FISH COMMUNITY ECOLOGY IN RELATION TO LAND USE AND LOTIC PARAMETERS IN THE MNEMBO RIVER CATCHMENT (SOUTHERN AFRICA)

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Fish Community Ecology in Relation to Land Use and Lotic Parameters in the Mnembo River Catchment (Southern Africa)

by

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Abstract

Endorheic Lake Chilwa is one of the most productive lakes in Africa, contributing up to 24% of total fish production in protein-starved Malawi. High population density and agricultural practices in the Chilwa catchment have been linked to declines in the number and size of the commercially important *Barbus* species. The Mnembo River is a major inflow into Lake Chilwa which has received little scientific study to date. In 2003/ 2004, water quality parameters and fish abundance and distribution were monitored monthly at 3 sites in the Mnembo River to provide data for a lake management plan. Studies on smaller inflows into Lake Chilwa have implicated sediment yield, discharge, conductivity and total suspended solids (TSS) as influences on *Barbus* migration. *Barbus* catch was negatively correlated with discharge and pH in the Mnembo River. Female *Barbus* spawning condition (Gonadosomatic Index) was positively correlated with rainfall and water temperature and negatively correlated with TSS concentrations. Within Lake Chilwa's watershed, sediment yield in the Mnembo River (56t km^{-2} yr^{-1}) was significantly lower than in the Likangala (374t $km^{-2}yr^{-1}$) and Domasi Rivers (315t $km^{-2}yr^{-1}$) likely due to lower agricultural activity in the Mnembo catchment. Elevated rates of soil loss (0.30t $km^{-2}yr^{-1}$) in the Mnembo catchment were mainly attributed to steep slopes rather than poor land use practices as is the case in the Likangala and Domasi catchments. Compared to Lake Chilwa's other catchments, the Mnembo River catchment is in better condition, however current land use practices will cause degradation to rapidly increase until a sustainable management strategy for the Lake Chilwa watershed is implemented.

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Chapter 1

General Introduction

1.1 Lake Chilwa and its catchments

Endorheic Lake Chilwa is one of the most productive lakes in Africa, contributing up to 24% of the total fish produced in Malawi. The lake and its surrounding wetland supports a vibrant small scale fishing industry, which at peak levels supports 6000 fishers and a fishery valued at US $17 million (Jensen *et al.* 2000). On average the lake yields 10,000 tonnes of fish per year, which varies with changes in the climate (Jensen *et al.* 2000) (Figure 1.1). The most commercially important species are *Barbus paludinosus* Peters, *B. trimaculatus* Peters, *Oreochromis shiranus chilwae* (Trewavas) and *Clarias gariepinus* (Burchell), which together comprise 80 percent of all fish caught (Furse *et al.* 1979a).

Being endorheic and subject to high evaporation rates, the lake is comprised of sub-saline (conductivity >800 µS/cm) waters (Msiska 2001) and experiences fluctuations in water quality such as dramatic changes in alkalinity, temperature and dissolved oxygen. It is dependent on the freshwater inputs from rainfall and its tributaries to moderate the fluctuations (McLachlan *et al.* 1972). There are 14 streams that empty into the lake of which 5 are perennial (Morgan and Kalk 1970). They are the Sombani, Likangala, Domasi and Phalombe in Malawi and the Mnembo in Mozambique. The catchments contribute 70 percent of the total water volume in the lake per year (Nyasulu *et al.* 2001) with peak flows from February to March (Jensen *et al.* 2000). Lake Chilwa is also relatively shallow with maximum depths no greater than nine meters. As a result of evaporation and unpredictable rainfall, the lake can experience as much as one meter fluctuations yearly in water level (Howard-Williams and Howard-Williams 1978). Average annual rainfall for the lake is 1,053 mm with January having the highest rainfall amount recorded (Msiska 2001).

Within the East African rift valley there are approximately 20 endorheic (closed) lakes, including Lakes Turkana, Rukwa and Chilwa. Lake Chilwa however is not located entirely within the rift valley but is the remnant of a shallow tectonic depression that has filled in gradually over time with sand and silt (Furse *et al.* 1979a). It is the second largest lake in Malawi and twelfth largest in Africa (Furse *et al.* 1979a). The lake is located in the southern portion of the country (15° 15' S and 35° 45' E) and is bordered by Mozambique to the east (Figure 1.1). The total area of the lake and its surrounding wetland is 2,400 km^2; one third of which is open water, one third swamp and marsh and one third comprised of floodplains. The total area for the catchment is 8,349 km^2 of which 30 percent is in Mozambique (Lancaster 1979).

The lake and its associated wetland is a dynamic ecosystem that dries up at intervals. The lake has dried up completely on three separate occasions over the last 100 years as a result of droughts. During the rainy season, the lake's tributaries and surrounding swamps are responsible for providing an influx of nutrients from the catchment and from the decomposition of aquatic vegetation. *Typha domingensis* surround the lake, occupying 1,000 km^2 along the lakes edges and within the lower river channels (Jensen *et al.* 2000). The fluctuation

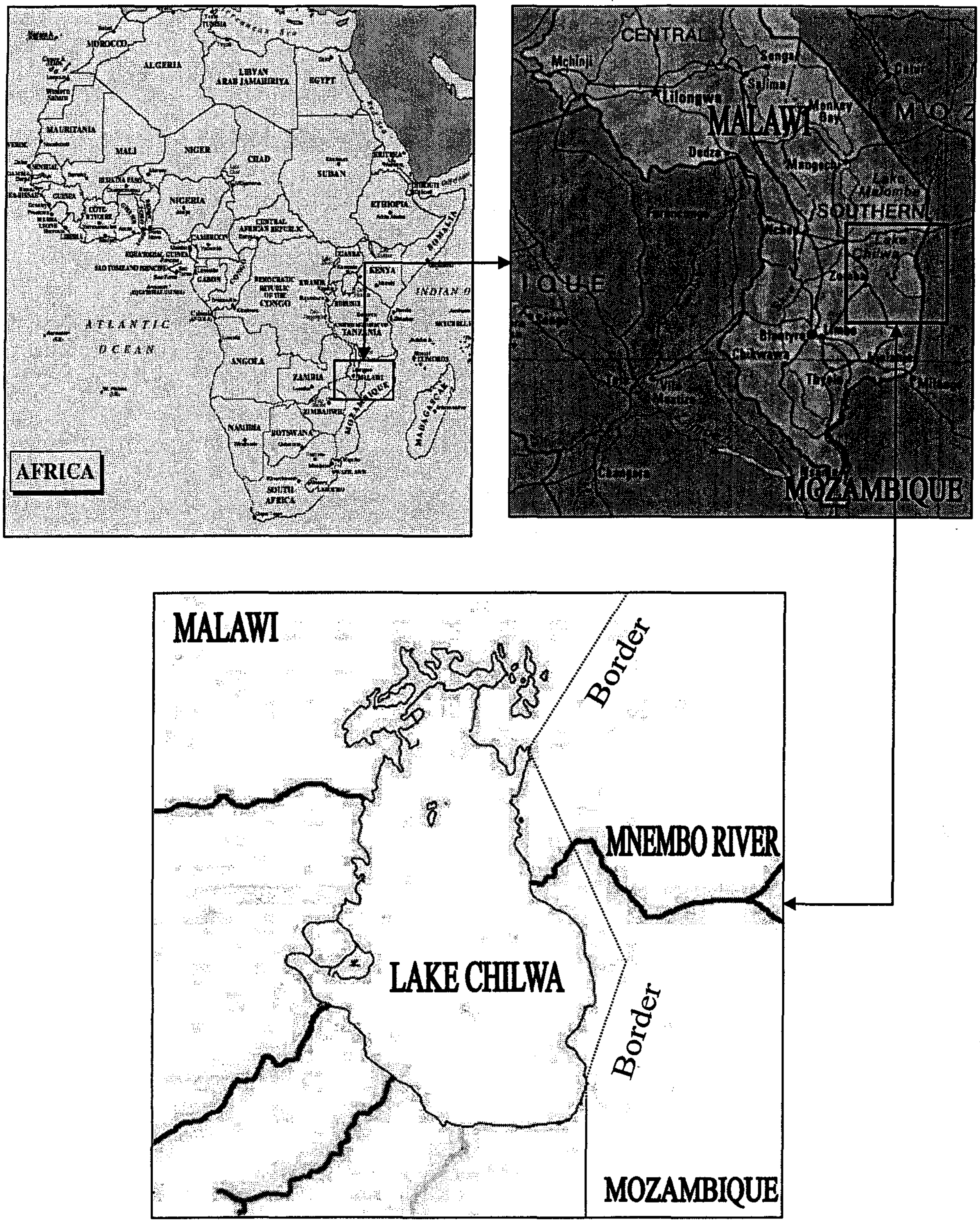


Figure 1.1 Map of Lake Chilwa and the Mnembo catchment.

of the lake level, with the annual flooding of the surrounding wetlands and runoff from the catchment basins contribute a high input of nutrients and make it a very productive system (Horne and Goldman 1994).

Lake Chilwa is low in fish species diversity with only 14 species, of which tilapias, clariids and small barbs (cyprinids of the genus *Barbus*) dominate. These species are prominent in the lake and in its tributaries because of drought resistant adaptations to extreme fluctuations in electrical conductivity, pH, dissolved oxygen and total suspended solid concentrations (Msiska 2001). Small barbs and clariids migrate seasonally between the lake and its tributaries, but during periods of lake level recession, some are then trapped near the outer edge of the lake in the marshlands, floodplains and rivers. Once water levels increase in the lake after the drought, the fishery is able to recover rapidly due to the fish populations that had remained in the watershed (Jamu and Brummett 1999) (Figure 1.2).

Biological investigations have determined the affinity of the fish fauna of Lake Chilwa to that in Lake Chiuta, including *Barbus paludinosus*, from the family Cyprinidae and *Haplochromis callipterus* (Gűnther), family Cichlidae. Lake Chilwa is approximately 35 km south of Lake Chiuta and is separated from it by an extensive sandbar. Both lakes were joined during the Shire Rift Valley development, but due to tectonic movements, began to separate with increasing fluvial and lacustrine sedimentation during the late Pleistocene (Lancaster 1979). The sub-species *Oreochromis shiranus chilwae* (Trewavas) is endemic to Lake

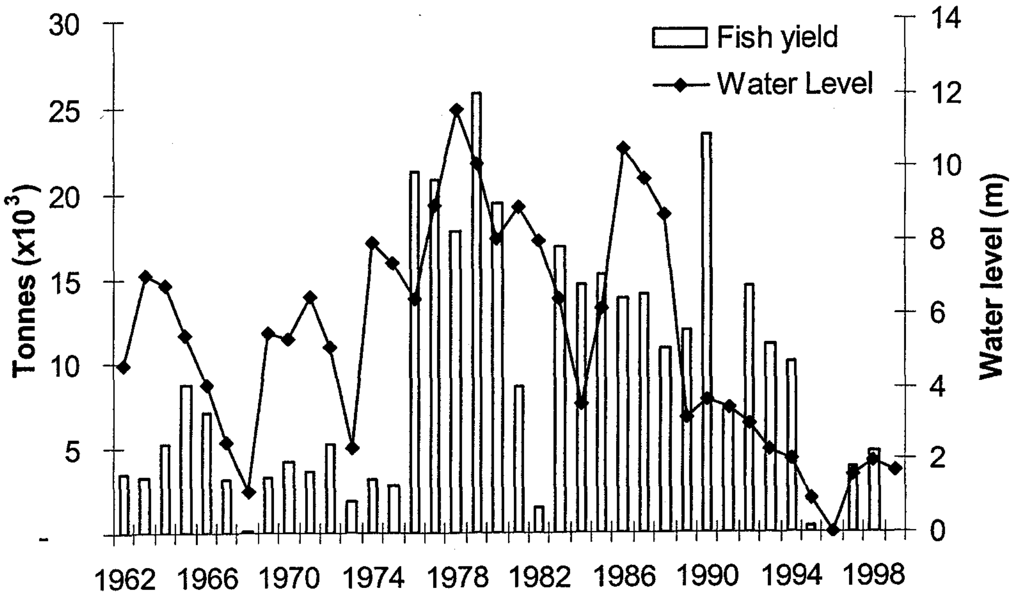


Figure 1.2 Total fish yield (metric tonnes) in Lake Chilwa in relation to water level (Jensen *et al.* 2000).

Chilwa. It evolved from *Oreochromis shiranus shiranus* (Boulenger), which is predominantly found in Lakes Malawi and Chiuta (Furse *et al.* 1979b). *Oreochromis. s. chilwae* is smaller than *O. s. shiranus*, and matures at a smaller size (Trewavas 1983). These differences have been attributed to the extreme environmental conditions characteristic of Lake Chilwa (Noakes and Balon 1982).

1.2 Project rationale for Mnembo study

Lake Chilwa and the surrounding wetland was declared a RAMSAR site on March 14th, 1997, and since that time management plans have been implemented within the watershed through the collaborative effort of the former Lake Chilwa Wetland and Catchment Project, the WorldFish Center and the Zomba District Assembly. The purpose of the collaboration was to monitor the impact of the catchment management plan on soil loss, the reproductive success of *Barbus* spp. and fish production within two of the lake's catchments: Domasi and Likangala. However, for the management plan to have a meaningful impact there was a need to scale up the study to other catchments of Lake Chilwa. Since previous studies were conducted on catchments in Malawi, it was important to expand the study area to the Mozambican side of the lake. Therefore, in 2003, land use patterns, river system flow patterns and the reproductive status of *Barbus* were characterized in the Mnembo catchment within the Lake Chilwa watershed. Little recent information was available on this large catchment due to the civil war in Mozambique from 1972 to 1992 which had severely curtailed studies on this Mozambican river basin.

The project titled ‘Lake Chilwa Catchment and Wetland Research: Linking Mnembo Catchment Processes and Fish Production in Lake Chilwa’ was developed to address the limitations and add further to the research conducted by Jamu and Brummett in 1999. In addition, our aim of the project was to gather baseline data from one of Lake Chilwa’s catchments where no data had been collected thus far. The current project consists of 3 separate research theses:

(1) Fish Community Ecology in Relation to Land Use and Lotic Parameters in the Mnembo River Catchment (Southern Africa) (Leanda Delaney, Canada)

(2) Influence of water quality/ food availability on seasonal and spatial distribution of *Barbus* spp. at the mouth of the Mnembo catchment in Lake Chilwa (Messias Macuiane, Mozambique)

(3) Geostatistical modelling of migratory fish populations of an influent river of Lake Chilwa, Malawi (Wouter Van Delm, Belgium)

The general objectives of my thesis were to quantify the reproductive state (Gonadosomatic index (GSI) levels) of *Barbus* spp. over one year of sampling and to describe the relationships between fish species abundance and diversity and water quality parameters in the Mnembo River. Then, additionally, to relate these fish and water quality factors to land use activities within the Mnembo River catchment. The more specific objectives were to:

- Analyze physio-chemical and hydrological parameters in the Mnembo over time

- Quantify the abundance and diversity of the fish community in the Mnembo River
- Biophysically quantify the variability between catchments of Lake Chilwa
- Develop a land use pattern map and associated rates of soil erosion within the catchment for the eventual dissemination of results to the surrounding village communities
- Analyze the association between land use patterns within the Mnembo catchment and river water quality, fish abundance and diversity, and the reproductive state of *Barbus*.

There are four major components to this thesis. Chapter 2 provides an introduction to the Mnembo River and the seasonal variations in the physio-chemical conditions of the river. Changes in water quality are evaluated over site and time and each site is analyzed and classified based on its unique assemblages of habitats. Comparisons are also made between three of Lake Chilwa's catchments: Domasi, Likangala, and Mnembo. In Chapter 3, the diversity, abundance and distribution of fish sampled in the Mnembo River are evaluated and analyzed with specific emphasis on time and spatial distributions, since little was known about the fish populations within the Mnembo River.

Chapter 4 uses the Soil Loss Erosion Model for Southern Africa (SLEMSA), to model sediment input patterns related to land use in the Mnembo River catchment (Chimphamba 2000). Chapter 4 also analyzes the influence of land use on river system health (river water quality parameters) and GSI levels in *Barbus* spp. The research examines these over both spatial and temporal scales.

In Chapter 5 village community activities within the Mnembo River and its catchment are evaluated through the analysis of village questionnaires and the two-day Participatory Rural Appraisal that was conducted with the assistance of the surrounding villages.

1.3 Location of sampling sites

The Mnembo River Catchment, located on the eastern side of Lake Chilwa, is located primarily in Mozambique. The research was coordinated from the WorldFish Center office in Malawi at the Malawi National Aquaculture Center, Domasi. Domasi is within the Lake Chilwa watershed and lies 78km west of the mouth of the Mnembo River on the Mozambican side of the lake. Sampling on the river was conducted once a month over three days. Sampling sites were selected based on accessibility, water depth and lack of human obstructions (i.e. permanent fish traps). Three major sample sites (designated as MSS1, MSS2 and MSS3) were selected and minor sample sites were designated approximately 250m upstream and downstream (MSS#U and MSS#D) of each major sample site (Figure 1.3) Each site was geographically positioned using a handheld Global Positioning System (GPS) (GPS 72 personal navigator, Garmin) (Table 1.1).

MSS1 was within Malawi and was approximately 1.8km north-east of the river mouth, whereas MSS2 and MSS3 were located further inland in Mozambique. All three sites were approximately 4km apart and were visually different (Figure 1.4). MSS1 is situated within the Lake Chilwa wetland and can be very difficult to reach by vehicle during the rainy season. The vegetation consists of short grasses and shrubbery around the river's edge with an abundance of instream vegetation. MSS2 is densely vegetated along the bank of the river with vegetation comprised mainly of tall grasses, large shrubs and trees. MSS3 is near the main road and the bridge that connects the district of Mecanhelas with the T/A (Traditional Authority) of Messossomera. Along the periphery of the river's edge tall grasses dominate. MSS3 also has instream vegetation and steeper bank slopes than the other two sites. At each major and minor sample sites limnological parameters were measured, excluding total suspended solids (TSS) which was only determined at the major sites. Fish biological parameters and their migratory behaviour were also only determined at the major sites (Table 1.2).

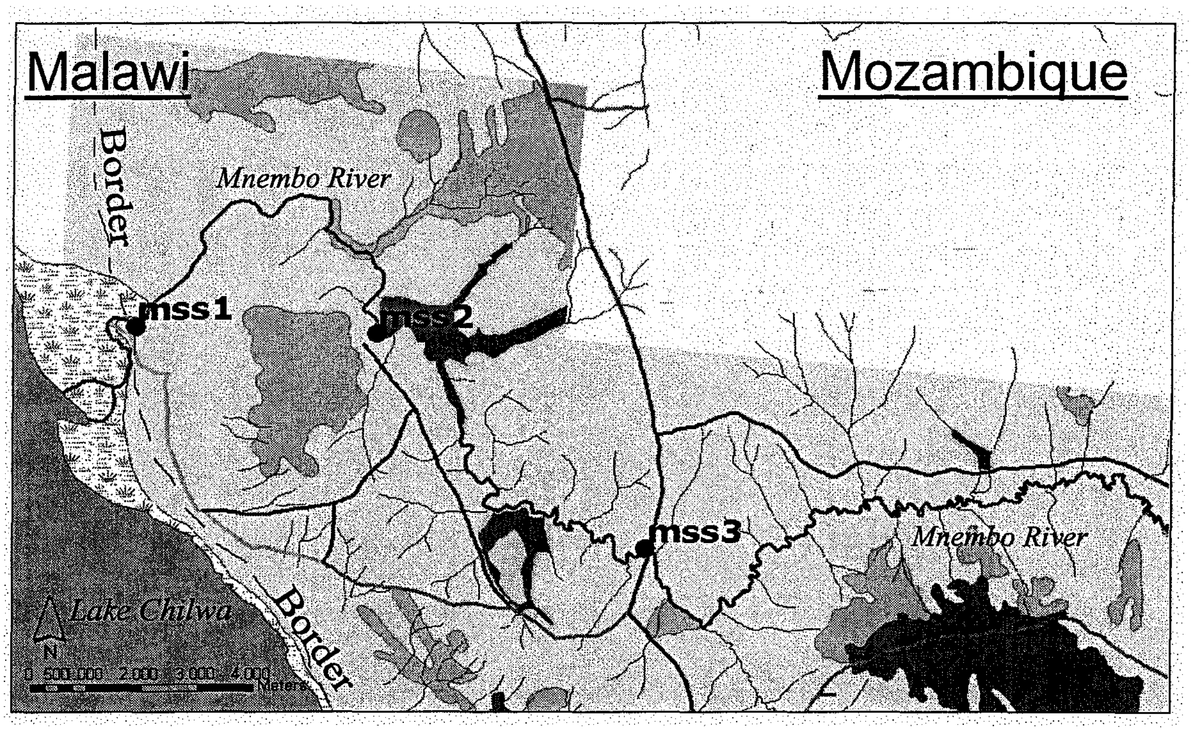


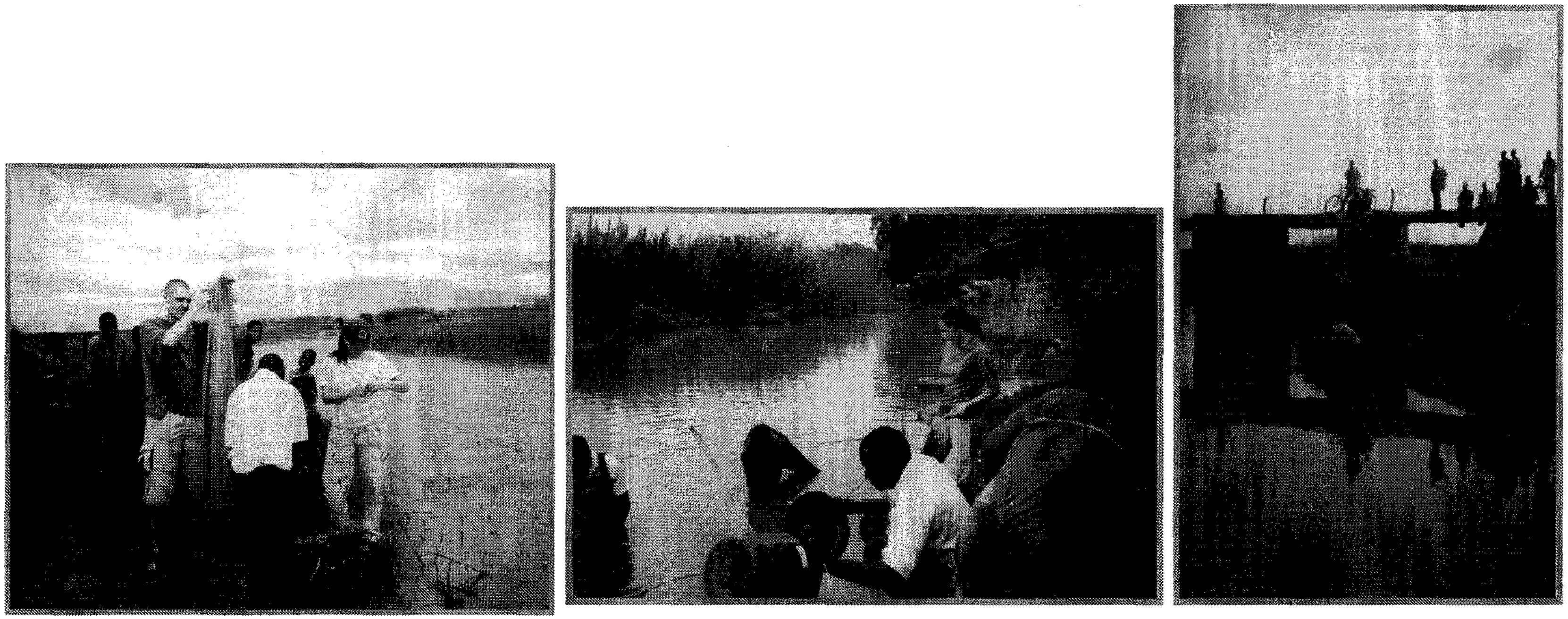
Figure 1.3 Location of major sampling sites (MSS#) along the Mnembo River.

Table 1.1. Universal Transverse Mercator (UTM) and latitude and longitude coordinates of the major and minor sampling sites, along the Mnembo River.

Sample site (MSS#)	Coordinates (UTM - 36 L)	Coordinates Lat and Long
1	0802225 8309918	15°16.166' 035° 48.826'
1U	0801955 8310149	15° 16.040' 035° 48.877'
1D	0801955 8309953	15° 16.148' 035° 51.237'
2	0806543 8309790	15° 16.204' 035° 51.237'
2U	0806750 8309823	15° 16.185' 035° 51.353'
2D	0806440 8310053	15° 16.063' 035° 51.178'
3	0811404 8305750	15° 18.358' 035° 53.981'
3U	0811504 8305516	15° 18.485' 035° 54.038'
3D	0811177 8305666	15° 18.406' 035° 53.854'

Table 1.2 Parameters measured and observed during each sampling visit to the Mnembo River from July 2003 to June 2004.

Grouped parameters	***Description***	***Location***
Physio-chemical measurements	pH	MSS# main sites, MSS# upstream and downstream
	Electrical Conductivity	MSS# main sites, MSS# upstream and downstream
	Dissolved Oxygen	MSS# main sites, MSS# upstream and downstream
	Temperature of water	MSS# main sites, MSS# upstream and downstream
	Total Suspended Solids	MSS# main sites
Fish biology	Species identification	MSS# main sites
	Weights of all fish sampled	MSS# main sites
	Total lengths of all fish sampled	MSS# main sites
	Standard length of all fish sampled	MSS# main sites
	Sex of *Barbus*	MSS# main sites
	Classification of *Barbus* gonadal maturity	MSS# main sites
Fish migratory direction	Lake to river (up)	MSS# main sites
	River to lake (down)	MSS# main sites
Habitat classification	River width	MSS# main sites, MSS# upstream and downstream
	River depth	MSS# main sites, MSS# upstream and downstream
	River velocity	MSS# main sites, MSS# upstream and downstream
	Classification of river substrate	MSS# main sites, MSS# upstream and downstream
	Classification of instream & bank vegetation	MSS# main sites, MSS# upstream and downstream
	Flow pattern of the river	MSS# main sites, MSS# upstream and downstream
	Visual estimate of human impact	MSS# main sites, MSS# upstream and downstream
Geo positioning	Global Positioning system. Geo-referencing of sites.	MSS# main sites, MSS# upstream and downstream



MSS1 **MSS2** **MSS3**

Figure 1.4 Photograph of each major sampling site within the Mnembo River, sampled monthly from July 2003 to June 2004.

Chapter 2

Seasonal Variations in the Physio-Chemical and Hydrological Characteristics (Limnological Parameters) of the Mnembo River

2.1 Introduction

Lake Chilwa is the second largest lake in Malawi and is considered to be in one of the hottest regions in the country with temperatures ranging from 32 to 34°C during the hot season and from 20 to 24°C during the cool season (Msiska 2001). The lake is shallow and endorheic and can experience extreme fluctuations in water quality including such variables as alkalinity, conductivity and dissolved oxygen depending on rainfall (McLachlan *et al.* 1972). Its five major influent rivers are the Domasi, Likangala, Mnembo, Phalombe and Sombani; however, it is suspected that the Mnembo which flows from Mozambique is the lake's major source of water (Jamu pers.com. 2004).

The major Malawian tributaries, the Domasi and the Likangala, in addition to the Mnembo, are considered to have the greatest influence on the limnological condition of the lake (Jamu pers coms. 2004). The habitats through which the three rivers flow are influenced by different anthropogenic factors. The drainage area for the Mnembo River is mainly comprised of subsistence farming of rice, tobacco and maize and does not drain large urban centres or areas of intensive agriculture (see Chapter 4). The Likangala River is primarily influenced by the municipal waste dumped into it from the densely populated town of Zomba. The Domasi River catchment is different than that of the Likangala and Mnembo rivers because it has a large percentage of dense woodlands at its headwaters; it does, however, drain smallholder cropland and, like the Likangala, is heavily diverted for the extensive rice irrigation scheme east of Zomba (Jamu and Brummett 1999; Sambo *et al.* 1999).

Jamu *et al.* (2003) concluded that because of the proximity of the Likangala River to the town of Zomba, its water quality with respect to suspended sediments and conductivity levels was markedly poorer than that of the Domasi River. They also speculated that the water quality of the Domasi and Likangala Rivers was significantly worse than the Mnembo River; however, no research had been conducted on the physio-chemical and hydrological characteristics of the Mnembo. Therefore, the objectives of this part of the study are to describe the physio-chemical and hydrological parameters of the Mnembo River over a period of 12 months, and 3 sites and to compare these with conditions in the Domasi and Likangala Rivers.

2.2 Material and methods

2.2.1 Physio-chemical water sampling

At each major and minor sampling site, pH, dissolved oxygen, conductivity and air and water temperature were measured using a multi-parameter water quality meter (WTW multi-parameter kit, Cole Parmer) during the morning of each day of sampling (Table 1.2; Chapter 1). Daily rainfall data were taken throughout the year using a rainfall gauge located within the catchment approximately 2km from the Mnembo River.

