

4. BIODIVERSITY ASSESSMENT SURVEYS

4.1 Introduction

Prior to the LTBP project, there was a lack of information on aquatic habitats and their associated biota in the areas within or adjacent to the terrestrial-based National Parks (Rusizi, Gombe, Mahale, Nsumbu). Some sampling activities had taken place in these areas, but this was not based on comparable standardised surveys (Chapter 3). There was clearly a need for a survey that established baseline information on measures of biodiversity for these areas, to support analysis of their conservation value to the lake, and to provide comparison with areas that had not benefited from protection of adjacent land areas. Before such surveys could be conducted, there was a considerable amount of work required to develop a survey procedure and build up capacity to implement surveys, from problem identification, through implementation, to reporting and analysis (Chapter 2). The present surveys aimed to build on local expertise, and minimise dependence on external inputs.

In this chapter, we present the results of the BLOSS survey programme carried out between 1997 and 2000. We use species richness and diversity indices for selected 'total biodiversity surrogates' to compare the diversity of similar habitats in different areas of the lake. This analysis informs our recommendations on the appropriate selection of protected areas, and on conservation strategy more broadly (Chapters 5 and 6).

4.2 Methods

4.2.1 BLOSS Survey activities, 1997-2000

A summary of survey activities undertaken by BLOSS teams is given in Table 4.1. The methods used are outlined in Chapter 2 and detailed in the BLOSS SOP. The table defines the areas and techniques that provide the basis for analyses reported in these chapters. Three maps indicate the areas surveyed (Figure 4.1, Figure 4.2 and Figure 4.3).

4.2.2 Habitat mapping

Sub-littoral habitats were mapped using the manta-board technique (and its modification, the "croc-box" where necessary). This gives broad substrate categorisation, which serves two functions: to describe the distribution of sub-littoral habitat types in waters of 2-10 m depth, and to provide the basis for stratifying subsequent habitat profile, fish and mollusc survey activities. The areas mapped by Manta board are listed in Table 4.1. During the fieldwork, the results from the manta surveys were drawn onto copies of maps to plan subsequent surveying. Figure 4.4 illustrates one of these 'working maps' from the survey of Nsumbu National Park. The categorisation and distribution of substrates is given in example larger-scale maps in the 'results' section, where it is also summarised in tabular form.

Profile dives were used to investigate habitat characteristics specific to the sites at which faunal surveys were subsequently undertaken. They also serve to extend the mapping of habitats to waters of up to 25 m deep, and to build up a bathymetric profile of surveyed areas. A sample habitat profile dive graphic is given in Figure 4.5. This figure shows only coarse-scale habitat features. Much finer detail was recorded and the data are available in the Survey database. If further survey work is conducted using these protocols, then sample sizes will become sufficient to attempt analysis linking these detailed habitat features to species assemblages through principal components analysis or other multivariate techniques. In the present analysis, we use only coarse-scale mapping to categories substrates broadly for comparative analysis of species richness and diversity.

Table 4.1 Summary of BLOSS survey activities.

Country	Area	Dates surveys	Manta (km) *	Profile (number)	SVC (number)	RVC (number)	Gill nets (number)	Mollusc transect (number)	Mollusc dredge (number)
Burundi	Rusizi	March-May 1998	-	4	-	-	86	3	2
	Gitaza	Dec 1998, Oct-Dec 1999	✓	9	6	4	1	6	
	Burundi South	June 1999	✓	6	7	6	2		-
	Bujumbura Bay	Jan, Feb, Nov, Dec 1999	-	4	-	-	18	2	3
DR Congo	Uvira	July, Oct, Nov 1998 and Oct, Dec 1999	✓	14	16	7	24	7	-
	Pemba, Luhanga, Bangwe	Dec 1998, Oct, Nov, Dec 1999	✓	11	11	7	10	7	-
Tanzania	Gombe	October 1997	20	19	16	-	6	-	-
	Kigoma	Dec 1999	✓	3	3	3	1	3	-
	Mahale	March to April 1999	60	27	27	26	26	27	-
Zambia	Kalambo/Lunzua	Jul, Sept, Oct 1998 and June, July Sept 1999	✓	-	-	-	15	-	-
	Chikonde	April, July, Oct 1998 and Jan, June, July Sept 1999	✓	-	-	-	8	-	-
	Mpulungu	May, June, Aug, Oct, Nov, Dec 1998 and Feb, April, July, Sept, Oct, Dec 1999	✓	2	-	2	30	-	3
	Lufubu / Chisala	Dec 1998, and Jan, Feb, May, June, July, Aug, Sept 1999	✓	-	-	-	16	-	-
	Katoto et al	Feb, April, May, June, July, Aug, Sept, Nov 1998 and Jan, Feb, May, June, July, Aug, Sept, Oct, Dec 1999	✓	20	5	16	11	-	-
	Nsumbu	July/August 1999	77	17**	-	-	38	-	23
	Cameron Bay	December 1999	✓	3	2	-	3	-	-

