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Biodiversity Special Study (BIOSS) Final Report

Mahale National Park, Tanzania March/April 1999 Aquatic Survey

Date of issue: May 2000

Pollution Control and Other Measures to Protect Biodiversity in Lake Tanganyika (RAF/92/G32)

Lutte contre la pollution et autres mesures visant à protéger la biodiversité du Lac Tanganyika (RAF/92/G32)

Le Projet sur la diversité biologique du lac Tanganyika a été formulé pour aider les quatre Etats riverains (Burundi, Congo, Tanzanie et Zambie) à élaborer un système efficace et durable pour gérer et conserver la diversité biologique du lac Tanganyika dans un avenir prévisible. Il est financé par le GEF (Fonds pour l'environnement mondial) par le biais du Programme des Nations Unies pour le développement (PNUD)"	The Lake Tanganyika Biodiversity Project has been formulated to help the four riparian states (Burundi, Congo, Tanzania and Zambia) produce an effective and sustainable system for managing and conserving the biodiversity of Lake Tanganyika into the foreseeable future. It is funded by the Global Environmental Facility through the United Nations Development Programme.

GEF

NRI MRAG Institute of Freshwater Ecology

Preface

This report is the record of a survey of Mahale Mountains National Park conducted by the Biodiversity Special Study regional team of the Lake Tanganyika Biodiversity Project. The names of all those who participated in the survey are listed below, as are those who contributed to the production of this report.

We would like to thank the Tanzanian National Parks Authority, and in particular Senior Park Warden Hassan Mohamed and the staff of Mahale Mountains National Park, for their valuable assistance and co-operation during the expedition.

In addition, we would like to acknowledge the unfailing support accorded the team by the ever cheerful and efficient LTBP administrative officer for Kigoma station, Mr Bahati Barongo.

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CHAPTER 1. INTRODUCTION

1.1 Mahale Mountains National Park

Mahale Mountains National Park lies on the Tanzanian shore of Lake Tanganyika, 120 km south of Kigoma town. It is situated on a large peninsula jutting out into the lake and covers an area of 1613 km^2 with its center at 6º 15´S, 29º55´E. It was gazetted as a national park in 1980 mainly for the purpose of protecting chimpanzees in their natural habitat. Access to the park is by aircraft or boat only.

The terrain is rugged and hilly, dominated by the Mahale Mountain chain running from north-west to south-east across the centre of the Park. The highest of the peaks, Mt. Nkungwe, rises to 2462 m above sea level. The western slopes of the main ridge drop precipitously down to the lake and receive the highest annual rainfall in the park (approximately 1870 mm). These slopes are covered by tropical rainforest typical of that in the Congo basin, to an elevation of 1,300 m. At higher altitudes the vegetation consists of a mosaic of montane forest, bamboo bush and montane grassland. The majority of the park is however dominated by dry forests and woodland savannah known collectively as miombo forest (*Caesalpinioidea* family), with narrow strips of riverine forest restricted to the watercourses. This wide variety of habitats supports an equally diverse array of fauna. A total of 55 mammal species, nine of them primates and 120 species of bird have been recorded at Mahale. Many of these are native to West Africa (JICA 1980).

The shoreline of the Park is about 60 km long with numerous bays and a few small rocky outcrops offshore. In parts of the north and centre deep water occurs within 50 m of the coast, but in some areas to the south shallow water (< 25m) extends to about a kilometre offshore. The western boundary of the park extends 1.6 km into the lake along its entire length, creating an aquatic reserve of 96 km^2. Fishing is not permitted within this area, but it is difficult to assess how much is carried out illegally by the inhabitants of nearby villages for whom fishing is the principal source of livelihood. Apart from isolated ranger posts, the only permanent human settlements in the park are the administrative headquarters at Bilenge Bay on the northern boundary and the tourist camp at Kasiha.

1.2 Survey Aims

The survey was conducted between 21st March and 8th April 1999, by a team from the Lake Tanganyika Biodiversity Project (LTBP), comprising divers from Tanzania, Burundi, Congo and Zambia. Comparable surveys have also been completed for the other protected areas bordering the lake including; Gombe Stream National Park, Tanzania (October 1997), Rusizi National Park, Burundi (March-May 1998) and Nsumbu National Park, Zambia (July/August 1999). These surveys were carried out in accordance with objectives one and two of the Biodiversity Special Study (BIOSS) which are to:

- Review current levels of biological diversity in Lake Tanganyika.
- Identify the distribution of major habitat types with particular focus on existing and suggested protected areas.

The specific goals of the Mahale survey were therefore to classify and map underwater habitat distribution within the park and to determine the diversity and the distribution of the fish and mollusc communities associated with these habitats. The survey was undertaken immediately after a period of training during which 2 new divers were qualified from each of the riparian countries and the identification skills of the whole regional dive team were enhanced by a course in fish and mollusc taxonomy. The Mahale expedition served to confirm the skills and knowledge acquired during this period through intense practise in the field. Team members were also involved at all levels in the planning, preparation and execution of the survey thereby enhancing

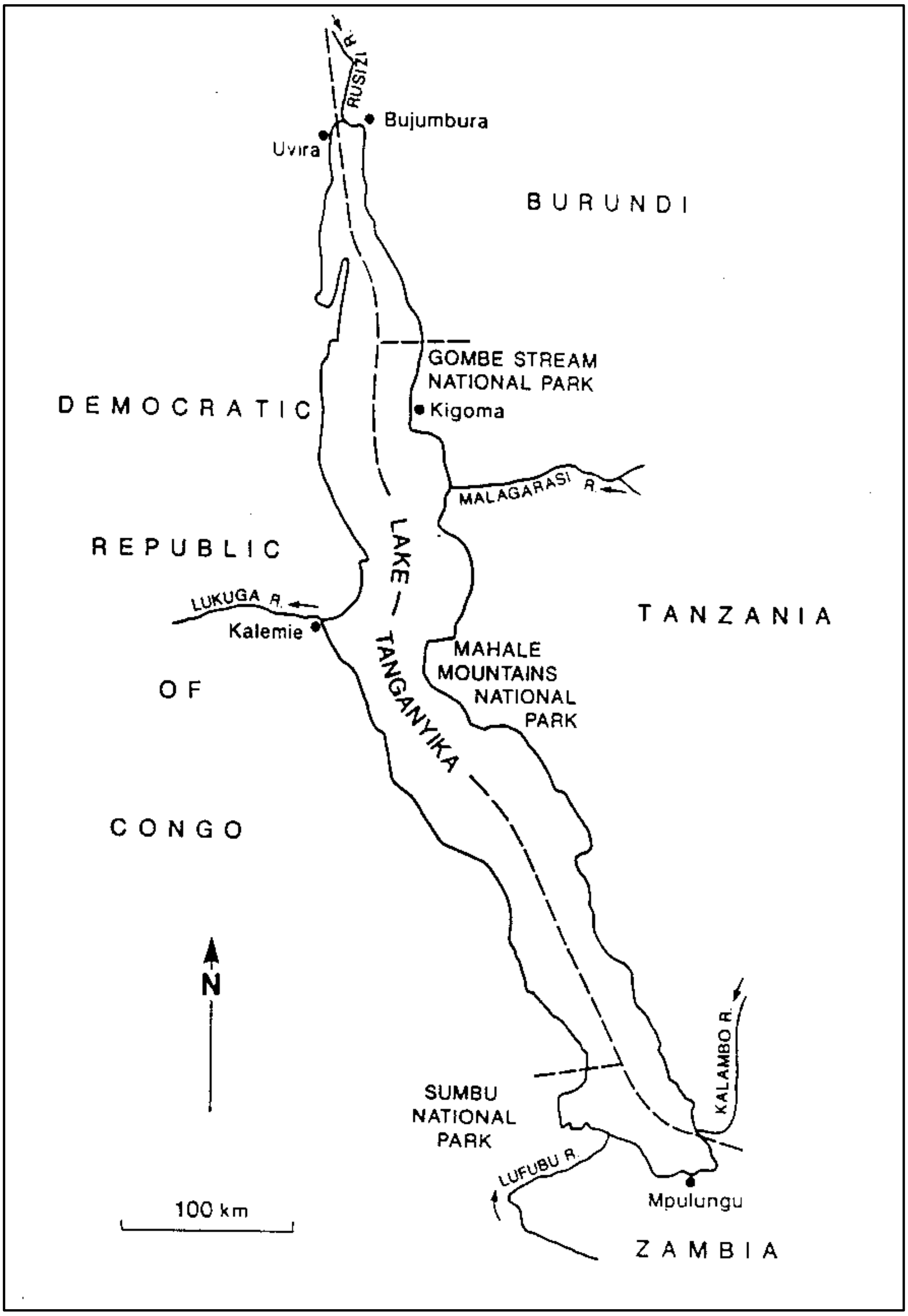

Figure 1.1 Map of Lake Tanganyika showing national parks, major rivers and population centres

regional capacity to mount similar survey expeditions in the future. Furthermore, the park authorities have hitherto had little access to data on the ecology of waters off Mahale. It is hoped therefore that results and conclusions contained in this report will prove of use in the future management of the park.

1.3 Review of Previous Work

A review of literature on Lake Tanganyika and enquiries to Tanzanian National Parks Authority (TANAPA) produced no reference to previous aquatic ecological survey work carried out in Mahale, though it is known that Japanese researchers conducted fish surveys off Myako Point during the 1980s. This expedition was therefore the first comprehensive survey of the aquatic habitats and fauna of Mahale National Park and will provide baseline data for future ecological surveys.

CHAPTER 2. METHODS

The techniques employed during the survey (Table 2.1) and the rational behind them are described in full in the 'Standard Operating Procedures for BIOSS Sampling' (Allison *et al* 1999). It should be noted however, that some have been modified subsequently as a result of the BIOSS teams experience during the Mahale survey. These changes are discussed in Chapter 4.1 of this report.

Table 2.1 Summary of survey methods

Method	Purpose	Depth Range
Manta Tow	Coarse-scale mapping of littoral zone habitats, coastal topography and land-use	3-10 m
Habitat Profile	Fine-scale habitat mapping	25-5 m
Stationary Visual Census	Fish species richness and abundance	15, 10 and 5 m
Rapid Visual Census	Fish species richness and relative rarity	15, 10, 5 and 0 m
Mollusc Census (dive and snorkel)	Mollusc species richness	25, 15, 5 and 0 m

2.1 Habitat Mapping

During the planning stage, features of the Mahale coastline and the boundaries of the survey were determined through reference to maps produced by the Tanzanian Government Mapping Division and in consultation with TANAPA staff. In phase one of the survey itself, coarse scale topographical and habitat mapping was conducted using the Manta Tow Technique. Finer scale mapping of individual sites was subsequently carried out using scuba techniques.

2.1.1 Manta tow surveys

The Manta Tow is the standard LTBP method for mapping the littoral zone and coastal topography. It involves a snorkeller being towed approximately 10 m behind a boat at a speed of 3-5 km/h. The boat follows a course parallel to the shore in 5–10 m of water, depending on visibility. The snorkeller holds on to a rectangular board, which acts as a hydroplane, while viewing the substrate below through an aperture cut in the board. Every three minutes the boat stops, permitting the snorkeller to note details of the substrate on a slate. The data recorded includes the percentage of each category of habitat (bedrock, rocks, boulders, gravel, sand), level of siltation and inclination. In addition, the presence of macrophytes or concentrations of mollusc shells is noted, since both provide habitats for particular communities of fish species.

Other responsibilities are shared amongst the remaining 3-4 team members in the boat such as, coxswain, timekeeper and GPS operator/position recorder. An individual is also designated to record the coastal topography, land cover and land use, since these can affect underwater biodiversity. All team members maintain constant observation for obstructions in the water and dangerous animals such as crocodiles and hippopotami. After every 18 minutes these tasks are rotated within the team.

Using the Manta Tow technique, three teams, each with an inflatable/fibre-glass boat, surveyed the 60-km coast of Mahale in two days. With reference to the Manta data, each section of shore sampled during a 3-minute period was given an overall substrate classification depending on the percentage of each substrate type recorded. The categories are as follows: Rock, Gravel, Sand, Mixed, Mixed Rocky and Mixed Sandy. This information was transferred onto photocopies of 1:50,000 maps of the area, with the substrates being represented by different symbols. These maps were then used to assist in the selection of survey sites.

2.1.2 Selection of survey sites

Site selection was carried out on the basis of stratified random sampling. The first step in the process was to determine the total number of sites, which could be sampled within the time and resources available. The sites were then allocated to each substrate type relative to the proportion of the Mahale shoreline represented by that substrate type. Location of sites was determined by giving a number to each 3-minute manta-survey period according to substrate type and then selecting from those numbers at random. The exact location of the sample transect was standardised to be as close to the centre of the shoreline represented by each 3 minute period as possible. This system retains the statistical features of random sampling, while reducing sample numbers through stratification according to habitat prevalence.

2.1.3 Habitat Profile

In addition to the coarse scale habitat mapping, surveys were conducted at a finer scale at each site using the habitat profile SCUBA technique. This served four principal purposes. It verified the results of the Manta Tow technique, extended the depth of the habitat survey to 25 m, provided habitat data on approximately the same spatial scale as the surveys of biota, and produced a depth profile for the sub littoral zone.

The profile dive was always the first dive to be carried out at each site. The GPS co-ordinates of the site were recorded on arrival and then the point at which the water depth was 25 m was located using a hand-held echo sounder. Having entered the water, the pair of divers took a compass bearing to the shore so that the profile could be conducted perpendicular to the shoreline. They then descended unreeling a line attached to a surface marker buoy at one end and a weight at the other. At the bottom they attached another reel, marked every 10 m, to the first and paused to record a summary of the habitat characteristics. They then swam towards the shore on the predetermined compass bearing, unreeling the second line. Every 10 m the divers stopped to describe the changes in habitat, recording data on depth, distance along the transect, features of the substrate and the presence of associated communities. At 5 m, the divers surfaced leaving the transect line in place to serve as a marker for fish and mollusc surveys.

The data recorded was subsequently used to create a profile of the gradient in each location and the habitats found every 10 m along that gradient. This data was then combined with that from the faunal surveys in order to establish associations between habitat and species composition/diversity. However, though habitat profile method allows for detailed information on habitat characteristics to be recorded, the data-set obtained during this survey was insufficient to examine these associations on a fine scale. For the purpose of this report habitats have been classified on the basis of three dominant physical substrata, sand, rock and shell beds (Table 2.2).

Table 2.1 Habitat categories used in data analysis

Habitat category	Substrate composition (%)
Sand-dominated	> 75% sand (including mud and fine gravel)
Rock-dominated	$\geq$ 25% rock (including bedrock, boulders and cobbles)
Shelled	> 50% *Neothauma* shells

The imbalance in the percentages of sand and rock which define the rock and sand dominated categories, is due to the disproportionate ecological effect that a comparatively small amount of rock has on an otherwise sandy habitat is contrast to vice-versa. Shell beds normally occur in large dense patches, where the shells usually comprise 100% and never less than 50% of the visible substrate.

2.2 Mollusc Census

In order to conduct comparable surveys of mollusc relative abundance in the heterogeneous habitats of Lake Tanganyika, it would be necessary to estimate accurately the area of each habitat at a site and conduct a large number of replicates. This was not possible with the time and resources available for the Mahale survey. The mollusc data provides information on species richness only and will not allow the calculation of diversity indices. Owing to the general lack of experience within the BIOSS team of mollusc taxonomy, in situ identification of species was often not possible. Specimens were therefore taken for subsequent identification on shore or at base camp.