From each main site on the river, three 500ml water samples were collected in clean Nalgene bottles and transported back to the WorldFish Center laboratory for analysis of total suspended solids (TSS). Standard methods were used, and an average was taken of all three water samples per site to obtain the average TSS for that site (Eaton *et al.* 1995). For each water sample, an aliquot of 400 ml was filtered through a pre-weighed 47 mm GF/C (1.2µm) filter (weight B), followed by 20 ml of distilled water. The paper was then placed in an aluminium dish and dried in an oven for one hour at 105°C (weight A). The calculation used to determine TSS was as follows:

$$\text{mg total suspended solids/L} = \frac{(A-B) \times 1000}{\text{Sample volume, ml}} \qquad \text{(Eaton } et\ al. \text{ 1995)} \qquad (2.1)$$

Where, A = weight of filter paper + dried residue, mg
B = weight of filter paper, mg

2.2.2 Hydrological and habitat classification

River width, depth and flow rate were taken at all sampling sites during each field visit. Width of the river was measured from the edge of the water on both sides, while depth was measured in the middle deep channel (thalweg) of the river. River flow was taken mid-water, three times at each site at one-minute intervals, using a hand-held flow-meter to determine mean flow (Geopacks). The following equation was used to calculate the actual rate of flow or river velocity.

Water velocity (V) (m/s) = $(0.000854C) + 0.05$ (Geopacks 2002) (2.2)

Where C represents the counts taken by the meter per minute.

The average river velocity and discharge measured at each sampling site was the average of the major and minor sampling sites. Estimated relative discharge was calculated as:

Discharge (m^3/s) = *Width (m) x average Depth (m) x average river flow (m/s)* (2.3)

Substrate, vegetation coverage and river flow were visually classified once in September/ October 2003 and once in February/ March 2004. The purpose was to qualitatively describe the changes in each habitat with the changes in the seasons Substrate was classified as a percentage of the riverbed. The classification of vegetation coverage was taken as an estimate, with each side of the river representing 50 percent of a 100 meter section up and downstream at each major sampling site (FAO-ISIRC 1990). To fully classify the habitat, river flow characteristics were also evaluated. The classification schemes for each habitat characteristic are shown in Table 2.1.

2.2.3 Statistical Procedure

Limnological parameters were assessed for normality through visual inspection of normal probability plots generated using the Minitab statistical software package version 13.2 (2000). All physio-chemical and hydrological parameters including DO, EC, TSS, pH, water temperature and discharge that were not normally distributed were log transformed. Normality was sufficiently improved for each parameter after the data were log transformed. For comparison between sites each parameter (except TSS) was statistically analyzed using Repeated Measures ANOVA which was performed in the SPSS for Windows statistical program (SPSS 2001). The non-parametric Friedman test was applied to TSS because only one observation was made at the major sample site each month (Dytham 2003). All regression models were evaluated using the statistical package Minitab (2000).

The Domasi and Likangala catchments were sampled over 12 months from November 1999 to October 2000 (Jamu *et al.* 1999), while the Mnembo was also sampled over 12 months, from July 2003 to June 2004. Total monthly rainfall

Table 2.1 Visual classification schemes for vegetation coverage, substrate and river flow characteristics applied to each designated site in the Mnembo River from July 2003 to June 2004 (FAO-ISIRC 1990).

Habitat characteristics	Classes	Description
Vegetation Coverage (%)	Trees	
	Grasses	
	Cultivated garden	
	Built-up area	Houses, buildings
	Shrubs	--
	None	No vegetations
Substrate Type (%) (diameter, cm)	Boulder	20 – 200
	Cobble	6 – 20
	Gravel	2 – 6
	Sand	0.2 – 0.6
	Silt	0.06 – 0.2
	Clay	>0.06
River flow characteristics (%)	Pool	No flow, stagnant waters
	Slow run	Continuous slow flow
	Fast run	Continuous fast flow
	Rapids	Fast and turbulent flow
	Riffle	Slow and turbulent flow

for 1999-2000 (903.1 mm) was not significantly different from the total monthly rainfall (844.5 mm) measured in the Mnembo catchment from 2003-2004 (one-way ANOVA, $F_{1,13}$=0.14, P=0.719). Since, however, the timeframe was not the same for all three catchments; the non-parametric Kruskal-Wallis for multiple comparisons test was applied (assuming that environmental conditions between rivers were similar at the time of sampling). The monthly data sets from the Mnembo, Domasi and Likangala Rivers were also not normally distributed (except for TSS) and normality was not improved after log transformation, therefore the non-parametric Kruskel Wallis for multiple comparisons test was applied. For seasonal comparisons between the rivers, a one-way ANOVA was applied to the normally distributed datasets (Minitab 2000). Data for TSS in the Domasi (n=6) and Likangala (n=6) were only available from November 1999 to May 2000 and were compared to the TSS concentrations measured in the Mnembo (n=6) from November 2003 to May 2004 using a Kruskal-Wallis test (Minitab 2000). A seasonal comparison of TSS was not conducted because only two seasons were represented (wet/hot and wet/warm) for the Domasi and Likangala Rivers.

2.3 Results

2.3.1 Hydrological and habitat characteristics

The Mnembo River catchment experiences four seasons with respect to rainfall and air temperature (Table 2.2). The seasons are the dry/hot (August to October), wet/hot (November to January), wet/warm (February to April) and the dry/cool (May to July).

MSS1, the site located near the mouth of the river, was the deepest site with maximum depths (3.14 m) measured in May, at the beginning of the dry and cool season and minimum depths (2.23 m) experienced near the end of the same season (July). For both MSS2 and MSS3, minimum depths were recorded in November and maximum depths in February. This also coincided with the minimum and maximum width of the river (Figure 2.1 a and b).

Table 2.3 describes the physical variations between each site based on their distance from the mouth of the river, substrate characteristics, percentage of instream and bank vegetation and river flow characteristics. MSS1 had the greatest percentage of instream vegetation, which was comprised of tall grasses (40% coverage). MSS2 had the highest bank vegetation cover and larger within stream substrate of boulders and cobble. Both MSS2 and MSS3 flow characteristics changed with the onset of the rains from a pool to a fast flow and from a pool to a riffle, respectively, however MSS1 maintained its steady flow throughout the season.

Table 2.2 Seasonal variability in rainfall and average air temperatures in the Mnembo catchment from July 2003 to June 2004.

Seasons	**Months**	**Total monthly rainfall (mm)**	**Average temperature (°C)**
Dry/hot	Aug -Oct	26	30
Wet/hot	Nov - Jan	148	28
Wet/warm	Feb - Apr	108	26
Dry/cool	May - July	0	21

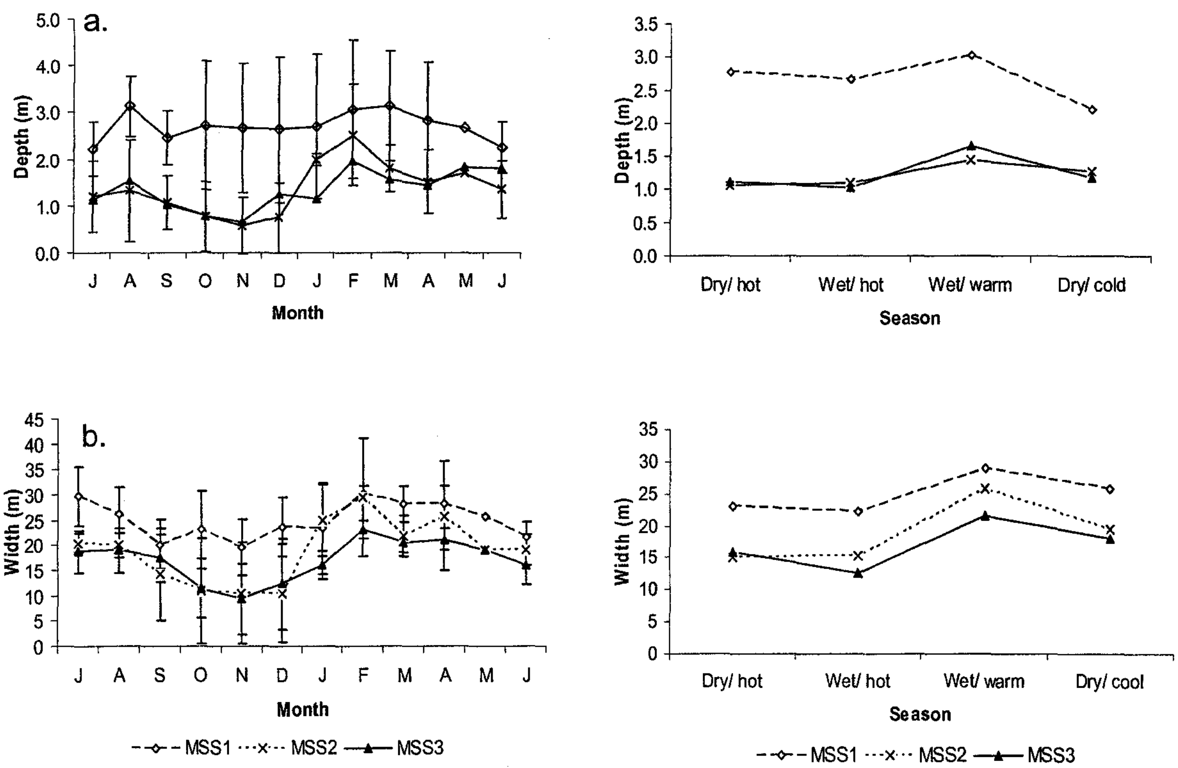


Figure 2.1 (a.) Monthly (left) and seasonal (right) variability of depth measured in the Mnembo River from July 2003 to June 2004. (b.) Monthly (left) and seasonal (right) variability in width measured in the Mnembo River from July 2003 to June 2004. Bars represent standard deviation around monthly means. *Seasons: Dry/hot (Aug. to Oct.), wet/hot (Nov. to Jan.), wet/warm (Feb. to Apr.) and dry/cool (May to July).*

Table 2.3 Habitat characteristics classified at each sampling site designated along the Mnembo River from July 2003 to June 2004.

Habitat Characteristics	MSS1	MSS2	MSS3
Distance from river mouth (km)	1.8	4.2	10.1
Substrate type	Clay/ silt	Boulder/cobble/ sand	Cobble/ gravel
Instream vegetation (% cover)	40	10	15
Bank vegetation (% cover)	50	75	50
Bank vegetation types	Grass	Trees/shrubs	Tall grasses/ shrubs
Flow characteristics*			
Dry seasons	Slow flow	Pool	Pool
Wet seasons	Slow flow	Fast flow	Riffle

* Variations in flow characteristics are related to the dry and wet seasons.

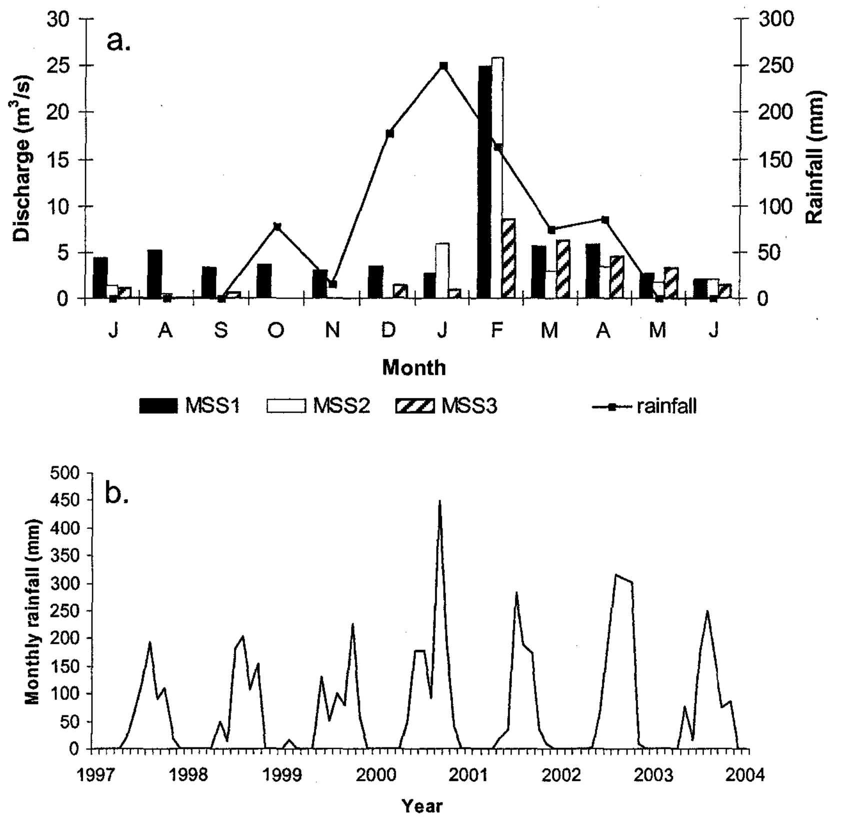


Figure 2.2 (a.) Mean monthly discharge (m^3/s) for the Mnembo River and monthly rainfall (mm) within the catchment from July 2003 to June 2004. (b.) Monthly rainfall measured in the Mnembo catchment from January 1997 to June 2004 (Dept. of Agriculture 2004).

Table 2.4 Analysis of seasonal between-site differences (MSS1, 2 and 3) of the physio-chemical parameters in the Mnembo River. Differences analyzed using Repeated Measures ANOVA. Level of significance 0.05.

Parameter	**Mean**	**±SD**	**$F_{2,5}$**	**p**
Discharge (m^3/s)	3.8	5.2	0.58	0.59
pH	7.2	0.4	1.52	0.29
DO (mg/l)	4.7	1.1	1651.82	0.00
Conductivity (µS/cm)	169.5	66.9	2.43	0.17
Water temp. (^oC)	23.9	3.2	0.47	0.67

During the dry seasons there was only flow at MSS1, and on average, the discharge at this site measured 5.54 m^3/s (Figure 2.2a). Once the rainy season began the greatest increase in discharge was at MSS2 in February 2004. The flow increased from a standing pool to 25.8 m^3/s. For site MSS3, there was a gradual increase in discharge during the rainy season.

2.3.2 Physio-chemical characteristics

All measured parameters (dissolved oxygen, conductivity, pH, water temperature, total suspended solids and discharge) showed monthly and seasonal variability, however, only dissolved oxygen (DO) concentrations were significantly different between sites (Table 2.4). The *a posteriori* Tukey test indicated that DO concentrations at MSS1 were significantly lower than at MSS2 and MSS3 (p-value 0.0191). MSS3 displayed the greatest variability in DO concentrations over time (Figure 2.3). However, the highest monthly recorded DO concentrations for all sites were measured during the dry/cool season and the lowest concentrations of DO were recorded during the wet/hot season (Figure 2.3 and Table 2.5).

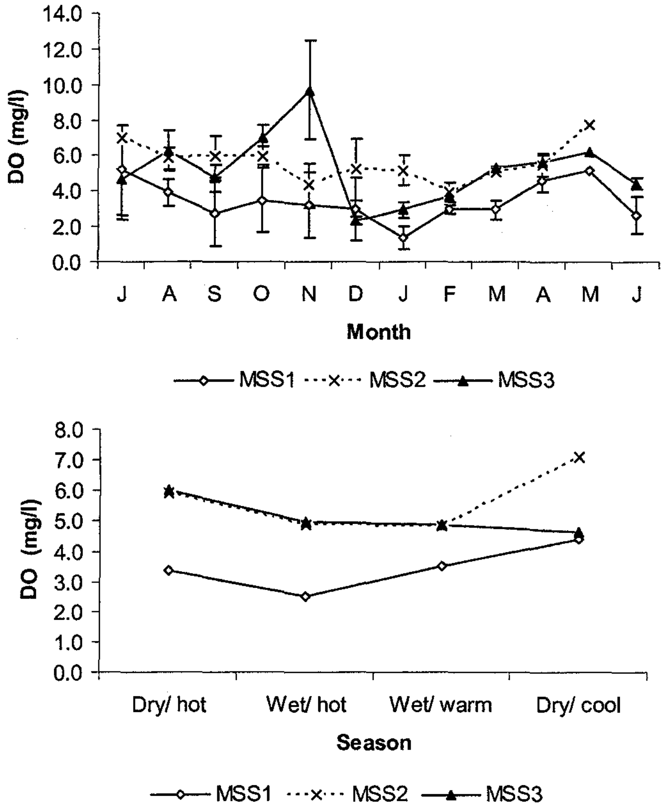


Figure 2.3 (top) Monthly variations in DO measured at each site in the Mnembo River from July 2003 to June 2004. (bottom) Seasonal variations of DO in the Mnembo River from July 2003 to June 2004. Bars represent standard deviation around monthly means. *Seasons: Dry/hot (Aug. to Oct.), wet/hot (Nov. to Jan.), wet/warm (Feb. to Apr.) and dry/cool (May to July).*

Table 2.5 Maximum, minimum and average DO concentrations measured in the Mnembo River at each-site from July 2003 to June 2004.

Site	Min. value (mg/l)	Max. value (mg/l)	Mean (mg/l)
MSS1	1.38 – Jan	5.21 – July	3.30
MSS2	3.94 – Feb	7.69 – May	5.82
MSS3	2.35 – Dec	9.68 – Nov	6.01

From July to November 2003, conductivity increased gradually until December when it declined by almost 50 percent at MSS1 and MSS3 (Figure 2.4a). The minimum conductivity levels recorded for all three sites were in February with an average of 97 μS/cm. The maximum was in November and December with the three sites having an average of 271 μS/cm. There was little variation in pH between sites or over time, however seasonal trends were evident (Figure 2.4b). The average throughout the year was 7.2 with a range from 6.7 in February and 7.7 in November. Monthly TSS concentrations were significantly different between sites (Figure 2.4c; $S_{adjusted}$= 0.010). Median TSS concentrations were much higher at MSS1 (0.023mg/l) than at MSS2 (0.008mg/l) and MSS3 (0.007mg/l).

A correlation matrix was performed on all water quality parameters measured in the Mnembo River from July 2003 to June 2004 and all significant correlations ($p<0.05$) are displayed in Table 2.6 and Table 2.7. Conductivity was negatively correlated with discharge at MSS2 and MSS3 (Table 2.6) and with the mean value of all three sites (Table 2.7) which represented the water quality of the entire Mnembo River (r = -0.895, -0.800 and 0.828, respectively). Recorded pH was also highly correlated with discharge (Table 2.7). Excluding MSS1, conductivity was strongly correlated with discharge ($p<0.05$) at each site. Rainfall was highly correlated with TSS at MSS2, MSS3 and Mean River (r = 0.866, 0.714 and 0.665, respectively).

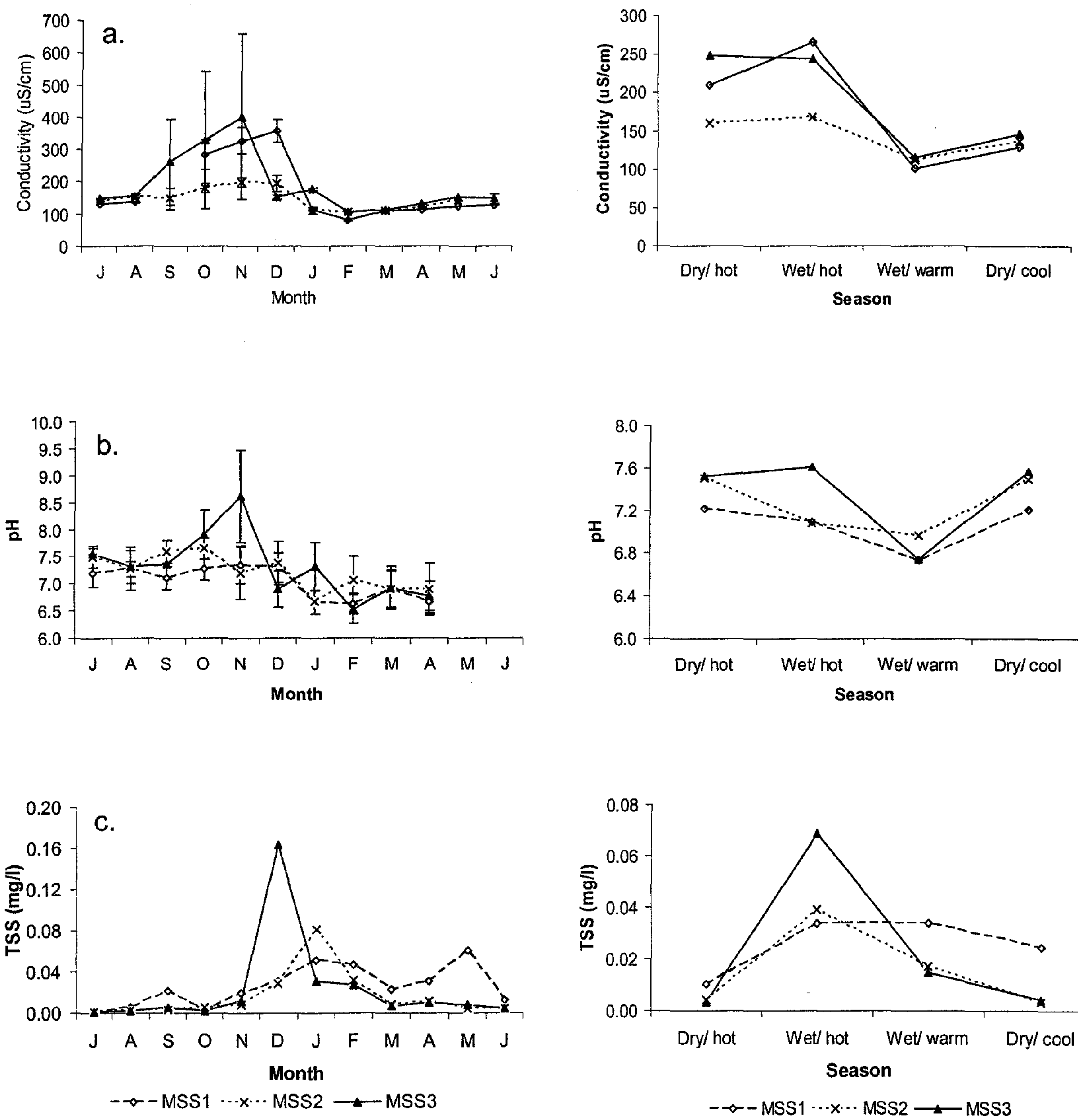


Figure 2.4 Monthly (left) and seasonal (right) variation at each site for (a.) conductivity, (b.) pH and (c.) TSS in the Mnembo River from July 2003 to June 2004. Bars represent standard deviation around the monthly means for conductivity and pH. *Seasons: Dry/hot (Aug. to Oct.), wet/hot (Nov. to Jan.), wet/warm (Feb. to Apr.) and dry/cool (May to July).*

Table 2.6 Significant Pearson correlation coefficients ($p<0.05$) and associated p-values for comparisons between all limnological parameters measured monthly at each-site in the Mnembo River from July 2003 to June 2004.

Site	Variable 1	Variable 2	r value	p-value
MSS1	pH	Conductivity	0.793	0.01
		TSS	-0.781	0.01
	Temp (H_2O)	Rainfall	0.780	<0.01
		DO	-0.613	0.03
MSS2	Conductivity	Discharge	-0.895	0.01
		pH	0.671	0.03
	Temp. (H_2O)	DO	-0.644	0.03
	TSS	Discharge	0.743	0.04
		DO	-0.649	0.04
	Rainfall	Discharge	0.814	0.01
		DO	-0.609	0.04
		TSS	0.866	<0.01
		Temp. (H_2O)	0.632	0.04
MSS3	Conductivity	pH	0.896	0.00
		Discharge	-0.800	<0.01
		DO	0.621	0.03
	pH	Discharge	-0.803	0.01
		DO	0.752	0.01
	TSS	Rainfall	0.714	0.01
		DO	-0.591	0.04

Table 2.7 Significant Pearson correlation coefficients ($p<0.05$) and associated p-values for mean comparisons of all three-sites between limnological parameters measured monthly in the Mnembo River from July 2003 to June 2004.

Variable 1	**Variable 2**	**r value**	**p-value**
Conductivity	Discharge	-0.828	<0.01
pH	Conductivity	0.853	0.00
	Discharge	-0.851	,<0.01
	DO	0.648	0.04
Rainfall	TSS	0.866	<0.01
	DO	-0.591	0.04
	Temp. (H_2O)	0.680	0.02

2.3.3 Comparison between river catchments

For each limnological parameter measured in the Mnembo River, the means of the 3 sites were used in the comparison between the three catchments: Domasi, Likangala and Mnembo (Appendix 1). Comparisons were made based on both mean monthly (n= 12 per river) and mean seasonal (n = 4 per river) data for the three catchments. Mean monthly conductivity and pH were significantly lower in the Mnembo River than in the Domasi and the Likangala (Table 2.8) and similar results were found with the seasonal comparisons of the three rivers (Table 2.9). Monthly TSS concentrations were significantly lower in the Mnembo (0.033mg/l) than in the Likangala (0.088mg/l) but TSS concentrations in the Mnembo were not significantly different from the Domasi (0.074mg/l).

The comparative analysis of the monthly pattern of discharge showed no significant differences between rivers as a probable consequence of extreme monthly variations. Trends were made clearer and significant differences were observed using seasonal mean data (Table 2.9, One-way ANOVA, $F_{2,6}$= 5.29, p= 0.030). Mean seasonal discharge was significantly higher in the Mnembo (3.8m^3/s) than in the Domasi or the Likangala rivers (1.8 and 2.2 m^3/s, respectively) primarily during the wet/warm season when the volume of discharge in the Mnembo was 72% greater than in the Likangala and 71% greater than in the Domasi (Figure 2.5b). However, total monthly rainfall between the Mnembo (107.8mm) and the Domasi/ Likangala (115.4mm) catchments displayed no marked difference during the same season.

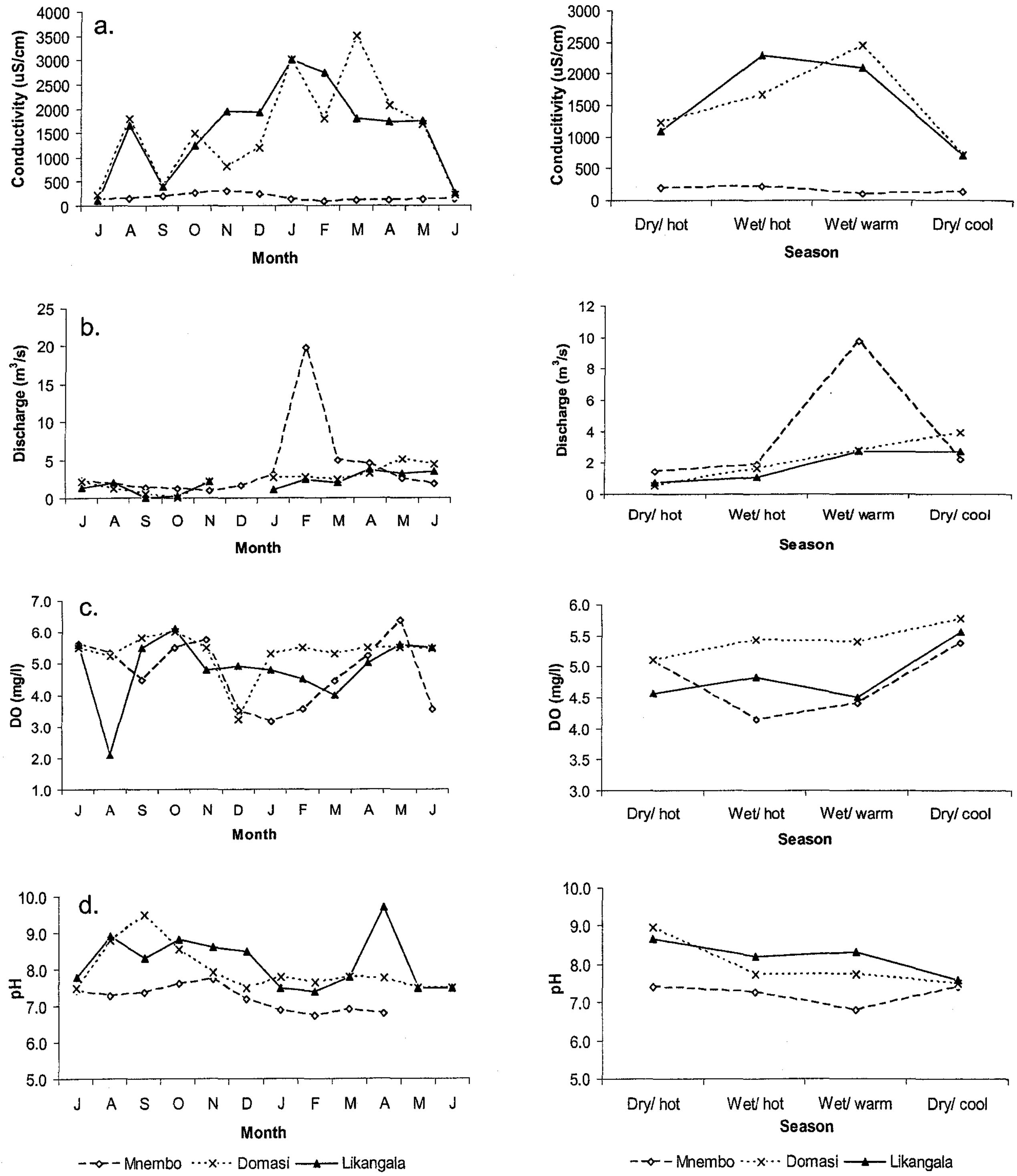
Table 2.8 Monthly comparisons of conductivity, DO, pH, TSS and discharge in the Mnembo River (from 2003-2004) with the Domasi and Likangala (from 1999 to 2000) using the Kruskal-Wallis multiple comparison non-parametric test. Lines connect values that are not significantly different as tested by *a posteriori* Tukey tests. *Total suspended solids, n=21

Variable	p-value (n=36)	Mnembo	Likangala	Domasi
Conductivity (*µS/cm*)	<0.001	138	1738	1576
DO (*mg/l*)	0.120	4.8	5.0	5.5
pH	0.001	7.2	8.1	7.8
Discharge (*m^3/s*)	0.742	3.1	2.1	2.4
TSS (*mg/l*)*	0.018	0.033	0.088	0.074

Table 2.9 Comparison of seasonal means in conductivity, DO, pH and discharge between the Mnembo (from 2003 to 2004), Domasi and Likangala (from 1999 to 2000) Rivers using a one-way ANOVA and *a posteriori* Tukey multi-comparison test. Lines connect values that are not significantly different as tested by *a posteriori* Tukey tests.

