained in the respective packages. Population divergence was estimated using Nei's genetic distances, calculated using Gendist (Phylip 3.5c; Felsenstein 1995). An unrooted UPGMA tree constructed using Neighbour (Felsenstein 1995) was used to cluster the distances. Multidimensional scaling techniques are suggested to provide a more accurate graphical representation of microsatellite data, as it doesn't cluster samples into groups. However, in the present study we are interested in the geographic distribution of the taxa, so an unrooted tree was considered the most appropriate method for displaying the data. Pairwise estimates of the number of migrants per generation ( $N_m$ ) were calculated using the rare allele based model of Barton & Slatkin (1985) using Genepop 3.1 (Raymond & Rousset 1995). Measures of geographic distance are expected to increase with geographic distance under isolation by distance models. The Mantel test (Genepop 3.1d, Raymond & Rousset 1995) with 5000 permutations was used to test for a significant correlation between  $F_{ST}/1-F_{ST}$  and distance between populations.  $\log_{10}M$  was also calculated ( $M=1/4(1/F_{ST})-1$ ) and regressed on  $\log_{10}$  (separation distance)

## Results

All loci were polymorphic for all the populations sampled. For the nine populations combined, the mean number of alleles per locus varied from 3.44 for TmoM11 to 17.7 for TmoM5. Mean  $H_e$  per locus ranged from 0.44 for TmoM11 to 0.89 for TmoM5. Within sample  $H_o$  ranged from 0.31 for CHI to 0.67 for S7. Observed and expected heterozygosities per sample, allele number, size ranges and significant deviations from Hardy Weinburg expectations are shown in Table 40. There was no evidence of linkage disequilibrium in any pair of loci ( $P > 0.05$ ). Deviations from Hardy Weinburg expectations were tested using Fisher's exact test. After Bonferroni correction 3 out of 36 tests revealed significant deviations from Hardy Weinburg equilibrium. Two of the significant tests were for CHI. This population has a sample size of 12, which is extremely small for a microsatellite study. Any comparisons involving this population or MB ( $n=15$ ) should be treated with caution. There was no evidence to suggest any populations had recently undergone large changes in  $N_e$  ( $P > 0.05$ ).  $F_{ST}$  over all populations was highly significant, 0.098,  $P < 0.001$ . A highly significant  $F_{ST}$  estimate was also obtained for the five populations not divided by physical barriers (BIS, TL, S5, S7 and KV),  $F_{ST} = 0.068$ ,  $P < 0.0002$ .  $F_{ST}$  revealed highly significant differences between all adjacent population pairs ( $P < 0.001$ ) (Table 41) with the exception of (TL and S5), (S7 and MB), (MI and KV).  $F_{ST}$  values ranged from 0.015 between MI and KV, to 0.174 between KV and CHI. All of the combined multi-locus exact tests for population pairs were significant (Table 41) with the exception of (TL and S5), and (S7 and MB). Single locus tests revealed that no single locus or group of loci was solely responsible for the multilocus differences. Nei's distances are displayed in Table 42. A UPGMA tree (Figure 14) plotted using Nei's distances suggests there are 4 lineages within the data set. Both K and CHI are situated at the extremes of the sampling range, isolated by long stretches of sand, and appear as independent lineages. KV and MI cluster together and appear to form a separate lineage from the other 5 populations (BIS, TL, S5, S7 and MB). There was a highly significant correlation between Ln distance (km) and  $F_{ST}/(1-F_{ST})$  ( $P=0.0016$ ) using a one sided Mantel test. A significant correlation was also found between  $F_{ST}/(1-F_{ST})$  and Ln distance (km) for the populations not divided by physical barriers ( $P=0.039$ ). Plots of  $\log_{10}M$  versus  $\log_{10}$  separation distance (Figure 15), revealed slopes of  $-0.72$  ( $r^2=0.68$ ) for all populations, and a slope of  $-0.88$  ( $r^2=0.72$ ) for the populations not separated by physical barriers. A Mantel test was again used to test for differences in  $F_{ST}$  values between populations separated by physical barriers and those not separated (in the form of a binary matrix). This revealed evidence of a relationship, but this was non-significant ( $P=0.0784$ ). A comparison of the current data

set with that of Ruber et al (submitted), reveals that the Zambian populations have a significantly lower average heterozygosity ( $H_o$ ) than the Democratic Republic of Congo (DRC) populations ( $t$ -test;  $tst=-3.187$ ,  $P=0.0086$ ). There was no significant difference in allele number between the Zambian and DRC populations ( $t$ -test,  $P>0.05$ ).