2.2.1 Mollusc dive transect

The protocols for each diver carrying out the mollusc transect differed depending on substrate type. Since verbal communication underwater is impossible, it was necessary for the divers to be briefed by the pair who had completed the profile dive before entering the water. With a clear idea of what habitats were present, the divers could confirm their actions at each depth before starting the dive.

The divers entered the water at the marker buoy and descended to 25 m. They then proceeded towards the shore along the transect line laid during the habitat profile. At depths of 25, 15 and 5 m respectively, sampling was carried out on both sides of the transect at a maximum distance of 5 m from the line. A mixture of search and sieving techniques were used depending on the proportion of rocks/boulders or sand comprising the substrate. At each depth specimens were collected in jars and a general note of the habitat was made. On reaching 5 m the divers ascended to the surface leaving the transect line for subsequent dives.

2.2.2 Mollusc snorkel search

Immediately after the mollusc transect the divers removed their SCUBA equipment and returned to the water to conduct a search for molluscs in the upper littoral zone (0-2 m). A start point was chosen in 1 m of water, aligned as near as possible with the transect line. The divers swam in opposite directions parallel to the shore for 10 minutes, searching carefully for molluscs and noting the habitat characteristics encountered. They normally covered a maximum of 20 m in each direction. In later stages of the survey, after a couple of close encounters with crocodiles, it was the technique was modified slightly so that both divers swam as a pair. In that way it was possible for the boat to remain close to the divers and extract them from the water quickly should the need arise.

2.3 Fish Census

Three different fish census techniques were employed during the survey. Each was particularly suited to specific sampling situations, but together they provided a sampling regime intended to produce the most comprehensive list of species inhabiting the park. When recording numbers within a species, juveniles were not included, since this might have skewed the figures for relative abundance and diversity indices.

2.3.1 Stationary Visual Census (SVC)

The SVC provided information on both the species richness and relative abundance of littoral fish species and was particularly sensitive to sedentary, cryptic and patchily distributed species. Two divers descended to 25 m on the same line used for the profile and mollusc dives. On reaching the bottom they swam along the transect to a depth of 15 m reeling in the line at the same time. Positioned above the transect they rotated 360^o, scanning an imaginary column of water extending from the lake bottom to the surface with a radius of 5 m. In the first 5 minutes they recorded all the species seen. No information was recorded on the number of individuals until the second 5-minute period, with the exception of species that were unlikely to remain in the cylinder for a sufficient length of time. For the final 5 minute period both divers search the lake bottom within the imaginary column for cryptic and crevice dwelling species which would not have been observed from the transect line. The divers then continued along the transect and repeated this process at 10 and 5 m.

2.3.2 Rapid Visual Census (RVC)

The large area covered by the RVC meant that it was likely to record species which are rarer and more shy, hence its use in combination with the SVC. As with the SVC, it provided information on species richness and some measure of abundance but not in a form that could be used to calculate diversity indices. A pair of divers descended to 15 m and swam along the depth contour in one direction for 5 consecutive time periods of 3 minutes. Each species encountered was recorded against the time interval in which it was first observed. The same procedure was repeated at 10, 5 and 0 m (the latter using a snorkel), at each depth swimming in the opposite direction above the area censused below.

Based on the assumption that the more abundant species would be encountered in the earlier time periods, an estimate of relative abundance was subsequently calculated. Each species was allocated a score depending on the time period in which it was observed. The earlier the time period the higher the score. Those species obtaining the highest score were deemed the most abundant.

2.3.3 Gillnetting

Gillnets were set at each site overnight, to provide data on crepuscular and nocturnal species and as another measure of diversity. They served the additional function of continuing the taxonomic training initiated before the survey and providing samples for the LTBP reference collection housed at TAFIRI Kigoma. Mono-filament gillnets were used, consisting of twelve panels of various mesh sizes ranging from 8 to 50 mm, a total length of 60 m. One net was set at each site parallel to the shore at a depth of 10 m. The nets were set at the end of the days diving and were retrieved the following morning. The soak time was not uniform owing to the fact that the distance between the sampling sites and the base camp varied greatly. After the nets had been hauled the catch was sorted according to species and the numbers of individuals counted. At first the length of each fish was measured and the total weight calculated but this proved too time consuming, so was discontinued.

2.4 Analysis Methods

A variety of simple techniques were used to analyse the data from the faunal surveys. These included similarity indices, diversity indices and the calculation of relative abundance from the RVC data.

2.4.1 Index of similarity

Having drawn up lists of species caught uniquely by each of the fish census methods (SVC, RVC and gillnets) it was possible to calculate a similarity index using the following formula:

$$Similarity = \frac{2c}{a+b} \qquad \text{Krebs, 1978.}$$

Where *a* is the number of the species recorded by one sampling method, *b* is the number of species recorded by the other sampling method and *c* is the number of species common to both. A high index would demonstrate that the two sampling methods were recording similar species. A low index would suggest that to obtain a comprehensive species list for a given area it would be necessary to use both methods.

2.4.2 Calculation of relative abundance from RVC data

As explained in Chapter 2.3.2 above each species recorded during and RVC transect is given a score depending on which of the 5-minute time periods it was first observed in (5 for the first, 4 for the second and so on down to 1 for the fifth time period). To calculate the relative abundance of a particular species across the whole survey (in this case Mahale National Park), all the scores for that species are added together and divided by the total number of transects in the survey. A transect is still included in the total even if a species was not observed during the transect.

2.4.3 Shannon-Weiner diversity index

Diversity indices provide a useful summary biodiversity measure. There are several different types of index, but they all include measures of species richness and abundance within those species. The Shannon-Weiner index was employed to calculate the fish diversity from Mahale. The formula used was:

$$H' = \frac{n \log n - \sum_{i=1}^{k} fi \log fi}{n}$$

where *H'* = amount of diversity in a group of *k* species, *k* = the number of species, *fi* is the frequency of each species and *n* is the sample size (total number of individuals recorded). The standard logarithm used by BIOSS was base 10. In effect what *H'* measures, is the uncertainty with which you can predict the species of the next individual in the sample. Therefore *H* for a given number of species will be highest when all species are equally abundant, since it is less easy to predict what species of an individual will belong to.

Nevertheless, diversity indices have their limitations. Caution should be exercised when attributing conservation importance on the basis of diversity indices. The index may measure species richness and species evenness, but it does not tell us anything about the levels of endemicity, number of rare species or whether a species has a limited or discontinuous range.

CHAPTER 3. RESULTS

3.1 Summary of Surveys Conducted

The survey of the Mahale National Park took place over a period of 18 days. The first phase, completed in two days, saw the coarse scale habitat mapping of the entire park shoreline. For this, the regional team divided into three groups of 6-7 divers, surveying approximately 10 km of coast per day using the Manta Tow technique. The second phase, which lasted 10 days, was spent in detailed surveys of the habitat and fauna at 25 sites along the length of the park shore. A further two sites were sampled just outside the northern to southern park boundaries, in Sitolo Bay and near to Sibwesa village respectively, to offer some comparison between protected and fished areas. Originally 28 sites were selected within the park boundaries using the stratified random sampling procedure described in Chapter 2.1.2 above. The distribution of sites between substrate categories is shown in Table 3.1. In the event the surveys of one mixed-sandy and 2 rocky sites were aborted, due to a variety of medical and logistical reasons.

Table 3.1 Number of sites selected in each habitat type

Stratum	Number of sites chosen
Rocky	12
Sandy	5
Mixed (rocky)	3
Mixed (sandy)	2
Mixed	5
Gravel	1
Total	28

During phase two the regional team continued to work in three smaller groups of divers, each sampling one site per day. Owing to the considerable distance from the base camp at Kasiha of some of the sites to the south, one group was detached to the ranger camp at the southern park boundary for the duration of the survey. All sites were surveyed using the full range of techniques, as listed in Figure 2.1, with the exception of Mankungwe South where no gillnet was set and Musilambula where the SVC was aborted due to a close encounter with a crocodile. A complete list of sites, GPS locations and sampling events is given in Appendix I.

3.2 Coarse Scale Distribution of Habitats

3.2.1 Shallow water habitats

The distribution of shallow water habitats is summarised in Table 3.2. Taking the park as a whole approximately 42% of the substratum was found to be rocky (inclusive of bedrock, cobbles and boulders), and a further 20% sandy. The majority of the rocky substrate was found in the southern half of the park, where it was the prevalent habitat at depths of 5-10 m, apart from isolated sections of sand in bays and at the mouths of rivers. Most of the shallow water sandy substrate was concentrated in a long uninterrupted strip of coast stretching from Mgansangombe Bay to Katwandul Bay. The term mixed was used to describe sections of the coast with an even representation of habitat types. About 21 % of the Mahale shoreline fell into this category, often occurring in areas of transition between rocky and sandy substrates. Mixed substrates where either rock or sand was predominant were described as mixed rocky or mixed sandy respectively. These were poorly represented in the littoral zone, as was gravel, which was found only one location, north of Lufungu Bay. No large mats of submerged macrophytes or shell beds were identified during the Manta tow surveys. Three short stretches of the Mahale coastline were not sampled due either poor visibility or the presence of hippos and crocodiles. These were in the area of Mkala, Muloba and Matumuka bays and had a combined length of approximately 5 km.

Habitat maps for the entire coast of Mahale can be found in Appendix II.

Table 3.1 Shallow water habitat distribution

Substratum	Length (km)	% of Total Shoreline
Rocky	25.2	42
Sandy	12	20
Mixed	12.6	21
Mixed (rocky)	6	10
Mixed (sand)	3.6	6
Gravel	0.6	1
Total	60	100

3.2.2 Coastal physiography, terrain and land-use

The coastline of Mahale National Park is predominantly open and linear, though it is punctuated by a number of large bays and river deltas. In addition there are numerous seasonal steams and watercourses which flow into the lake. These areas are characterised by sandy beaches and in some of the larger bay, reed beds. The rest of the shoreline was fringed by stretches of rock, boulder or to a less extent gravel beaches. In some areas, notably between Musofwe and Luahagala bays, cliffs drop precipitously to the water.

As was to be expected in a protected area, human activity is minimal. There are two locations which are inhabited by park staff and their families, the park headquarters at Bilenge Bay and the camp at Kasiha. The latter is also periodically used by researchers, as in the case of this survey, and the occasional tourist to the park. In addition there is a permanently manned ranger post on the southern boundary of the park at Mabilibili Bay. In these areas a limited amount of fishing conducted by park staff and their families. The rest of the coastal landscape covered with forest and dense patches of scrub, except for an extensive area of low lying, marshy land between Sinsiba and Ng'anja Bay, through which the Ntale, Manya and Ng'anja rivers flow into the lake.

3.3 Habitat Profiles

The habitat profile results from Mahale showed that, contrary to expectations, the bottom profile at a significant proportion of the sites surveyed was very gently sloping and occasionally nearly horizontal. This was particularly true of sandy sites such as Sinsiba (TZ006/11[1]), Nsele (TZ006/26), Mikamba (TZ006/31), Takata (TZ006/36), Mankungwe South (TZ007/11). This presented problems in that it meant that at these locations divers were forced to surface before completing the transect having expended much of their air supply while still at depth. The result was that for many sites there is no habitat data for the shallower waters and therefore little or no overlap with species data from the fish and mollusc censuses. This limits the extent to which habitat/species associations can be made. The profile chart of Mikamba at Appendix III illustrates a typical shallow sloping sandy site.

Along much of the Mahale shore the substrates were found to occur in zones running parallel to the shore at different depths. It was therefore, not possible to classify the majority of sites by a single substrate type, since at different depths in the profile they were characterised by discrete habitats. The exceptions being certain sandy bays and river deltas where the substrate was uniform along the entire transect. The composition of substrates by depth is indicated in Table 3.3. The data shown is for the 11 sites where it was possible to conduct habitat profile dives covering the whole range of depths from 25 to 5 m. This comprised the following sites; Kabwe North (TZ006/41), Kabwe South (TZ006/46), Kahinfye Bay (TZ006/56), Siyeswe (TZ006/61), Lumbye North 1 (TZ007/1), Mikakwe (TZ007/15), Mikakwe South (TZ007/20), Nkwasi

[1] Codes correspond to BIOSS survey database and original data entry sheets

(TZ007/40), Mankungwe North (TZ007/45), Lufungu Bay North 2 (TZ006/55) and Musilambula (TZ007/60).

Table 3.1 Composition of substrate by depth for the 11 sites for which complete habitat profiles were recorded

Depth	25 m	20 m	15 m	10 m	5 m
Substrate (%)					
Bedrock	0.5	0	0	0	5.5
Boulders	2	14	20	41.5	47
Rocks	4	14	22	32	28.5
Gravel	0.5	0.5	3	0.5	0
Sand	93	71	55	26	19

As can be seen the proportions of each substrate varied greatly with depth. Sand was the dominant substrate between 25 and 15 m depth, but was much less widespread at 10 and 5 m. Conversely, at shallower depths the habitat was composed of between 75 and 80% rocky substrates, decreasing to 6.5 % at 25 m (see habitat profile chart of Kahinfiye at Appendix III). Other hard substrates such as gravel were hardly represented. Bedrock was recorded at Kabwe South and Nsele only. Nsele was also the only site at which stromatolites were encountered (at 24-27 m). Beds of *Neothauma tanganicensis* shells were found 3 sites at the southern extremity of the park, Lyamembe, Busisi Bay and Mabilibili Bay and one outside the northern boundary of the park at Sitolo Bay. At all these sites the shells occurred at between 25 and 15 m and the lakebed sloped very gently. The habitat profile chart for Mabilibili Bay is shown in Appendix III)

3.4 Mollusc Census

3.4.1 Sampling effort for molluscs

Species-area accumulation curves can be used to determine whether the sampling effort for a given data set is sufficient. Each sub-set of data is randomly selected in turn and the number of new species encountered added to the cumulative total of species recorded, which is then plotted against the cumulative sample area. If the resulting curve reaches asymptote (in other words, levels out), it indicates that all species in that area (except those for which the survey method is inappropriate) have been sampled. Figure 3.1 shows a species-area curve for the complete mollusc data set. It suggests that the sampling effort was sufficient and therefore the list of recorded species reflects the total mollusc species richness in Mahale.

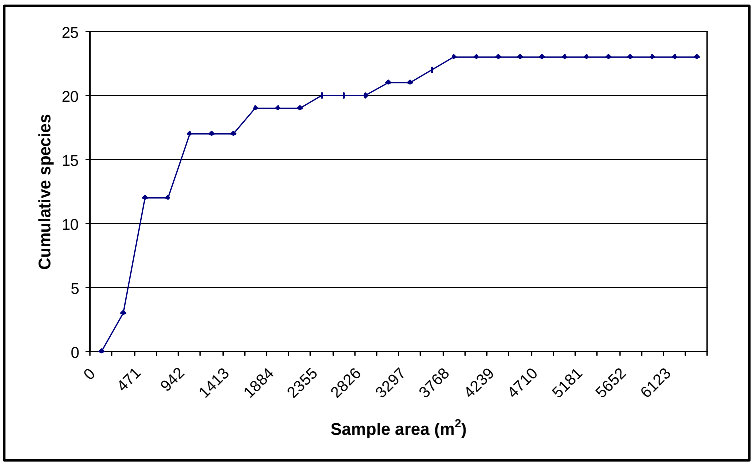

Figure 3.1 Species-area accumulation curve for molluscs

Additional species-area curves have been plotted for the mollusc data for which corresponding habitat data was recorded. The curves for sand and rock dominated habitats are presented at Appendix IV. In both cases, they indicate that sampling was sufficient and therefore the species recorded reflect the species associated with these substrates in Mahale. No curve was plotted for shell beds owing to the small size of the data set.