Variable	$F_{2,6}$	p	Mnembo	Domasi	Likangala
Conductivity (*µS/cm*)	6.53	0.018	169	1513	1548
DO (*mg/l*)	2.38	0.148	4.7	5.4	4.9
pH	4.34	0.048	7.2	8.0	8.2
Discharge (*m^3/s*)	5.29	0.030	3.8	2.2	1.8

Figure 2.5 Monthly (left) and seasonal (right) variability in the rate of discharge (a), conductivity (b), dissolved oxygen (c) and pH (d) in the Mnembo, Domasi and Likangala Rivers. *Seasons: Dry/hot (Aug. to Oct.), wet/hot (Nov. to Jan.), wet/warm (Feb. to Apr.) and dry/cool (May to July).*



a.
Conductivity (uS/cm)
4000 3500 3000 2500 2000 1500 1000 500 0
J A S O N D J F M A M J
Month
3000 2500 2000 1500 1000 500 0
Dry/ hot Wet/ hot Wet/ warm Dry/ cool
Season
b.
Discharge (m³/s)
25 20 15 10 5 0
12 10 8 6 4 2 0
c.
DO (mg/l)
7.0 6.0 5.0 4.0 3.0 2.0 1.0
6.0 5.5 5.0 4.5 4.0 3.5 3.0
d.
pH
10.0 9.0 8.0 7.0 6.0 5.0
Mnembo Domasi Likangala

2.4 Discussion

2.4.1 Physio-chemical and hydrological characteristics of Mnembo River

The Mnembo catchment experiences four distinct seasons (dry/hot, wet/hot, wet/warm and the dry/cool) based on temperature and total monthly rainfall. It is influenced by the inter-tropical convergence zone (ITCZ) and associated southeast trade winds, its proximity to the very shallow Lake Chilwa and its placement on the low-lying plains of the Lake Chilwa watershed (Msiska 2001; Mudolole and Chavula 1999). In general, Malawi experiences three major seasons: the hot and wet (November to March), cool and dry (April/ May to August) and the hot and dry season (September to November). However, local air movements have created microclimates around Lake Malawi (Msiska 2001), and in this case, Lake Chilwa and its watershed. The four distinct seasons in the Mnembo catchment strongly influence river water dynamics.

Annual variation in pH and conductivity in the Mnembo was similar across sites; with a peak in November (end of dry/hot season) before river depth had significantly increased as a result of increased rainfall. Due to evaporation, ionic concentration increased in the Mnembo River over the dry seasons when river flow had slowed or completely stopped and water levels had decreased, thus resulting in an increase in conductivity and pH (Caruso 2002). Conversely, in December, conductivity and pH began to decrease as water levels increased and ion concentration was diluted (Moss 1979).

MSS3 was heavily utilized by humans and was situated near a frequently used bridge. It was the main site where villagers from the surrounding communities washed clothes, bathed and planted their gardens (dimbas). Fertilizer usage in the dimbas was not thought to be an influential factor at MSS3 because several villagers stated that fertilizers were too expensive (Delaney, pers. obs. 2004). During the wet/hot season (November, December and January) the peaks measured in pH, conductivity and TSS were higher (Figure 2.4 a-c) at MSS3 than at MSS1 or 2.

MSS2 was also a popular site for bathing and washing clothes, however there were no major roads, bridges or footpaths to intensify disturbance (through soil erosion) at the site once the rains had begun (Dunne 1979). At MSS1, there were major footpaths and a boat transport service that gave people access to both sides of the river. No spikes in pH, conductivity, DO and TSS were observed at MSS1 and MSS2 as at MSS3 (Figure 2.4). This was likely related to the two prominent marshlands situated near MSS2 and not due to human disturbance. Marshes and swamps are excellent sediment and nutrient traps, which likely caused suspended sediment to settle out of the lower part of the Mnembo River. Dissolved oxygen concentrations in the river were also most likely lowered through plant decomposition within the marshlands. As a result, hydrogen ion concentrations could have increased thereby causing electrical conductivity and pH to decrease in the water before reaching MSS2 and MSS1 (Hecky *et al.* 2003; Horne and Goldman 1994; Howard-Williams and Howard-Williams 1978). The pH in the Mnembo River was relatively neutral throughout the year with the greatest seasonal variability occurring during the wet/hot and wet/warm seasons.

Osmundson *et al.* (2002) suggested that suspended sediment in the water column significantly increased in the Colorado River with river flow. Although there was a lack of correlation between discharge and TSS concentrations at MSS1, TSS was highly correlated with rainfall at MSS2, MSS3 and for the entire river. This would suggest that in the Mnembo River, it was the increase in rainfall which increased discharge and ultimately TSS concentrations. Rainfall also prompted the agricultural growing season in the catchment and potentially increased TSS concentrations through erosion at the beginning of the planting season (November). But once vegetation was firmly established (February), nutrients and sediment were most likely retained and the rate of erosion from the catchment reduced. Ground water and the influx of water from higher elevations could also have increased river flow however neither were accounted for during this study.

Dissolved oxygen (DO) concentrations at MSS1 were significantly lower than at MSS2 and 3. At the mouth of every catchment of Lake Chilwa, typha swamps (*Typha australis, Pragmites mauretanus, Vossia cuspidate* and *Cyprus* spp.) dominate (Cantrell 1988; Moss and Moss 1969). MSS1 was situated near a typha marsh, with its large volumes of decomposing vegetation and high biological oxygen demand (BOD). Thus it was not surprising that DO was significantly lower at this site. The lack of a fast flow at MSS1 might have minimized diffusion of atmospheric oxygen across the air/ water interface (Horne and Goldman 1994).

As expected, river depth increased dramatically once the rains began, but during the dryer seasons, flow was very slow or there was no flow measured. The rate of discharge increased considerably by February during the wet/warm season. However, in the Mnembo River, the estimated relative discharge was low compared to previous years because the annual rainfall for the 2003/ 2004 season was only 844mm. This was approximately 30% below the average for the last five seasons (Figure 2.2b).

Variation in the measured parameters is controlled by lithological, climatological, vegetative, land use and hydrological factors (Wolock *et al.* 1989). In the Mnembo River total monthly rainfall was likely the dominant factor that influenced the physio-chemical and hydrological factors. With the exception of DO, the physio-chemical condition of the Mnembo River was more related to climatological and hydrological variability rather than the vegetation composition present along each site. The effect of land use on the limnological condition of the Mnembo River will be explored further in Chapter 4.

2.4.2 Comparison between river catchments

Comparisons between catchments indicated that conductivity, pH, and TSS were significantly lower in the Mnembo than in the Domasi and Likangala rivers. This possibly indicates better river system health for human populations, given the greater size of the Domasi (440 km^2) and Likangala (474 km^2) compared to the Mnembo catchment (approx. 400 km^2). Moreover, during the wet/warm season discharge was significantly higher in the Mnembo River than in the other two catchments (Table 2.9). The Domasi and Likangala catchments are situated in the densely populated country of Malawi. They are extensively diverted for smallholder and commercial purposes and large quantities of natural vegetation have been removed for urbanization, land cultivation and charcoal production (Dunne 1979). The Mnembo River has also been diverted for agricultural purposes, but has not been influenced by urbanization because of the lower population density (catchment density of 17 persons km^{-2}; Dept. of Agriculture 2004). According to the 1998 population census conducted by the Department of Statistics of Malawi, there were over a half million people residing in the Lake Chilwa basin (catchment density of 93 persons km^{-2}) (Ngulube *et al.* 1999; Population Reference Bureau 2004). Despite the differences when parameters were measured in each river, it can be argued that there was some validity in these comparisons, especially since there was similar total annual rainfall between the years. Given this, the observed differences in physio-chemical and hydrological conditions between the three catchments and the difference in population pressures suggest that human activity has had less impact on river health in the Mnembo River.

Chapter 3

Abundance and Distribution of Fish in the Lower Mnembo River

3.1 Introduction

Fish abundance and diversity in tropical rivers are affected by a complex of hydrological, climatological, anthropogenic, and landscape factors within the watershed (Lowe-McConnell 1987; Mathews 1998; Welcome 2003). Details of a large variety of more specific factors related to food availability, predation, water quality, flood regimes, fishing pressures, physical habitat characteristics and land use activities within a catchment basin was summarized by Mathews (1998). An understanding of these ecological factors may help explain the changes in fish abundance, diversity, distribution, community structure and species interactions resulting from increasing human impacts within tropical river catchments.

Fish families existing in Lake Chilwa are Alestiidae (*Brycinus imberi* (Peter,1852) and *Hemigrammopetersius barnardi* (Herre, 1936)), Cichilidae (*Pseudocrenilabrus philander philander* (Weber,1897), *Oreochromis shiranus chilwae* (Trewavas,1966), *Tilapia rendalli* (Boulenger,1897) and *Haplochromis calliptera* (Günther,1894)), Clariidae (*Clarias gariepinus* (Burchell,1822) and *Clarias theodorae* Weber,1897), Cyprinidae (*Barbus paludinosus* Peters,1852, *B. trimaculatus* Peters,1852 and *Labeo cylindricus* Peters,1862), Mormyridae (*Marcusienis macrolepidotus* (Peters,1852) and *Petrocephalus catastoma* (Günther,1866)) and Schilbeidae (*Pareutropius longifilis* (Steindachner,1914)). Each species exploits Lake Chilwa's rivers and swamps, including its major inflows - the Likangala, Domasi, Phalombe, Sombani and Mnembo, as potential spawning areas and refugia during periods of lake desiccation (Jamu and Brummett, 1999).

Studies have been conducted on two of Lake Chilwa's river catchments in Malawi (Jamu and Brummett 1999; Jamu *et al.* 2003). However, due to the civil war in Mozambique no recent research has been done to evaluate fish species abundance, diversity or their distribution in the Mnembo River. Therefore, from July 2003 to June 2004 a study was conducted on the Mnembo River to collect baseline data on fish species abundance, diversity and distribution in the river.

3.2 Materials and methods

From July 2003 to June 2004, fish were sampled monthly at each of three sites (MSS1, MSS2, MSS3, see Chapter 1) over a three-day period with one site sampled per day. During the evening hours, a multi-mesh gill net (survey nets type 'Norden', Lundgrens Fiskredskapsfabrik AB) with mesh sizes ranging from 5 mm to 43 mm was placed across the river and left overnight. A variety of mesh sizes was used to reduce species and size selectivity characteristic of gillnets (van der Mheen 1995). The net was removed the following morning after approximately 10 hours and all the fish collected were placed in plastic buckets containing water from the river. All fish that appeared to be on the lake side of the net were placed in a bucket labelled 'Lake to River' and fish that were on the river side were placed in a bucket labelled 'River to Lake'. The purpose of separating the fish was to determine if there was a tendency for species to be moving upstream or downstream.

Once all the fish had been removed from the net, they were anesthetized using sodium bicarbonate (Alka Seltzer) tablets and were then identified, weighed using a portable scale (digital meter, Kern and Sohn) and their total and standard lengths measured using a portable metric measuring board. As fishing time varied between sites (from 8 to 10 hours), catch per unit effort (CPUE) was calculated for each species as fish biomass caught per hour. CPUE was determined for each sampling date and on a seasonal basis. No samples were collected in May due to illness. Four seasons were delineated, as outlined in Table 2.2 (dry/hot, wet/hot, wet/warm, dry/cool).

The Shannon Diversity Index (H′) and Shannon's equitability (evenness, E_H) measure community composition and species diversity (Beals *et al.* 2000). These indices take into account both species abundance and evenness which is defined as the equitable distribution of individuals among a species (Krebs 1994). The following formula was applied at each site and over time in the Mnembo.

$$H = -\sum_{i=1}^{S} p_i \ln p_i \tag{3.1}$$

.Where, H= Shannon diversity index
i =The proportion of species in sample
p_i = total number of species in sample
lnp_i.= the natural logarithm of this proportion

'Equitability assumes a value between 0 and 1 with 1 being complete evenness' (Beals *et al.* 2000) To calculate evenness of species distribution:

$$E_H = H / H_{max} = H / \ln S \tag{3.2}$$

Where, E_H= Shannon's equitability
H_{max} (or lnS) = natural log of total population size at that site or at that time.

A one-way ANOVA was applied to *B. paludinosus* and *B. trimaculatus* CPUE to determine if there were significant differences in abundance between the two species. To ascertain relationships between abundances (CPUE) of all fish species and distribution between sites, the Pearson product-moment correlation was applied using Minitab statistical package 13.2 (2000). Prior to the correlation analysis, data for each species were tested for normality and normality was sufficiently improved through log transformation where necessary.

3.3 Results

3.3.1 Fish diversity in the Mnembo River

All 6 families found in Lake Chilwa were present in the Mnembo River; however only 12 species were represented of the 14 found in the lake (Table 3.1). Four of these are predominantly riverine species, (*Labeo cylindricus, Pareutropius longifilis, Brycinus imberi* and *Marcusenius macrolepidotus).*

Species diversity (measured by Shannon diversity and evenness), and abundance (# of fish caught) over time were highest at MSS1 (Table 3.2). Shannon diversity ranged among the sites from 0.635 to 1.721 during the year, with the lowest value from MSS2, which also had the lowest index, 7 times out of the 11 times measured. Average evenness measured at MSS1 and MSS3 was very similar (0.292 and 0.290, respectively) while species evenness at MSS2 was the lowest, 0.186. Fish abundance decreased by approximately 50% from MSS1 to MSS2 for the majority of the species (Figure 3.1, Appendix 2). Shannon Diversity and evenness indices were not high, however, because *Barbus* and *Labeo* spp. dominated each site (Figure 3.1), together comprising 77% of the total catch.

3.3.2 Abundance and size of fish in the Mnembo River

Fish CPUE for each species oriented upriver compared to the CPUE of fish oriented downriver showed high correlations at each site ($r > 0.850$). Thus for further analysis, CPUE of those oriented upriver were pooled with those oriented downriver (i.e. total of upriver + downriver fish).There was also no significant difference in CPUE between *B. paludinosus* and *B. trimaculatus*

Table 3.1 List of fish species, and the geographical distribution for each, sampled in the Mnembo River from July 2003 to June 2004.

Family	**Scientific name**	**Common name**	**Geographical distribution**	**River/ Lake**
Alestiidae	*Brycinus imberi* (Peters, 1852)	Nghalala	Widely distributed throughout Africa	River
Cichlidae	*Haplochromis calliptera* (Gűnther, 1894)	Makwale	Southern Africa	River/ Lake
	Oreochromis shiranus Chilwa (Trewavas, 1966)	Chambo	Lakes Malawi and Chilwa	River/ Lake
	Tilapia rendalli (Boulenger, 1897)	Chilinguni	Widely distributed throughout Africa	River/ Lake
Clariidae	*Clarias gariepinus* (Burchell, 1822) *C. theodorae* (Weber, 1897)	Mlamba	Africa, Asia, introduced to Europe	River/ Lake
Cyprinidae	*Barbus paludinosus & B. trimaculatus* Peters, 1852	Matemba	South, east and central Africa	River/ Lake
	Labeo cylindricus Peters, 1868	Chonjo	East and southern Africa	River
Mormyridae	*Petrocephalus catastoma* (Gűnther, 1894)	Kanenele	Central and southern Africa	River/ Lake
	Marcusenius macrolepidotus (Peters, 1852)	Mphuta	Widely distributed throughout Africa	River
Schilbeidae	*Pareutropius longifilis* (Steindachner, 1914)	Namwembeya	Malawi & Mozambique	River

Table 3.2 Shannon fish diversity index (H′), evenness (E_H) values and total number of fish caught at each site, in the Mnembo River, from July 2003 to June 2004.

	Diversity Index (H')			Evenness (E_H)			# of fish caught		
Month	MSS1	MSS2	MSS3	MSS1	MSS2	MSS3	MSS1	MSS2	MSS3
July - 2003	0.937	0.800	0.802	0.365	0.223	0.188	13	36	71
August	1.475	1.016	1.396	0.277	0.199	0.267	207	164	185
September	1.219	1.173	1.105	0.198	0.232	0.246	468	141	89
October	1.434	1.074	1.378	0.240	0.216	0.314	395	137	81
November	1.565	1.293	0.835	0.350	0.283	0.181	88	88	102
December	1.535	1.426	0.945	0.270	0.332	0.231	294	73	60
January	1.529	1.195	1.367	0.256	0.228	0.344	392	201	53
February	1.721	1.339	1.338	0.497	0.291	0.454	32	100	19
March	1.354	0.635	1.573	0.227	0.113	0.396	391	280	53
April	1.445	0.920	1.184	0.278	0.229	0.298	182	56	53
May									
June - 2004	1.307	0.980	1.205	0.264	0.186	0.273	141	194	83

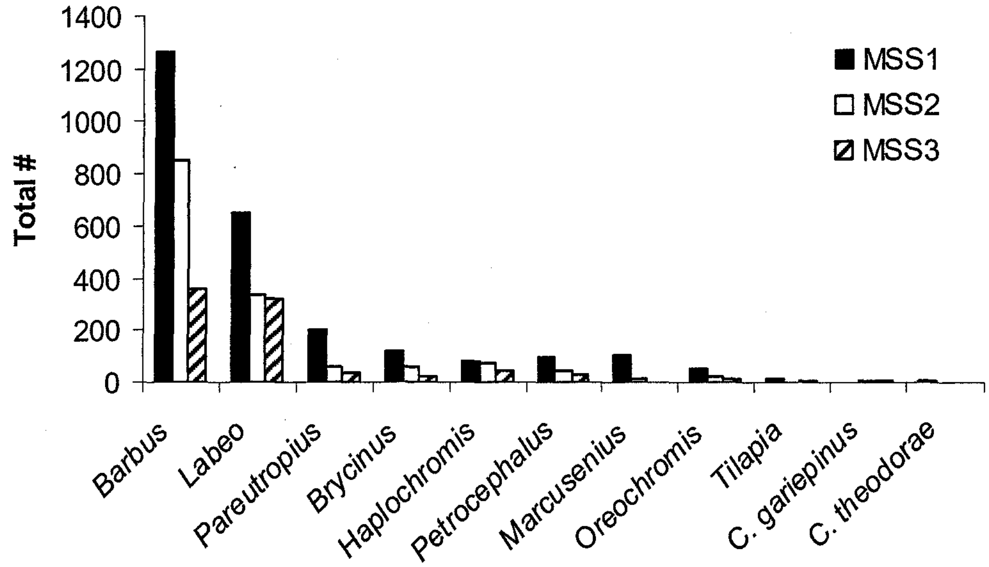


Figure 3.1 Total number of fish sampled at each site in the Mnembo River from July 2003 to June 2004.

(One-way ANOVA, $F_{1,17}$=1.29, P=0.273). Therefore, all further analysis of *Barbus* spp. will include both *Barbus paludinosus* and *B. trimaculatus*. Both species are morphologically very similar and it was difficult to distinguish between them as fry (Figure 3.2). *Barbus paludinosus* and *B. trimaculatus* are also distributed throughout eastern and southern Africa, prefer similar environmental conditions and are not separated in the Lake Chilwa fishery (Skelton 1993). In the Mnembo River, *B. trimaculatus* was more abundant than *B. paludinosus* by approximately 25%, except during the dry/hot season when CPUE of *B. paludinosus* was slightly higher (Figure 3.3a, b).

Of the 12 species collected throughout the year, all were collected at each site except for *Clarias theodorae* which was only taken at MSS1 during the month of February (Table 3.3). The most abundant species were *Barbus* spp. (matemba) and *Labeo cylindricus* (chonjo). The biomass (total weight) of *Labeo* (10,434 g), however, was much higher than that of *Barbus* (6,709 g), *Pareutropius* (1,741 g) and *Oreochromis* (1,630 g). In the lake, the most abundant and commercially important species are *Oreochromis shiranus chilwae, Clarias gariepinus* and *Barbus* spp., however *Oreochromis* and *C. gariepinus* were not abundant in the Mnembo River, nor were they viewed as important to the Mnembo fishing community. Nonetheless, their combined biomass (2,901 g) did contribute over ten percent to the total biomass collected from the Mnembo River (Table 3.3).

CPUE by site, month and season is shown in Figure 3.4. The highest values for each species in the Mnembo River were at MSS1, near the river mouth. *Brycinus imberi* was most abundant at site MSS1 from January to May

2004, while *Haplochromis callipterus* was much higher during the drier seasons (August to October, 2003). Both *Petrocephalus catastoma* and *Marcusenius macrolepidotus* were very abundant during the sampling in January at MSS1 (Figure 3.4), but otherwise were not abundant during the remainder of the year.

Tilapia, C. gariepinus and *Oreochromis* are relatively large fish which, while not abundant in the Mnembo, together represented 14% of the total fish biomass in the river (Table 3.3). Maximum total length (TL) measured for *Tilapia, C. gariepinus* and *Oreochromis* were 35cm, 31cm and 28cm, respectively (Table 3.4), while the more abundant fish in the Mnembo, *Barbus* and *Labeo,* had maximum TL's of 13cm and 20cm, respectively.

3.3.3 Seasonal distribution of species

CPUE was highest during the dry/hot and wet/hot seasons when air temperatures were above 29 degrees Celsius (Table 3.5, Figure 3.5). Similar seasonal trends were evident for *Barbus* and *Labeo* CPUE as both species were positively correlated with each other at MSS1, MSS3 and the mean of all three sites (r-value=0.860, 0.807 and 0.763, respectively) (Table 3.6). Both *Petrocephalus catastoma* and *Marcusenius macrolepidotus* from the family Mormyridae were also positively correlated at MSS1 (r=0.890, P=0.001) and in the Mnembo River (r = 0.895 and P<0.001).

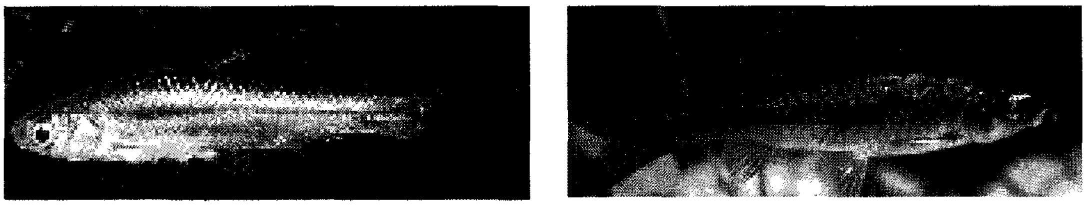


Figure 3.2 The most important commercial species to Lake Chilwa and to the smallholder fishery of the Mnembo River: (left) *Barbus paludinosus* and (right) *Barbus trimaculatus*. Average size 6 centimetres.

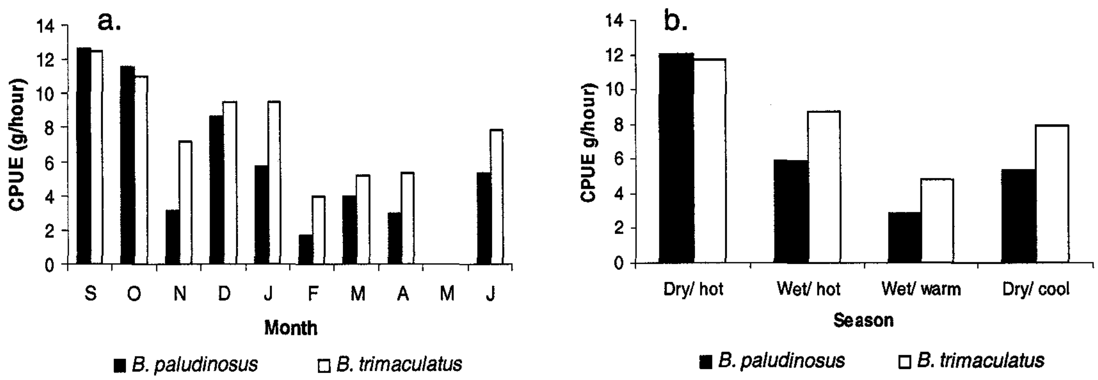
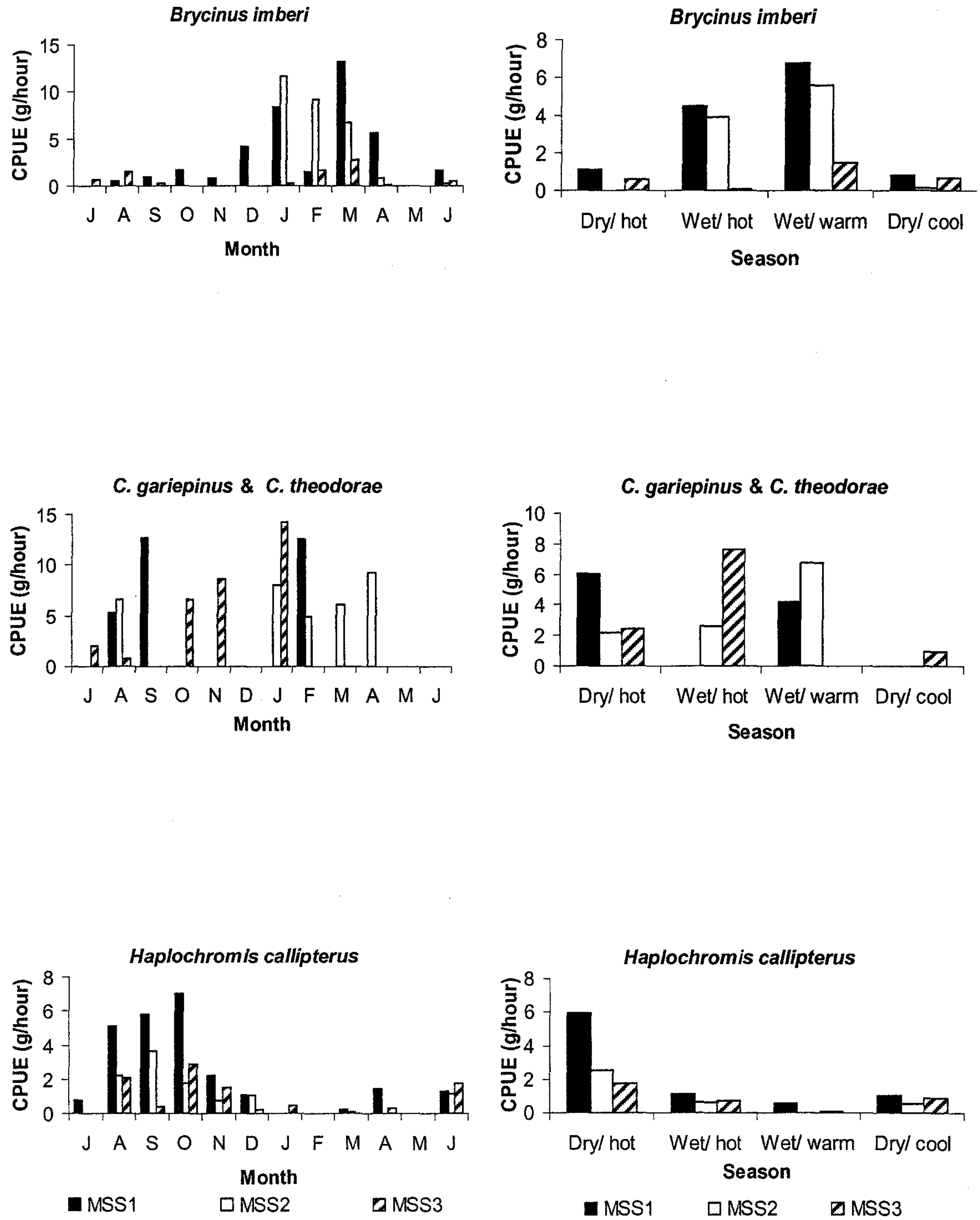
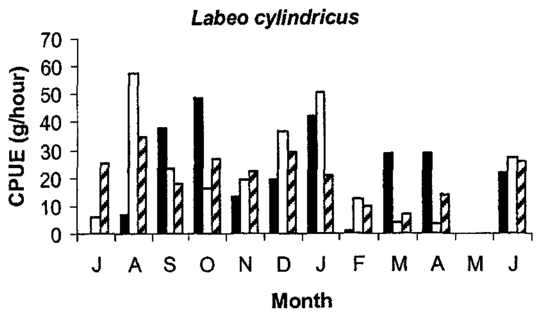


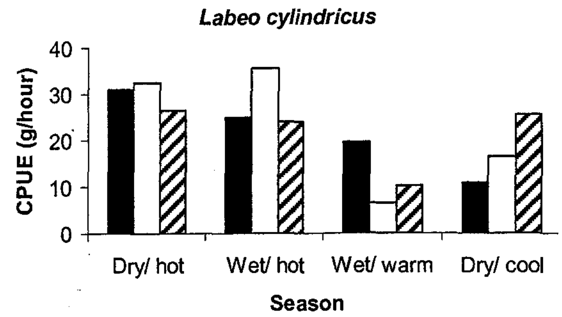
Figure 3.3 (a.) Monthly trends in CPUE of *B. paludinosus* and *B. trimaculatus* in the Mnembo River from July 2003 to June 2004. (b.) Seasonal trends in CPUE of *B. paludinosus* and *B. trimaculatus* in the Mnembo River from July 2003 to June 2004.