## Discussion

This is the first study to reveal fine scale population substructuring between cichlid populations not isolated by physical barriers. Microsatellite markers reveal an overall  $F_{ST}$  of 0.098,  $P<0.001$ , with the five populations on inhabiting a continuous rocky shoreline exhibiting an  $F_{ST}$  of 0.068,  $P<0.0002$ . Previous studies of rock dwelling cichlid species in Lake Malawi (van Oppen *et al.* 1997; Arnegard *et al.* 1999; Markert *et al.* 1999), also found high levels of population substructuring. However, physical barriers such as sandy areas or stretches of deep water were necessary to significantly reduce gene flow between adjacent populations. These physical barriers do not appear to be necessary to reduce gene flow in *E. cyanostictus*, which suggests it is an even poorer disperser than the mbuna of Lake Malawi, previously noted for their stenotopy.

### *Genetic divergence and separation by sedimented areas*

Dividing the populations into two groups, those separated by barriers and those that were not, revealed the group separated by physical barriers had an average  $F_{ST}$  of almost double that of the group not separated by barriers. However, a statistical analysis using a Mantel test which corrects for non-independence of data, revealed a evidence of a relationship, but this was non-significant ( $P=0.0784$ ). This suggests that physical barriers do not significantly increase the levels of genetic substructuring in *E. cyanostictus*. However, more populations (at least 15 in total) need to be included to reduce the potential of a Type I error (not possible at this time owing to insufficient suitable sampling). A highly significant relationship between genetic differentiation and geographic distance was revealed using a Mantel test. By regressing  $M$  on log separation distance between populations, it is possible to make tentative inferences concerning past colonisation events and current gene flow.  $M$  is preferable to genetic distance for these analyses as it is nearly independent of mutation rate, when this is low, the relationship between  $M$  and distance can be easily predicted, and for populations differing only slightly in genetic composition,  $M$  expands the scale of measurement. The significant relationship between  $\log_{10} M$  and log separation distance suggests that the populations are at, or near equilibrium with respect to genetic variation. This makes it unlikely that

the populations are recently descended from a single ancestral population (Slatkin 1993). In this scenario, all populations would be expected to be equally divergent. Inferences concerning the mechanisms of migration can also be made (Slatkin & Maddison 1990; Slatkin 1993). A slope of  $-1.00$  is expected if the gene flow follows a one-dimensional stepping stone model, and a slope of  $-0.5$  is expected if a two dimensional pattern is followed. The slope for five populations not separated by physical barriers is  $-0.72$ , compared with a slope of  $-0.88$  for all the populations. The pattern of migration/gene flow in *E. cyanostictus* is unlikely to follow a strict one or two dimensional model. Some populations, will follow a strict one dimensional stepping stone model (K – Bis), (S5-S7), whereas others are likely to follow a two dimensional model.

### ***Genetic variation in impacted Zambian versus pristine DRC populations***

The reduced levels of heterozygosity found in the Zambian populations relative to the DRC populations could have several possible explanations: firstly, the Zambian populations may have smaller effective population sizes than the DRC populations. Unfortunately, the DRC populations were not sampled on such a fine scale as the Zambian populations. This precludes any comparisons of levels of population substructuring between the two groups, which would have allowed a comparison of effective population sizes to be made.

Human impact is likely to differ between the Zambian and DRC populations. The DRC populations inhabit a relatively pristine environment, whereas the Zambian populations inhabit an area which has been subject to significantly more intensive agricultural activity. This is likely to have led to a greatly increased level of sedimentation in that area of the lake. This may have reduced the effective population sizes of the Zambian populations with a concomitant reduction in genetic variability.