3.4.2 Species richness

A total of 23 mollusc species were recorded for the whole park (Table 3.4), of which two (*Caelatura burtoni* and *Mutela spekia*) are bivalve molluscs and the remainder gastropods. All these species are endemic to Lake Tanganyika. Of particular interest is the presence of *Reymondia species A*, which prior to this survey was only known from the Burundian coast of the lake. Certain individual molluscs could not be identified to the level of species with certainty, but were not considered to be new species. Since these all belonged to genera recorded elsewhere in the survey, they were not included in the total count of species. The taxonomic classification of the two species, which are here given the genus name *Novel Genus*, has yet to be resolved (Pers. com. K. West).

Table 3.1 List of mollusc species recorded and they habitat in which they were found

Number	Species	Habitat		
		Sand Dominated	Rock dominated	Shelled
1	*Anceya giraudi*			✓
2	*Bridouxia giraudi*	✓	✓	✓
3	*Cealatura burtoni.*	✓	✓	✓
4	*Lavigeria grandis.*	✓	✓	
5	*Lavigeria species A*			
6	*Lavigeria species B*	✓	✓	✓
7	*Lavigeria paucicostata*	✓		
8	*Mutela spekii*	✓		
9	*Neothauma tanganyicensis*	✓		
10	*Novel Genus new species*	✓	✓	
11	*Novel Genus spinulosa*	✓	✓	✓
12	*Paramelania crassigranulata*	✓	✓	
13	*Paramelania iridescens #2*	✓		
14	*Pseudospatha tanganyicensis*	✓	✓	
15	*Reymondia horei*	✓	✓	✓
16	*Reymondia minor*			✓
17	*Reymondia species A*			
18	*Spekia zonata*		✓	
19	*Stormsia minima*			
20	*Syrnolopsis lacustris*	✓		
21	*Syrnolopsis minuta*	✓		
22	*Tanganyicia neritinoides*	✓		
23	*Tanganyicia rufofilosa*	✓		✓
	Totals	17	10	8

Table 3.4 lists each species and indicates the habitats in which they were encountered with a tick. Where none of the habitats is marked this means that the species in question was recorded during a sampling event for which no corresponding habitat data exist. This occurred when the species was found at depths of less than 5 m, which is outside the range of fine scale habitat mapping; or when the gradual slope of the substrate prevented completion of the habitat profile dive. As can be seen the number of species found on sand-dominated substrates was greater than for either rock-dominated or shell bed habitats and 5 species were found in all the three habitat categories. In some instances these findings contradict previous assumptions about the habitat associated with a particular species. This is partially explained by the broad scope of the

habitat categories, which means both sand and rock dominated substrates can contain an element of other substrates.

At a site level, highest species richness was found at Mankungwe South (TZ007/12) with 14 species, followed by Mabilibili Bay (TZ006/52) with 12 species. Mikakwe South (TZ007/21) and Mankungwe North (TZ007/46) each supported 10 species, and Musilambula (TZ007/61) Kasiha 1 (TZ006/2) and Busisi Bay (TZ006/67) nine species. The smallest number of species recorded (two) was at Sinsiba (TZ006/12).

3.5 Fish Census

The analysis of the fish census data was carried out both at the level of the whole park and at discrete sampling sites. Where corresponding habitat data existed, individual RVC transects and SVC samples were also compared, since habitats were not evenly distributed by depth. Otherwise, as no major differences were detected in species composition in the depth range of 0 to 15 m, samples were pooled across depths.

3.5.1 Fish sampling effort

As with the mollusc results, species accumulation curves were plotted for the complete data set of each technique (Figure 3.2) and for sub-sets of data according to habitat category, with the exception of shell beds (Appendix IV). No curves based on habitat type were produced for gillnet data, because the data sets were of insufficient size. For SVC the cumulative species totals were plotted against sample area. For RVC, sampling effort was expressed by cumulative sampling time, since in practice divers surveyed variable distances along the transect depending on their identification skills and the numbers of species they encountered. Similarly, it proved difficult to standardise soak-times for the gill nets, largely for logistical reasons, and so the number of nets set was used as the sampling unit.

The curves in Figures 3.2 – 3.4 indicate that, with the possible exception of SVC, the sampling effort across the techniques was sufficient. The combined species list from all three techniques can therefore be taken as a good measure of the total species richness of Mahale National Park. In contrast, the curves for both rock-dominated and sand-dominated habitats at Appendix IV do not appear to have reached asymptote. It is likely that further sampling is required to record all the species found in these habitats and therefore caution should be exercised in drawing conclusions from the species/habitat results.

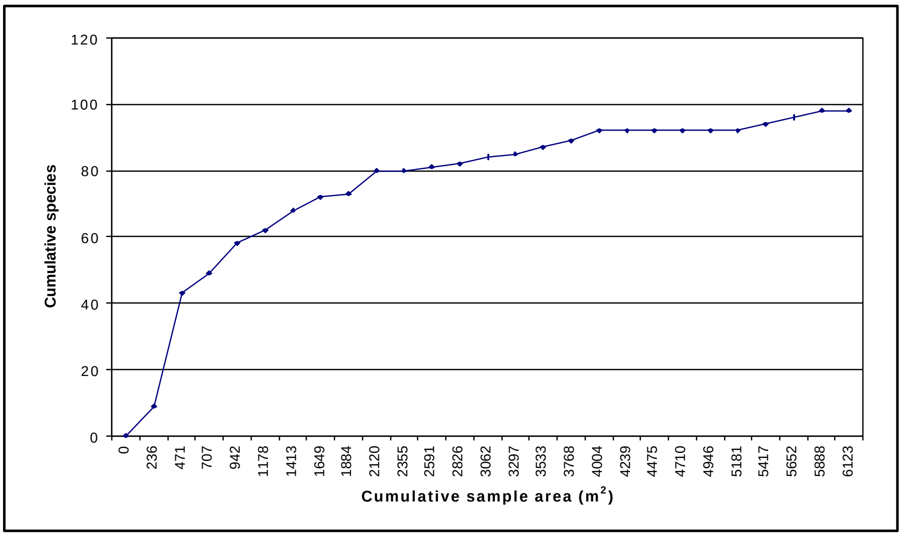

Figure 3.1 Species-area accumulation curve for SVC

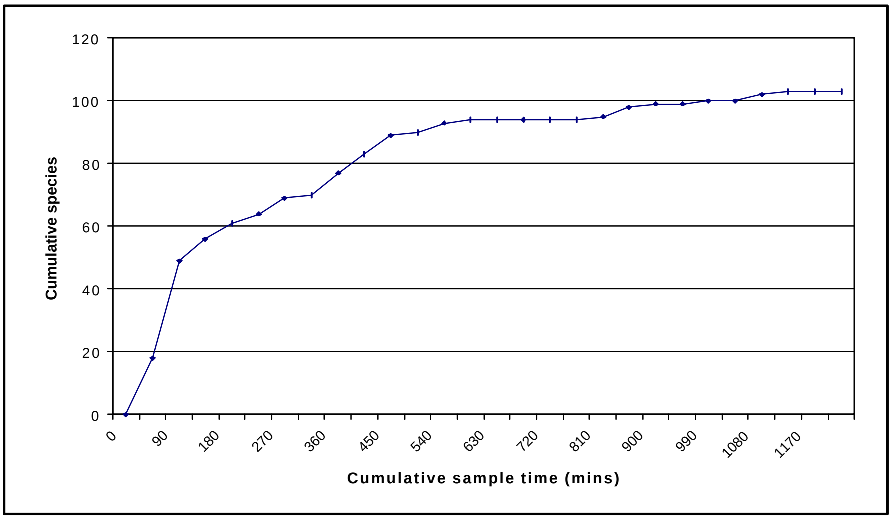

Figure 3.2 Species–sampling time curve for RVC

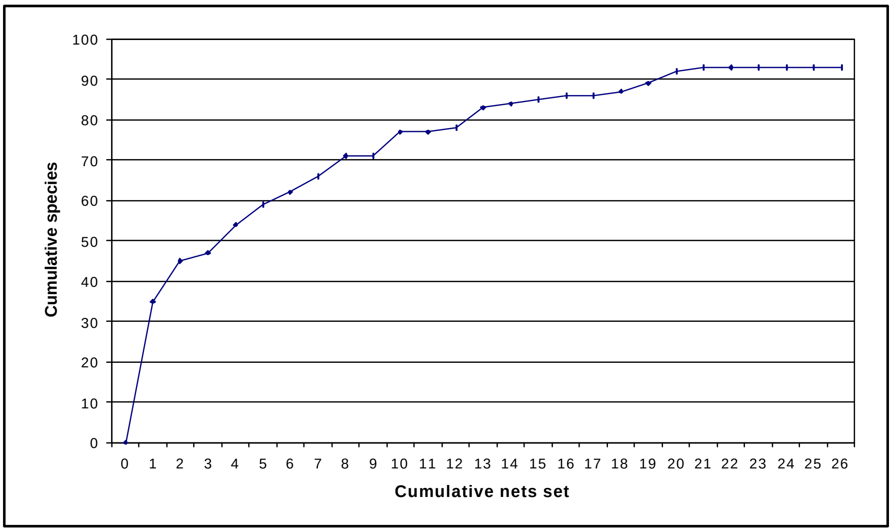

Figure 3.3 Species-sample curve for gillnets

3.5.2 Species richness

A total of 128 fish species from 53 genera and 11 families were identified in Mahale National Park. Cichlids constituted 79% of the species. As with the mollusc census, species were not included in the total list where identification was only possible down to genus level. Of the total number of species 96% are endemic to Lake Tanganyika. A full list of species is given in Appendix V.

3.5.2.1 Species unique to technique

Comparison was made between the species lists produced by each sampling technique and the species that were uniquely sampled by any one of them are given at Appendix VI. Only 5 unique species were recorded by SVC and 6 by RVC. However, despite the fact that gillnets recorded fewer species overall, they caught 18 species that were not sampled by the other techniques.

Many of these species were from non-Cichlid families and are normally found at depth, such as *Bathybates sp., Chrysicthys sp., Trematocara sp.* and *Tanganykallabes mortiauxi.*
The assumption is that they were caught in the nets when moving to shallower depths to feed at night. Similarity indices were calculated between each pair of techniques (Table 3.5) and revealed a high level of similarity between SVC and RVC. A much lower index was computed when each of these techniques were compared to gillnetting. This suggests that a number of species would have been missed from the overall list had night gillnets not been set as part of the sampling regime.

Table 3.1 Krebs similarity index between techniques

Compared techniques	Similarity index
SVC with RVC	0.91
SVC with Gillnet	0.72
RVC with Gillnet	0.74

3.5.2.2 Species unique to a habitat

Likewise the lists of species encountered in rock-dominated and sand-dominated substrates were compared (lists at Appendix VII). Out of a total of 104 species recorded in rock-dominated habitats 26 were found to be exclusive to that habitat, whereas from a total of 88 species, 10 species were found to be unique to sand-dominated habitats. The calculated index of similarity between these two substrate types was 0.81. The value of this index is perhaps higher than expected, which may be a reflection of the broadness of these two major habitat categories. They both include elements of rock and sand substrates and therefore are likely to support species normally associated with either habitat type.

3.5.2.3 Species richness at site level and by habitat

A full list of sampling sites and the species recorded at them can be found at Appendix VIII. Table 3.5 shows the 5 sites with the highest species richness in rank order by each sampling technique in turn. There is a degree of correlation with 4 sites (Kahinfinye, Lumbiye North 2, Mikakwe and Lyamembe) appearing in more than one list. Nearly all the SVC and RVC sites are situated in the central portion of the park, whereas the majority of gillnet sites are situated close to the northern (Nsele and Mikamba) and southern (Mankungwe Mid) park boundaries. Lyamembe is just to the south of the park and is therefore not officially protected. The species totals for SVC and RVC are generally higher than for gillnets, a trend that is also discernible for the sites with the lowest species totals.

Species richness was investigated in relation to habitat at the level of individual sample (SVC) and transect (RVC), because few sites were characterised by a uniform habitat along the entire depth gradient. As can be seen from Table 3.7, species richness was considerably higher on rock-dominated substrates. The notable exception is TZ007/4 (Lumbiye North 1) from a sand-dominated habitat which had the highest species total of any sample. The majority of samples irrespective of technique or habitat are from sites in the centre of the park, though some sites in the south (Mankungwe North) and north (Kabwe) are represented. Kahinfinye is represented in all four lists.

Table 3.1 Sites with the highest species richness: SVC, RVC and gillnet

Location	Sample/transect	Species total
SVC		
Kahinfiye	TZ006/ 58	48
Lufungu Bay North 1	TZ007/ 52	45
Mikakwe South	TZ007/ 22	41
Lumbiye North 2	TZ007/ 8	40
Mikakwe	TZ007/ 17	39
RVC		
Nkwasi	TZ007/ 43	48
Kahinfiye	TZ006/ 59	47
Lyamembe	TZ007/ 33	47
Mikakwe	TZ007/ 18	44
Lufungu Bay North 2	TZ007/ 58	44
Gillnet		
Nsele	TZ006/ 30	37
Mikamba	TZ006/ 35	35
Mankungwe Mid	TZ007/ 29	32
Lyamembe	TZ007/ 34	31
Lumbiye North 2	TZ007/ 10	28

Table 3.2 Most species rich samples/transects by habitats

Location	Sample	Depth (m)	Species total
ROCK-DOMINATED			
SVC			
Lufungu Bay North 1	TZ007/ 52	10	33
Kahinfiye	TZ006/ 58	5	31
Lufungu Bay North 1	TZ007/ 52	5	31
Mikakwe	TZ007/ 17	5	29
Kahinfiye	TZ006/ 58	10	29
RVC			
Nkwasi	TZ007/ 43	10	34
Mankungwe North	TZ007/ 48	15	32
Mikakwe	TZ007/ 18	15	30
Lufungu Bay North 1	TZ007/ 53	10	29
Kahinfiye	TZ006/ 59	10	28
SAND-DOMINATED			
SVC			
Kabwe North	TZ006/ 43	10	22
Kabwe South	TZ006/ 48	5	19
Kahinfiye	TZ006/ 58	15	18
Siyeswe	TZ006/ 63	5	16
Mikakwe South	TZ007/ 22	15	15
RVC			
Lumbiye North 1	TZ007/ 4	5	39
Kabwe North	TZ006/ 44	10	28
Kahinfiye	TZ006/ 59	15	28
Mikakwe South	TZ007/ 23	15	24
Lufungu Bay North 1	TZ007/ 53	15	21

3.5.3 Abundance

A total of 11,949 individuals were recorded by SVC and 2,396 by gillnet during the survey (numbers for each species are given in Appendix V). Table 3.8 shows the dominant species observed by SVC or caught in gillnets. The first 5 species represent almost 40% of individuals observed by SVC and 34% of gillnet catch. Table 3.9 ranks species recorded by RVC in order of their relative abundance (calculated as outlined in Chapter 2.4.2). There is considerable overlap between techniques with *Lepidiolamprologus attenuatus, Lamprologus callipterus* and *Limnotilapia dardennii* appearing prominently both tables. Neverthelss, the species with the highest relative abundance value for RVC, *Lepidiolamprologus elongatus,* does not appear among the dominant species of the other techniques, which underlines the fact that different techniques have inherent sampling biases. The least encountered species across all techniques were representatives of the Mastacembelidae, Bagridae and Mochokidae families. Whilst this is partially a reflection of their abundance it is probably reinforced by characteristics such as nocturnal feeding, sedentary behaviour and habitation in burrows and crevices.