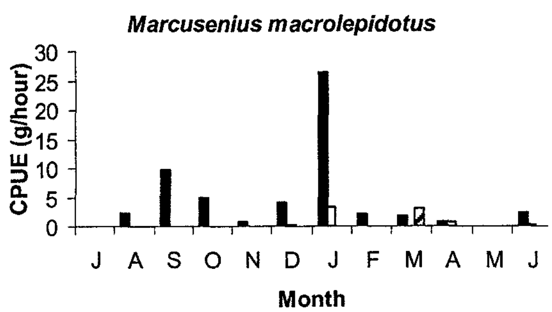
Table 3.3 Total number and % of total number and the total biomass (g) and % of total biomass of fish species collected in the Mnembo River from July 2003 to June 2004.

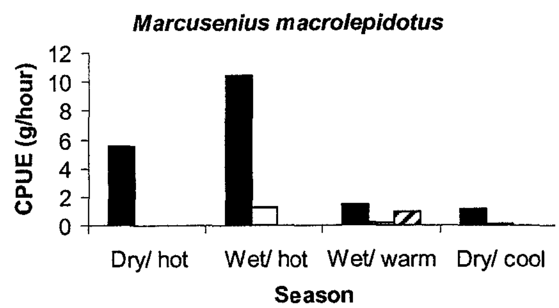
#	**Scientific name**	**Total collected (#)**	**% collected**	**Total biomass (g)**	**% biomass**
1	*Barbus paludinosus, B. trimaculatus* Peters, 1852	2,478	50.3	6,709	24.9
2	*Labeo cylindricus* Peters, 1968	1,312	26.7	10,434	38.7
3	*Pareutropius longifilis* (Steindachner, 1914)	300	6.1	1,741	6.0
4	*Brycinus imberi* (Peters, 1852)	201	4.1	1,174	4.5
5	*Haplochromis callipterus* (Gűnther, 1894)	201	4.1	680	3.9
6	*Petrocephalus catastoma* (Gűnther, 1866)	174	3.5	838	4.7
7	*Marcusenius macrolepidotus* (Peters, 1852)	126	2.6	1,084	3.2
8	*Oreochromis shiranus chilwae* (Trewavas, 1966)	93	1.9	1,630	4.4
9	*Tilapia rendalli* (Boulenger, 1897)	21	0.4	1,225	6.5
10	*Clarias gariepinus* (Burchell, 1822)	12	0.2	1,271	2.5
11	*C. theodorae* (Weber, 1897)	7	0.1	188	0.7

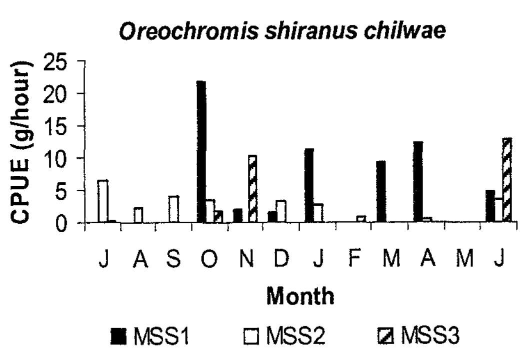

Brycinus imberi
CPUE (g/hour)
15
10
5
0
J A S O N D J F M A M J
Month
Brycinus imberi
CPUE (g/hour)
8
6
4
2
0
Dry/ hot
Wet/ hot
Wet/ warm
Dry/ cool
Season
C. gariepinus & C. theodorae
CPUE (g/hour)
15
10
5
0
J A S O N D J F M A M J
Month
C. gariepinus & C. theodorae
CPUE (g/hour)
10
8
6
4
2
0
Dry/ hot
Wet/ hot
Wet/ warm
Dry/ cool
Season
Haplochromis callipterus
CPUE (g/hour)
8
6
4
2
0
J A S O N D J F M A M J
Month
MSS1
MSS2
MSS3
Haplochromis callipterus
CPUE (g/hour)
8
6
4
2
0
Dry/ hot
Wet/ hot
Wet/ warm
Dry/ cool
Season
MSS1
MSS2
MSS3

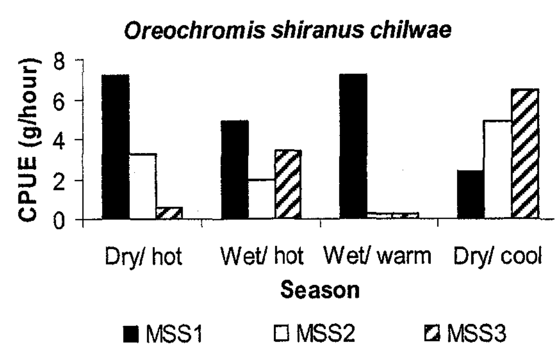

Labeo cylindricus
CPUE (g/hour)
70
60
50
40
30
20
10
0
J A S O N D J F M A M J
Month

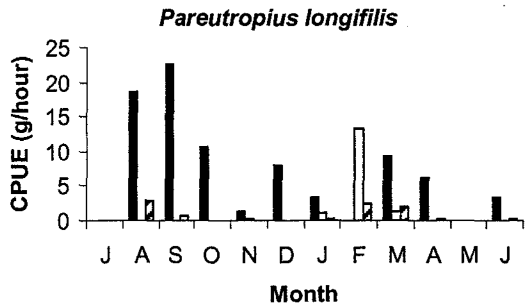

Labeo cylindricus
CPUE (g/hour)
40
30
20
10
0
Dry/ hot
Wet/ hot
Wet/ warm
Dry/ cool
Season

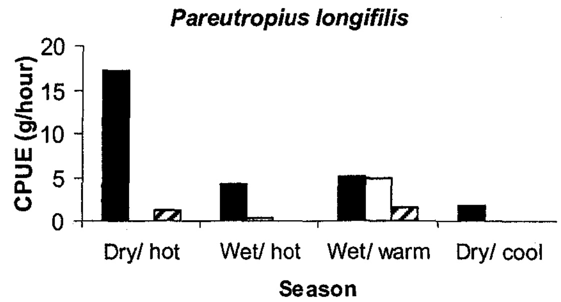

Marcusenius macrolepidotus
CPUE (g/hour)
30
25
20
15
10
5
0
J A S O N D J F M A M J
Month

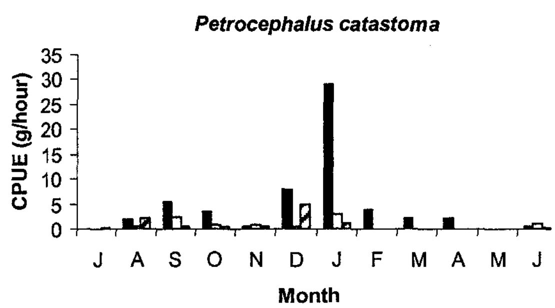

Marcusenius macrolepidotus
CPUE (g/hour)
12
10
8
6
4
2
0
Dry/ hot
Wet/ hot
Wet/ warm
Dry/ cool
Season

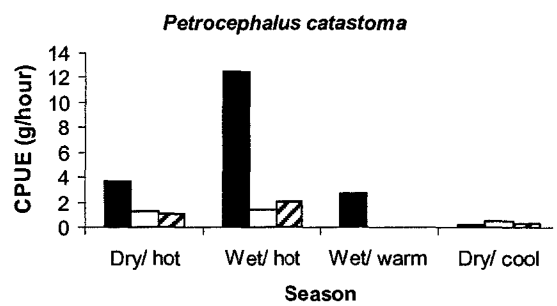

Oreochromis shiranus chilwae
CPUE (g/hour)
25
20
15
10
5
0
J A S O N D J F M A M J
Month
MSS1
MSS2
MSS3

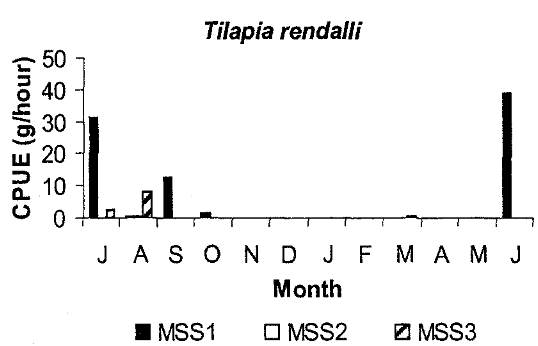

Oreochromis shiranus chilwae
CPUE (g/hour)
8
6
4
2
0
Dry/ hot
Wet/ hot
Wet/ warm
Dry/ cool
Season
MSS1
MSS2
MSS3


Pareutropius longifilis
CPUE (g/hour)
0 5 10 15 20 25
J A S O N D J F M A M J
Month


Pareutropius longifilis
CPUE (g/hour)
0 5 10 15 20
Dry/ hot Wet/ hot Wet/ warm Dry/ cool
Season


Petrocephalus catastoma
CPUE (g/hour)
0 5 10 15 20 25 30 35
J A S O N D J F M A M J
Month


Petrocephalus catastoma
CPUE (g/hour)
0 2 4 6 8 10 12 14
Dry/ hot Wet/ hot Wet/ warm Dry/ cool
Season


Tilapia rendalli
CPUE (g/hour)
0 10 20 30 40 50
J A S O N D J F M A M J
Month
MSS1 MSS2 MSS3

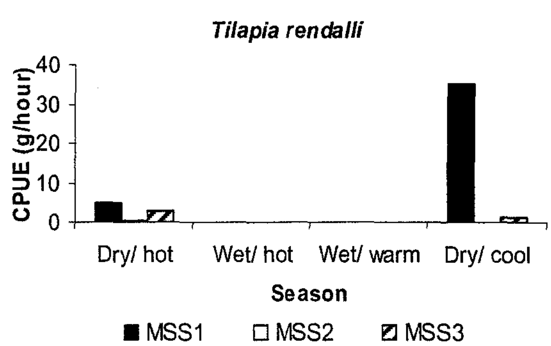

Tilapia rendalli
CPUE (g/hour)
0 10 20 30 40
Dry/ hot Wet/ hot Wet/ warm Dry/ cool
Season
MSS1 MSS2 MSS3

Table 3.4 Maximum, minimum and mean total length (TL) of each species sampled and the sites in which they were collected within the Mnembo River from July 2003 to June 2004.

	Mean	Maximum		Minimum	
Species	TL (cm)	TL (cm)	Site (MSS#)	TL (cm)	Site (MSS#)
Barbus	6	13	1	3	3
Brycinus	7	17	2	4	2
C. gariepinus	22	31	1	13	3
C. theodorae	18	20	1	15	1
Haplochromis	6	12	1	3	1
Labeo	9	20	2	4	1
Marcusenius	8	19	1	5	2
Oreochromis	10	28	1	3	3
Pareutropius	8	16	1	4	3
Petrocephalus	8	20	1	5	2
Tilapia	12	35	1	3	3

Table 3.5 Seasonal distribution of each species sampled in the Mnembo River at each site from July 2003 to June 2004. D/H = dry/hot, W/H = wet/hot, W/W = wet/warm and D/C = dry/cool.

	MSS1				MSS2				MSS3			
Species	D/H	W/H	W/W	D/C	D/H	W/H	W/W	D/C	D/H	W/H	W/W	D/C
Barbus	+	+	+	+	+	+	+	+	+	+	+	+
Brycinus	+	+	+	+		+	+	+	+	+	+	+
C. gariepinus	+				+	+	+		+	+		+
C. theodorae			+									
Labeo	+	+	+	+	+	+	+	+	+	+	+	+
Haplochromis	+	+	+	+	+	+	+	+	+	+	+	+
Marcusenius	+	+	+	+		+	+				+	
Pareutropius	+	+	+	+		+	+		+		+	
Petrocephalus	+	+	+	+		+		+	+	+		+
Oreochromis	+	+	+	+	+	+	+	+	+	+	+	+
Tilapia	+			+	+				+		+	+

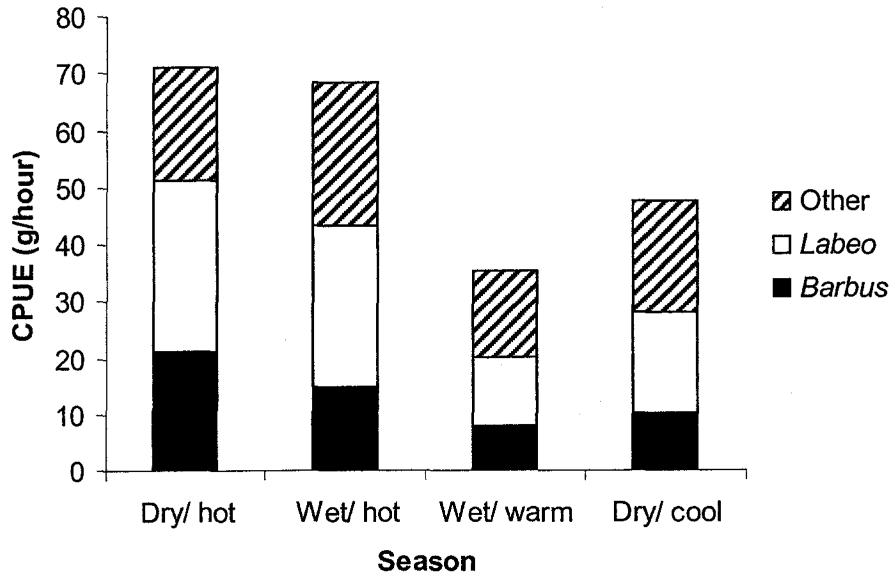


Figure 3.5 Seasonal trends in fish CPUE in the Mnembo River from July 2003 to June 2004.

Table 3.6 Significant Pearson product-moment correlation coefficients and associated p-values for comparisons between species sampled monthly in the Mnembo River from July 2003 to June 2004. Mean = mean of all 3 sites.

	Species 1	Species 2	r-value	p-value
MSS1	*Barbus*	*Labeo*	0.860	0.001
		Marcusenius	0.765	0.006
		Pareutropius	0.816	0.002
		Petrocephalus	0.648	0.031
	Brycinus	*Oreochromis*	0.669	0.024
	Haplochromis	*Pareutropius*	0.632	0.037
	Labeo	*Oreochromis*	0.701	0.016
		Pareutropius	0.716	0.013
	Marcusenius	*Petrocephalus*	0.890	0.001
MSS2	*Labeo*	*Petrocephalus*	0.671	0.024
MSS3	*Barbus*	*Brycinus*	-0.662	0.027
		Haplochromis	0.605	0.049
		Labeo	0.807	0.003
	Brycinus	*Pareutropius*	0.851	0.001
	Labeo	*Haplochromis*	0.612	0.045
		Petrocephalus	0.641	0.033
Mean	*Barbus*	*Haplochromis*	0.622	0.041
		Labeo	0.763	0.006
		Marcusenius	0.710	0.014
	Brycinus	*Haplochromis*	-0.644	0.032
	Labeo	*Marcusenius*	-0.663	0.026
		Petrocephalus	0.726	0.012
	Marcusenius	*Petrocephalus*	0.895	0.000

3.4 Discussion

Of the 14 species of fish found in Lake Chilwa, 12 species were collected in the Mnembo River. During July 2003 to June 2004, the majority of the commercially important Chilwa species were found at least 10 kilometres upriver several times throughout the sampling period even when lake levels were above average (6 meters). This suggests that fish could be accessing the Mnembo River for spawning and that some may be resident there. The Mnembo should be a suitable environment for spawning by lake and riverine species, including *Barbus*, *Clarias* and *Labeo*. *Clarias*, for example, prefer shallow grassy edges (Furse *et al.* 1979b) of rivers or recently flooded land for spawning, while *Barbus* prefer slow moving, highly vegetated areas (Skelton 1993). *Labeo* characteristically prefer clear running water in rocky habitats (Reid 1985) and it was interesting that they were found in higher numbers at MSS1, the only site that displayed measurable river current all year round.

Labeo spp. are considered commercially important in many African water bodies, yet *L. cylindricus* does not significantly contribute to the Lake Chilwa commercial fisheries. However, it is important to the Mnembo catchment community since it is predominantly a riverine species (Weyl and Booth 1999). For villagers near the Mnembo River, *Labeo* can be as abundant and as an important food source as *Barbus* spp. depending on the time of the year and environmental conditions. Only in Malawi's Lake Chilwa has *Barbus* been recognized as an important part of an African fishery (Bourn 1974).

In the Likangala River of Lake Chilwa, *B. paludinosus* was more abundant than *B. trimaculatus*. *B. paludinosus* is generally found in muddy waters and appears to be more tolerant of higher concentrations of total suspended solids than is *B. trimaculatus* (Jamu *et al.* 2003). In the Mnembo River, *B. trimaculatus* was the more abundant of the two species. while TSS concentrations were not as high as had been recorded in the Likangala River and were not correlated with fish abundance (Chapter 4). Lower TSS coupled with *B. trimaculatus* abundance could suggest that the water quality of the Mnembo River was potentially better than that of the Likangala for human use.

Fish species diversity in the Mnembo River was low due to the dominance of the cyprinids *Barbus* and *Labeo,* which are widely distributed throughout most small water bodies in Africa (Marshall and Maes 1994). *Barbus* and *Labeo* were the most abundant contributors to the river's total catch; however *Barbus* is potentially more important to the lake fishery because of its higher capacity for population growth (Skelton 1993). It takes *Labeo* 4.5 to 14 years to double its population whereas it takes *Barbus* less than 15 months (Reid 1985; Skelton 1993). *Brycinus imberi, Marcusenius macrolepidotus, Pareutropius longifilis* and *Petrocephalus catastoma* are primarily riverine species and all four species can double their population in the same amount of time as *Barbus*. Yet, *Barbus* species were significantly more abundant in the Mnembo River and in Lake Chilwa, possibly because they are extremely hardy, have a high fecundity, flexible feeding habits and can adapt to a wide range of habitats (Furse *et al.* 1979b). It is these attributes that likely aided *Barbus* in rapid re-colonization (within 2 years) after a drying phase of the lake (Furse *et al.* 1979b).

Another explanation for the high number of *Barbus* caught in the Mnembo River could be related to gear type and net location. Effectiveness of fishing gear is dependent on fish size and body shape, mesh size, net location, water depth and rate of flow (Mattson 1994; van der Mheen 1995). Gillnets can be very selective for species and size, such as for pelagic *Barbus*, but by using a multi-mesh gillnet with a wide range of mesh sizes, selectivity was probably reduced. Net location can also affect gear selectivity. Net placement within areas of high instream vegetation for example, could tend to select species that only reside in those areas, whereas the height of the net in relation to the depth of the water could allow fish to swim under the net (van der Mheen 1995). In the Mnembo, a multi-mesh gillnet (5-43mm) was used and sampling sites were selected where impacts of gear selectivity were thought to be reduced.

Positive correlations in CPUE were observed between *Labeo* and *Barbus* and between *Marcusenius* and *Petrocephalus.* Both cyprinids, *Barbus* and *Labeo*, displayed similar trends in population size (Table 3.6); hence it was not surprising that the correlation was found to be highly positive, The fact that *Marcusenius* and *Petrocephalus* possess electroreceptors and tend to school with each other (Gosse 1984) could explain the high positive correlation between these two species.

During periods of lake level recession, Lake Chilwa's catchment becomes significantly more important to the sustainability of the lake fisheries.

It is apparent that fish species such as *Barbus* spp., *Oreochromis shiranus chilwae* and the catfish, *Clarias gariepinus,* use the rivers and swamps of Lake Chilwa as a refuge during periods of lake desiccation, and as sites for feeding and spawning (Cantrell 1988: Furse *et al.* 1979b; Jamu and Brummett 1999). During periods of extreme lake level decrease and increased salinity, *C. gariepinus B. paludinosus, B. trimaculatus* and *Oreochromis shiranus chilwae* can likely adapt to changes in food availability, being non-specialized opportunistic feeders (Furse *et al.* 1979b). For example, *Oreochromis* are primarily herbivorous; however within Lake Chilwa they also consume zooplankton during the drying phases of the lake (Bourn 1974). *Clarias gariepinus* is tolerant of harsh environmental conditions due to specific morphological adaptations (Furse *et al.* 1979). They can, for example, withstand periods of anoxia because of their accessory respiratory organs in the branchial cavity (Furse *et al.* 1979b). However compared to *Barbus*, it takes *Clarias* a longer time to double its population (1.4 to 4.4 years) (Teugels 1986).

The other clariid species sampled in the Mnembo River, *C. theodorae*, was only caught once and that was when discharge was at its peak (February). *C. theodorae* prefer slow moving waters and lagoonal floodplains along river banks for spawning (Skelton 1993). The one time sampling of *C. theodorae's* in the Mnembo River (at MSS1) may be related to the dramatic reduction in discharge (March) and lack of rainfall thereby decreasing lagoonal habitat. Catches of *Clarias* in the Mnembo could also have been low due to the gear type. In Lake Chilwa long-lines are the most effective gear for catching *Clarias* spp. followed by seines and then gillnets (Nyasulu *et al.* 2001). Gillnets tend to catch larger fish however the probability of encountering the net is proportional to swimming speed and river flow rate (Mattson 1994; van der Mheen 1995). Gill nets are therefore less-likely to catch slow-moving, bottom dwelling fish (*Clarias* spp.) than the pelagic *Barbus* and *Labeo* (Nyasulu *et al.* 2001).

In Lake Chilwa, *Tilapia rendalli* can reach lengths four times greater than these caught in the Mnembo while *Clarias gariepinus* can reach lengths eight times greater (Teugels and Thys van den Audenaerde 1991). The maximum size for *Labeo cylindricus* (20cm) was also smaller than in other African rivers (40 cm). Reasons for this are unclear. Thus further studies are needed to determine what factors are associated with the smaller fish sizes present in the Mnembo. Based on Skelton (1993), the maximum size of *Barbus* caught in Lake Chilwa was 15 cm whereas in the Mnembo the maximum size was marginally smaller (13 cm). It does not appear that size in *Barbus* has changed substantially over the last 12 years; however, fish sellers report that the average size of *Barbus* is decreasing in the local city markets and in the daily fish catch at Kachulu Harbour on Lake Chilwa (Delaney, pers. obs. 2003). The Mnembo River is suspected to be the largest source of fresh water to Lake Chilwa (Jamu pers com. 2004) and based on the CPUE and abundance of *Barbus trimaculatus* and *B. paludinosus*, the river is potentially in much better condition than the other catchment basins of Lake Chilwa. Reduction in *Barbus* size does appear to be a concern for the entire Lake watershed and this apparent trend needs to be further examined.

Chapter 4

Effect of Land Use in the Mnembo River Catchment on Limnological Parameters and the Reproductive Status of *Barbus* spp.

4.1 Introduction

Siltation, damming, warming, pollution and changes in hydrological regimes are some of the more obvious potential causes of fish reproductive failure in Lake Chilwa (Furse *et al.* 1979b; Jamu *et al.* 2003). Fish mortalities have resulted from low dissolved oxygen (DO), high silt load, high alkalinities, low water levels and high pH in the lake (Msiska 2001); these environmental stressors can be directly related to human activities in the watershed. Increased human pressure through poverty has led to the unsustainable use of water, forestry and fishery resources and subsequently to fish spawning failures throughout Africa, including in the Zambezi, Senegal and Niger Rivers (Bousso 1997; Folack 1997; Welcomme 1996).

Nutrients such as nitrogen, phosphorus and carbon enter Lake Chilwa via 2 pathways: (1) decomposition of semi-aquatic vegetation from the surrounding swamps and (2) rivers that flush sediment-containing nutrients into the lake from the catchment, including the deposition of allochthonous material brought in from the overflow of river banks. The catchment inputs to the lake are enhanced via surface and subsurface runoff from the catchment resulting from deforestation, irrigation practices, agricultural activities and urban development (Horne and Goldman 1994; Howard-Williams and Howard-Williams 1978). Various materials and pollutants generated in the catchment that eventually find their way into Lake Chilwa include pesticides, topsoil, and other organic and inorganic pollutants (Jamu *et al.* 2003;

Kalindekafe 1999). Human usage of the watershed's arable land has markedly increased sedimentation into the lake's basin with resultant decrease in mean depth (Morgan 1971).

Sediment loads and yields reflect patterns of land use (Hecky *et al.* 2003) and can be evaluated through models that link soil erosion to riverine health (Chimphamba 2000). Factors that influence riverine habitats include climate, geology, catchment slope, soil type, vegetation and land use patterns in the catchment and riparian zones (Johnson and Gage 1997). Changes in land use thus influence water quality and hydrology which can influence fish distribution, their food availability and spawning success (Jamu *et al.* 2003; Osmundson *et al.* 2002).

In the Lake Chilwa basin, *Barbus* spp. are economically very important and may be also useful indicators of watershed health. Jamu and Brummett (1999) studied watershed processes, land use activities, river system dynamics and the reproductive success of *Barbus* spp. in two river catchments in the Lake Chilwa basin: the Domasi and Likangala. Due to a lack of data on landscape patterns and soil erosion rates, the study failed to establish a relationship between status of the watershed and fish reproduction. Jamu *et al* (2003) estimated soil erosion losses in the Likangala catchment and indicated that sediment yield, river flow, electrical conductivity and TSS were significant predictors of *Barbus* reproductive state. For these two studies to provide the information for constructive watershed management there was a need to include data on the other major river catchments of Lake Chilwa. Thus the purpose of this chapter is to examine potential linkages between patterns in land use within the Mozambican Mnembo River catchment and river water quality and the reproductive state of *Barbus* spp. Information on the most abundant fish species caught in the Mnembo (*Labeo cylindricus*) will be included as well.

4.2 Materials and Methods

4.2.1 Fish abundance and distribution

Refer to Chapter 3.2 for the field sampling methodology used to evaluate fish abundance and distribution at MSS1, MSS2 and MSS3 as described in Chapter 1 (Figure 1.3). Data were assessed monthly and seasonally (four seasons as described in Table 2.2).

4.2.2 Barbus reproductive status

At each sampling site, a sub-sample of 30 *Barbus* spp. (15 from the 'river to lake' bucket and 15 from the 'lake to river' bucket) were randomly selected and then killed with an overdose of anaesthetic. These individuals were sexed, their gonads removed and gonadal maturation stages classified based on visual inspection of the size, colouration, and location of the gonad along the wall of the abdomen (Bagenal 1978; Table 4.1). The gonads were removed and placed in separate labelled 10ml sterilized plastic bottles and preserved in 5 ml of Gilson's fluid. Gilson's fluid is a preservative that contains 100ml of 60% ethanol, 880 ml of distilled water, 15 ml of 80% nitric acid, 18 ml of glycol acetic acid and 20 grams of mercuric chloride (Eaton *et al.* 1995). A pilot study had indicated that 5ml of Gilson's was adequate for preservation of an entire gonad.

Barbus life stages were distinguished based on weight. All sampled *Barbus* that weighed less than 1 gram were classified as immature, 1 to 5 grams as sub-adults, and *Barbus* greater than 5 grams were classified as adults (Jamu and Brummett 1999). Catch per unit effort (CPUE) for

Table 4.1 Stages of gonadal maturation of female and male *Barbus* based on visual inspection utilized in the classification of *Barbus* sampled in the Mnembo River from July 2003 to June 2004 (Bagenal 1978).