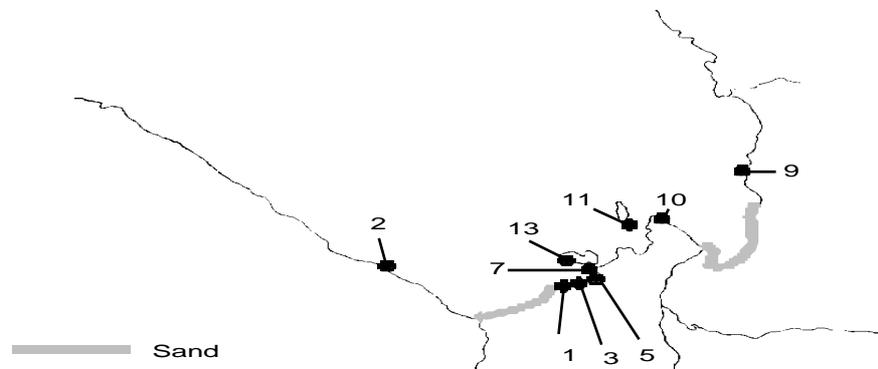
Alternatively, the reduction in heterozygosity may suggest the Zambian populations have been bottlenecked at some time during their history. However, there was no evidence that any of the populations in the current study had been through a population bottleneck. The coastline in the DRC is predominately rocky, and extremely steeply sloping; changes in water level, are unlikely to split and reunite populations. In comparison, the Zambian shoreline is gently sloping and complexly structured. Changes in water levels are likely to lead to large horizontal migrations of populations, possibly leading to frequent isolation and reunification of populations. This may result in smaller effective population sizes and associated reductions in genetic diversity in the Zambian populations.

### ***Genetic divergence among Zambian populations***

Water changes are likely to have had a major influence on species population distributions in Lake Tanganyika. Kohda *et al.* (1996) estimated the putative rocky and sandy areas of shoreline down to 600m below current water levels. Using a large scale contour map of the lake bed, we have plotted the lake shore outline at -300, -200 and -100 metres below current levels, and superimposed Kohda *et al's* (1996) substrate estimates (Figure 16). It reveals an extremely complicated history for the central rocky area. The rocky areas on the extreme east and west of the lake, inhabited by Kombe and Chisansa populations are likely to have been isolated for at least 30,000 years. The central section appears to be currently inhabited by two population lineages. The complicated history of this central area could have led to the isolation of separate groups of populations during the rise in water levels.

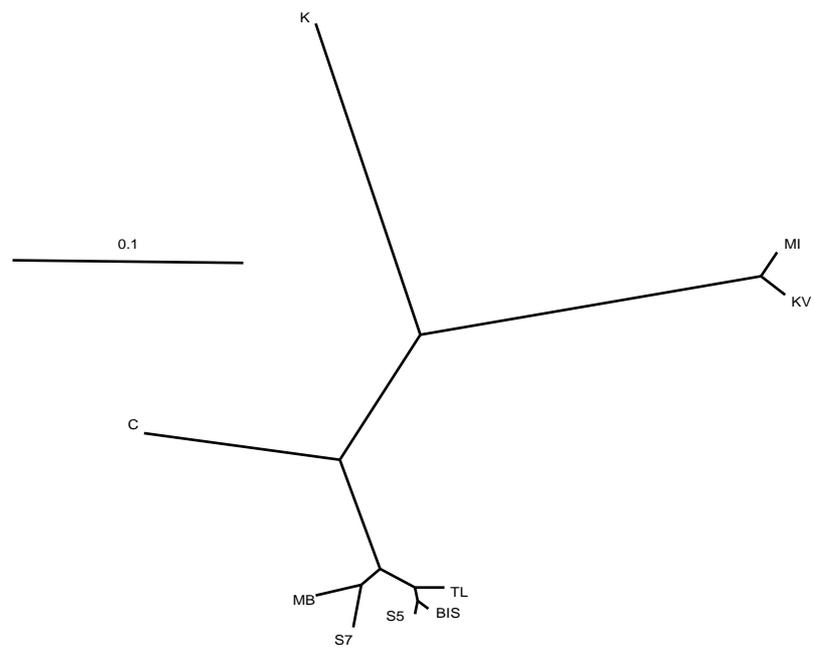
It is unlikely that all rock dwelling species are as stenotopic as *E. cyanostictus*. Therefore, further rock-dwelling species, which differ in their breeding system and depth ranges, need to be investigated. This will provide vital information for planning conservation strategies for these unique species.