Table 3.1 Dominant species in SVC and gillnet surveys

SVC			Gillnet		
Species	**Number**	**% of total**	**Species**	**Number**	**% of total**
Grammatotria lemairii	1671	14	*Lamprologus callipterus*	268	11.2
Neolamprologus brichardi	1418	12	*Haplotaxodon microlepis*	172	7.18
Lepidiolamprologus attenuatus	864	7.2	*Enantiopus melanogenys*	147	6.14
Lamprologus callipterus	750	6.3	*Grammatotria lemairii*	113	4.72
Xenotilapia flavipinnis	407	3.4	*Synodontis multipunctatus*	110	4.59
Enantiopus melanogenys	387	3.2	*Limnotilapia dardennii*	99	4.13
Limnotilapia dardennii	375	3.1	*Xenotilapia ochrogenys*	84	3.51
Telmatochromis bifrenatus	337	2.8	*Lepidiolamprologus attenuatus*	76	3.17
Lepidiolamprologus elongatus	328	2.7	*Plecodus paradoxus*	72	3.01
Haplotaxodon microlepis	291	2.4	*Lestradea perspicax*	69	2.88

Table 3.2 Species with the highest relative abundance index in RVC surveys

RVC	Relative abundance
Lepidiolamprologus elongatus	2.47
Lamprologus callipterus	2.16
Lepidiolamprologus attenuatus	1.9
Lobochilotes labiatus	1.87
Plecodus paradoxus	1.75
Telmatochromis temporalis	1.66
Telmatochromis bifrenatus	1.65
Neolamprologus tretocephalus	1.61
Limnotilapia dardennii	1.48
Cyathopharynx furcifer	1.38

3.5.4 Diversity Indices

The Shannon-Weiner indices calculated for the whole park are 1.30 and 1.29 for SVC and gillnet respectively. At site level (Table 3.10), gillnet results conform closely to those for species richness as did those for SVC in sand-dominated habitats. For rock-dominated habitats only one of the samples in Table 3.11 corresponds to a species rich sample as listed in Table 3.7. The sites with highest diversity indices are more widely distributed along the Mahale shoreline than the most species rich sites. They are not principally concentrated at the centre of the park but instead towards the north (Mikamba, Nsele, Kabwe) and south (Mankungwe, Lyamembe). It is not clear why the correlation between species richness and high diversity index is not greater. Nevertheless, it should be noted that the range of values for diversity indices is very narrow both at site and sample level (Appendices VIII and IX). Furthermore, diversity indices are known to be reduced by uneven abundance between species. At Kahinfinye and Lufungu Bay North 1, which both scored highly in species richness but less so for diversity indices, one or two species dominated in terms of numbers of individuals whereas many other species were very low in abundance. The converse is true of Kabwe North and Mikamba where individuals were much more evenly distributed between species.

Table 3.1 Sites with the highest diversity indices

Location	Sample	Diversity index
SVC		
Mikakwe	TZ007/ 17	1.41
Lyamembe	TZ007/ 32	1.36
Mankungwe South	TZ007/ 13	1.35
Mankungwe Mid	TZ007/ 27	1.34
Mankungwe North	TZ007/ 47	1.34
Gillnet		
Mikamba	TZ006/ 35	1.41
Nsele	TZ006/ 30	1.35
Lyamembe	TZ007/ 34	1.34
Kasiha 1	TZ006/ 5	1.34
Kasiha 2	TZ006/ 10	1.32

Table 3.2 Samples with the highest diversity in rock and sand dominated habitats

SVC			
Location	**Sample**	**Depth (m)**	**Diversity index**
Rock-dominated			
Mikakwe	TZ007/ 17	5	1.33
Lufungu Bay North 2	TZ007/ 57	10	1.24
Mikakwe	TZ007/ 17	10	1.20
Mikakwe	TZ007/ 17	15	1.18
Mankungwe North	TZ007/ 47	10	1.15
Sand-dominated			
Kabwe North	TZ006/ 43	10	1.18
Kabwe South	TZ006/ 48	5	1.06
Siyeswe	TZ006/ 63	5	1.02
Mankungwe South	TZ007/ 13	10	0.98
Lufungu Bay North 1	TZ007/ 52	15	0.92

CHAPTER 4. DISCUSSION

4.1 Suitability of methods

The Mahale survey provided an opportunity to evaluate BIOSS sampling techniques, both in terms of their practical application and the results they yielded. In this section, each technique is assessed in turn and where appropriate changes are recommended. Some of these changes have already been adopted and are reflected in the most recent version of the BIOSS Standing Instructions document (Allison *et al*., 1999).

4.1.1 Manta Tow Technique

The Manta Tow proved to be a useful technique for assessing the coarse scale distribution of substrates along the Mahale shoreline, prior to selecting representative sites for more detailed sampling. It was found to be robust and cost effective and required no sensitive or expensive equipment. Large stretches of coastline were sampled rapidly, and though for planning purposes it had been estimated that 10 km could be covered per day, in practice after a short time the teams could have surveyed 15 km per day given good weather. A further advantage of Manta was the fact that it enabled team members to become acquainted with the survey area prior to commencing diving.

Nevertheless, Manta Tow technique is not without its limitations. Though it provided good data on the nature of substrates down to 5 or 10 m, experience showed it to be an unreliable indicator of substrates at greater depth. This underlined the necessity for confirmation by habitat profile dive, in order to obtain accurate data on the habitats at each survey site. Furthermore, its effectiveness was reduced considerably in areas of low visibility, such as river mouths, or places where the bottom depth varied constantly. In these circumstances the diver was required to signal the coxswain to manoeuvre the boat in order maintain visual contact with the substrate, but inevitably areas were left unrecorded. In rough weather the towing boat was compelled to slow down thus reducing the sampling rate and the diver was buffeted in the water making his task difficult to carry out.

Nor is Manta Tow suitable for areas with a high density of crocodiles or hippos, since the diver being towed is vulnerable to attack. A couple of potentially dangerous encounters with crocodiles led the teams to investigate possible modifications to the technique for use in areas where such creatures were known or likely to be. These included the substrate observer remaining in the boat but positioning himself head and shoulders in the water while observing the substrate below. By this method it was possible to gather satisfactory data, but it was uncomfortable and did not guarantee safety. It was agreed that a more effective alternative to Manta Tow would have to be developed prior to the survey of Nsumbu National Park, Zambia where the incidence of crocodiles is expected to be high.

4.1.2 Dive techniques

The dive techniques employed during the Mahale survey differed widely in minimum and maximum sampling depths and the depth for each data point. For reasons of safety, logistics and conformity it was decided to standardise the techniques for subsequent surveys. In future all techniques will sample at 0, 5, 10 and 15 m respectively. Previous survey results suggest that the decision not to sample molluscs down to 25 m will not lead to a significant loss of data.

4.1.2.1 Habitat profile dive

Two specific problems were encountered with the profile dive. The data points were determined by distance along the transect rather than depth, which meant that linking habitat with fish or mollusc census data was difficult. Furthermore, in areas where the bottom profile was particularly gentle numerous data points could occur over distance with very little change in depth. Consequently, divers were often forced to surface having expended their air supply without having completed the habitat profile. This resulted in some site surveys where the habitat and fish/mollusc data only partially overlapped or not at all. A solution would be to amend the technique so that data points are determined by depth and therefore corresponded exactly to those of species censuses. It is hoped that this will also ameliorate the problem of gently sloping substrates, though in extreme cases it will be necessary to devise an alternative technique.

4.1.2.2 Mollusc transect

The mollusc transect incorporated both sieving and search techniques and was therefore flexible enough to sample both hard and soft substrates. Nevertheless, range of sampling options subject to substrate were found to be too numerous and complex. These should therefore be simplified for future surveys. There seemed to be no clear reason why the sampling at 0 m should be conducted using a separate method, in other words parallel to the shore as opposed to perpendicular to it as for all other depths. It is recommend that the technique should be amended so that the census at 0 m should be a continuation of the Mollusc transect and carried out in the same way, as is the case with the fish techniques.

4.1.2.3 SVC

The SVC proved effective as a means of collecting data on fish species richness and abundance. However, the practice by which each diver observed species for 5 minutes and then recorded numbers of each species for the following 5 minutes, was found to be impractical. In effect divers found themselves noting both species and abundance at the same time, to ensure that a species did not disappear from view before all individuals had been counted. It is recommend that this de facto change to the technique should be incorporated in the BIOSS Standing Instructions for Sampling.

4.1.3 Multiple fish census techniques

The results of the fish surveys appear to vindicate the decision to employ a combination of different fish census techniques. While RVC recorded the highest number of species, gillnets proved useful in catching species which were not recorded by the dive techniques. SVC is important because it provides both information on species richness and the most comprehensive data on abundance, from which diversity indices can be calculated. The number of species recorded by RVC was only marginally greater than the other techniques and only 6 of those were unique to that technique. Given the considerable demand on resources that conducting underwater fish censuses entails, the necessity of retaining RVC in the inventory of techniques should be reviewed in the light of results from this survey.

4.2 Overview of Findings

4.2.1 Habitats

The habitat surveys of Mahale reveal a wide spectrum of habitats, based on the principal substrate components of rock and sand. A few sites were uniform in composition, the majority were characterised by both substrate types. Occasionally these were patchily distributed, but more commonly found in bands determined by depth and the angle of slope of the lake bottom. It is this mosaic of varied habitats, which probably explains the great richness and diversity of fish and molluscs found in the park.

In addition, more specialised habitats such as shell beds, stromatolites and small stands of emergent macrophytes are also present in Mahale. Shell beds are known to support a distinct community of shell-dwelling Cichlids and it had been hoped to establish detailed associations between different sand and rock habitats and fish and mollusc communities. But for reasons already explained, the collected data was insufficient to enable this analysis to take place. In spite of the fact that the two categories of Rock-dominated and Sand-dominated were very broad, it proved possible to construct lists of which species were unique to each of them. More detailed investigation of habitat/species associations will however require a data set large enough to be able to define habitat categories more precisely.

As was to be expected within a protected area, the habitats surveyed were in general pristine and there were few indications of human disturbance. The adjacent land area was covered mostly by natural forest and there was no evidence of excessive sedimentation deposition. There was no evidence of eutrophication or discernible sources of pollution aside from a limited amount of domestic waste emanating from the camp at Kasiha.

4.2.2 Mollusc Census

In terms of the total number of mollusc species recorded in Lake Tanganyika, Mahale supports 40% of the gastropod species and 13% of the bivalves. The species-area accumulation curves, which were plotted, suggest that this is an accurate reflection of the numbers in Mahale and therefore further surveys are not likely to detect additional species. Nevertheless it should be noted that at the time of the survey, the majority of the regional team were still relatively inexperienced in mollusc taxonomy and in search techniques. It is therefore reasonable to assume that certain small or cryptic species may have been overlooked, particularly those which bury themselves in the sand or dwell in rock crevices. Of the 10 most species rich sites, eight were grouped in a cluster near the southern end of the park. Whilst this may be an indication that this area of the park is a hot-spot for mollusc diversity, it may also be significant that those sites were sampled by a group of divers which included a specialist in Lake Tanganyika molluscs.

The number of species found on sand-dominated substrates was significantly higher than that on rock-dominated substrate. Nevertheless, at the level of individual samples it was the rocky habitats, which recorded the highest number of species. This would suggest that there was little variation in species composition between rocky areas, but that the species found on sand-dominated substrates varied greatly from sample to sample.

4.2.3 Fish Census

Sampling effort for fish appears to have been sufficient, in spite of the fact that Mahale supports a high diversity of species of which many are only present in small numbers. However when effort was considered in association with habitat, the species-area curves indicate that further sampling on sand-dominated substrates in particular would probably identify additional species. The survey revealed that 53% of all the species known to inhabit Lake Tanganyika (excluding associated water bodies) are found in Mahale. This is significant in conservation terms in that it means that over half the fish species of the lake enjoy a measure of protection in a single protected area. When this is combined with results from the surveys of other National Parks, it is likely to underline the importance of the existing protected area network in maintaining the current levels of biodiversity within the lake.

Another aspect of community structure is abundance. This was not evenly distributed between species in Mahale. A few species, particularly from the Lamprologini and Ectodini tribes, were found to be very numerous whereas many other species were represented by a few individuals only. Further sampling is required however before it can be established whether these species are simply less abundant or patchily distributed or even rare.

The sites with the greatest diversity of species were for the most part concentrated in the central portion of the park between Luahagala point and Lumbiye Bay. Though other locations both in the north (Nsele) and south (Lyamembe and Mankungwe) were also rich in species. The same pattern did not emerge from the diversity indices. A number of sites, which supported many species, were not among those with the highest diversity indices and the converse was also true. This is almost certainly due to the differences in relative abundance, with the diversity index of some species-rich sites being reduced by the presence of a few very abundant species. It is interesting to note that the site at Lyamembe registered both a high species count and diversity index. This is one of two sites sampled during the survey, which was outside the park boundaries and subject regular low intensity fishing with gillnets by villagers from nearby Sibwesa (Pers. com.

R. Lindley, Fishing Practices Special Study Facilitator, LTBP). This suggests that limited resource exploitation within areas of high biodiversity is possible without severe degradation. It is not possible to establish in any detail the extent to which diversity was a function of habitat composition given the incomplete nature of the habitat/census data. However where data exists, the results show clearly that rock-dominated habitats support greater fish diversity than sand dominated sites.

Ideally, in assessing the biodiversity importance of Mahale other factors in addition to species richness and diversity indices should be considered. The list of species for Mahale included a very high proportion of endemics. This was due not only to the large representation of Cichlids, but because those non Cichlid species that were recorded were from families with high levels of endemicity such as Mastacembelidae, Mochokidae and Bagridae. Rarity, restricted range and habitat specificity do not lie within the limited scope of this survey. Nevertheless, it is hoped that as data from other surveys as well as from the BIOSS literature database is analysed it will be possible to assess the results from Mahale in the context of these factors.

4.3 Future Work

The Mahale survey conducted by BIOSS is at best a baseline study and there is much work that could be done to achieve a fuller understanding of the biodiversity of the park. Below are some suggested priorities for future work.

- *Habitat/species associations*. The relationship between habitats and fish and mollusc community structure requires more detailed survey. With the revision of the habitat profile techniques it will be possible to record detailed descriptions of habitat characteristics from the precise locations where faunal surveys are conducted. From analysis of this data, associations between distinct communities and their habitats can be established, which in turn can support a more habitat based approach to conservation.

- *Neothauma shell habitats*. The majority of shell beds were encountered at depths outside the range of the fish surveys. If a more detailed understanding of the fish community associated with this type of habitat is to be obtained, then these areas may should be sampled as a distinct entities and not as part of the standard sampling procedures laid down in the BIOSS Standing Instructions.

- *Additional biodiversity surrogates.* BIOSS only surveyed fish and mollusc species in Mahale. There are many other taxonomic groups, such as macro invertebrates, that might prove equally suitable for use in biodiversity assessment. Keys for identification of these taxa should be developed and taxonomic training undertaken, to ensure that they are included in future survey work.