Gonad maturity stage	**Symbol**	**Appearance of male gonad**	**Appearance of female gonad**
Immature	Im	Testes thin thread-like flesh coloured, colourless to transparent	Threadlike, transparent and along the abdomen wall
Inactive	In	Translucent, wider than above.	Cream colour, translucent, elongated wider than testes. No oocytes visible.
Inactive-Active	In/A		Opaque to translucent occupy half of the visceral cavity. Few oocytes barely visible.
Active	A	Dull white/yellowish, thickened and elongated, about ¾ visceral cavity.	Ovary not yet swollen, but oocytes visible, yellowish with red hue.
Ripe	R	Cream white, distended fully over length of visceral cavity, milt evident if testes cut.	Yellow, green or orange eggs characteristic of species large uniform size. Occupies all available space in the visceral cavity.
Ripe running	RR	White silvery, fully distended, milt runs freely under pressure.	Ovary extremely swollen and eggs run under hand pressure or separate if ovary is cut.
Spent	S	Gonad flesh/red colour shrunken with blood capillaries evident.	Flaccid shrunken ovary, reddish with blood capillaries and small eggs discernable.

Barbus spp. was defined as total number of individuals of all life stages sampled per hour.

4.2.3 Gonad Preservation Time

Gonads were stored in the field (over approximately 3 days) and in the lab until they could be weighed. It was thus important to know the impact of the preservative on gonad weight over time. Therefore, before field sampling commenced in July 2003 a preliminary study was conducted on *Barbus* gonads to determine the amount of time, and the quantity of preservative, needed to properly store them. Gonads were preserved over 14 days and weighed initially plus every second day thereafter. The Gonadosomatic index was calculated as (weight of gonad/ weight of the fish)*100. GSI represents the percentage of the total weight of the fish that is comprised of gonad and is used as a measure of the reproductive status of the fish (Wootton 1992).

4.2.4 Limnological parameters

Limnological parameters (Table 1.2) were measured as outlined in Chapter 2.

4.2.5 Land use patterns

Land use patterns and practices within the Mnembo River catchment were evaluated based on results from the questionnaire (Chapter 5) and the Participatory Rural Appraisal (PRA) that were administered to the catchment community in July, 2003 (Chapter 5). Land use patterns were evaluated through aerial photo interpretation and ground truthing.

4.2.6 Soil Erosion Modelling

The Soil Loss Erosion Model for Southern Africa (SLEMSA) developed by Elwell (1978) uses a mathematical modelling approach to calculate mean annual soil loss from sheet erosion on arable lands. It has been widely used throughout Southern Africa and data for the model are easy to acquire. The SLEMSA model divides the soil erosion environment into four physical systems: climate, soil, crop and topography, which is applied in the following calculation:

$$Z = KCX\,(2) \quad \text{(Elwell 1978)} \qquad (4.1)$$

Where

Z = the predicted mean annual soil loss (tonnes/ha/yr) from the study area

K = Erodability factor

X = Topographic factor

C = Vegetation canopy factor

Soil erosion management units (SEMUs) are areas which contain a unique combination of the topography (X), vegetation canopy cover (C) and soil erodability (K), that, in combination define the areas as having similar slope, soil characteristics and mean annual rainfall (Jamu *et al.* 2003). SEMUs are created by overlaying a land cover map (tree canopy cover) and a slope unit map (topography), which creates the distinctive combinations of the sub-models.

Land cover classes of the Mnembo catchment were visually interpreted from aerial photographs that were taken of the study area in 1969 and were classified based on the types of vegetation cover. Unfortunately, no recent photos or topographic maps were available of the study area due to the civil war that occurred in Mozambique. There were however, aerial photos of the small Malawian segment of the catchment and based on visual comparisons of the area from 1969 to 1992, the change in land cover was not markedly different. The only obvious difference was the level of the lake, because in 1969 Lake Chilwa was drying up.

The following vegetation canopy cover types were classified for the Mnembo Catchment and are displayed in Figure 4.1.

Cultivated land with 0 – 5% tree canopy cover
Cultivated land with 5 – 10% tree canopy cover
Woodland 20 – 70% tree canopy cover
Wetland / Dimba (irrigated garden)

4.2.7 Topographic Factor (X)

The topographic factor (X) takes into account slope steepness and slope length as a measure of soil loss. Erosion and slope are positively correlated therefore an increase in slope will increase the rate of soil loss. For the Mnembo catchment four slope classes were designated: 0-6, 6.1-13, 13.1-20 and greater than 20%. One limitation of the SLEMSA is that areas with slope angles greater than 20% cannot be applied to the model. Based on interpretation of a topographic map of the study area (Figure 4.2), slope percentage was calculated as follows:

$$\text{Slope percentage} = \frac{A-B}{C} \times 100 \qquad (4.2)$$

Where A = topographic contour line A on map
B = topographic contour line B on map
C = true distance between topographic contour lines A and B on the ground

The formula used for calculating the topographic factor (X) is

$$X = \frac{\sqrt{L(0.76 + 0.53S + 0.076^2)}}{25.65} \qquad \text{(Elwell 1978)} \qquad (4.3)$$

Where X = the ratio of soil loss
L = ground slope length in metres
S = slope percentage

4.2.8 Soil erodability (K)

Sub-model K takes into account both climate and soil and the corresponding control variables, rainfall energy (E), and soil erodability. Seasonal rainfall energy (E) is influenced by duration, intensity and the total energy content of all rainfall events and was shown to be strongly correlated with soil loss (Mughogho 1998). Mean seasonal rainfall energy was calculated using the following equation:

$$E = 18.846P \qquad \text{(Elwell 1978)} \qquad (4.4)$$

Where,

E = mean seasonal energy in Joules/m^2
P = mean annual rainfall in mm

Soil erodability is dependent on the physical and chemical properties of the soil and is expressed based on its ability to resist erosion. Variations in farming practices are taken into account when calculating soil erodability. Thus the erodability index (Fb) ratings (Table 4.3) are modified by adding or subtracting the incremental rating associated with each farming practice (Fm) in each SEMU (Table 4.3; Elwell 1978).

The sub-model K was then calculated.

$$K = Exp[(0.4681 + 0.7663F)\ln E + 2.884 - 8.120F] \text{ (Elwell 1978)} \qquad (4.5)$$

Where, K = soil loss from bare fallow
F = soil erodability (modified Fb value)

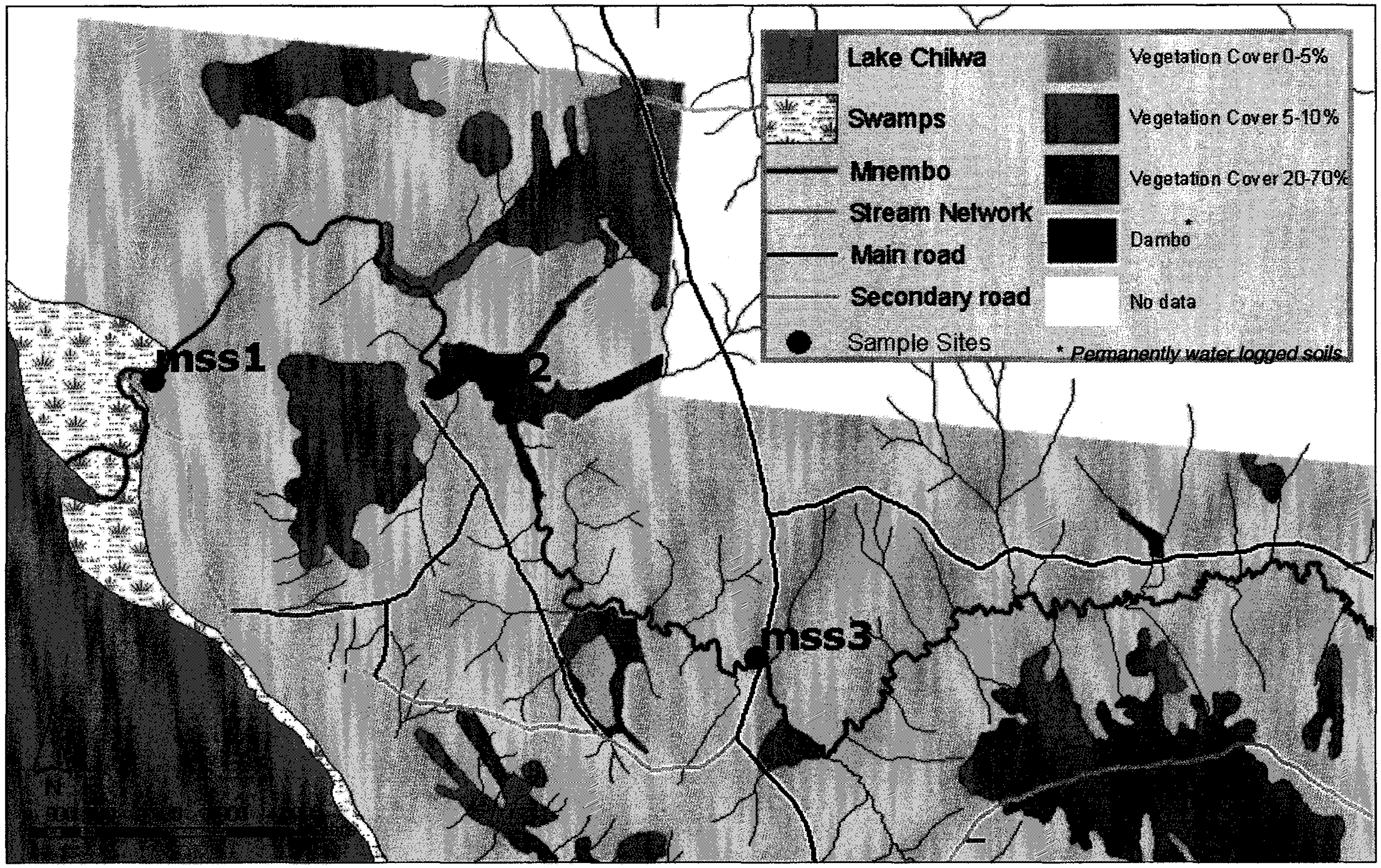


Figure 4.1 Vegetation canopy cover of the Mnembo Catchment for 1969.

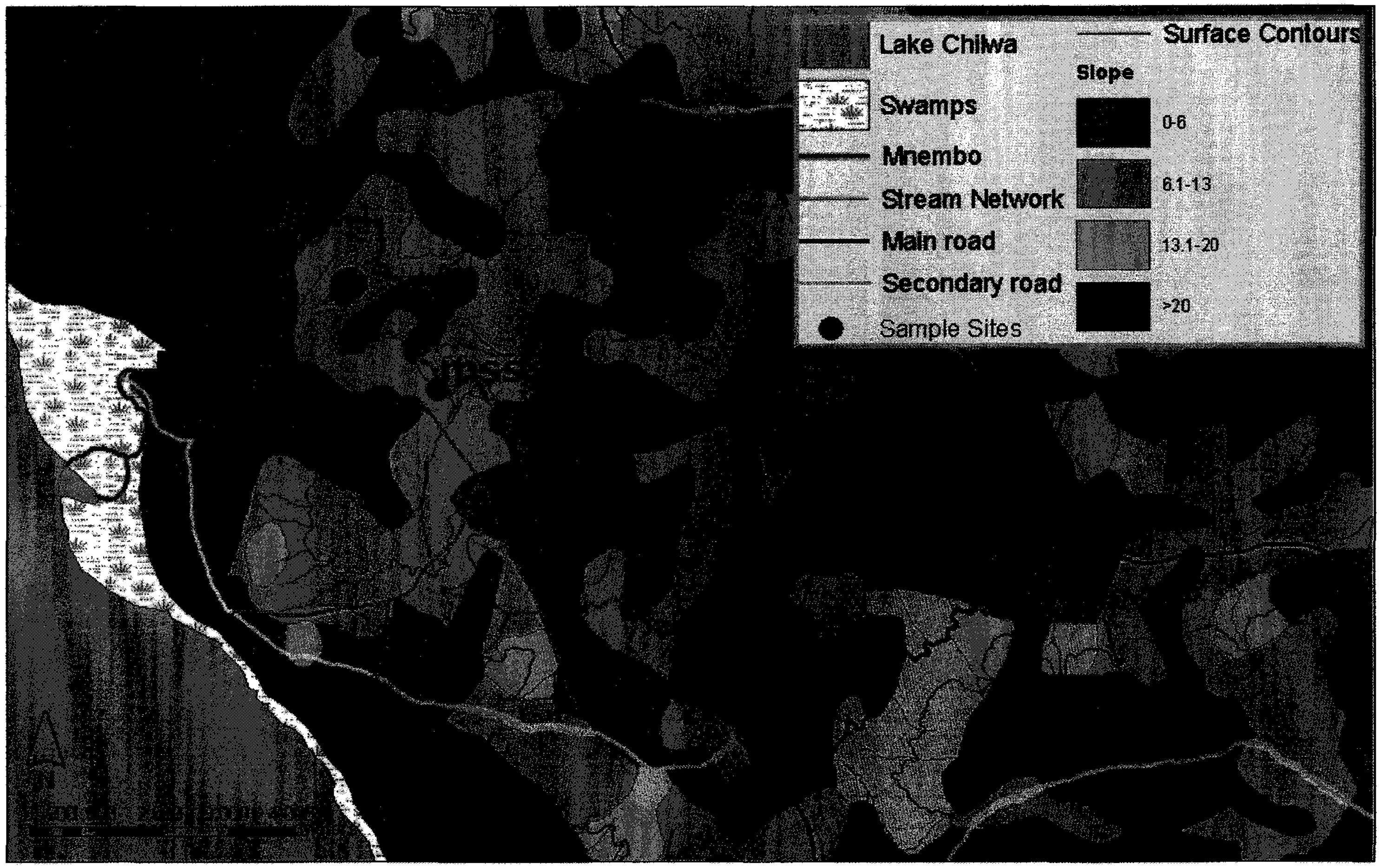


Figure 4.2 Slope and physiographic map of the Mnembo Catchment from 1969.

Table 4.2 Erodability index (Fb) ratings for the SLEMSA model which was applied to the Mnembo catchment. (-- indicates no designated value) from (Chimphamba 2000).

Topsoil Texture	Basic Index	Soil Pedological Classification (soil group)	Soil erodability (Fb) Index
Sands Loamy sands Sandy loams	4	Lithic Palalithic Fluvic Gleyic Arenic Eutric-fersialic Calcaric	4.5
Sand clay loams Clay loams Sand clays	--	Orthic luvisol Chromic luvisol Fluvic Palalithic Gleyic luvisol	5.5
Clays Heavy clays	6	Rhodic ferralsol Eutric-fersialic Dystric-fesialic	--

Table 4.3 Farming Practices Index (Fm) used in the application of the SLEMSA to the Mnembo catchment (Chimphamba 2000). *Good farming practices (+), bad farming practices (-).*

Farming Practises	**Incremental Value**
Ridging Practices	
• Contour ridging	+1
• Contour ridging with tie-ridges	+1.5
• Ridges at 1-2% grade	0
• Zero tillage	0
• Up-and-down ridging	-1
• Ridging at 8% grade	-0.5
Fallow and Leys	
• First year fallow or ley	0
• Second year fallow or ley	+1
• Medium to heavy green application of manure	+1
• Third year fallow or ley	+2
• Permanent pasture in good condition	+2
Perennial crops and orchards	
• Perennial crops under heavy mulching	+2
• Perennial crops under medium mulching	+1

Table 4.4 Estimated soil erosion rating and associated delivery ratios applied to the Mnembo Catchment (Jamu *et al.* 2001).

Estimated soil erosion rate	Delivery ratio
> 55	0.20
35-50	0.15
15-35	0.10
<15	0.05

4.2.9 Vegetation Canopy Factor (C)

The vegetation canopy factor is dependent on the percentage of rainfall energy intercepted by crop cover. Variations in vegetation cover correct for the variations in soil loss such as the comparison of soil loss of bare soil to that of a fallow or cropped field (Chimphamba 2000; Mughogho 1998). The vegetation canopy factor, C is calculated by applying the following equation.

$$C = e(-0.06)\tau \ , \quad \textit{when } \tau \ < 50\% \qquad (4.6)$$

$$C = \frac{2.3 - 0.01\tau}{30} \ , \quad \textit{when } \tau \ > 50\% \qquad (4.7)$$

Where,

C = the ratio of soil loss from a vegetation canopy with interception value τ.

e = base of the natural logarithm

τ = the percentage rainfall energy intercepted by the vegetation canopy. τ is <50% for annual cropping and >50% for perennial cropping (Chimphamba 2000).

The percentage of rainfall intercepted by vegetation (τ) was proportionate to the percentage of tree canopy cover, which was assessed from aerial photographs.

4.2.10 Estimated Sediment Yield

Rate of sedimentation in the catchment is related to the delivery ratio, which is the ratio of eroded soil that has been carried downstream proportional to what is remaining in the field (Jamu *et al.* 2003) or it can also be defined as the ratio of basin sediment yield to the amount of soil eroded from hillsides

(Dunne 1979). By multiplying the estimated soil loss for each SEMU with a delivery ratio, the sediment yield for the Mnembo catchment was obtained and by summing all the sediment yields for each SEMU above an outlet point the overall sediment yield for the entire catchment was determined. Within the Mnembo Catchment, MSS2 (middle site) was used to calculate the overall sedimentation yield for the catchment. It is difficult to calculate delivery ratios for each individual catchment because eroded material can travel downstream at any distance. Therefore, delivery ratios (Table 4.4) that were developed for the Lower Shire in Southern Malawi by Green *et al.* (1996) and by Jamu *et al.* (2001) were applied to the Mnembo Catchment.

The rate of soil loss and sediment yield (tonnes/ site) at each major sample site in the Mnembo River catchment was estimated using a 300 km^2 perimeter at each site. For each SEMU represented within a major sample site perimeter, an average was taken to signify the average amount of sediment yield at that site.

4.2.11 Statistical procedure

For the two-week trial study of *Barbus*, the change in both male and female gonad weight over time spent in the preservative was analyzed using linear regression (Minitab version 13.2 (2000)). Data were normally distributed and hence not transformed prior to regression analysis.

All field data collected from the Mnembo River from July 2003 to June 2004 were also statistically analyzed using Minitab (2000). A two-way ANOVA was applied to log-transformed monthly data of male and female GSI

(Gonadosomatic Index) to determine if GSI varied significantly between months and between sites for either sex. A one-way ANOVA was applied to look at differences in male and female GSI in the Mnembo River between the four seasons, using male and female GSI values averaged over the three sites. For comparisons of CPUE of each *Barbus* life stage (adult, sub-adult and immature) between months and between sites, a two-way ANOVA was applied (Minitab 2000). A one-way ANOVA was then administered to look at differences in life-stage CPUE between the four seasons, using values averaged over the three sites.

All fish data were inspected for normality (based on graphs of residuals). Those not normally distributed were log-transformed. Pearson's correlation matrices were then applied (Minitab 2000) relating the fish parameters to rainfall and limnological variables of the river. Only such variables showing significant correlations ($p < 0.05$) with the reproductive status of *Barbus* life stages or fish species CPUE were then used in subsequent multiple linear regression analyses.

4.3 Results

4.3.1 Trial preservative study

Gonad weight of female *Barbus* was more sensitive to the Gilson's preservative over time but the trend was not markedly different from male gonad weight. Figures 4.3 and 4.4 display the rate of change in gonad weight over time while in preservative and the associated regression equations. It was also determined during the trial study that gonads should not be kept longer than seven days in the Gilson preservative because they would disintegrate beyond measurement.

4.3.2 Barbus reproductive status and limnological parameters

Barbus GSI and CPUE for both sexes were positively correlated between *Barbus* sampled upriver and downriver at each site ($r > 0.850$). Therefore GSI and CPUE of female and male *Barbus* were taken as gender-specific means per site and were not separated in the analysis of *Barbus* reproductive status and abundance in the Mnembo. Only the female GSI (consistently larger than the male) was used in the regression analysis.

GSI of male (two-way ANOVA, $F_{2,20}= 0.49$, $P= 0.618$ for site; $F_{10,20}= 5.51$, $P= 0.001$ for months) and female (two-way ANOVA, $F_{2,20}= 2.44$ $P= 0.113$ for site; $F_{10,20}= 32.68$, $P< 0.001$ for months) *Barbus* showed significant differences over time but not between sites (Figure 4.5). There was a consistent trend upriver with GSI higher at MSS3, and gradually decreasing down river (Figure 4.5b).

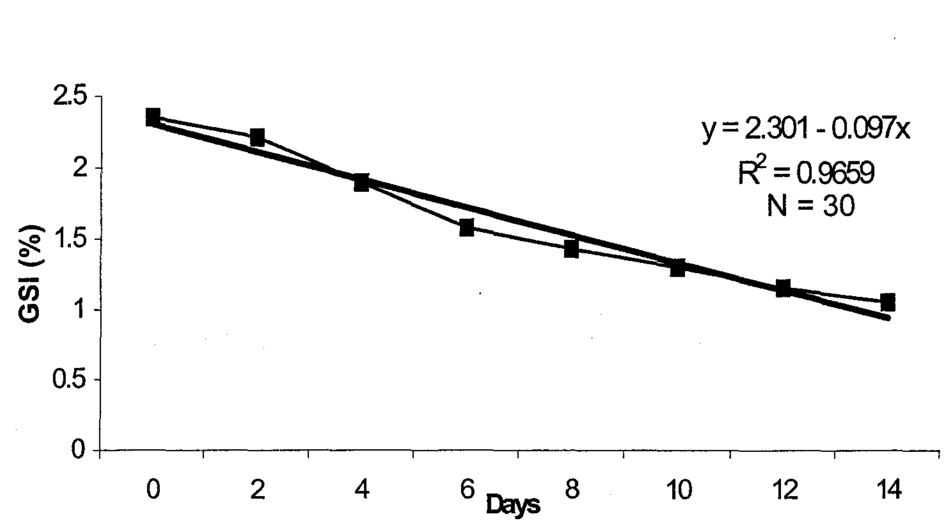


Figure 4.3 Rate of change of gonad weight over time in preservative of male *Barbus* spp. GSI (Gonadosomatic Index), in 5 ml of Gilson's fluid over a two-week trial period in May 2003.

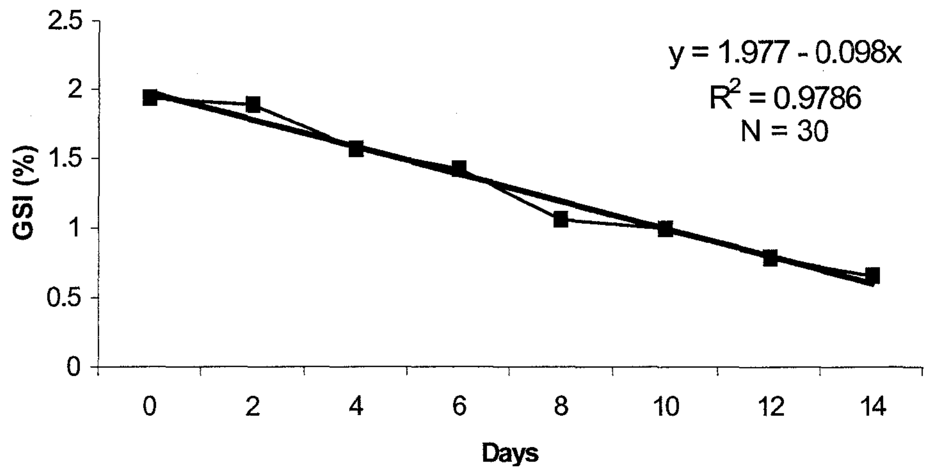


Figure 4.4 Rate of change of gonad weight over time in preservative of female *Barbus spp.* GSI (Gonadosomatic Index), in 5 ml of Gilson's fluid over a two-week trial period in May 2003.

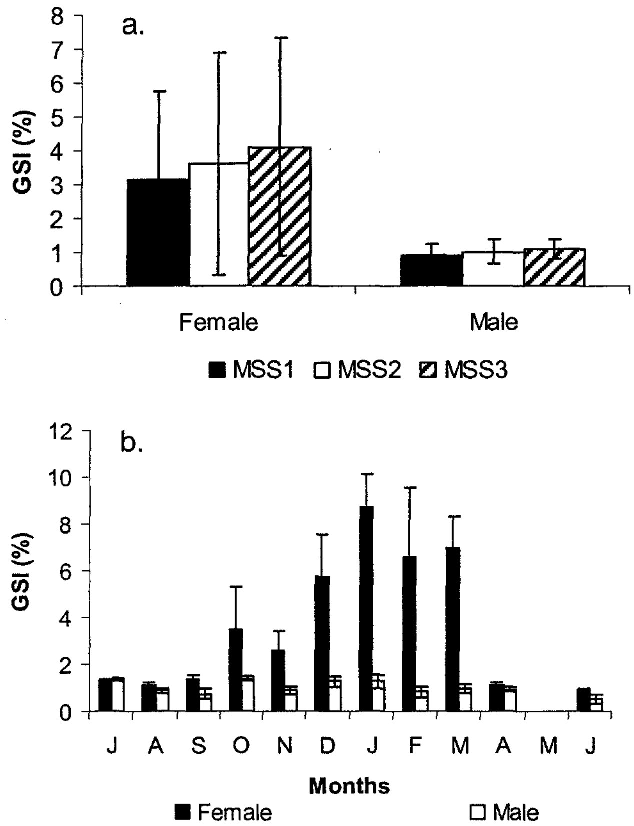


Figure 4.5 (a.) Mean GSI for male and female *Barbus* at each site in the Mnembo River from July 2003 to June 2004. (b.) Monthly mean GSI for male and female *Barbus* for the entire Mnembo River from July 2003 to June 2004.

Table 4.5 Monthly and seasonal maximum and minimum GSI values for male and female *Barbus* at each site and means for the entire Mnembo River from July 2003 to June 2004. *M=months, S=seasons, W/H=wet/hot, W/W=wet/warm, D/C=dry/cool and D/H=dry/hot.*

	Female						Male					
Site	**Min**	**M**	**S**	**Max**	**M**	**S**	**Min**	**M**	**S**	**Max**	**M**	**S**
MSS1	0.88	June	D/C	8.19	Jan	W/H	0.55	June	D/C	1.49	Oct	D/H
MSS2	0.93	June	D/C	10.31	Jan	W/H	0.31	June	D/C	1.51	Dec	W/H
MSS3	0.91	Aug	D/H	9.57	Feb	W/W	0.65	June	D/C	1.55	Jan	W/H
Mean	0.93	June	D/C	8.68	Jan	W/H	0.50	June	D/C	1.38	Oct	D/H

Barbus GSI at each site was highest during the rainy seasons (wet/warm and wet/hot) for both males and females (Table 4.5, Figure 4.6a). Male GSI did not differ significantly between seasons (one-way ANOVA $F_{3,8}$= 2.90, P= 0.102) however based on Figure 4.6a during the wet/hot season GSI was slightly higher for males, compared to female GSI. Mean female GSI did differ significantly between seasons (one-way ANOVA $F_{3,8}$ = 42.87, P<0.001).

GSI of female *Barbus* was the highest at site MSS3 during each season (Figure 4.6b) implying that females that were ripe-running were found farther upstream rather than near the river's mouth. The wet/warm season also displayed the highest GSI recorded for the entire year. Near the end of the wet/warm season, female GSI had decreased by 50 percent (Figure 4.6).

Barbus life-stage data also showed strong monthly and seasonal patterns in the Mnembo River (Figure 4.7). Overall, sub-adult *Barbus* were the most abundant life-stage. Mean monthly CPUE of sub-adult *Barbus* was significantly greater than that of the immature and adult *Barbus* (one-way ANOVA, $F_{2,96}$= 15.82, P<0.001). Total *Barbus* numbers were highest at MSS1 (1,263), then MSS2 (851) and MSS3 (356) (Table 4.6). During the dry/cool season at MSS1 and MSS2 no adult *Barbus* were sampled, and at MSS3 no adults were sampled during the wet/warm season (Figure 4.7a). At MSS1, maximum CPUE for adult and sub-adult *Barbus* occurred during the months of September and October (51 and 204 individuals, respectively). During June, sub-adult *Barbus* dominated the catch at MSS2 with 92 individuals (Figure 4.8b). Immature *Barbus* were most abundant at each site in March (over 70% of total catch; Figure 4.8c).