**Figure 13.** Southern end of Lake Tanganyika, showing numbered collection sites.

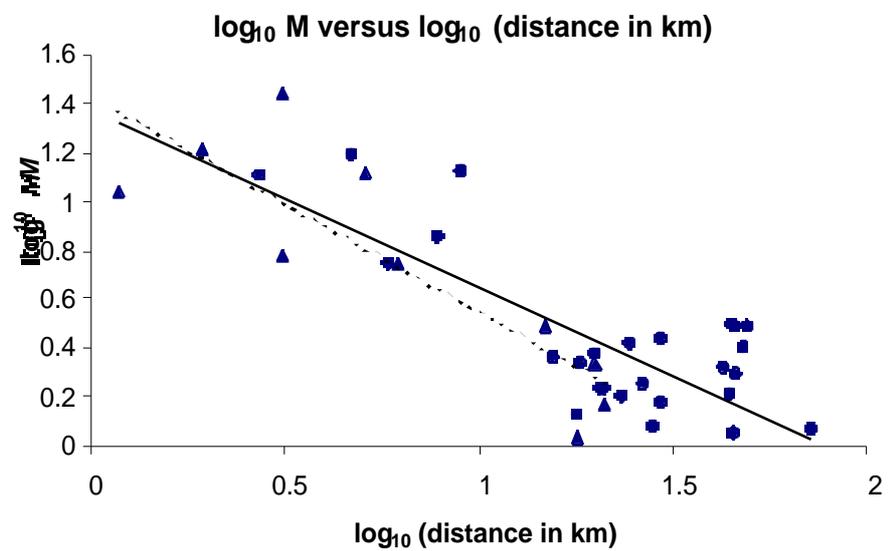


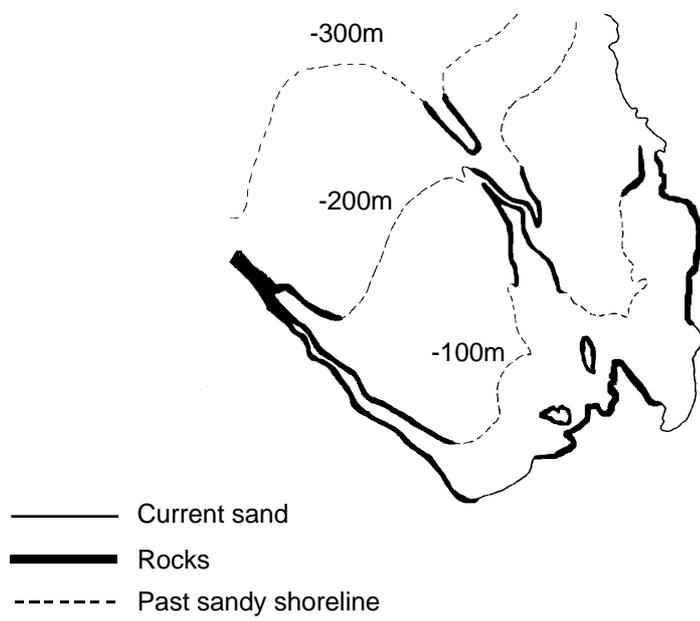
Site Number	Name	Co-ordinates
1	<b>BIS</b>	S 08 47 167 E 31 04 664
2	K	Na
3	TL	S 08 46 997 E 31 04 907
5	S5	S 08 46 501 E 31 06 444
7	S7	S 08 45 877 E 31 06 203
9	C	Na
10	KV	Na
11	MI	Na
13	MB	S 08 45 214 E 31 05 153

**Figure 14.** Unrooted tree of Nei's genetic distances for the Zambian populations.



**Figure 15.** Plot of  $\log_{10}M$  against  $\log_{10}$  separation distance between populations. The triangles correspond to populations not separated by physical barriers. The circles + triangles correspond the entire data set, The slope of the regression line for the entire data set was  $-0.72$ ,  $r^2=0.67$ ; the slope of the reduced data set is  $-0.88$ ,  $r^2=0.72$ .





**Figure 16.** Inferred past shorelines in the southern part of Lake Tanganyika

**Table 40.** Levels of genetic diversity for 9 populations of *Eretmodus cyanostictus* from the Zambian shoreline using four microsatellite loci.