- *Monitoring techniques*. The techniques developed by BIOSS were designed for use by underwater survey specialists with a high level of taxonomic training. Though it is hoped that the BIOSS national teams will continue operating beyond the life of LTBP, it is unlikely that they will have the resources to undertake regular monitoring in the park. TANAPA is probably in the best position to carry out monitoring, but have no current expertise in this field. Alternative assessment methods, which require less field time and detailed taxonomic knowledge, should therefore be investigated to facilitate future monitoring at Mahale. The range of options includes the use of recognisable taxonomic units (RTU), higher-taxon approaches and local knowledge.

4.4 Management Recommendations

The findings of this survey have confirmed Mahale status as a centre for fish and mollusc diversity. Irrespective of the policies adopted for the wider management of Lake Tanganyika, protected areas such as Mahale are likely to constitute an important component of any strategy to conserve the lake's biodiversity. Monitoring should be a key element in the management of the park's aquatic zone. It will provide important information on changes that may take place over time, in the health of the underwater habitats and the structure of the faunal community. As discussed in Chapter 4.3, the park staff are probably best placed to carry out this task, however at present their knowledge and experience is primarily terrestrial. It is recommended that TANAPA improve the capacity of their staff at Mahale to monitor and manage the aquatic zone of the park. The monitoring programme and methods need not be as sophisticated as those adopted by BIOSS. A combination of snorkel census for the shallow water zone and gillnets for greater depths would still provide valuable information and would be much more sustainable in the future. The park ecologist for Gombe and Mahale National Parks is a fully trained member of the BIOSS team and would be in a position to assist with implementation of such a programme.

At present, the lacustrine component of the park is well protected from the major threats to the biodiversity of the lake (sedimentation, fishing and pollution). Nevertheless, demographic changes are likely to increase pressure on both the terrestrial and aquatic resources of the park. In spite of the admirable co-operation between the park authorities and the adjacent villages, local communities derive little value from the park and its resources. Tourism currently brings them limited benefit and there is no reason for assuming this will change in the immediate future. However, the survey results show that at least one location outside the park where fishing takes place and supports a fish community as diverse as the richest sites within it. The park management are encouraged promote further research into whether utilisation of the fish resources within the park can be sustainable, and if so to actively seek ways of establishing opportunities for improved benefit sharing with neighbouring communities.

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Appendix I Summary of survey sites and sampling events, Mahale National Park

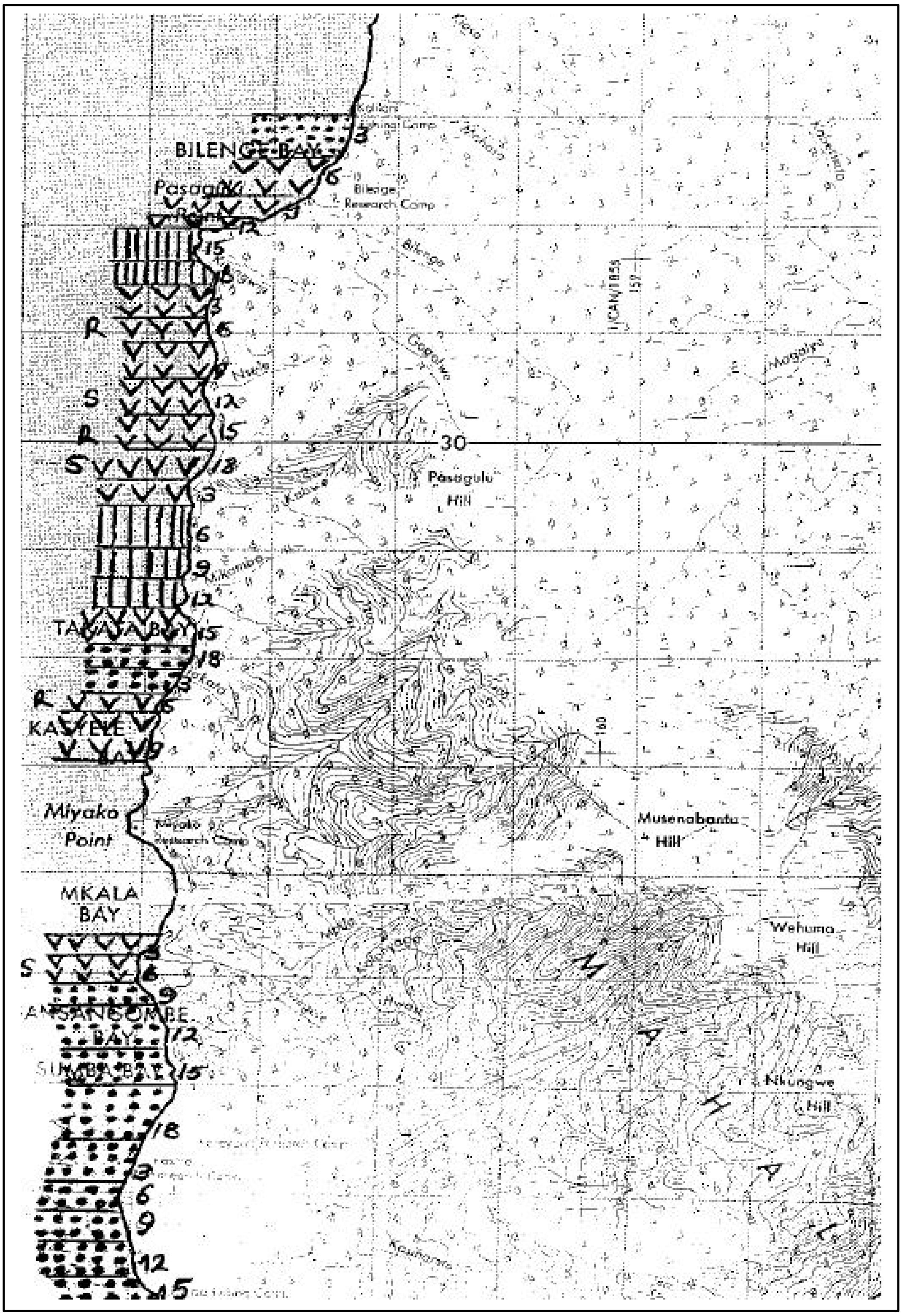
Location	Lat/Long (decimal	Sample	Activity
Kasiha 1	06.08 E, 029.73 S	TZ006/ 1	Habitat Profile
		TZ006/ 2	Mollusc Census
		TZ006/ 3	SVC
		TZ006/ 4	RVC
		TZ006/ 5	Gillnet (night)
Kasiha 2	06.11 E, 029.73 S	TZ006/ 6	Habitat Profile
		TZ006/ 7	Mollusc Census
		TZ006/ 8	SVC
		TZ006/ 9	RVC
		TZ006/ 10	Gillnet (night)
Sinsiba	06.14 E, 029.73 S	TZ006/ 11	Habitat Profile
		TZ006/ 12	Mollusc Census
		TZ006/ 13	SVC
		TZ006/ 14	RVC
		TZ006/ 15	Gillnet (night)
Sitolo Bay	06.01 E, 029.76 S	TZ006/ 16	Habitat Profile
		TZ006/ 17	Mollusc Census
		TZ006/ 18	SVC
		TZ006/ 19	RVC
		TZ006/ 20	Gillnet (night)
Bilenge Bay	06.03 E, 029.74 S	TZ006/ 21	Habitat Profile
		TZ006/ 22	Mollusc Census
		TZ006/ 23	SVC
		TZ006/ 24	RVC
		TZ006/ 25	Gillnet (night)
Nsele	06.05 E, 029.73 S	TZ006/ 26	Habitat Profile
		TZ006/ 27	Mollusc Census
		TZ006/ 28	SVC
		TZ006/ 29	RVC
		TZ006/ 30	Gillnet (night)
Mikamba	06.07 E, 029.73 S	TZ006/ 31	Habitat Profile
		TZ006/ 32	Mollusc Census
		TZ006/ 33	SVC
		TZ006/ 34	RVC
		TZ006/ 35	Gillnet (night)
Takata	06.08 E, 029.73 S	TZ006/ 36	Habitat Profile
		TZ006/ 37	Mollusc Census
		TZ006/ 38	SVC
		TZ006/ 39	RVC
		TZ006/ 40	Gillnet (night)
Kabwe North	06.06 E, 029.73 S	TZ006/ 41	Habitat Profile
		TZ006/ 42	Mollusc Census
		TZ006/ 43	SVC
		TZ006/ 44	RVC
		TZ006/ 45	Gillnet (night)
Kabwe South	06.06 E, 029.72 S	TZ006/ 46	Habitat Profile
		TZ006/ 47	Mollusc Census
		TZ006/ 48	SVC
		TZ006/ 49	RVC
		TZ006/ 50	Gillnet (night)

Location	Lat/Long (decimal	Sample	Activity
Mabilibili Bay	06.45 E, 029.91 S	TZ006/ 51	Habitat Profile
		TZ006/ 52	Mollusc Census
		TZ006/ 53	SVC
		TZ006/ 54	RVC
		TZ006/ 55	Gillnet (night)
Kahinfiye	06.29 E, 029.76 S	TZ006/ 56	Habitat Profile
		TZ006/ 57	Mollusc Census
		TZ006/ 58	SVC
		TZ006/ 59	RVC
		TZ006/ 60	Gillnet (night)
Siyeswe	06.30 E, 029.78 S	TZ006/ 61	Habitat Profile
		TZ006/ 62	Mollusc Census
		TZ006/ 63	SVC
		TZ006/ 64	RVC
		TZ006/ 65	Gillnet (night)
Busisi Bay	06.45 E, 029.91 S	TZ006/ 66	Habitat Profile
		TZ006/ 67	Mollusc Census
		TZ006/ 68	SVC
		TZ006/ 69	RVC
		TZ006/ 70	Gillnet (night)
Lumbiye North 1	06.34 E, 029.80 S	TZ007/ 1	Habitat Profile
		TZ007/ 2	Mollusc Census
		TZ007/ 3	SVC
		TZ007/ 4	RVC
		TZ007/ 5	Gillnet (night)
Lumbiye North 2	06.34 E, 029.80 S	TZ007/ 6	Habitat Profile
		TZ007/ 7	Mollusc Census
		TZ007/ 8	SVC
		TZ007/ 9	RVC
		TZ007/ 10	Gillnet (night)
Mankungwe South	06.44 E, 029.90 S	TZ007/ 11	Habitat Profile
		TZ007/ 12	Mollusc Census
		TZ007/ 13	SVC
		TZ007/ 14	RVC
Mikakwe	06.39 E, 029.84 S	TZ007/ 15	Habitat Profile
		TZ007/ 16	Mollusc Census
		TZ007/ 17	SVC
		TZ007/ 18	RVC
		TZ007/ 19	Gillnet (night)
Mikakwe South	06.40 E, 029.84 S	TZ007/ 20	Habitat Profile
		TZ007/ 21	Mollusc Census
		TZ007/ 22	SVC
		TZ007/ 23	RVC
		TZ007/ 24	Gillnet (night)
Mankungwe Mid	06.43 E, 029.89 S	TZ007/ 25	Habitat Profile
		TZ007/ 26	Mollusc Census
		TZ007/ 27	SVC
		TZ007/ 28	RVC
		TZ007/ 29	Gillnet (night)

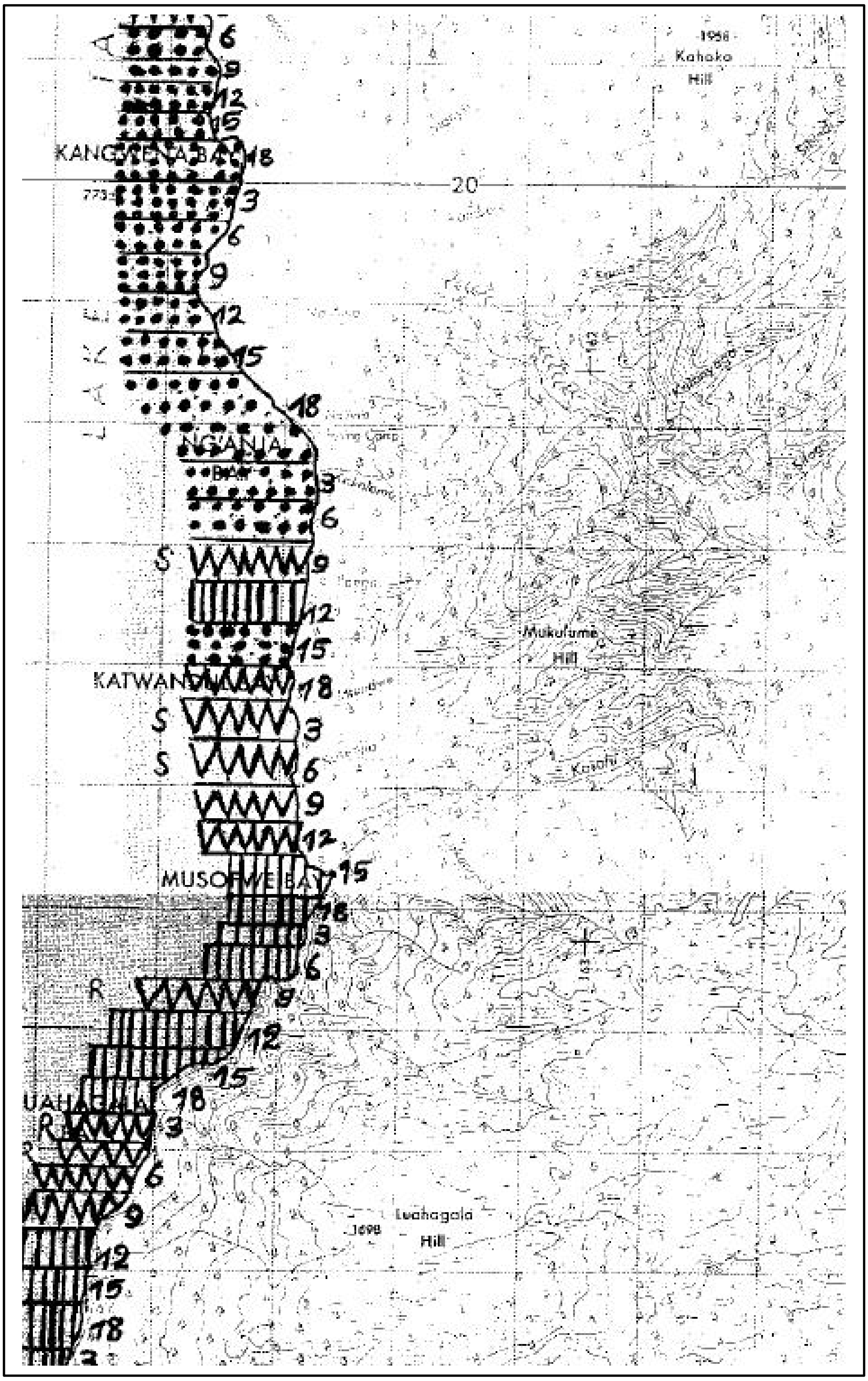
Location	Lat/Long (decimal	Sample	Activity
Lyamembe	06.46 E, 029.92 S	TZ007/ 30	Habitat Profile
		TZ007/ 31	Mollusc Census
		TZ007/ 32	SVC
		TZ007/ 33	RVC
		TZ007/ 34	Gillnet (night)
Luahagala North	06.24 E, 029.72 E	TZ007/ 35	Habitat Profile
		TZ007/ 36	Mollusc Census
		TZ007/ 37	SVC
		TZ007/ 38	RVC
		TZ007/ 39	Gillnet (night)
Nkwasi	06.26 E, 029.74 S	TZ007/ 40	Habitat Profile
		TZ007/ 41	Mollusc Census
		TZ007/ 42	SVC
		TZ007/ 43	RVC
		TZ007/ 44	Gillnet (night)
Mankungwe North	06.43 E, 029.88 S	TZ007/ 45	Habitat Profile
		TZ007/ 46	Mollusc Census
		TZ007/ 47	SVC
		TZ007/ 48	RVC
		TZ007/ 49	Gillnet (night)
Lufungu Bay North 1	06.29 E, 029.74 S	TZ007/ 50	Habitat Profile
		TZ007/ 51	Mollusc Census
		TZ007/ 52	SVC
		TZ007/ 53	RVC
		TZ007/ 54	Gillnet (night)
Lufungu Bay North 2	06.27 E, 029.75 S	TZ007/ 55	Habitat Profile
		TZ007/ 56	Mollusc Census
		TZ007/ 57	SVC
		TZ007/ 58	RVC
		TZ007/ 59	Gillnet (night)
Musilambula	06.42 E, 029.87 S	TZ007/ 60	Habitat Profile
		TZ007/ 61	Mollusc Census
		TZ007/ 62	RVC
		TZ007/ 63	Gillnet (night)