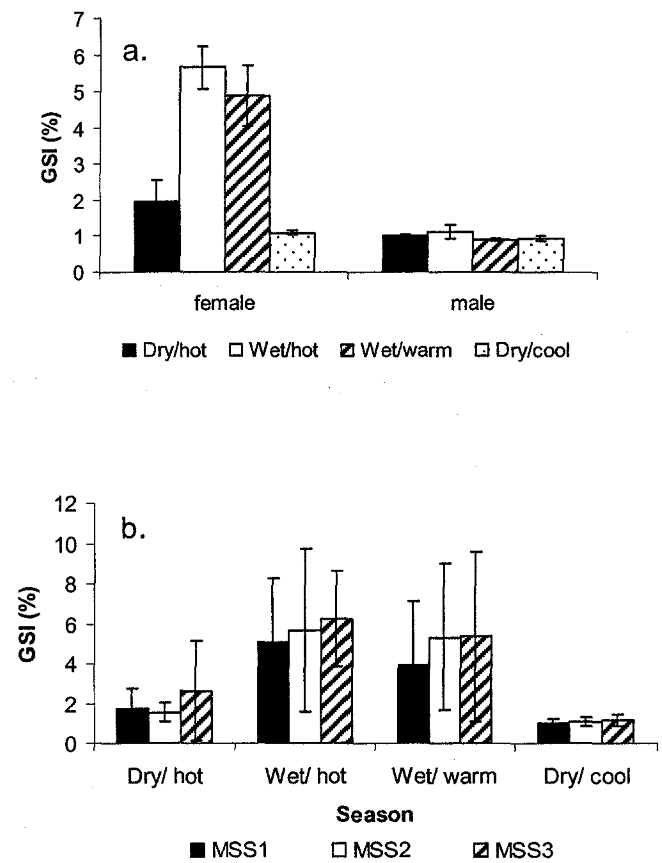


Figure 4.6 (a.) Seasonal trends of *Barbus* male and female GSI in the Mnembo River from July 2003 to June 2004. (b.) Seasonal trends of female *Barbus* GSI at each site in the Mnembo River from July 2003 to June 2004. *Seasons: Dry/hot (Aug. to Oct.), wet/hot (Nov. to Jan.), wet/warm (Feb. to Apr.) and dry/cool (May to July).*

Table 4.6 Total number of individual *Barbus* at each life-stage sampled monthly in the Mnembo River at each site from July 2003 to June 2004.

Site	Adult	Sub-adult	Immature
MSS1	236	766	261
MSS2	45	472	334
MSS3	72	233	51
all sites	353	1471	646

While CPUE of adult (two-way ANOVA, $F_{2,20}$= 9.21, P= 0.001) and sub-adult (two-way ANOVA, $F_{2,20}$ = 4.44, P=0.025) *Barbus* differed significantly between sites, there was no significant difference for adult (two-way ANOVA, $F_{10,20}$ = 1.14, P=0.381) or sub-adult (two-way ANOVA, $F_{10,20}$= 1.83, P=0.121) CPUE between months. CPUE of immature *Barbus* differed significantly both between sites and over the year (two-way ANOVA, $F_{2,20}$= 5.99, P=0.009 between sites, $F_{10,20}$= 6.68, P<0.001 between months; Figure 4.8). CPUE of each life stage was higher at MSS1 than upstream at MSS3 (Figure 4.8).

Based on Figure 4.8b, the CPUE of sub-adult *Barbus* was higher during the hotter seasons and lowest in the wet/warm season during the month of February. However, only CPUE of immature *Barbus* showed any significant seasonal differences (one-way ANOVA, $F_{3,8}$= 4.48, P= 0.040). During the wet/warm season, primarily in March, immature *Barbus* CPUE was noticeably higher in the river, with a catch size of 7 immature *Barbus* per hour (129 individuals in total), compared to the month of December when the catch of immature *Barbus* was 0 (Figure 4.8c).

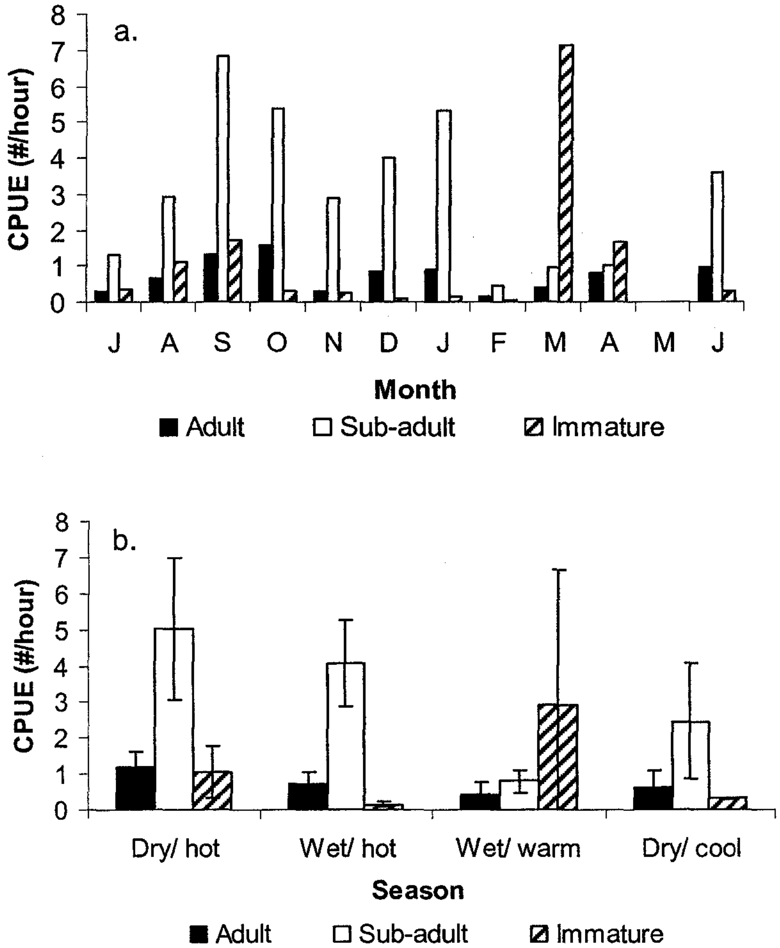


Figure 4.7 (a.) Monthly and (b.) seasonal variability of CPUE for each *Barbus* life stage in the Mnembo River from July 2003 to June 2004 for all sites combined. *Seasons: Dry/hot (Aug. to Oct.), wet/hot (Nov. to Jan.), wet/warm (Feb. to Apr.) and the dry/cool (May to July).*

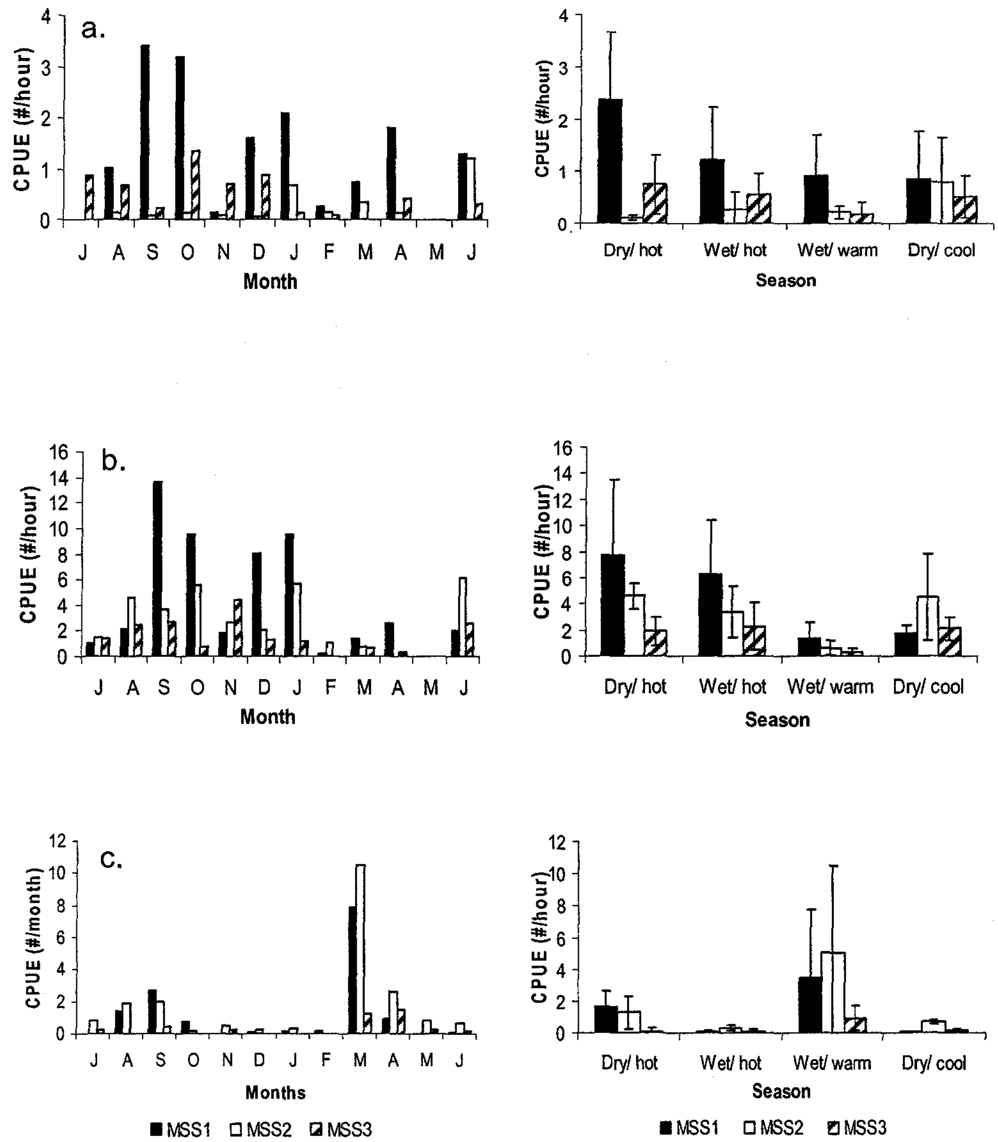


Figure 4.8 Site differences in monthly (left) and seasonal (right) CPUE data for (a.) adult (b.) sub-adult and (c.) immature *Barbus* sampled in the Mnembo River from July 2003 to June 2004. *Seasons: Dry/hot (Aug. to Oct.), wet/hot (Nov. to Jan.), wet/warm (Feb. to Apr.) and the dry/cool (May to July).*

Total monthly rainfall was the most frequent significant predictor in the regression models predicting female GSI for all sites, as well as for the mean Mnembo value (Table 4.7 and Figure 4.9). Female GSI also showed positive association with water temperatures and negative association with TSS concentrations. Mean TSS concentrations, rainfall and water temperatures within the river were linearly correlated with female GSI (R^2= 0.749, p= 0.005).

Regression models predicting abundance (CPUE) of *Barbus* life-stages indicated that abundance of adult *Barbus* was negatively associated with discharge at MSS1 and pH at MSS2 (Table 4.8). At MSS1, CPUE of sub-adult *Barbus* was also negatively correlated with discharge (Table 4.8). There were no significant correlations between lotic parameters and CPUE of immature *Barbus* ($P>0.05$).

4.3.3 Relationships between limnological parameters and fish abundance

Rainfall, albeit a predictor of female GSI for *Barbus* spp., was not an important factor with regards to CPUE variability in *Labeo cylindricus,* the most abundant species sampled in the Mnembo River (Table 3.3 in Chapter 3). Combined, CPUE of *Barbus* and *Labeo* constituted 64% of the total catch in the Mnembo and discharge was the most significant predictor of CPUE for both species (Table 4.9). At MSS3 the CPUE of *Labeo* and *Barbus* were negatively correlated with discharge (Table 4.9 and Figure 4.10). In August and December of 2003, CPUE of *Barbus* and *Labeo* were highest, when there was no flow or the rate of discharge was noticeably low.

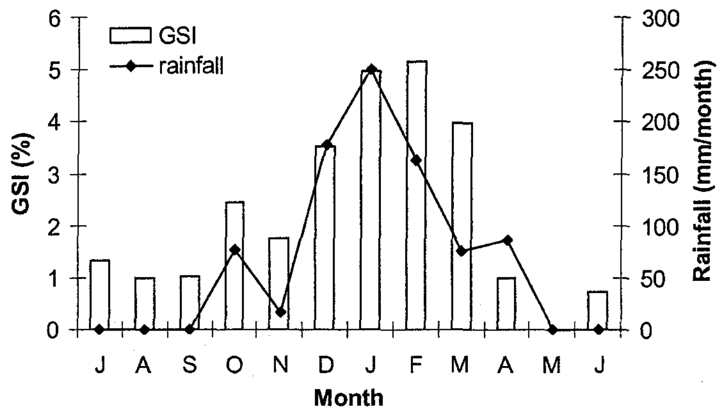


Figure 4.9 Total monthly rainfall and mean monthly GSI of female *Barbus* sampled in the Mnembo River from July 2003 to June 2004.

Table 4.7 Multiple regression analysis of female *Barbus* GSI within the Mnembo River. Only independent variables displaying significant Pearson's product-moment correlations with the dependent variables are presented in the models. Mean values represent means of all 3 sites for each measured variable.

Site	Independent variables	Female GSI
MSS1	Temperature (H_2O)	0.073
	Rainfall (mm)	0.303
	R^2	0.765
	Constant	-1.528
	p-value	0.001
MSS2	Rainfall	0.919
	R^2	0.586
	Constant	1.316
	p-value	0.004
MSS3	Rainfall	0.964
	R^2	0.692
	Constant	1.680
	p-value	0.001
Mean	Rainfall (mm)	0.832
	Temperature (H_2O)	0.056
	TSS (mg/l)	-20.680
	R^2	0.749
	Constant	-5.324
	p-value	0.005

Table 4.8 Multiple regression analysis of *Barbus* spp. life-stages collected within the Mnembo River. Only independent limnological variables displaying significant Pearson product-moment correlations with the dependent variables are presented in the models.

Site	Dependent variables	Independent variables	Regression coefficient	Constant	R^2	p-value
MSS1	Sub-adult	Discharge	-1.356	1.309	0.479	0.011
MSS2	Adult	pH	-0.732	4.422	0.470	0.025

Table 4.9. Multiple regression analysis of the CPUE of *Barbus* spp and *Labeo cylindricus* at site MSS3 with discharge from July 2003 to June 2004 in the Mnembo River.

Dependent variable	Regression coefficient	Constant	R^2	p-value
Barbus	-1.325	11.448	0.667	0.001
Labeo	-0.390	1.379	0.563	0.019

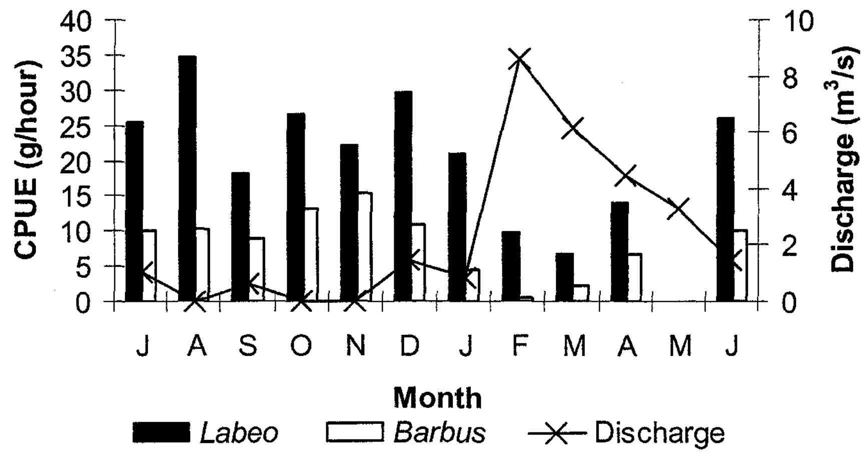


Figure 4.10 Variation in CPUE (catch per unit effort) of *Barbus* spp. and *Labeo cylindricus*, and rate of discharge in the Mnembo River at MSS3. Sampling period: July 2003 to June 2004.

4.3.4 Rate of soil loss and sedimentation in the Mnembo

Estimated soil loss in the Mnembo catchment is outlined in Table 4.10 and Figure 4.11 for each SEMU. Within the catchment 16 SEMUs were represented, however only 12 were applied in the Soil Loss Erosion Model for Southern Africa (SLEMSA). SEMU 13 to 16 could not be applied because the model is unable to quantify management units that have slope angles greater than 20 percent. SEMU 10 had the greatest rate of soil loss, 30.0 tonnes/hectare/year, which was due to its high degree of slope (16.5%). SEMU 6 had the second highest estimated rate of soil loss, 19.1 t/ha/yr, and SEMU 9 was only slightly lower (18.8 t/ha/yr). The calculated sediment yield into the Mnembo River was highest at SEMU 10 (4.5 tonnes/ha; 180.0 tonnes/SEMU) while SEMU 6 had a sediment yield of 2.9 tonnes/ha (1,251.8 tonnes/SEMU) and SEMU 9 had a rate of 2.8 tonnes/ha (296.4 tonnes/SEMU; Table 4.10). The estimated rate of soil erosion for SEMU 1 was 6.6 t/ha/yr and its sediment yield was one of the lowest measured in the catchment (1.0 tonnes/ha), however it covered the largest area (3,800 ha) and hence had the second highest measured sediment yield per SEMU (3,743.9 tonnes/SEMU). Soil loss and sediment yield at SEMU 5 was moderately higher (12.9 t/ha/yr and 1.9 tonnes/ha, respectively) than SEMU 1 and the sediment yield per SEMU was higher (5,614 tonnes/SEMU), however, SEMU 5 represented a much smaller area (2,904 ha).

The lowest rate of soil loss was estimated for SEMU 4 and 2, the respective soil loss estimates were 4.0 t/ha/yr and 4.8 t/ha/yr. The sediment yield at both sites were also the lowest for all SEMUs; 0.6 tonnes/ha (60 tonnes/SEMU) and 0.7 tonnes/ha (620 tonnes/SEMU) respectively due to the low slope (Table 4.10).

Both MSS1 and 3 were located within SEMU 1 and MSS2 was found within SEMU 5 representing the left side of the river bank and SEMU 8 representing the right side of the bank (Table 4.11). Based on field inspection, MSS1 and MSS3 were mainly comprised of grasses and sandy soils and in addition, MSS3 was also highly utilized for agricultural purposes along the river banks. MSS2 did show signs of agricultural usage within the wetland portion of the site (SEMU 8) however the banks were highly vegetated with tall grasses, trees and shrubs (Table 2.2).

No marked trends were identified between sediment yield (tonnes/site) with male or female *Barbus* GSI at any site (Figure 4.12). In contrast, conductivity and TSS concentrations did appear to be positively associated with sediment yield at each site (Figure 4.13). Sediment yield at each site was also negatively correlated with *Labeo* CPUE (Figure 4.14).

Table 4.10 Estimated soil loss (Z) using the SLEMSA (Soil loss erosion model for southern Africa) in the Mnembo River catchment. *tonnes/hectare/year

Soil Erosion Management Unit (SEMU)		X – Topographic Factor			K – Soil Erodability and Rainfall Factor					C – Vegetation Canopy Factor			Z – Estimated Soil Loss	
SEMU	Vegetation Unit	Degree of Slope (%)	Slope Length (m)	X value	Soil Erod Index (Fb)	Soil mgt Index (Fm)	Mean annual rainfall (mm)	Kinetic Energy Joules/ m	K value	Proportion of tree canopy (%)	Tree Interception τ (%)	C Value	Z value	Common Soil loss factors
1	At 1	3	100	0.215	5.4	-0.1	844.0	15915	36.61	0-5	3	0.835	6.6	Annual rainfall Poor canopy cover Poor soil mgt
2	At 2	3	100	0.215	5.5	5.5	844.0	15915	34.12	5-10	7	0.6570	4.8	Annual rainfall Poor soil mgt Reduced cover
3	Gwt	3	100	0.215	4.5	4.5	844.0	15915	69.12	20-70	35	0.4649	6.9	Vegetation cover Poor soil mgt Light soils
4	W	3	100	0.215	5.5	5.5	844.0	15915	34.12	0-5	10	0.5488	4.0	Poor soil mgt Annual rainfall Poor canopy cover
5	At 1	9.5	100	0.421	5.4	-0.1	844.0	15915	36.61	5-10	3	0.8353	12.9	Slope angle Poor soil mgt Poor canopy cover
6	At 2	9.5	100	0.421	4.5	4.5	844.0	15915	69.12	20-70	7	0.6570	19.3	Light soils Poor soil mgt Annual rainfall
7	Gwt	9.5	100	0.421	5.5	5.5	844.0	15915	34.12	0-5	35	0.4632	6.7	Annual rainfall Slope angle
8	W	9.5	100	0.421	5.5	5.5	844.0	15915	34.12	5-10	10	0.5488	7.9	Poor canopy cover Annual rainfall Poor soil mgt
9	At 1	16.5	100	0.660	5.5	5.5	844.0	15915	34.12	20-70	3	0.8353	18.8	Steep slope angle Annual rainfall Poor canopy cover
10	At 2	16.5	100	0.660	4.5	4.5	844.0	15915	69.12	0-5	7	0.6570	30.0	Steep slope angle Annual rainfall
11	Gwt	16.5	100	0.660	4.5	4.5	844.0	15915	69.12	5-10	15	0.4066	18.6	Steep slope angle Annual rainfall
12	W	16.5	100	0.660	5.5	5.5	844.0	15915	34.12	20-70	10	0.5488	12.4	Steep slope angle Annual rainfall Poor soil mgt

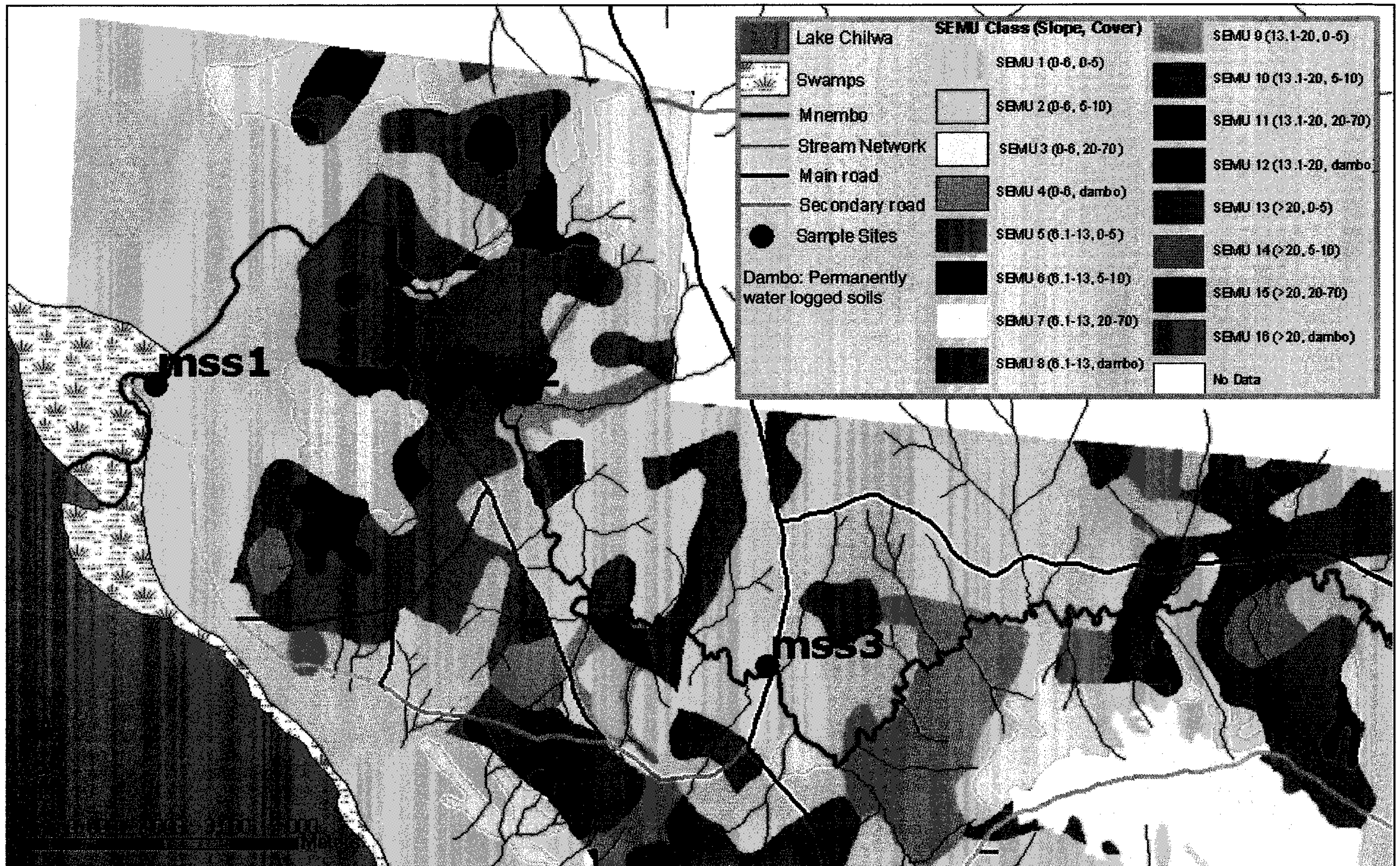


Figure 4.11 Classified soil erosion management units (SEMU) for the Mnembo River Catchment.

Table 4.11 Estimated soil loss for each SEMU and associated sediment yields at each site in the Mnembo River Catchment.

MSS#	Slope angle (%)	Land cover (%)	SEMU (#)	SEMU (ha)	Site coverage (%)*	Estimated soil loss per SEMU (tonnes/ha/yr)	Sediment yield (tonnes/site)
1	3	2.5	1	3800	0.3	6.6	14.78
2	9.5	7.5	5	2904	0.3	12.9	17.40
	9.5	Wetland	8	100	7.0	7.9	8.29
							#*Mean=12.8*
3	3	2.5	1	3800	0.3	6.6	14.78

**Site coverage (%) is the percentage of each SEMU represented by each site*
 # the mean is an estimation of sediment yield at that site.

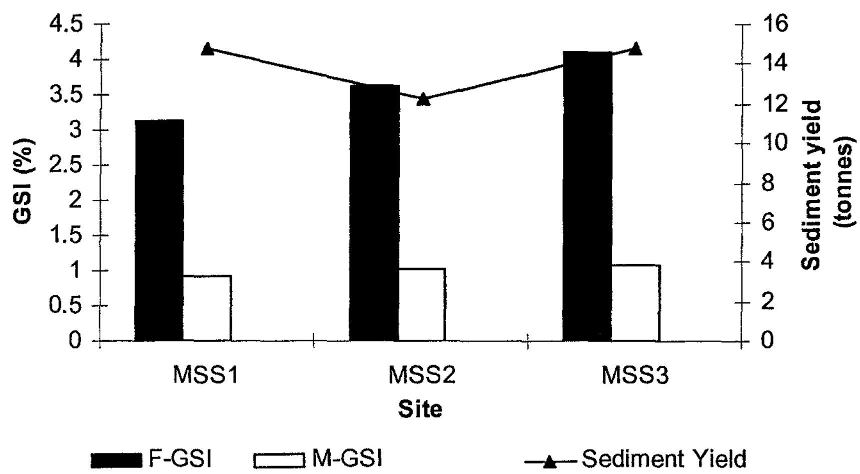


Figure 4.12 Comparison between male and female *Barbus* spp. GSI with sediment yield in the Mnembo River at each site. Sampling season: July 2003 to June 2004.

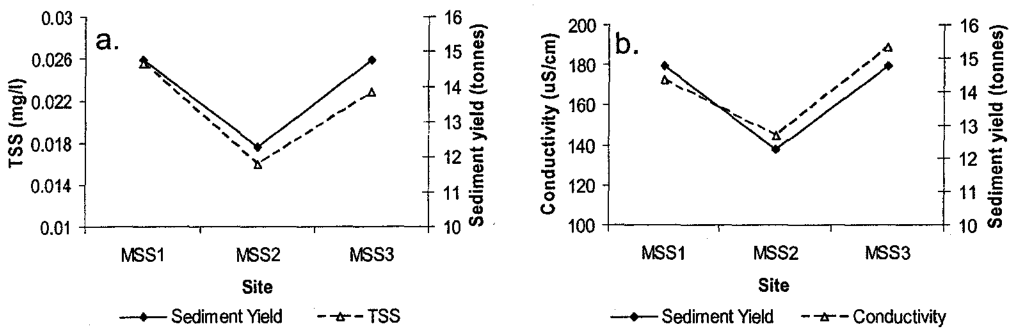


Figure 4.13 Comparisons between (a.) TSS and (b.) conductivity with the rate of sedimentation measured in the Mnembo River catchment. Sampling period: July 2003 to June 2004.

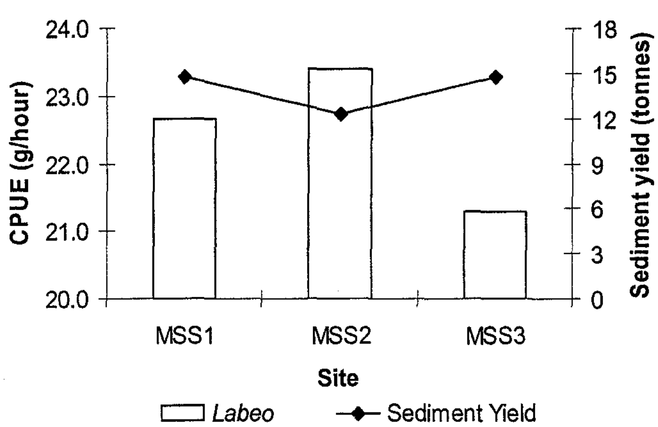


Figure 4.14 Comparison between *Labeo* sp. CPUE and sediment yield at each site sampled in the Mnembo River.

4.4 Discussion

The major environmental factors associated with female *Barbus* GSI in the Mnembo River were total monthly rainfall, temperature, and TSS concentrations. Once the rains began in October and water temperatures increased, female GSI increased dramatically in the river especially upstream at MSS3.