Locus	Population									Mean
	MI	K	BIS	TL	KV	S5	S7	MB	C	
Pzeb1										
No. Alleles	10	9	9	10	7	10	11	10	5	9.00
Allele min	128	129	134	131	134	132	128	128	131	128
Allele max	144	143	146	150	142	141	148	143	139	150
Ho	0.783	0.688	0.652	0.675	0.667	0.478*	0.652	0.800	0.167*	0.618
He	0.770	0.855	0.763	0.840	0.654	0.757	0.822	0.760	0.601	0.758
Pzeb3										
No. Alleles	3	5	6	6	6	5	3	5	2	4.56
Allele min	321	319	317	317	317	317	319	319	319	317
Allele max	325	331	327	327	331	327	323	337	323	337
Ho	0.326	0.594	0.244	0.447	0.500	0.304	0.522	0.286	0.167	0.377
He	0.377	0.607	0.363	0.518	0.557	0.274	0.492	0.533	0.278	0.444
TmoM11										
No. Alleles	4	3	5	3	3	3	4	4	2	3.44
Allele min	157	155	159	159	159	159	159	159	159	155
Allele max	165	161	167	163	165	163	165	165	161	167
Ho	0.435	0.375	0.478	0.405	0.313	0.609	0.652	0.333	0.000*	0.400
He	0.540	0.330	0.469	0.518	0.491	0.507	0.617	0.429	0.375	0.475
TmoM5										
No. Alleles	21	16	21	24	22	14	16	10	15	17.67
Allele min	216	218	216	216	216	216	216	216	216	216
Allele max	286	264	304	282	288	282	286	268	296	304
Ho	0.674	0.875	0.796	0.854	0.766	0.636	0.870	0.733	0.917	0.791
He	0.779	0.799	0.894	0.882	0.807	0.835	0.911	0.836	0.903	0.849
Mean No. alleles	9.50	8.25	10.25	10.75	9.50	8.00	8.50	7.25	6.00	
Mean Ho	0.553	0.633	0.543	0.595	0.561	0.507	0.674	0.538	0.313	
Mean He	0.624	0.658	0.629	0.698	0.634	0.607	0.727	0.662	0.563	

Denotes significant deviation from Hardy Weinberg equilibrium after tablewide Bonferroni correction

**Table 41.** Genetic differentiation of Zambian populations. For each pairwise comparison, the table indicates the respective sample sizes, the distance between the populations (km), the intervening substrate, multilocus  $F_{ST}$ 's, number of migrants, multilocus exact tests and individual locus exact tests.

Pairwise comparison	Sample sizes	Distance (km)	Intervening substrate	Four locus $F_{ST}$	$N_m$	Exact test P values				
						Multi-locus $P$ value	$PZ1$	$PZ3$	TMO11	TMO5
K-BIS	32, 46	23.4	rocky coast; sandy beach	0.137 **	2.67	$P<0.00001$	$P=0.000$	$P=0.0016$	$P=0.00000$	$P=0.00000$
BIS-TL	46, 41	1.17	rocky coast	0.022 **	6.07	$P=0.0003$	$P=0.000$	ns	ns	ns
TL-S5	41, 23	1.95	rocky coast	0.015 ns	6.10	Ns	$P=0.018$	ns	ns	ns
S5-S7	23, 23	3.12	rocky coast	0.038 **	3.71	$P<0.00001$	ns	$P=0.0016$	ns	$P=0.0018$
S7-MB	23, 15	2.73	sandy bay	0.019 ns	3.36	Ns	ns	ns	ns	ns
S7-KV	23, 48	14.8	rocky coast	0.069 **	3.39	$P<0.00001$	$P<0.000$	$P=0.0002$	$P=0.005$	$P=0.00000$
S7-MI	23, 47	15.6	rocky coast; sandy bay	0.099 **	2.25	$P<0.00001$	$P<0.000$	$P=0.00000$	$P=0.008$	$P=0.00000$
MI-KV	47, 48	4.7	rocky coast; sandy bay	0.016 ns	3.55	$P<0.00001$	$P<0.000$	ns	$P=0.00303$	ns
KV-CHI	48, 12	28.1	rocky coast; sandy beach	0.174 **	1.07	$P<0.00001$	$P<0.000$	$P=0.00000$	ns	$P=0.00000$
K-CHI	32, 12	72.5	(whole study area)	0.177 **	1.44	$P<0.00001$	$P<0.000$	ns	$P=0.00000$	$P=0.00000$

\*\*= $p<0.001$ ,

**Table 42.** Matrix of Nei's genetic distances estimated from 4 microsatellite loci for 9 *Eretmodus cyanostictus* populations.