Appendix II   Coarse scale habitat maps for Mahale National Park

MAP 1

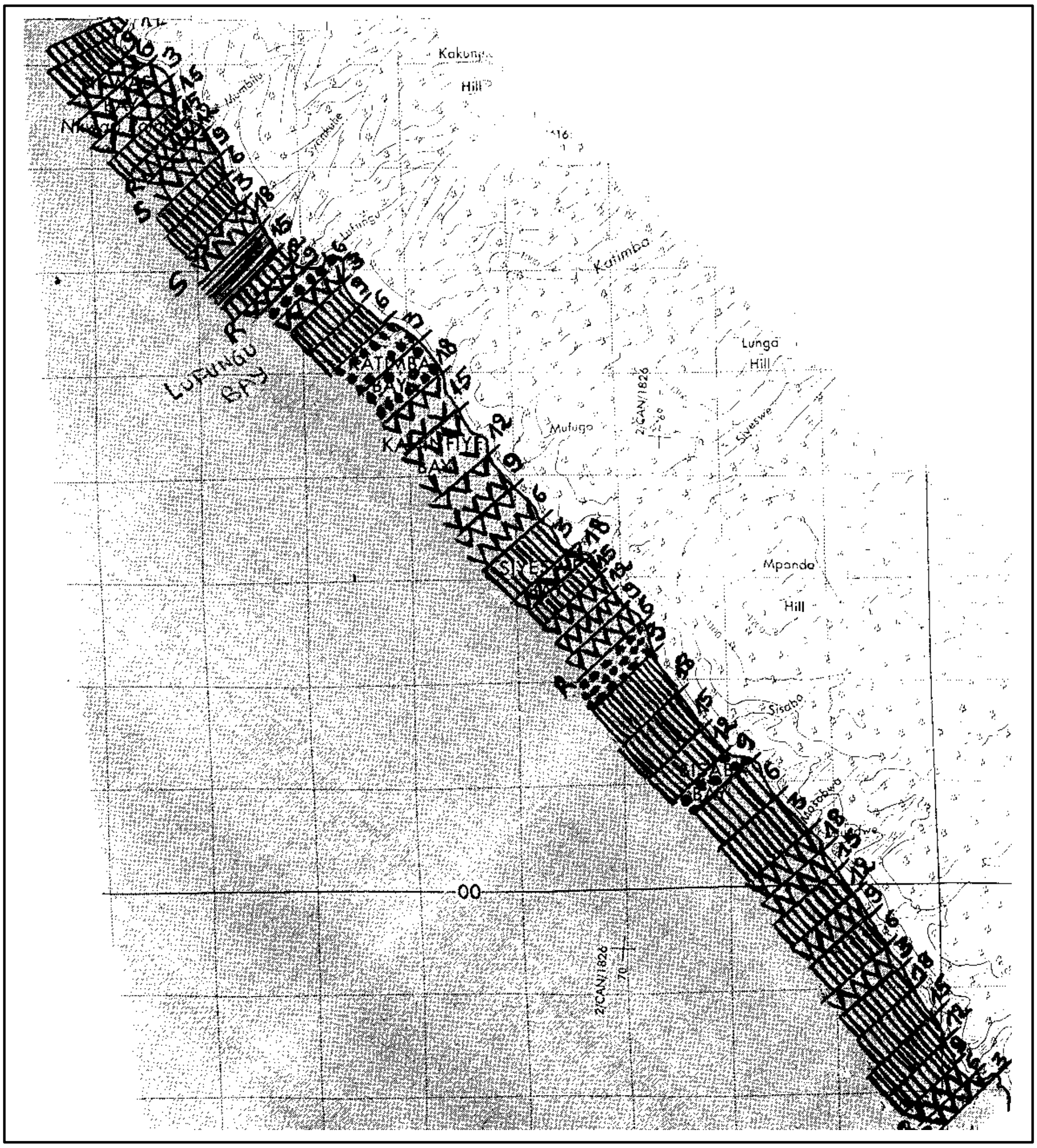


MAP 2

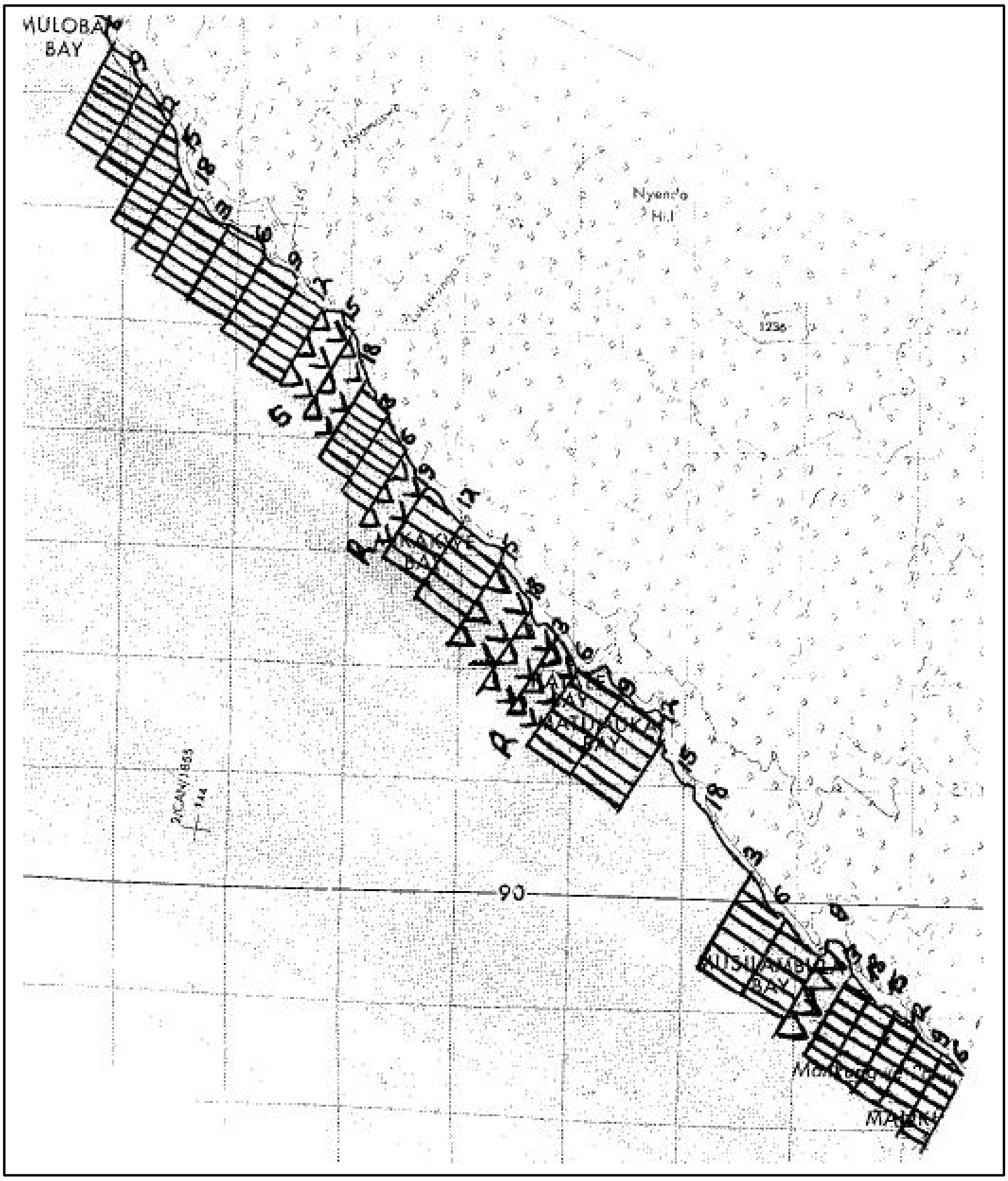


Kahoko
Hill
KANGWENA BAY
20
NGANJA
Bay
KATWANDAI BAY
Mukulume
Hill
MUSOFWE BAY
Luahagala
Hill

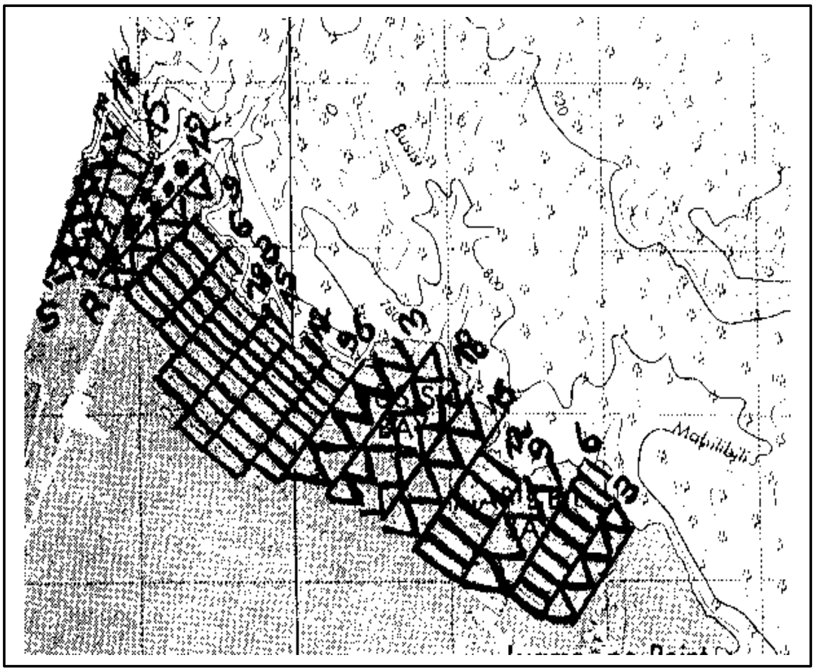
MAP3


Kakungu
Hill
Katimba
Lunga
Hill
Mufugo
Mpondo
Hill
Sisaba
LUFUNGU
BAY
00
2/CAN/1826