Annually, *Barbus* seems to experience two migratory events into Lake Chilwa's Malawian catchments (Furse *et al.* 1979b; Jamu *et al.* 1999), Similar patterns are conjectured to exist in the Mnembo catchment. First, *Barbus* spp. migrate from the lake into the river, triggered primarily by environmental conditions in the lake, including increased salinity, conductivity and pH. Once in the catchment, rainfall, water temperature and TSS concentrations trigger a further secondary migration upriver, possibly for the purpose of spawning. East of Lake Chilwa is a chain of low hills ranging from 800 to 900 meters, with intermittent peaks such as Mount Pera and Mount Tecone rising to 1,000 to 1,300 m above sea level (Lancaster 1979). People from the Mnembo catchment community stated that *Barbus* migrate to the base of Mount Tecone and when the rains begin, the fish move out of the river channel to spawn in the river's floodplain. *Barbus* spp., like many riverine fishes, spawn on floodplains to take advantage of the food and protective resources that floodplains provide to larval fish (Welcomme 1996).

In the Mnembo River, catches of sub-adult and adult *Barbus* varied considerably with discharge and pH throughout the year. It appears that sub-adult and adult *Barbus* migrated upstream during the dry/hot season when river flow was slow and depths were lower, then would initiate spawning when the rains had commenced in December. *Barbus* are prolific breeders (Skelton 1994), but based on the Mnembo data there was only one spawning event during the year. If so, this is contradictory to the assumption made by Furse *et al.* (1979b) that *Barbus* spawn several times a year within the Lake Chilwa watershed.

By the end of March discharge in the river had increased dramatically and adults, sub-adults and newly hatched immature *Barbus* were most abundant downstream. Similarly, the major migration of *Barbus* upstream in the Domasi and Likangala rivers was during the months of January and February while the greatest movement downstream occurred in March (Jamu and Brummett 1999). Once environmental conditions were favourable *Barbus* migrated back into the lake and surrounding swamps (Jamu and Brummett 1999). However some *Barbus* were unable to reach the lake before the flow in the Mnembo River had slowed in June and July, where they were trapped in small pools till the next rainy season (Skelton 1993). During the last lake recession in 1995 communities from the Domasi and Likangala catchments protected pools and resident fish populations until water levels in the lake had normalized (Ambali and Kabwazi 1999). Pools could therefore, be important sanctuaries that play an important role in the recovery of Lake Chilwa's fisheries.

Barbus paludinosus and *B. trimaculatus* are commercially very important and as with *Labeo cylindricus*, their abundance was negatively associated with increased river discharge at MSS3. *Barbus* are highly tolerant of increased ionic stress (Furse *et al.* 1979b) and during the current study high numbers of both species were sampled in small isolated pools on the river floodplain. *Labeo cylindricus* is predominantly a riverine species that builds nests within the river bed to spawn shortly after the rains begin (Weyl and Booth 1999) and will only travel into the lake during the rainy season when alkalinity is reduced (Morgan 1971). Once discharge was high in the Mnembo River, both *Barbus* and *Labeo* could have retreated into the instream aquatic grasses until conditions became more favourable or they could have been carried downstream to the lake, as was seen in the Domasi/ Likangala catchments (Jamu and Brummett 1999). An increase in discharge can normally increase the effectiveness of a gill-net because gill-nets are passive gears that require the fish to encounter the net for it to be retained by the net (van der Mheen 1995). During this study, however it is possible that the gill-net was less efficient when river flow and depth increased, and smaller fish such as *Barbus* and *Labeo* could have swam under the net. It is also possible that smaller fish (including immature *Barbus*) were pushed by the current through the larger mesh.

The estimated soil loss for the Mnembo River catchment was markedly lower than estimates from other catchments (World Bank 1992, cited in Jamu et al. 2003). On average, the Mnembo catchment was losing 12.4 tonnes per hectare per year, compared to losses in the Likangala catchment area of 24.95 t/ha/yr (Crossley 1985, cited in Jamu *et al.* 2003). The Mnembo River originates from mountainous areas that are highly forested whereas the Likangala originates from highly deforested areas with dense human populations (Jamu *et al.* 2003; Sambo *et al.* 1999). A study conducted on the catchment areas of Lake Malawi estimated that increasing populations, associated agricultural development and clearing of forests had increased sedimentation and nutrient loading to Lake Malawi by 50% (Hecky *et al.* 2003). Decreased tree canopy cover and increased agricultural activities leave large expanses of topsoil exposed to wind and rain erosion. For these reasons, the rate of soil loss in the Likangala catchment was much higher than in the Mnembo.

The degree of sedimentation into the Mnembo River was related to tree canopy cover and slope as well as rainfall (Chapter 2). Estimated soil loss for SEMUs 1, 2, 3, 4 and 8 in the Mnembo catchment was lower than the estimated rate of soil formation of 12 t/ha/yr for southern Africa as determined by Shaxton et al. 1977 (cited in Jamu *et al.* 2003). However, estimated soil loss for SEMUs 5, 6, 7 and 9, 10, 11 was higher than 12 t/ha/yr. SEMUs 1 to 4 and 8 had, in fact, retained an average 50% of the topsoil, while SEMUs 5 to 7 and 9 to 11 contributed to excessive soil loss, ranging from 5% to 150% more soil lost than was formed. Sediment yields of SEMUs 5 (5,614 tonnes per SEMU) and 1 (3,743 tonnes per SEMU) were significantly more than the other SEMUs due to their larger areas: combined, SEMU 1 and 5 comprised approximately 70% (including MSS1 and MSS3) of the entire Mnembo catchment.

Higher sediment yields were found to be strongly associated with electrical conductivity and total suspended solid concentrations in the Mnembo River. Such was also the case in New Zealand where between 60 to

80% of the variability in conductivity in 101 catchments was attributable to land use and landscape factors (Close and Davies-Colley 1990).

Sediment yield from the catchment into the Mnembo River was not correlated with *Barbus* GSI but was negatively associated with *Labeo* abundance. Walling (1999) determined that for soil eroded from catchments into rivers, only small percentages of sediment are transported out of the basin while most is retained in the river itself. Amphlett and Tucker (1984) also reported that in Malawi the rate of soil erosion due to intensive land use practices was very high in areas where there were large population densities such as within the Likangala catchment. High sediment yield could cause sediment build-up on *Labeo* spawning nests. Given the higher sediment yield and higher human pressures experienced in the Likangala it was not surprising that *Labeo* abundance was substantially lower there compared to the Mnembo. Furthermore, unlike the Domasi and Likangala rivers, the Mnembo can be classified as a baseline river for future environmental comparisons, wherein environmental conditions and presence of *Labeo cylindricus* could be a good indicator of less human impact in this part of the Lake Chilwa watershed.

Table 4.12 analyzes the application of two potentially effective methods for reducing soil loss: contour ridging and increased tree canopy cover which complements the management strategies applied by Jamu *et al.* 2003. Contour ridging is an agricultural technique that reduces the amount of soil and nutrient loss by placing crop ridges perpendicular to the angle of slope thereby reducing runoff. Increased tree canopy cover leads to increased soil stability and lowers rain impact energy (Environmental Affairs Dept. 2000b). Soil loss at each SEMU in the Mnembo catchment in Malawi could be reduced by more than half with a 20% increase in tree canopy cover. Increasing land under contour ridging also displayed similar results. The SEMU that most benefited by each management strategy in the Mnembo catchment was SEMU 10. There was a 21 t/ha/yr reduction in soil loss in SEMU 10 once contour ridging was implemented and a 4.0 t/ha/yr reduction with increased land under 20% tree canopy cover. SEMU 4 was least affected by the introduction of the management strategies (1.2 and 0.5 t/ha/yr, respectively). SEMU 10 was primarily cultivated with only 5 to 10% tree canopy cover and was located on steep slopes, greater than 13%, whereas SEMU 4 was located within a wetland with a very low percentage of vegetation cover (0-6%).

Malawi's dependence on subsistence farming has been expanding exponentially (Hyde and Seve 1993), and with its ever-expanding population and increased need for arable land comes increased demand and exploitation of its river catchments. For example, the rate of deforestation in Malawi, at 3.2% per annum was the highest in all of Africa (Hyde and Seve 1993). Within Lake Malawi's catchments, forest coverage had been reduced by 13% from 1982 to 1995 (Calder *et al.* 1995), while forest and woodlands along river courses within the Lake Chilwa catchments, including the Mozambican catchments, were disappearing at an estimated rate of 3.5% or 150,000 ha/yr (Sambo *et al.* 1999). Both the increase in tree canopy cover and use of contour ridging as sustainable farming practices demonstrate how such practices could prevent soil loss and in so doing reduce the rate of sedimentation into the river. Increasing vegetation cover and implementing sustainable agricultural practices could also increase the water storage capacity of the catchment thereby improving river flow rates (Jamu *et al.* 2003). Resultant improvements in water quality would then result in increased populations of fish, particularly riverine specialists.

Table 4.12 Potential total reductions in soil loss once land under tree canopy and contour ridging is increased by 20% for each SEMU (t/ha/yr) in the Mnembo catchment, based on the soil loss erosion model for Southern Africa (SLEMSA).

		Management Intervention			
		Increase land under tree canopy by 20%		**Increase land under contour ridging by 20%**	
SEMU	Current Erosion Rates	Soil loss	Total reduction in soil loss	Soil loss	Total reduction in soil loss
1	6.6	2.0	4.6	5.7	0.9
2	4.8	1.4	3.4	4.1	0.6
3	6.9	2.6	4.3	6.0	0.9
4	4.0	1.2	2.8	3.5	0.5
5	12.9	3.9	9.0	11.2	1.7
6	19.3	5.8	13.4	16.6	2.5
7	6.7	2.5	4.2	5.8	0.9
8	7.9	2.4	5.5	6.9	1.0
9	18.8	5.7	13.2	16.3	2.5
10	30.0	9.0	21.0	26.0	4.0
11	18.6	5.6	13.0	16.1	2.4
12	12.4	3.7	8.6	10.7	1.6

Chapter 5

Community Concerns and Contributions to the 'Health' of the Mnembo River Catchment

5.1 Introduction

Despite its relatively small size (average surface area 750 km^2), Lake Chilwa supports a lucrative fishery and a large fishing community. The most productive areas of Lake Chilwa are located near the fishing villages of Kachulu (S 15°13'26.6" and E 35°47'30.6) on the western portion of the lake and Chinguma (S 15°22'17.8" and E 35°35'24.4") on the eastern portion (Furse *et al.* 1979a). Fishermen from Chinguma consider one of the best fishing sites to be at the mouth of the nearby Mnembo River (Delaney, pers. obs. 2003). However, only recently have any environmental studies been conducted on the Mnembo River or its catchment to see if these assertions are true.

To fully understand the relationship between the riparian corridor and river water quality it is necessary that human activities in the catchment be known so as to predict its direct impact on water quality and the biota (Johnson *et al.* 1997; Richards *et al.* 1996). Human activities within a watershed, for instance can have a noticeable effect on river water chemistry (Morgan *et al.* 1993). Thus, to assess catchment activity, a participatory rural appraisal (PRA) was conducted in August 2003 with the assistance of villagers residing in the Mnembo catchment. PRAs are informal tools used to share and learn ideas between local people and the researchers. In a PRA the local people are involved rather than just sources of information, and both the researcher and the local community work together to gather and analyze or interpret data (Townsley 1996). A PRA also enables local communities to gauge their knowledge base and helps them develop an overview of the status and priorities they deem as the way forward to development (Mascarenhas *et al.* 1991). The purpose of the PRA and the main objective of this chapter were to gather information from the Mnembo catchment communities pertaining to their land use activities and also to evaluate the level of importance that the Mnembo River played in their lives.

5.2 Materials and methods

5.2.1 Participatory Rural Appraisal

From August 13 to 14, 2003 the Participatory Rural Appraisal (PRA) was conducted with the Mnembo catchment community with the assistance of Mr. Patrick Viyazyi an Agriculture Technician from the Department of Agriculture in Malawi. Two tools were used during the PRA: village mapping and 'the road to progress' (Townsley 1996). Several groups of villagers were put together according to sex and age. Both the village mapping and road to progress tools are interactive and greatly dependent on the involvement of the community members. The purpose of the village mapping tool was to help geographically orient the village participants and the facilitator based on major landmarks. Major landmarks were the main channel of the Mnembo River and its tributaries, schools, villages and religious symbols. To assess the amount of agricultural activities within the catchment, participants were asked to draw where their Dimbas (irrigated gardens) were located along the river and the proximity of the main river channel and the tributaries to the villages. The initial groups used in the village mapping were broken and reformed according to village. One map for each village was drawn using a large writing pad and markers.

To represent the various issues that were discussed in the road to progress PRA tool, groups used symbols including tree leaves, stones and plastic. These items were utilized to allow participants the opportunity to express what they thought were important issues facing the productivity and health of the Mnembo River.

5.2.2 Questionnaire

Randomly selected members from 16 villages within the Mnembo catchment were asked a series of carefully constructed questions relating to the history of their community and their fishing and farming practices (Appendix 3).

The questionnaire was administered in Chichewa (the local language spoken in Malawi and Northern Mozambique) and was comprised of five sections, including household information, household size, water and fishery resources and farm location. Forty questionnaires were disseminated within the Mnembo catchment with 14 villages in Mozambique and 2 villages in Malawi participating (Figure 5.1).

5.3 Results

The number of respondents from the 16 villages is displayed in Table 5.1. The majority of respondents were landowners, owning on average 108m^2 of farmland per household. One hundred percent of respondents use the main river for washing, bathing and livestock watering, while 75% and 88% of the respondents said they used the water for irrigation and human consumption, respectively. Sixty percent of respondents believed that the water quality of the river had decreased over the last five years, and that it was related to soil erosion.

Most of the farmers live in proximity to the river, on average 248 m away. However, a few live near the Mnembo tributaries (Figure 5.1). Of the people interviewed, 72.5% are fishermen (in the Mnembo River and in Lake Chilwa) with at least one person in the household involved. Approximately 103 kg/month of fish are caught per household from the Mnembo River with only 54.1 kg/month consumed. The remainder is sold or bartered. Most fishermen are seasonal fishermen. They begin fishing in December and end in March. Catch rates are highest in February and lowest in June. Forty-one percent of fishermen interviewed use traps. Twenty-eight percent use gillnets, which are mainly fished closer to the mouth of the river. When asked what species comprise their catch all the fisherman said that matemba (*Barbus paludinosus* and *B. trimaculatus*) were always found. Sixty percent of fisherman also said they were catching chonjo (*Labeo cylindricus*) followed by mlamba (55%) (*Clarias gariepinus*), mphuta (47%) (*Marcusenius macrolepidotus*) and nghalala (42.5%) (*Brycinus imberi*).

The average size of *Barbus* most fishermen were catching was 6.3 cm in total length. When asked if they had noticed a decline in the size of *Barbus* over the last five years 93% said yes, estimating a size reduction of 2.5 cm. The fishermen also believed that their catch size had also decreased within the last five years by an estimated average of 541 kg per month.

The Participatory Rural Appraisal (PRA) was conducted within the Mnembo River catchment and village maps were constructed for the Liwonde, David, Howa, Maria and Kachiwanda village by the villagers (Appendix 4). During the discussion period of the PRA, the catchment community were asked what were the benefits derived from the Mnembo River. It was agreed by the community that the river provided a good source of water for domestic use, fresh fish, reeds for mat making and enabled dimba construction for vegetables and tobacco.

Participants were also asked what they thought were some of the problems they had noticed about the health of the river. The problems outlined by the participants were a reduction in their fish catch and the contamination of the water. They assumed the reasons why they were experiencing low fish catch resulted from river bank cultivation and the usage of small mesh nets. The communities said that the small mesh-gillnets were very unselective. The smaller mesh was catching small fish and even sometimes sweeping away the fish eggs along the river basin. The last cause outlined by the community was riverbank cultivation. The constriction of Dimbas along the riverbanks and poor cropping practises were easily washing away soil into the water and filling in potential fish breeding sites, thereby interfering with the natural breeding patterns of fish in the river. Other concerns about river health included waste disposal and particular herbs used for catching fish, as well as increases in water-borne diseases, such as cholera.

Table 5.1 Communities, villages and number of the respondents interviewed in the Mnembo catchment from July 2003 to December 2003. Total of 40 respondents.

#	Community	Village	# of Respondents
1	Messossomera	Chitimbe	1
2		Kamwenji	1
3		Kamaliza	2
4		Khaba	1
5		Liwonde	3
6		Malia	1
7		Mbatata	4
8		Muanabua	2
9		Somaje	3
10	Msaka	Mwiliya	2
11	Mukhanheya	Mpoya	10
12	Nssomera	Chiuanda	1
13		Namayenda	1
14	Nsala	Cavava	4
15	Muambo	Mpambidji	1
16	Nkumbila	Thomo	3

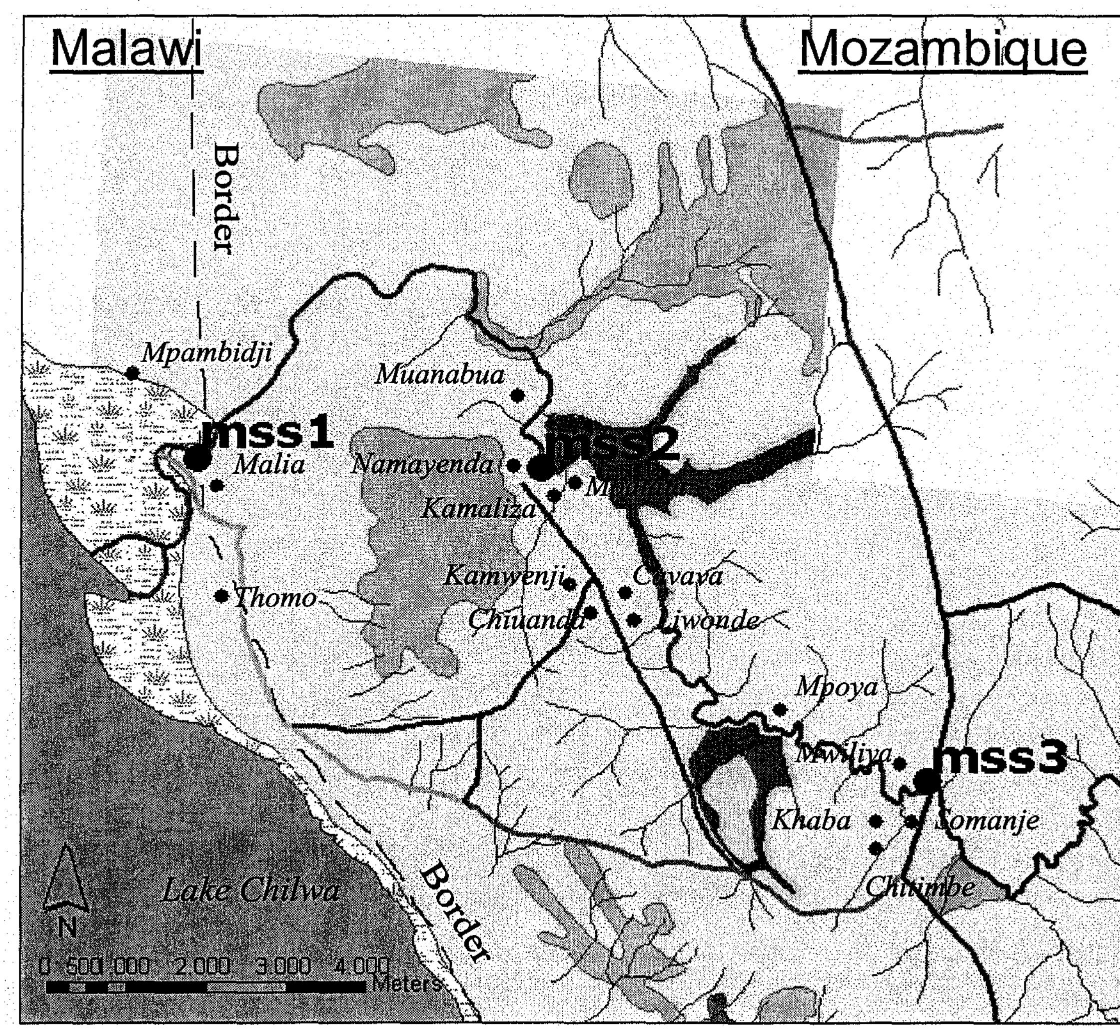


Figure 5.1 Location of participant villages in the questionnaire that was conducted from July 2003 to January 2004, throughout the Mnembo catchment.

5.4 Discussion

Members of the Mnembo catchment community are mainly subsistence farmers who depend greatly on the Mnembo River for a source of fish protein and as the primary water source for bathing, washing and for irrigation of their Dimbas. For these reasons the community members are very aware and sensitive to changes in the health of the Mnembo River.

Only half of the total weight of fish caught in the Mnembo River was consumed by the family and the remainder was sold, however over the last five years their total fish catch has reduced by half, implying that on average families in the Mnembo catchment community are consuming less fish (protein source) than they had five years previously. Furthermore, the maximum total length of *Barbus* measured in the Mnembo River during the study was smaller than the maximum total length measured in southern Africa (Chapter 3). This also coincided with the observations made by the Mnembo community that over the last five years the total length of *Barbus* had decreased by approximately 2 cm (Chapter 3).

The concerns outlined by the catchment community were mainly reductions in their fish catch and water quality. The majority of the community have acknowledged the reduction in the quality of the Mnembo River and total fish catch over the last five years, resulting from soil erosion caused by river bank cultivation and over fishing using small mesh seine nets.

Fish and water quality data were collected for only one year for this thesis and the project was considered a baseline study for the Mnembo River catchment. For these reasons it was difficult to evaluate and determine if there had indeed been annual changes in water quality or fish abundance as a result of over fishing or changes in land use. However, compared to other catchments of Lake Chilwa (Domasi and Likangala) it has been concluded that the Mnembo catchment is in much better condition. Higher abundance of *Barbus trimaculatus* versus *B. paludinosus,* better river water quality (i.e. lower TSS and conductivity), greater fish diversity and lower rates of soil loss and sediment yield were the main distinguishing factors between the Mnembo River and the more heavily impacted Domasi and Likangala River catchments.

In the Bua River located in the Nkhotakota Wildlife Reserve, and in the Domasi and Likangala Rivers of Malawi, similar concerns and observations have been made towards the reduction in river water quality and fish abundance by the catchment communities (Jamu *et al.* 2003; Tweddle 1997). However few preventive measures have been adopted by the government or by the communities themselves. In 1995 the River Committee (RC) for the Lake Chilwa watershed and the more local Beach Village Committees (BVCs) were established with the aim of conserving lake and river fisheries during lake drying phases (Ambali and Kabwazi 1999; Lowore and Lowore 1999). These committees exist today, however they only represent the Malawian portion of the Lake and thus there is a need to introduce such committees into the Mozambican catchments.

Observed declines in river water quality and fish abundance within the Mnembo River catchment should also be an indicator of the need for more sustainable measures in the catchment, such as the use of buffer strips along the river. The presence of riparian vegetation can greatly minimize bank erosion and help maintain nutrient availability for inland subsistence farming (Chimatiro and Vitsitsi 1997; Osbourne and Wiley 1988). These conservational methods need to be implemented within the Lake Chilwa watershed by the responsible government authorities, the BVC and the watershed communities. With the expansion of BVCs into Mozambique there is also potential that the concerns and opinions of the Mnembo community could be addressed and this could help the Mnembo community feel included in the managerial decision making and conservational efforts for the entire Lake Chilwa watershed.

Chapter 6

Conclusion

Fish constitutes twenty-two percent of the protein consumed by the entire world (Delgado *et al.* 2003) and in Malawi it is even higher at 28 percent (Department of Fisheries, 2004). As of 2002, the Malawi fish industry supported 1.6 million people along the Lakes Malawi, Malombe and Chilwa. However, in Malawi and Africa in general, fish demand has increased while supply has decreased and, at present, the availability of fish in Africa is below 1 kg per person per year. If this major problem persists, by the year 2020 Africa will require a 61 percent increase in fish production to counteract the rate of consumption on the continent (Delgado *et al.* 2003). To address this, a better understanding of factors effecting fish production must be undertaken and this thesis is a part of that research effort.

The results from this thesis indicate that:

- Climatic and hydrological conditions within the Mnembo River are potentially very important factors associated with abundances of *Barbus* spp. and *Labeo cylindricus*, and the distribution and the reproductive state (GSI) of *Barbus* in the Mnembo River.
- Soil erosion and sedimentation in the Mnembo catchment were not significantly associated with the abundance or reproductive state of *Barbus* spp. but sediment yield was negatively associated with *Labeo* abundance.
- Predominance of the riverine species, *Labeo cylindricus*, *Brycinus imberi* and *Pareutropius longifilis,* in conjunction with relatively good water quality (i.e. low TSS and conductivity) in the Mnembo River indicated a much healthier ecosystem in comparison to the Domasi and Likangala catchments. The

extent of human impacts appears to be the main reasons for these differences.

- The majority of the Mnembo catchment community believed that water quality and fish abundance have declined over the last five years due to soil erosion and land use activities and agreed that a management strategy was needed to successfully protect the Lake Chilwa watershed.

Without the implementation of a management strategy for the entire Lake Chilwa watershed the quality of the Mnembo River could drastically decline and in so doing affect fish productivity and water quality of the river and lake. Strategies must be developed with the combined efforts of all stakeholders involved, including the Malawi and Mozambican Governments, the local communities and environmental non-governmental organizations. The strategy would have to be at the community level thereby empowering the community so that they can make decisions that will best help themselves and the catchment (Mattson and Kaunda 1997; Osbourne and Wiley 1988).

As Moss (1979) stated, 'the Chilwa fishes are clearly well fitted to persist in the unpredictable Chilwa ecosystem, provided the refugium of swamps and streams are maintained.' The results of this study reinforces the need to redirect management efforts to protection of wetland processes for the entirety of the Lake Chilwa watershed rather than towards regulating fishing efforts within just the Lake itself. In conclusion, management efforts must be broadened to include Lake Chilwa's catchments if hopes of conservation are to be attained.

Chapter 7

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Appendix 1 Minimum and maximum values for each limnological parameter measured in the Mnembo River from July 2003 to June 2004 and in the Likangala and Domasi rivers from November 1999 to October 2000. *Seasons: wet/ warm (W/W), wet/ hot (W/H), dry/ hot (D/H) and dry/ cool (D/C).*

River	Minimum			Maximum			Mean
MNEMBO	**Value**	**Month**	**Season**	**Value**	**Month**	**Season**	**Value**
pH	6.7	Feb	W/W	7.7	Nov	W/H	7.2
Cond. (µS/cm)	97	Feb	W/W	308	Nov	W/H	169
DO (mg/l)	3.2	Jan	W/H	6.4	May	D/C	4.7
T °C	18.4	June	D/C	27.9	March	W/W	23.9
Depth (m)	1.3	Nov	W/H	2.5	Feb	W/W	1.8
TSS (mg/l)	0.000	July	D/C	0.074	Dec	W/H	0.033
Discharge (m^3/s)	1.0	Nov	W/H	19.8	Feb	W/W	3.8
***LIKANGALA**	**Value**	**Month**	**Season**	**Value**	**Month**	**Season**	**Value**
pH	7.4	Feb	W/W	9.7	April	W/W	8.2
Cond. (µS/cm)	118	July	D/C	3000	Jan	W/H	1548
DO (mg/l)	2.1	Aug	D/H	6.1	Oct	D/H	4.9
T °C	--	--	--	--	--	--	--
Depth (m)	--	--	--	--	--	--	--
TSS (mg/l)	0.165	Nov	W/H	0.042	Feb	W/W	0.088
Discharge (m^3/s)	0.0	Dec	W/H	3.7	Aug	W/W	1.8
***DOMASI**	**Value**	**Month**	**Season**	**Value**	**Month**	**Season**	**Value**
pH	7.5	May & June	D/C	9.5	Sept	D/H	8.0
Cond. (µS/cm)	210	July	D/C	3500	Aug	W/W	1513
DO (mg/l)	3.2	Aug	D/H	6.3	Oct	D/H	5.4
T °C	--	--	--	--	--	--	--
Depth (m)	--	--	--	--	--	--	--
TSS (mg/l)	0.048	Jan	W/H	0.116	Nov	W/H	0.074
Discharge (m^3/s)	0.0	Oct	D/H	5.1	March	W/W	2.2

*Data from the Domasi and Likangala Rivers were attained from the WorldFish Center, Malawi.

Appendix 2 Total number of individuals of each species sampled monthly in the Mnembo River per site, from July 2003 to June 2004.