	<b>MI</b>	<b>K</b>	<b>BIS</b>	<b>TL</b>	<b>KV</b>	<b>S5</b>	<b>S7</b>	<b>MB</b>	<b>C</b>
<b>MI</b>									
<b>K</b>	0.500								
<b>BIS</b>	0.380	0.330							
<b>TL</b>	0.333	0.224	0.037						
<b>KV</b>	0.028	0.323	0.288	0.230					
<b>S5</b>	0.497	0.275	0.014	0.016	0.364				
<b>S7</b>	0.238	0.220	0.081	0.050	0.157	0.068			
<b>MB</b>	0.236	0.387	0.029	0.070	0.162	0.071	0.040		
<b>C</b>	0.498	0.430	0.129	0.164	0.390	0.200	0.239	0.126	

## **Recommendations for Continued Monitoring**

The project established field monitoring at fixed locations off two of the main rivers flowing into the southern end of Lake Tanganyika in the vicinity of Mpulungu, Zambia. Less frequent monitoring was done off the mouth of the Lufubu, the largest river flowing into the southern end of the lake, several hours boat-time from the Zambian Fisheries laboratory at Mpulungu. Field sites were also established a few minutes from the laboratory for the investigation of impact of sediment load onto rocky substrata. At each of these study sites Zambian Fisheries personnel participated in each monitoring trip. On a number of occasions these sites were monitored without the presence of any of ex-patriot consultants or the sediment facilitator. The required training to enable national staff to continue the monitoring of these sites was afforded through discussion, demonstration and participation with consultant scientists and the project facilitator. This included work with sampling of sediment and zooplankton, the readings of Secchi disc, the fixing of position through GPS, and making effective field records. Protocols for diving and underwater recording were provided through BioSS dive training programmes and through additional instruction provided specifically for the underwater field experimental sites. In the early stages of the project detailed guidelines were prepared for the monitoring and processing of benthic invertebrate samples and sample record sheets. During the project assistance was provided for data entry and data handling. The project has established a simple facility for aquarium-related work. The model of the project in that it relied heavily on external consultants in itself provided some difficulties and without the presence of a full-time project administrator and facilitator, it is our opinion that much less could have been achieved than actually was. Short-term consultants can rarely obtain an accurate perception of the workings of a national institution and its staff. Travel time to most of Lake Tanganyika is long and this further diminishes the effectiveness of outside consultants in establishing programmes required by the project.

While the training provided has provided the skills base required to continue monitoring, there remains a need for experienced scientific supervision. Sampling was often quite undisciplined, resulting in simple mistakes such as incorrect filling in of data record sheets and GPS position. Sampling was also often not done as effectively as required and data sometimes “lost” or misrepresented. A rigorous approach appears difficult to maintain. More training is clearly needed in scientific protocol and data processing. This would usefully include instruction in basic word processing. This project demonstrated that ongoing monitoring is a feasible option providing some additional input to the maintenance of programmes is provided externally. It would also appear to be an

unfortunate reality that without external funding for staff allowances as well as consumables and maintenance of equipment that further monitoring is an unobtainable aspiration. In light of the above and in view of the fact that both of the European participant institutions are prepared to maintain a role in the development of the Mpulungu laboratory and research on the lake we make the following recommendations.

2. Serious consideration is given to the means for establishing further basic training and for maintenance of skills among personnel of the Zambian Fisheries in connection with a future monitoring programme. This could include focussed on-job refreshment courses in Mpulungu and external educational opportunities for new graduate recruits to the Department of Fisheries (or other relevant Zambian Institutions).
3. That monitoring of the field experimental site continues for one more year with use of the Zambian divers who are trained and capable of confident fish identification. This work is willing to be funded through a consortium involving Dublin University and The Royal Belgium Institute of Natural Sciences.
4. Pending further and more detailed analysis of the results and samples collected from the mouths of the Kalambo and Lunzua Rivers between January 1999 and March 2000, that a six-monthly programme of sediment sampling for invertebrates, sediment description and Secchi depth measurement are taken at the same locations used in the intensive monitoring programme described in this work.
5. Although not within the direct remit of this project we recognise the high desirability of long-term monitoring of suspended solids in the rivers entering the waters, not only of Zambia but throughout the lake. In Zambia, however, this seems to be an effective and readily achievable goal.
6. That the Consortia of institutions that have been involved in the Special Studies of the LTBP continue to develop a dialog in order to realise funding and research collaborations with national institutions of the riparian countries of Lake Tanganyika. This will build upon rather than reestablish experience of the lake and its problems.

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