MAP 4



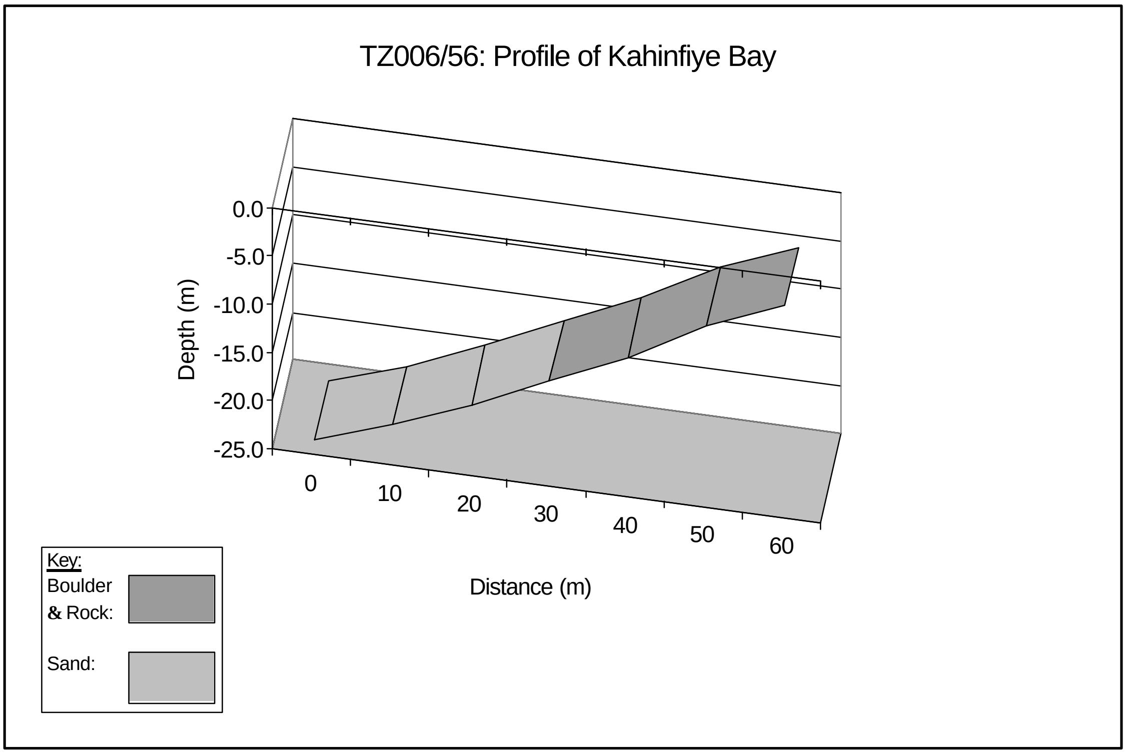
MAP 5

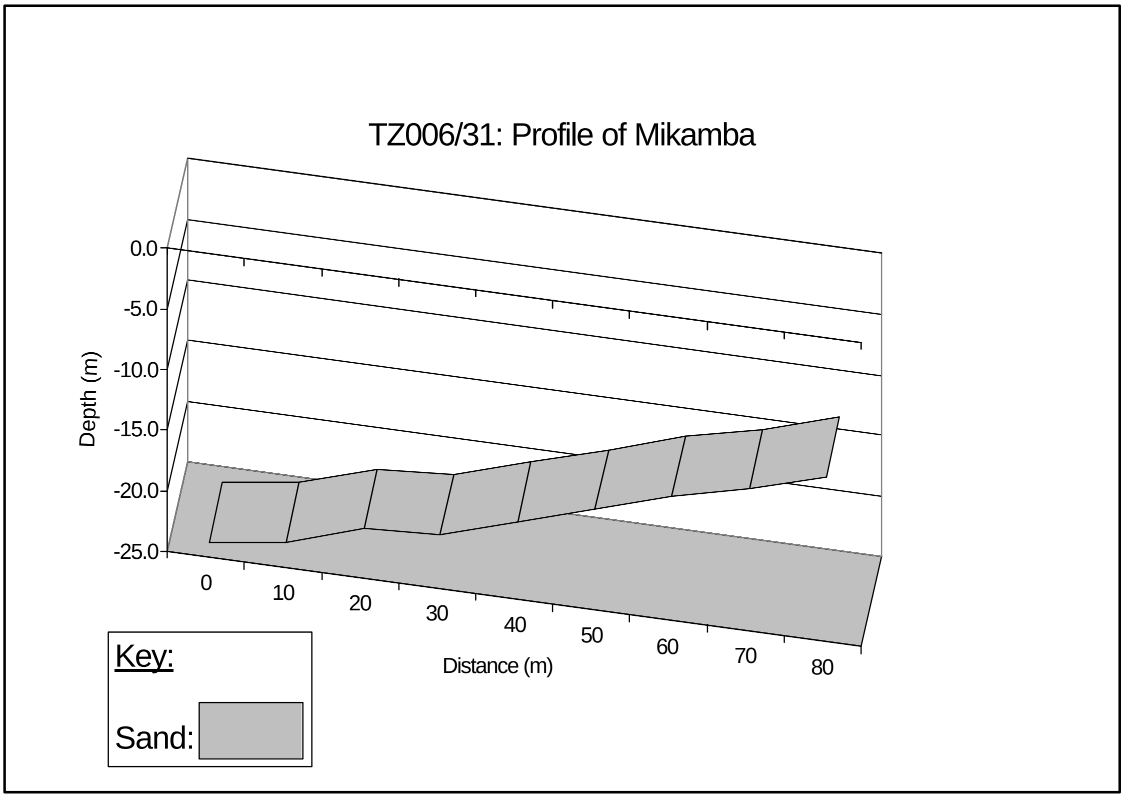


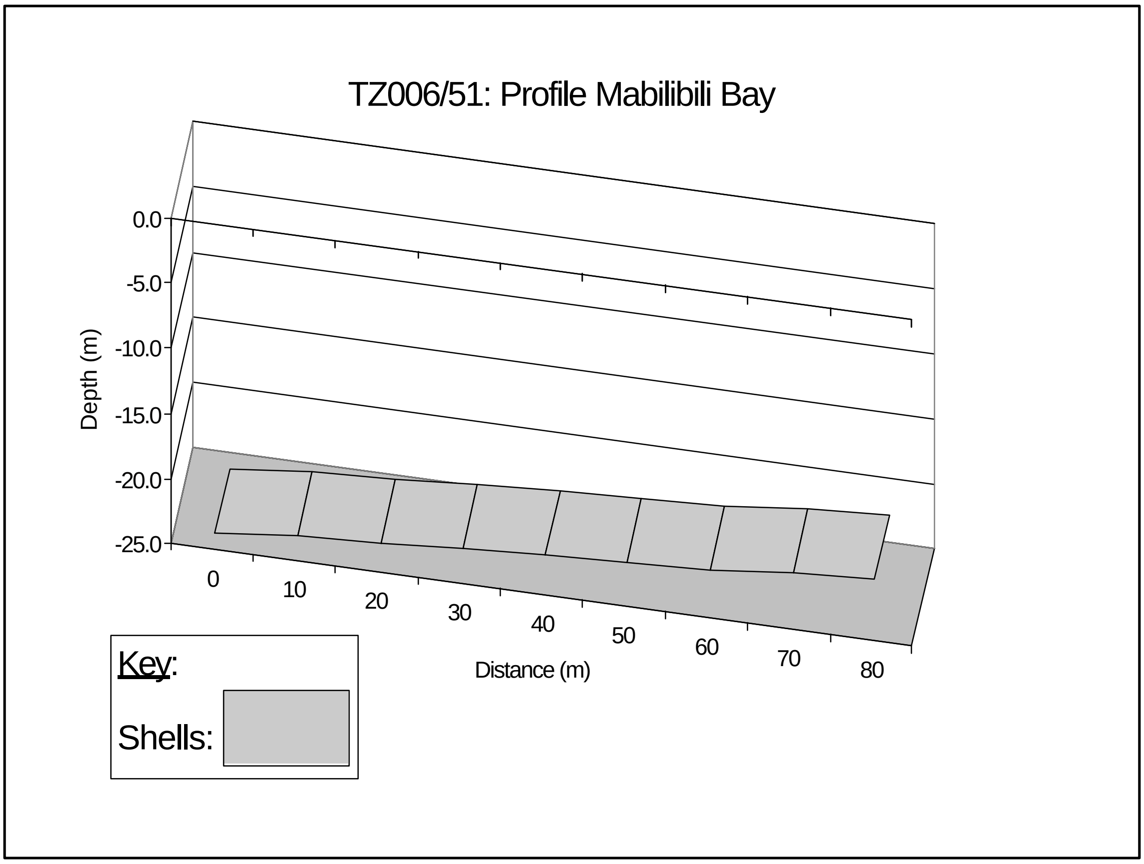
Key to symbols	
Symbol	Substrate type
	Sand
	Rock
	Gravel
	Mixed

Note: where the symbol for a Mixed substrate is annotated with an **S** or **R** it indicates a Mixed Sandy or Mixed Rocky substrate respectively

Appendix III Habitat profile charts for Kahinfinye Bay, Mabilibili Bay and Mikamba

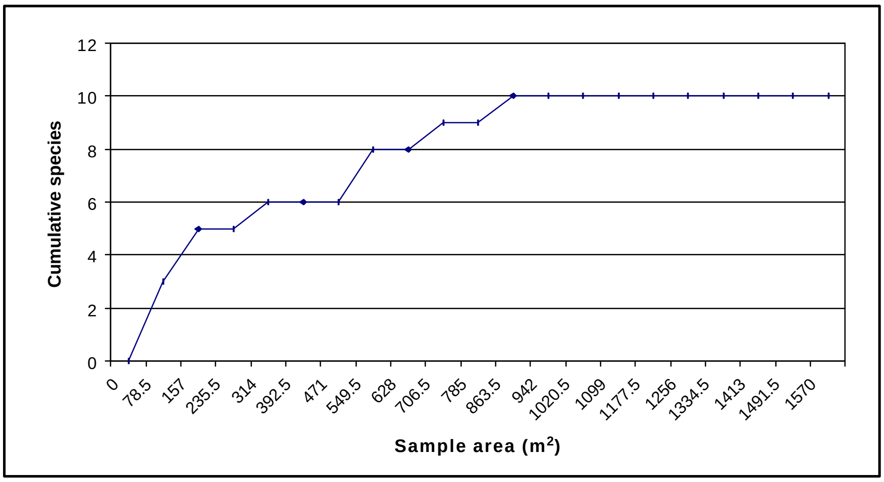




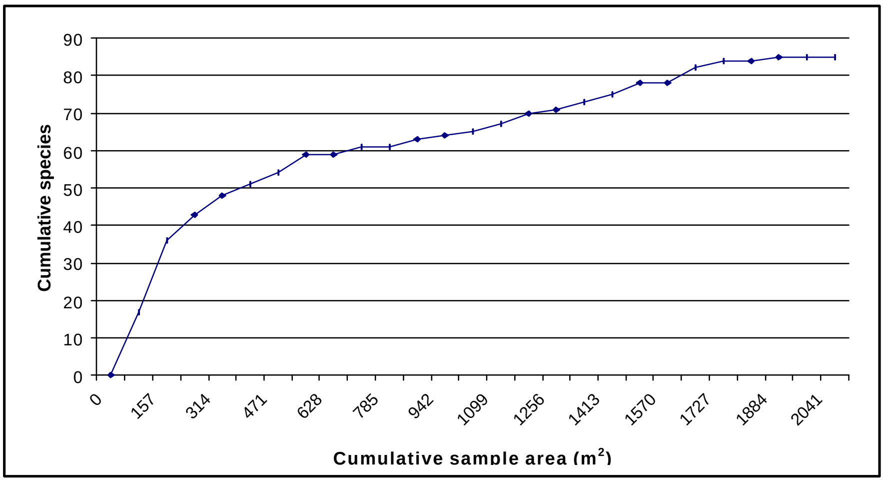

TZ006/51: Profile Mabilibili Bay
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
Depth (m)
0
10
20
30
40
50
60
70
80
Distance (m)
Key:
Shells:

Appendix IV Species accumulation curves by sample method and habitat.
Rock-dominated: a) Molluscs b) SVC c) RVC Sand-dominated; d) Molluscs e) SVC f) RVC

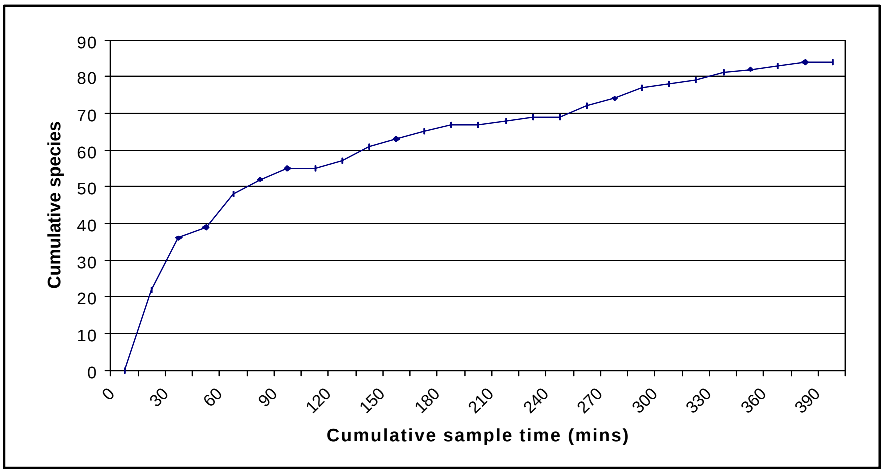
a)



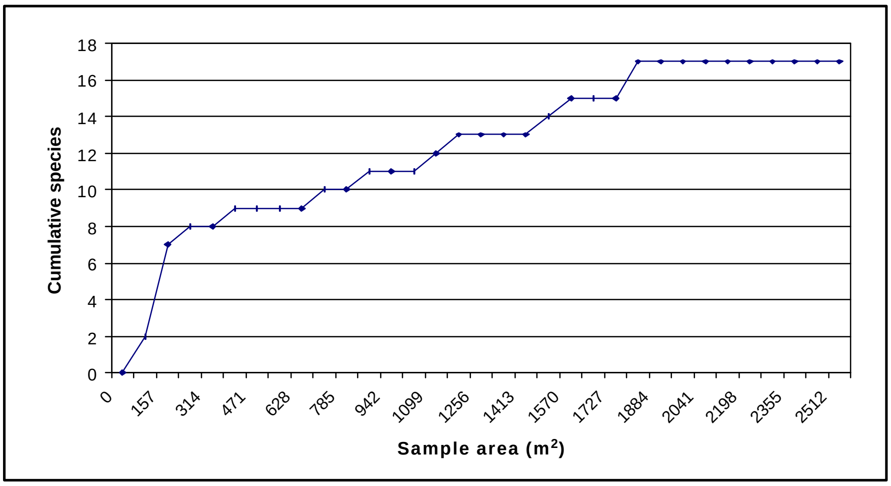
b)



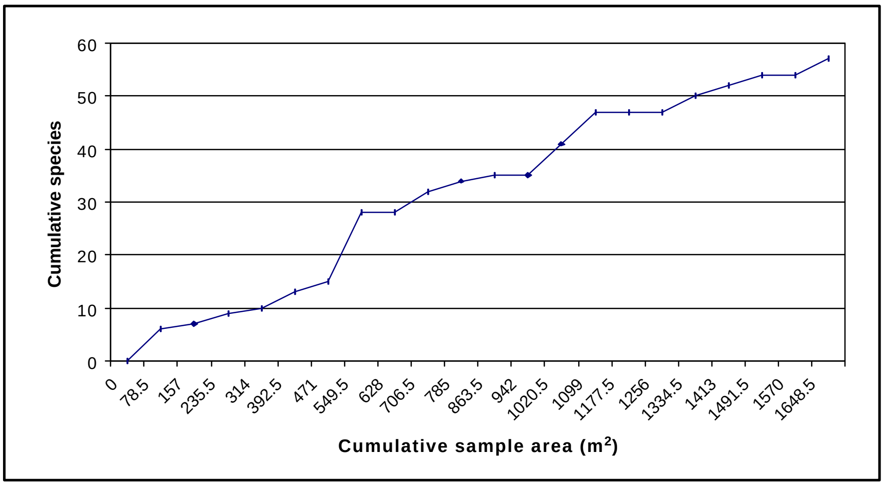
c)



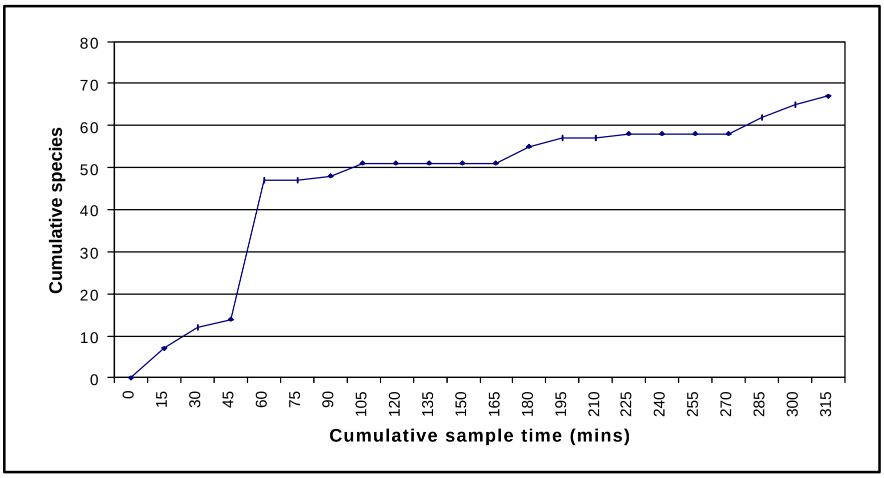
d)


Cumulative species
18
16
14
12
10
8
6
4
2
0
0
157
314
471
628
785
942
1099
1256
1413
1570
1727
1884
2041
2198
2355
2512
Sample area (m^2)

e)


Cumulative species
60
50
40
30
20
10
0
0
78.5
157
235.5
314
392.5
471
549.5
628
706.5
785
863.5
942
1020.5
1099
1177.5
1256
1334.5
1413
1491.5
1570
1648.5
Cumulative sample area (m^2)

f)


Cumulative species
80
70
60
50
40
30
20
10
0
0
15
30
45
60
75
90
105
120
135
150
165
180
195
210
225
240
255
270
285
300
315
Cumulative sample time (mins)