	July	August	September	October	November	December	January	February	March	April	May	June	Total
MSS1													
Barbus	9	95	293	197	29	151	142	9	204	79		53	1261
Brycinus	0	3	5	9	3	19	27	4	35	13		4	122
C. gariepinus	0	0	2	0	0	0	0	0	1	0		0	3
C. theodorae	0	0	0	0	0	0	0	7	0	0		0	7
Haplochromis	2	9	18	25	9	5	0	0	2	4		6	80
Labeo	0	50	81	108	33	46	118	4	91	59		65	655
Marcusenius	0	4	5	6	1	10	71	3	5	1		1	107
Oreochromis	0	1	0	19	6	8	10	0	2	5		3	54
Pareutropius	0	33	39	18	5	27	14	0	42	15		6	199
Petrocephalus	1	11	15	12	2	28	10	5	8	6		2	100
Tilapia	1	1	7	1	0	0	0	0	1	0		1	12
MSS2													
Barbus	17	89	80	85	45	33	90	18	233	42		120	852
Brycinus	0	0	0	0	0	0	5	17	28	7		2	59
C. gariepinus	0	1	0	0	0	0	0	1	1	1		0	4
C. theodorae	0	0	0	0	0	0	0	0	0	0		0	0
Haplochromis	0	13	25	14	8	9	0	0	1	1		2	73
Labeo	18	58	18	29	21	17	83	20	10	3		59	336
Marcusenius	0	0	0	0	0	2	12	0	0	1		1	16
Oreochromis	1	0	2	3	4	10	2	0	0	1		3	26
Pareutropius	0	0	0	0	1	0	8	44	7	0		1	61
Petrocephalus	0	2	16	6	9	2	1	0	0	0		6	42
Tilapia	0	1	0	0	0	0	0	0	0	0		0	1
MSS3													
Barbus	20	42	43	29	75	33	19	1	26	32		41	361
Brycinus	0	4	1	0	0	0	3	1	5	2		4	20
C. gariepinus	1	0	0	1	1	0	1	1	0	0		0	5
C. theodorae	0	0	0	0	0	0	0	0	0	0		0	0
Haplochromis	0	19	3	16	6	1	1	0	0	1		1	48
Labeo	48	95	35	29	18	22	22	6	4	12		30	321
Marcusenius	0	0	0	0	0	0	0	0	3	0		0	3
Oreochromis	1	0	0	2	1	0	0	1	3	1		4	13
Pareutropius	0	13	2	1	0	0	1	9	8	4		2	40
Petrocephalus	0	9	4	3	1	4	6	0	0	1		1	29
Tilapia	1	3	0	0	0	0	0	0	4	0		0	8

QUESTIONNAIRE –CCLF

Officer ________________ **Farmer ID** ________________
(Mlimi)

HOUSEHOLD INFORMATION
(Zochitika za pa banja)

Farmer – Respondent ________________ ________________
(Woyankha) Dzina La Bambo Dzina lanu

Sex: Male / Female ________ **Birth Year**__________
Mwamuna / Mkazi (Chaka Chobadwa)

Address: **Community** ________________________
(T.A)

Village ________________________
(Mfumu ya m'mudzi)

District ________________________
(Boma)

Province (region) ________________________
(Chigawo)

Country ________________________

HOUSEHOLD SIZE
(KUKULA KWA BANJA)

Adult: Male_________ Female_________
Akulu (Amuna) (Akazi)

Child: Male _________ Female _________
Ana: (Amuna) (Akazi)

Farmer status (encircle)
Udindo Wa mlimi (zongulizani)

Landowner: Tenant /Subtenant / Sharecropper /Leaseholder /
Mwini Malo Wobwereka / Wobwereketsa /Wogawana naye zokolola / Wokhomela Malo

Landless / Other
Wopanda Malo / Zina

Total area cultivated _________ **acres / m^2**
Kukula kwa malo wolimidwa

WATER RESOURCE:

Principal water sources (encircle)
Madzi wodalilika

Rainfall / Stream / Main river / Lake / Reservoir / Water wells / Other
Mvula / Khwawa / Mtsinje / Nyanja / Thamanda / Chitsime / Zina

Availability of water source (encircle) – Seasonal / Perennial
Kapezekedwe ka madzi wodalilika (Zongulizani) Panyengo / Chaka chonse

Water source quality
Ukhondo wa Madzi

1.Polluted Owonongeka **0 Unpolluted** Wosawonongekha **+1 High quality** Abwino ndithu

How is water utilized?
Kodi Madzi amagwiritsidwa bwanji ntchito?

- ☐ **Irrigation of crops**
  Kuthirira chimanga
- ☐ **Human consumption**
  Kumwa anthu
- ☐ **Animal consumption**
  Kumwa zinyama
- ☐ **Washing clothes / dishes**
  Kuchapira Zomvana / ziwiya
- ☐ **Bathing**
  Kusamba
- ☐ **Fishing**
  Kupha Nsomba
- ☐ **Sewage outflow**
  Kotayila zinyasi

Have you noticed a decline in water quality _____ yes _____ no
Kodi mwaonapo kusintha kwa maonekedwe amadzi

If yes, what do you think are the causes?
Ngati ndi choncho mukuganiza kuti chikupangitsa ndi chyani?

- ❑ **Animals**
  Nyama
- ❑ **Soil erosion**
  Kukokoloka kwa nthaka
- ❑ **No Vegetation**
  Kopanda mitengo
- ❑ **Heavy rains**
  Mvula yambiri
- ❑ **Foot traffic**
  Kuyenda yenda
- ❑ **Gardens**
  Kulima madimba
- ❑ **Others**
  Zina

Over the last five years has there been a noticeable decline in the water level of the river? _______ yes _______ no.
Pa zaka five (5) zapitazi, kodi mwaonapo kusintha (kupwera) kwa madzi mutsinjewu

If yes, by how much?_________ m
Ngati ndi choncho, ndiwochuluka bwanji?

FARM LOCATION

Is your farm located directly on the river edge? ______yes ______ no
Kodi munda wanu wayandikira ku mtsinje?

How close is your farm located near the river? ______m
Nanga ya wandikira bwanji ndi mtsinjewo?

Is your farm located near a tributary? ______yes ______no
Kodi munda wanu wayandikira pakhumaniro pa mitsinje?

If yes, what is the proximity of the farm to the tributary? ______m
Ngati ndi choncho, Nanga zomera zayandikira bwanji pa khumaniropo?

FISHERY RESOURCE

Is fishing practiced in your household? _____ yes ______ no.
Kodi mumapha nsomba pa banja panu

If yes, how many participants _______
Ngati ndi choncho, ndi anthu angati

Approximately how many kilograms of matemba caught per month_____kg.
Mongoyerekeza, ndi kuchuluka kwanji kwa nsomba zomwe zimagwidwa pa mwezi?

Approximately,how many kilograms of matemba are consumed by your household per month? _______ kg
Mongoyekeza, ndikuchuluka kwanji kwa matemba womwe mumadya pa mwezi pa banja lanu.

Are you a seasonal fisherman? ______ yes ______ no
Kodi ndinu msodzi wa nyengo (nthawi)

If yes, when is your fishing season? _____________
Ngati ndi choncho, mumakonda kusodza nyengo yiti?

What month is your catch the largest? _____________
Mwezi uti womwe mumapha nsomba zambiri?

What month is your catch the smallest? _____________
Mwezi uti womwe mumapha nsomba zochepa?

What type of fishing equipment do you use?
Ndi mtundu wanji wachophera nsomba mumagwiritsa?

Angling __________
Mbeza
Gilnet __________
Matchera
Scoop nets __________
Msapulo
Fish trap __________
Mono
Seine Nets __________
Khoka

What time of the day is the best to fish matemba?
Kodi ndi nthawi yanji ya tsiku imakhala bwino kupha matemba?

Early in the morning _________
Kubandakucha
Morning _________
Kumawa
Afternoon _________
Masana
Evening _________
Madzulo
Nighttime _________
Utsiku

How far will matemba migrate up river?
Kodi matemba amakwala mtunda wautali bwanji mutsinje?

Generally what is the average size of matemba caught per month?
________ cm
Mwachizolowezi kodi mumapha matemba wotalika bwanji pa mwezi?

Have you noticed a decline in the size of the matemba over the last five years? _______ yes _______no
Kodi mwaonapo kusintha kochepa msinkhu wa matemba pa zaka zisanu zapitazi?

> **If yes, by how much? ______cm.**
> Ngati ndi choncho, ndiwochepa bwanji?

What other species are caught?
Kodi ndi mitundu ina iti imagwidwa?

Have you noticed a decline in your catch size over the last five years?
_______yes _______no
Kodi mwaonapo kusintha pakagwidwe kapena Kuchuluka kwa nsomba pa zaka five (5) zapitazi.

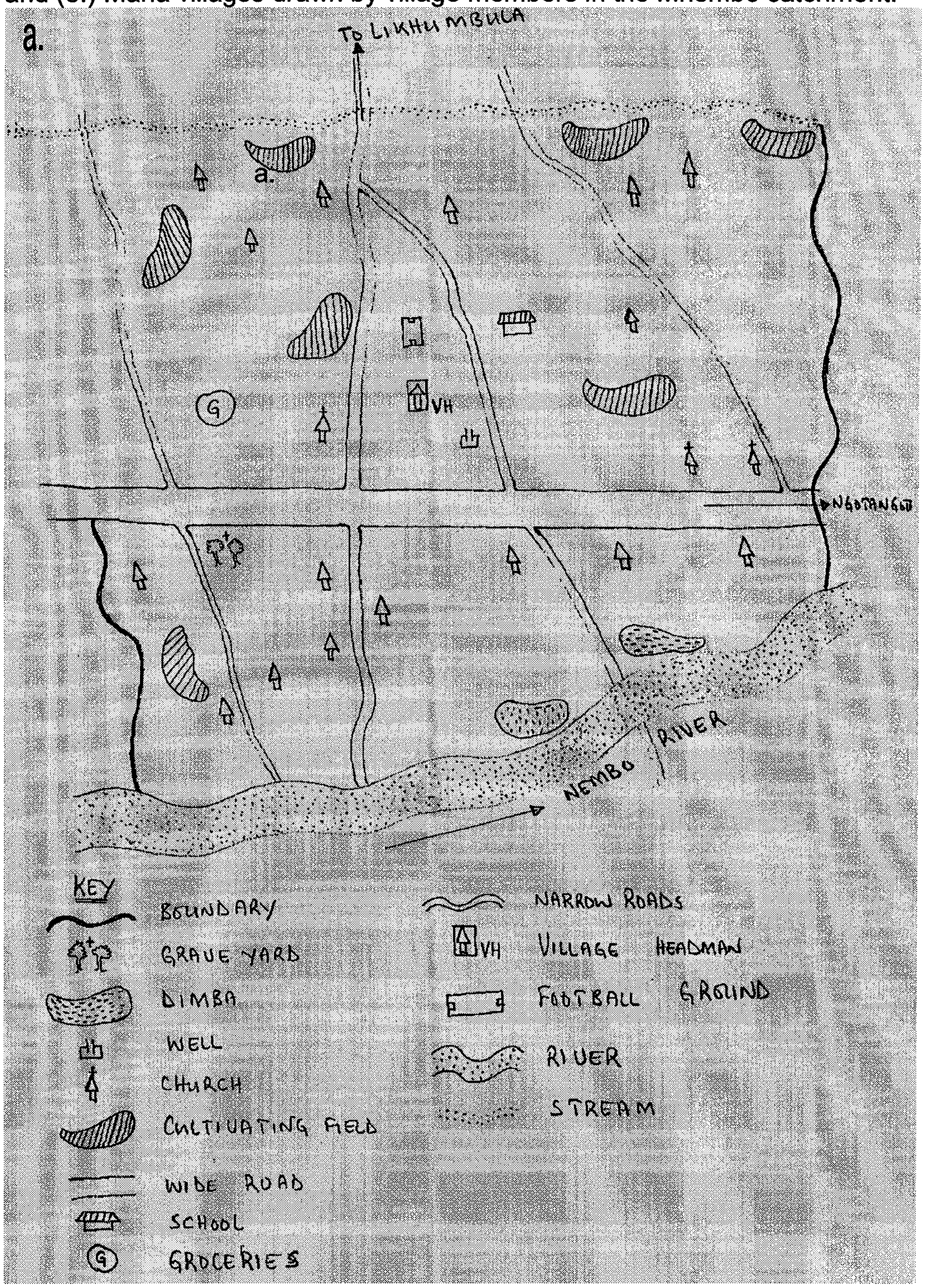
> **If yes, how much per year _______ kg**
> Ngati ndi choncho, ndiwochuluka bwanji?

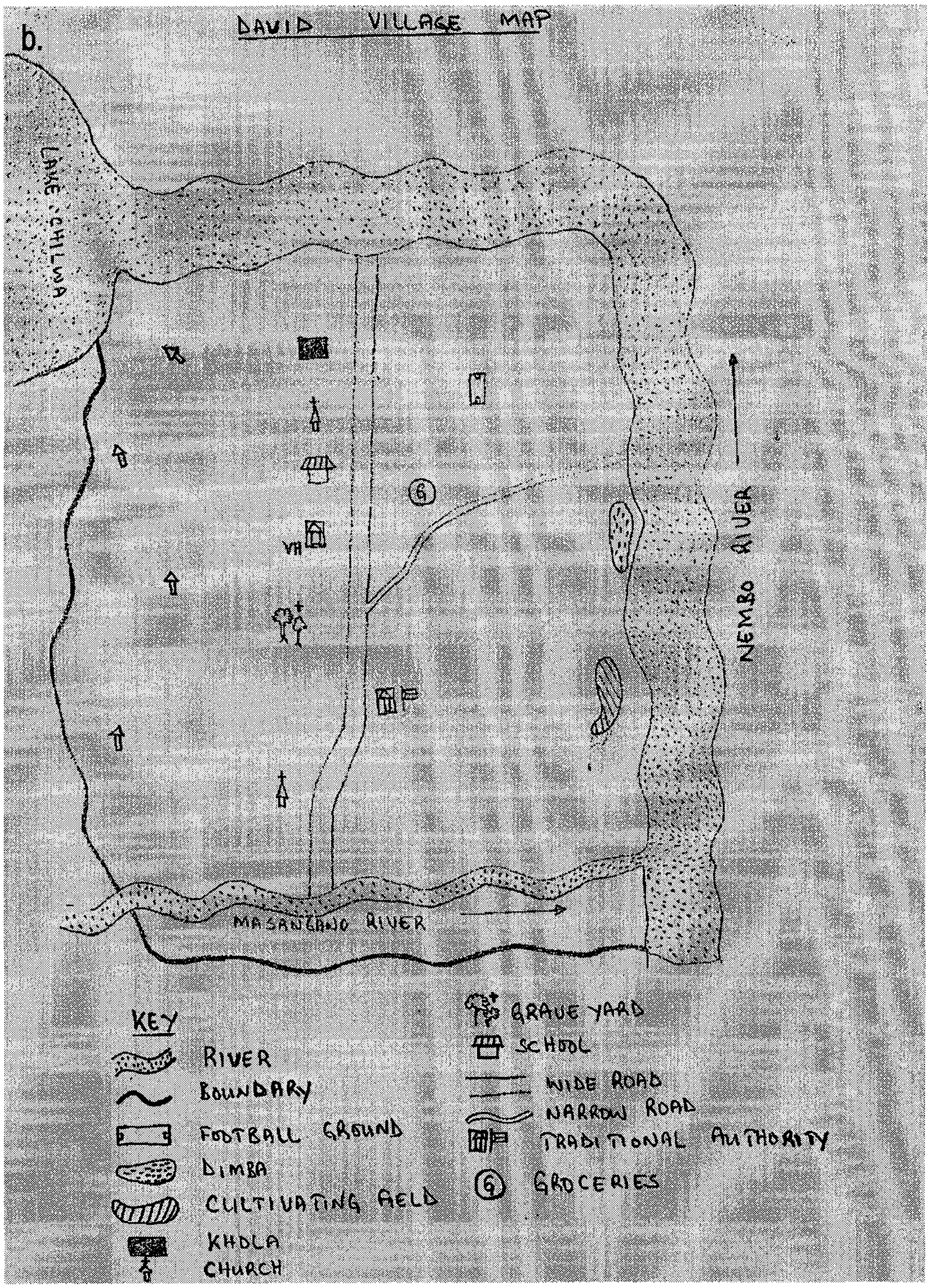
GENERAL COMMENTS
Ndemanga

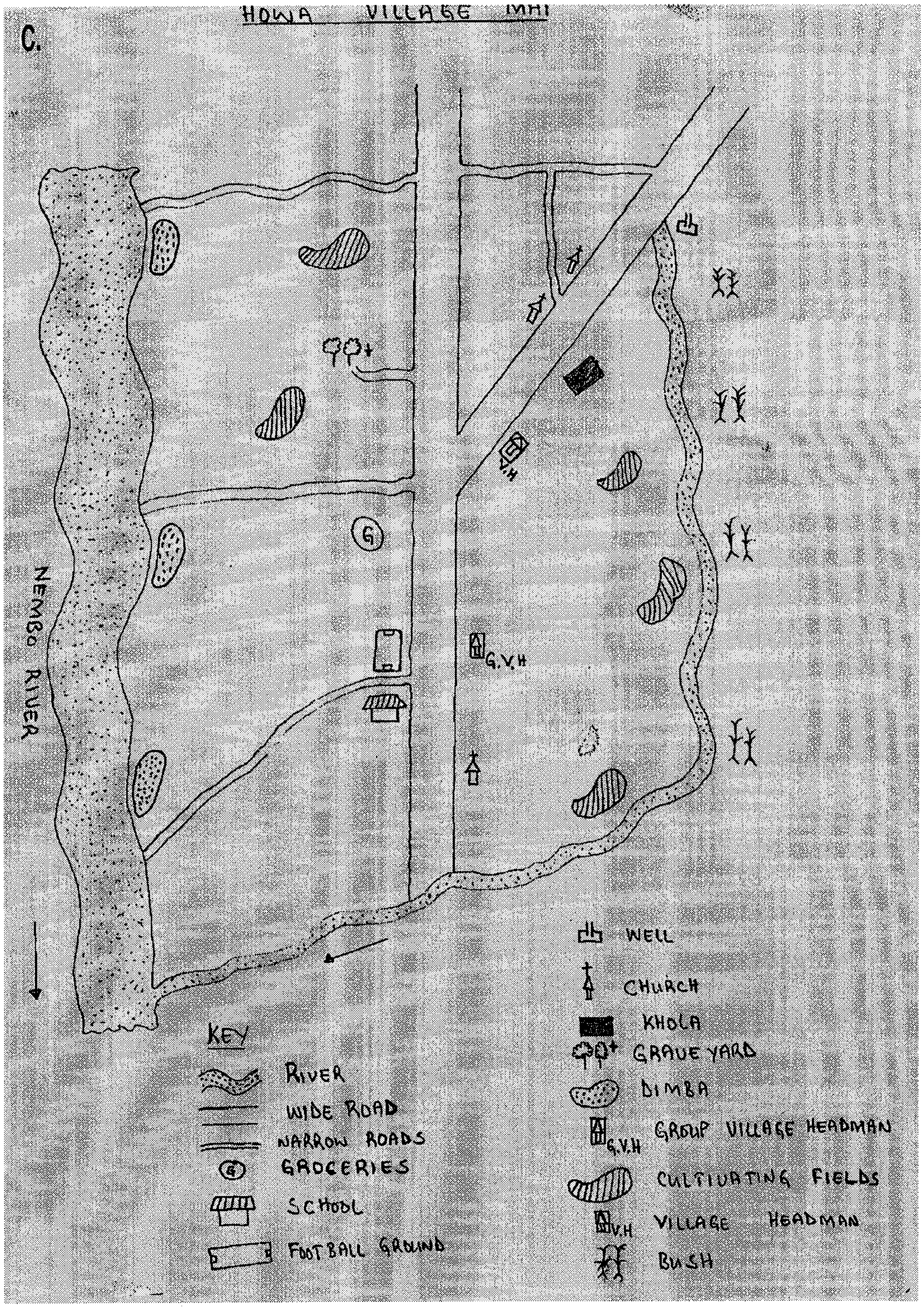
General comments by farmer
Ndemanga za mlimi

General comments by the Officer
Ndemanga za wofunsa

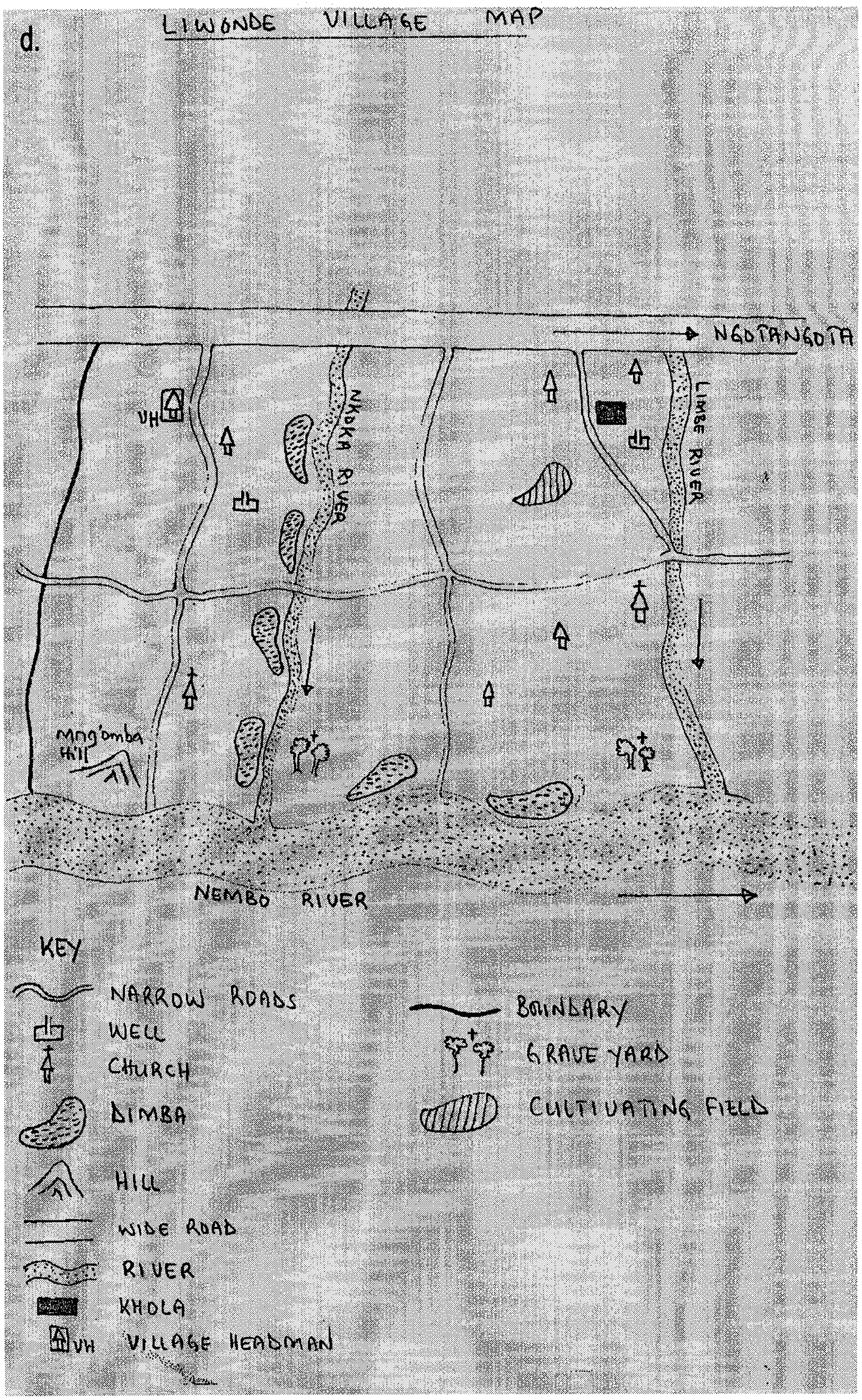
Appendix 4 Maps of the (a.) Chiwanda, (b.) David, (c.) Howa, (d.) Liwonde and (e.) Maria villages drawn by village members in the Mnembo catchment.

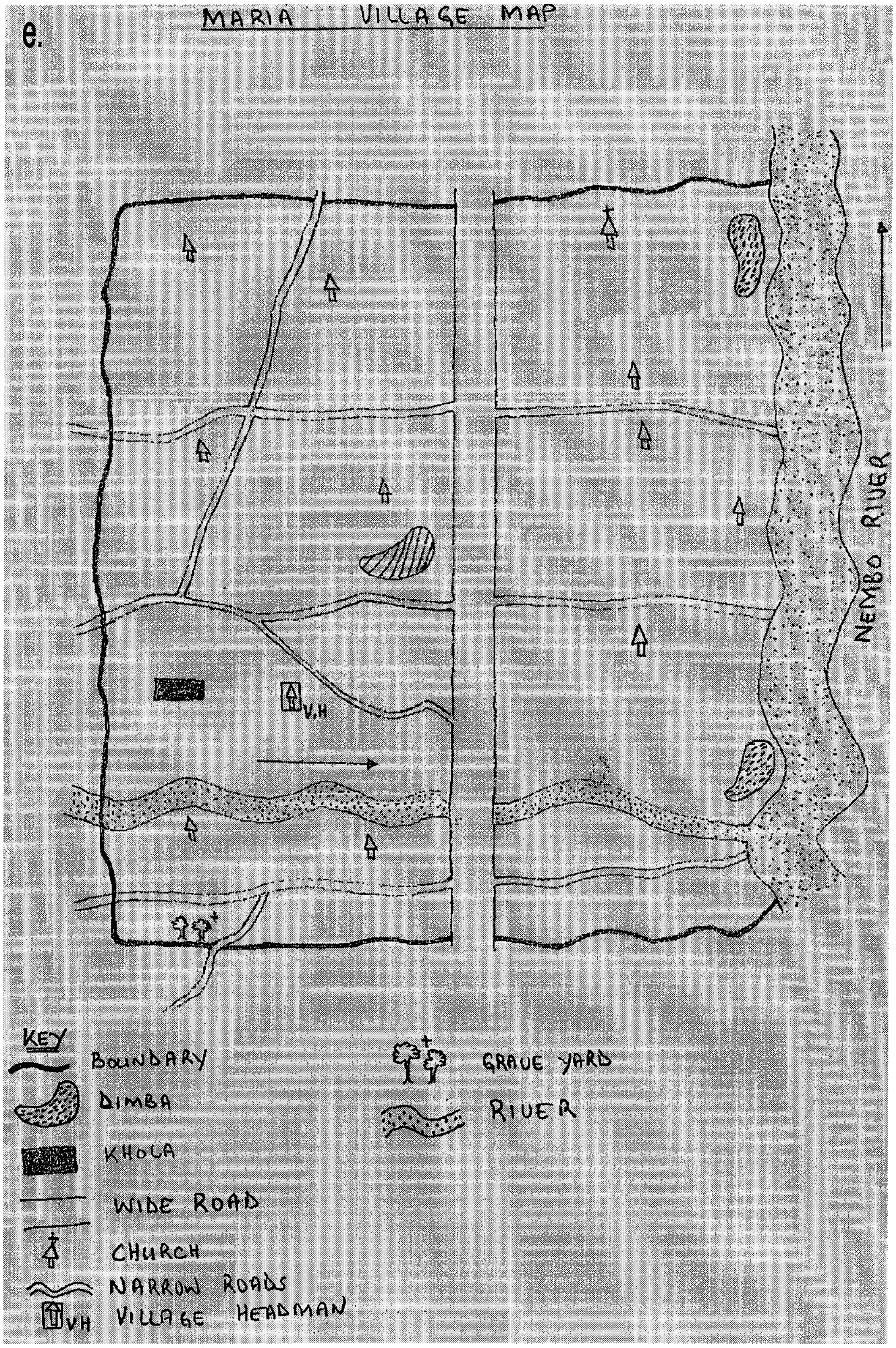



b.
DAVID VILLAGE MAP
LAKE CHILWA
VH
NEMBO RIVER
MASANGANO RIVER
KEY
RIVER
BOUNDARY
FOOTBALL GROUND
DIMBA
CULTIVATING FIELD
KHOLA
CHURCH
GRAVE YARD
SCHOOL
WIDE ROAD
NARROW ROAD
TRADITIONAL AUTHORITY
GROCERIES


C.
HOWA VILLAGE MA
NEMBO RIVER
G.V.H
G
KEY
RIVER
WIDE ROAD
NARROW ROADS
GROCERIES
SCHOOL
FOOTBALL GROUND
WELL
CHURCH
KHOLA
GRAUE YARD
DIMBA
G.V.H GROUP VILLAGE HEADMAN
CULTIUATING FIELDS
V.H VILLAGE HEADMAN
BUSH

d.


LIWONDE VILLAGE MAP
NGOTANGOTA
NKOKA RIVER
LIMBE RIVER
VH
Mng'omba Hill
NEMBO RIVER
KEY
NARROW ROADS
WELL
CHURCH
DIMBA
HILL
WIDE ROAD
RIVER
KHOLA
VH VILLAGE HEADMAN
BOUNDARY
GRAVE YARD
CULTIVATING FIELD


e.
MARIA VILLAGE MAP
V.H
NEMBO RIVER
KEY
BOUNDARY
DIMBA
KHOLA
WIDE ROAD
CHURCH
NARROW ROADS
VH VILLAGE HEADMAN
GRAVE YARD
RIVER