Appendix V Total fish species lists and relative abundance by sampling technique

	Species	SVC Total abundance	RVC Relative rarity	Gillnet Total catch
1	*Acapoeta tanganicae*	4	0.99	60
2	*Aethiomastacembelus ellipsifer*	1	0.14	2
3	*Aethiomastacembelus platysoma*	-	0.03	-
4	*Altolamprologus calvus*	42	0.15	-
5	*Altolamprologus compressiceps*	82	1.21	9
6	*Asprotilapia leptura*	25	0.21	2
7	*Auchenoglanis occidentalis*	1	-	1
8	*Aulonocranus dewindti*	15	0.11	3
9	*Barbus taeniopleura*	-	0.07	1
10	*Barbus tropidolepis*	-	0.25	7
11	*Bathybates fasciatus*	2	0.11	43
12	*Bathybates ferox*	26	-	23
13	*Bathybates graueri*	-	-	15
14	*Bathybates horni*	-	-	13
15	*Bathybates leo*	-	-	2
16	*Bathybates vittatus*	-	-	2
17	*Benthochromis tricoti*	-	-	5
18	*Boulengerochromis microlepis*	43	0.68	2
19	*Caecomastacembelus frenatus*	-	0.04	-
20	*Caecomastacembelus moorii*	4	0.17	3
21	*Caecomastacembelus ophidium*	2	-	-
22	*Callochromis macrops*	-	-	2
23	*Callochromis melanostigma*		-	5
24	*Chalinochromis brichardi*	42	0.89	2
25	*Chrysichthys brachynema*	-	-	52
26	*Chrysichthys platycephalus*	-	-	20
27	*Chrysichthys sianenna*	-	-	23
28	*Cyathopharynx furcifer*	290	1.38	55
29	*Cyphotilapia frontosa*	69	0.71	3
30	*Cyprichromis leptosoma*	161	0.24	25
31	*Cyprichromis microlepidotus*	-	0.13	20
32	*Ectodus descampsi*	175	0.08	24
33	*Enantiopus melanogenys*	387	0.19	147
34	*Eretmodus cyanostictus*	3	0.65	1
35	*Gnathochromis pfefferi*	38	0.87	1
36	*Grammatotria lemairii*	1671	1.02	113
37	*Haplotaxodon microlepis*	291	1.11	172
38	*Hippopotamyrus discorhynchus*	-	-	7
39	*Julidochromis marlieri*	34	0.29	-

40	*Julidochromis regani*	38	0.30	-
41	*Julidochromis transcriptus*	-	0.12	-
42	*Labeo dhonti*	-	0.04	-
43	*Lamprichthys tanganicanus*	118	0.85	5
44	*Lamprologus callipterus*	750	2.16	268
45	*Lamprologus lemairii*	120	1.02	25
46	*Lamprologus ocellatus*	71	0.55	-
47	*Lamprologus ornatipinnis*	6	0.17	-
48	*Lamprologus signatus*	18	0.15	-
49	*Lates angustifrons*	-	0.11	13
50	*Lates mariae*	5	0.19	45
51	*Lates microlepis*	-	-	44
52	*Lepidiolamprologus attenuatus*	864	1.90	76
53	*Lepidiolamprologus cunningtoni*	199	0.91	48
54	*Lepidiolamprologus elongatus*	328	2.47	41
55	*Lepidiolamprologus profundicola*	28	0.66	5
56	*Lestradea perspicax*	63	0.02	69
57	*Limnochromis auritus*	11	0.08	-
58	*Limnothrissa miodon*	-	-	62
59	*Limnotilapia dardennii*	375	1.48	99
60	*Lobochilotes labiatus*	139	1.87	15
61	*Malapterurus electricus*	4	0.08	-
62	*Neolamprologus brevis*	102	0.75	1
63	*Neolamprologus brichardi*	1418	1.31	20
64	*Neolamprologus buescheri*	22	0.30	-
65	*Neolamprologus caudopunctatus*	217	0.49	2
66	*Neolamprologus christyi*	13	0.07	-
67	*Neolamprologus fasciatus*	152	1.17	3
68	*Neolamprologus furcifer*	33	0.26	1
69	*Neolamprologus gracilis*	8	0.02	-
70	*Neolamprologus hecqui*	12	0.05	-
71	*Neolamprologus leleupi*	6	0.19	2
72	*Neolamprologus meeli*	49	0.28	-
73	*Neolamprologus modestus*	89	0.63	17
74	*Neolamprologus mondabu*	267	1.29	1
75	*Neolamprologus moorii*	26	0.25	4
76	*Neolamprologus multifasciatus*	17	0.08	-
77	*Neolamprologus niger*	12	-	-
78	*Neolamprologus pleuromaculatus*	24	0.46	9
79	*Neolamprologus savoryi*	167	1.04	8
80	*Neolamprologus sexfasciatus*	25	0.42	-
81	*Neolamprologus tetracanthus*	115	0.74	18
82	*Neolamprologus toae*	59	0.98	9
83	*Neolamprologus tretocephalus*	131	1.61	10
84	*Neolamprologus wauthioni*	92	0.12	-

85	*Ophthalmotilapia heterodonta*	20	-	-
86	*Ophthalmotilapia nasutus*	69	0.26	1
87	*Ophthalmotilapia ventralis*	36	1.19	12
88	*Oreochromis tanganicae*	20	-	-
89	*Perissodus microlepis*	52	0.81	36
90	*Perissodus straeleni*	1	0.01	8
91	*Petrochromis famula*	2	0.04	-
92	*Petrochromis fasciolatus*	46	0.68	1
93	*Petrochromis macrognathus*	1	0.14	-
94	*Petrochromis orthognathus*	63	0.24	3
95	*Petrochromis polyodon*	110	0.96	25
96	*Petrochromis trewavasae*	72	0.88	17
97	*Phyllonemus filinemus*	-	-	49
98	*Plecodus multidentatus*	-	0.05	1
99	*Plecodus paradoxus*	207	1.75	72
100	*Plecodus straeleni*	87	1.31	34
101	*Simochromis babaulti*	6	0.16	-
102	*Simochromis diagramma*	23	0.44	-
103	*Spathodus erythrodon*	-	0.26	-
104	*Synodontis granulosus*	1	0.04	1
105	*Synodontis multipunctatus*	16	0.32	110
106	*Synodontis nigromaculatus*	-	0.05	1
107	*Synodontis petricola*	-	0.05	12
108	*Syondontis polli*	-	-	7
109	*Tanganicodus irsacae*	6	0.02	-
110	*Tanganikallabes mortiauxi*	-	-	4
111	*Telmatochromis bifrenatus*	337	1.65	-
112	*Telmatochromis brichardi*	5	0.04	-
113	*Telmatochromis burgeoni*	-	0.04	-
114	*Telmatochromis dhonti*	59	0.42	1
115	*Telmatochromis temporalis*	196	1.66	8
116	*Telmatochromis vittatus*	20	0.01	-
117	*Trematocara marginatum*	-	-	1
118	*Tropheus brichardi*	2	0.20	-
119	*Tropheus duboisi*	6	0.24	3
120	*Tropheus moorii*	51	1.23	4
121	*Tropheus polli*	18	0.98	6
122	*Tylochromis polylepis*	-	-	4
123	*Xenochromis hecqui*	3	-	-
124	*Xenotilapia boulengeri*	29	0.58	51
125	*Xenotilapia flavipinnis*	407	1.07	21
126	*Xenotilapia ochrogenys*	63	0.30	84
127	*Xenotilapia sima*	113	0.41	10
128	*Xenotilapia spilopterus*	201	0.48	24
	Totals	11949	-	2396

Appendix VI Species uniquely recorded by each sampling technique

	SVC	RVC	Gillnet
	Number of surveys: **77**	Number of transects: **100**	Number of nets set**: 26**
	Total species recorded: **98**	Total species recorded: **103**	Total species recorded**: 93**
1	*Caecomastacembelus ophidium*	*Aethiomastacembelus platysoma*	*Bathybates graueri*
2	*Neolamprologus niger*	*Caecomastacembelus frenatus*	*Bathybates horni*
3	*Ophthalmotilapia heterodonta*	*Julidochromis transcriptus*	*Bathybates leo*
4	*Oreochromis tanganicae*	*Labeo dhonti*	*Bathybates vittatus*
5	*Xenochromis hecqui*	*Spathodus erythrodon*	*Benthochromis tricoti*
6		*Telmatochromis burgeoni*	*Callochromis macrops*
7			*Callochromis melanostigma*
8			*Chrysichthys brachynema*
9			*Chrysichthys platycephalus*
10			*Chrysichthys sianenna*
11			*Hippopotamyrus discorhynchus*
12			*Lates microlepis*
13			*Limnothrissa miodon*
14			*Phyllonemus filinemus*
15			*Syondontis polli*
16			*Tanganikallabes mortiauxi*
17			*Trematocara marginatum*
18			*Tylochromis polylepis*

Appendix VII Fish species recorded uniquely on rock or sand dominated habitats from SVC, RVC and gillnet techniques combined

	Rock-dominated	Sand-dominated
	Total species recorded by all techniques: **104**	Total species recorded by all techniques: **88**
1	*Caecomastacembelus ophidium*	*Bathybates graueri*
2	*Aethiomastacembelus platysoma*	*Chrysichthys sianenna*
3	*Barbus taeniopleura*	*Ectodus descampsi*
4	*Barbus tropidolepis*	*Lamprologus ocellatus*
5	*Benthochromis tricoti*	*Lamprologus signatus*
6	*Cyprichromis leptosoma*	*Neolamprologus buescheri*
7	*Julidochromis transcriptus*	*Neolamprologus hecqui*
8	*Labeo dhonti*	*Neolamprologus meeli*
9	*Neolamprologus christyi*	*Plecodus multidentatus*
10	*Neolamprologus furcifer*	*Tylochromis polylepis*
11	*Neolamprologus leleupi*	
12	*Neolamprologus multifasciatus*	
13	*Neolamprologus niger*	
14	*Petrochromis famula*	
15	*Petrochromis macrognathus*	
16	*Petrochromis orthognathus*	
17	*Simochromis babaulti*	
18	*Spathodus erythrodon*	
19	*Synodontis granulosus*	
20	*Synodontis nigromaculatus*	
21	*Synodontis petricola*	
22	*Syondontis polli*	
23	*Tanganicodus irsacae*	
24	*Tanganikallabes mortiauxi*	
25	*Telmatochromis brichardi*	
26	*Tropheus duboisi*	

Appendix VIII SVC and Gillnet; total number of species, total number of individuals and Shannon-Weiner index for each sampling location

Location	Sample	Total number of species	Total number of individuals	Shannon Weiner Index
SVC				
Kasiha 1	TZ006/ 3	21	465	0.99
Kasiha 2	TZ006/ 8	13	206	0.78
Sinsiba	TZ006/ 13	8	321	0.56
Sitolo Bay	TZ006/ 18	24	558	1.07
Bilenge Bay	TZ006/ 23	7	146	0.52
Nsele	TZ006/ 28	19	120	0.99
Mikamba	TZ006/ 33	26	210	1.04
Takata	TZ006/ 38	4	195	0.22
Kabwe North	TZ006/ 43	28	376	1.25
Kabwe South	TZ006/ 48	26	569	1.15
Mabilibili Bay	TZ006/ 53	9	241	0.51
Kahinfiye	TZ006/ 58	48	495	1.22
Siyeswe	TZ006/ 63	30	499	1.17
Busisi Bay	TZ006/ 68	30	405	1.22
Lumbiye North 1	TZ007/ 3	8	1011	0.42
Lumbiye North 2	TZ007/ 8	40	992	1.29
Mankungwe South	TZ007/ 13	31	345	1.35
Mikakwe	TZ007/ 17	39	550	1.41
Mikakwe South	TZ007/ 22	41	477	1.03
Mankungwe Mid	TZ007/ 27	36	724	1.34
Lyamembe	TZ007/ 32	37	537	1.36
Luahagala North	TZ007/ 37	19	258	0.67
Nkwasi	TZ007/ 42	38	938	1.32
Mankungwe North	TZ007/ 47	34	420	1.34
Lufungu Bay North 1	TZ007/ 52	45	507	1.27
Lufungu Bay North 2	TZ007/ 57	29	495	1.22

Location	Sample	Total number of species	Total number of individuals	Shannon Weiner Index
Gillnet				
Kasiha 1	TZ006/ 5	26	132	1.24
Kasiha 1	TZ006/ 10	23	81	1.24
Sinsiba	TZ006/ 15	25	79	1.28
Sitolo Bay	TZ006/ 20	7	73	0.49
Bilenge Bay	TZ006/ 25	18	68	1.03
Nsele	TZ006/ 30	37	136	1.33
Mikamba	TZ006/ 35	35	52	1.71
Takata	TZ006/ 40	16	44	1.05
Kabwe North	TZ006/ 45	23	130	0.94
Kabwe South	TZ006/ 50	13	38	1.03
Mabilibili Bay	TZ006/ 55	23	283	1.15
Kahinfiye	TZ006/ 60	7	14	0.73
Siyeswe	TZ006/ 65	12	54	0.81
Busisi Bay	TZ006/ 70	20	93	1.13
Lumbiye North 1	TZ007/ 5	17	103	1.06
Lumbiye North 2	TZ007/ 10	28	129	1.17
Mikakwe	TZ007/ 19	3	5	0.41
Mikakwe South	TZ007/ 24	11	33	0.92
Mankungwe Mid	TZ007/ 29	32	253	1.14
Lyamembe	TZ007/ 34	31	104	1.30
Luahagala North	TZ007/ 39	10	18	0.90
Nkwasi	TZ007/ 44	26	105	1.11
Mankungwe North	TZ007/ 49	17	65	1.04
Lufungu Bay North 1	TZ007/ 54	7	28	0.82
Lufungu Bay North 2	TZ007/ 59	7	17	0.68
Musilambula	TZ007/ 63	22	98	1.12

Appendix IX SVC; total number of species, individuals and Shannon-Weiner index for sampling locations where substrate type was recorded

Rock-dominated					
Location	**Sample**	**Depth (m)**	**Total number of species**	**Total number of individuals**	**Shannon Weiner Index**
Kabwe North	TZ006/ 43	5	17	147	1.11
Kabwe South	TZ006/ 48	10	10	70	0.88
		15	16	139	1.00
Kahinfiye	TZ006/ 58	5	31	207	1.10
		10	29	184	1.01
Siyeswe	TZ006/ 63	10	19	176	1.02
		15	15	181	0.98
Lumbiye North 2	TZ007/ 8	10	28	325	1.11
		15	26	362	1.10
Mikakwe	TZ007/ 17	5	29	223	1.33
		10	22	155	1.20
		15	22	168	1.18
Mikakwe South	TZ007/ 22	5	23	122	1.02
		10	28	214	0.80
Mankungwe Mid	TZ007/ 27	15	23	213	1.11
Nkwasi	TZ007/ 42	5	23	306	1.14
		10	23	281	1.12
		15	22	329	1.10
Mankungwe North	TZ007/ 47	5	13	60	1.00
		10	22	181	1.15
		15	19	168	1.06
Lufungu Bay North 1	TZ007/ 52	5	31	166	1.10
		10	33	257	1.06
Lufungu Bay North 2	TZ007/ 57	5	12	53	0.92
		10	22	155	1.24
		15	20	275	0.92
Sand-dominated					
Location	**Sample**	**Depth (m)**	**Total number of species**	**Total number of individuals**	**Shannon Weiner Index**
Kasiha 1	TZ006/ 3	10	5	124	0.50
		15	8	98	0.72
Sinsiba	TZ006/ 13	10	6	103	0.42
		15	5	38	0.54
Bilenge Bay	TZ006/ 23	10	4	69	0.39
		15	6	68	0.54
Kabwe North	TZ006/ 43	10	22	138	1.18
		15	2	90	0.30
Kabwe South	TZ006/ 48	5	19	353	1.06
Kahinfiye	TZ006/ 58	15	18	102	0.74
Siyeswe	TZ006/ 63	5	16	129	1.02
Lumbiye North 1	TZ007/ 3	5	5	234	0.47
		10	6	417	0.41
		15	3	360	0.35
Mankungwe South	TZ007/ 13	10	11	142	0.98
Mikakwe South	TZ007/ 22	15	15	134	0.80
Luahagala North	TZ007/ 37	10	3	101	0.24
		15	2	27	0.11
Lufungu Bay North 1	TZ007/ 52	15	14	82	0.92