* Manta distances have been calculated for surveys in national parks. However it is not possible to retrospectively calculate the distances covered by manta at other sites. The ticks indicate where Manta surveying was complete.

** Profile data collected using grab from a boat, as diving not safe

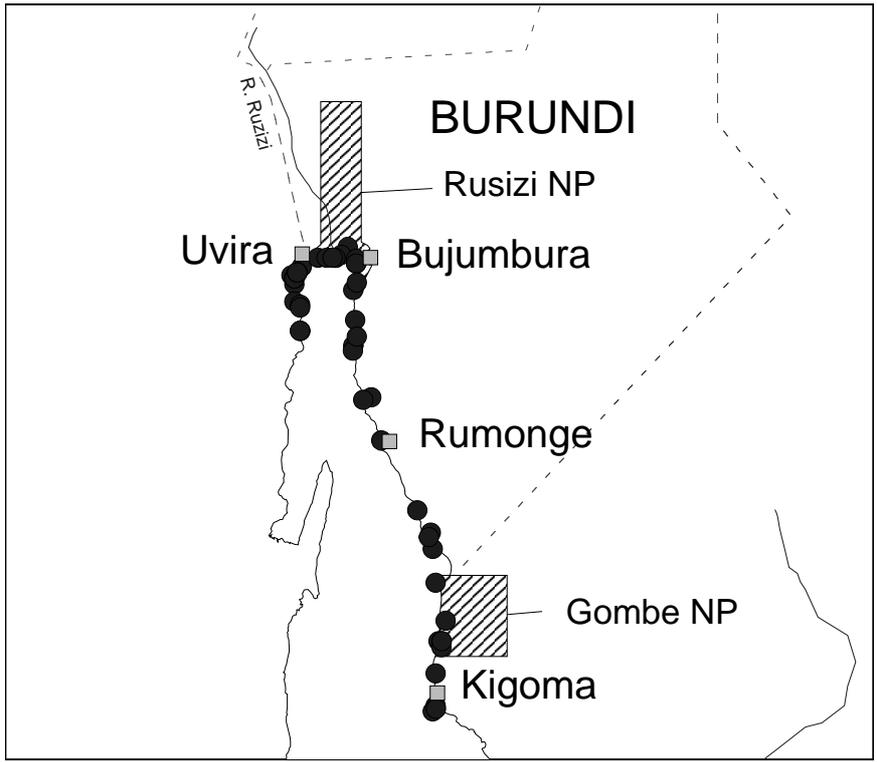


Figure 4.1 Map of BIOS sampling sites in the north of the lake

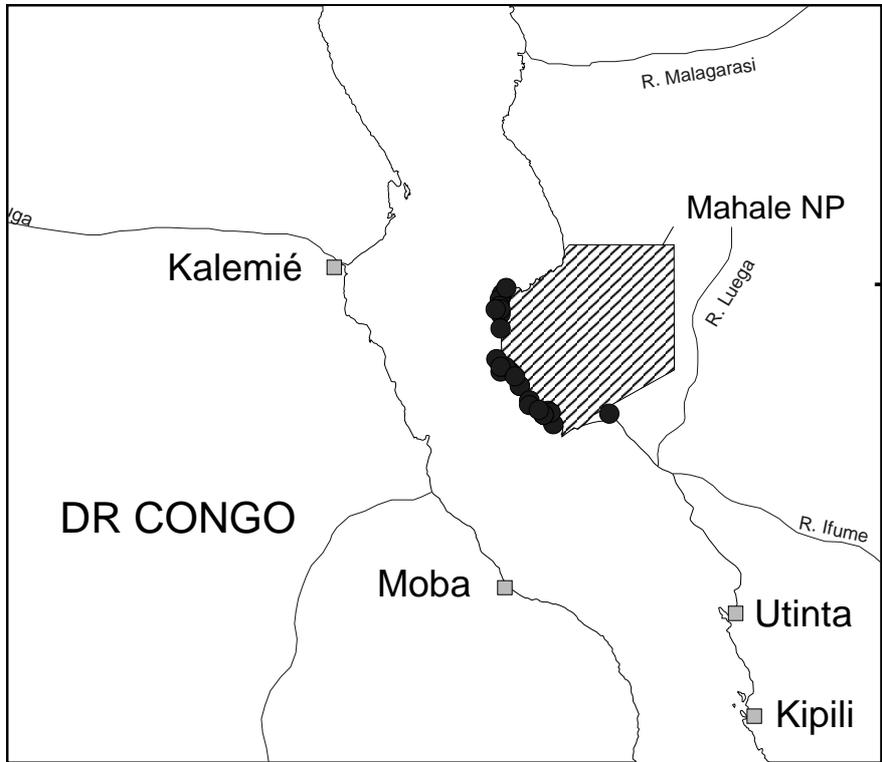


Figure 4.2 Map of BIOS sampling sites in the Mahale area

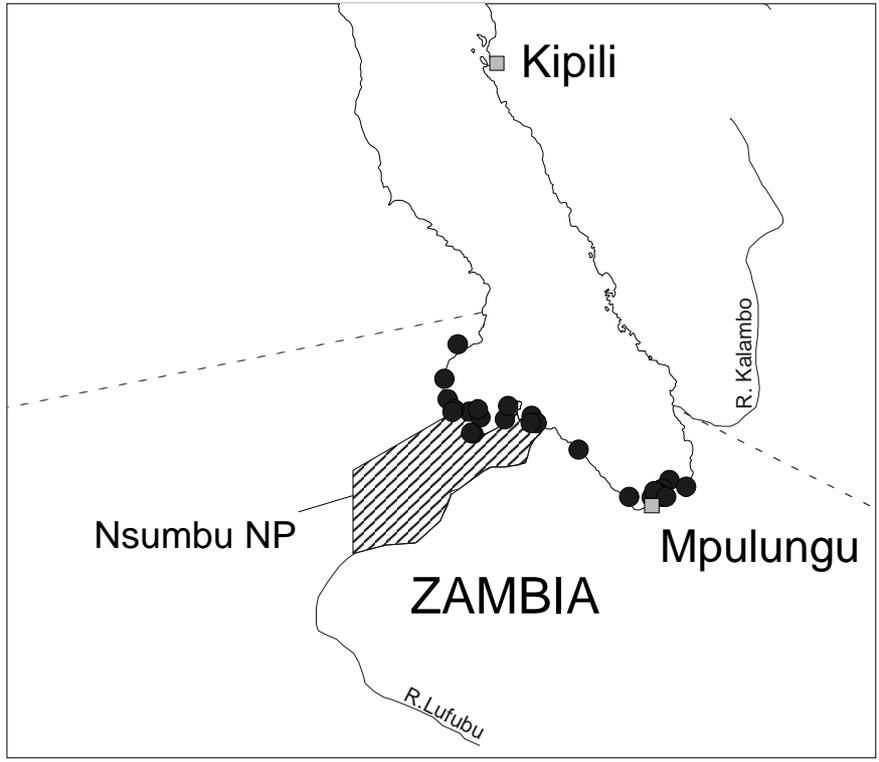
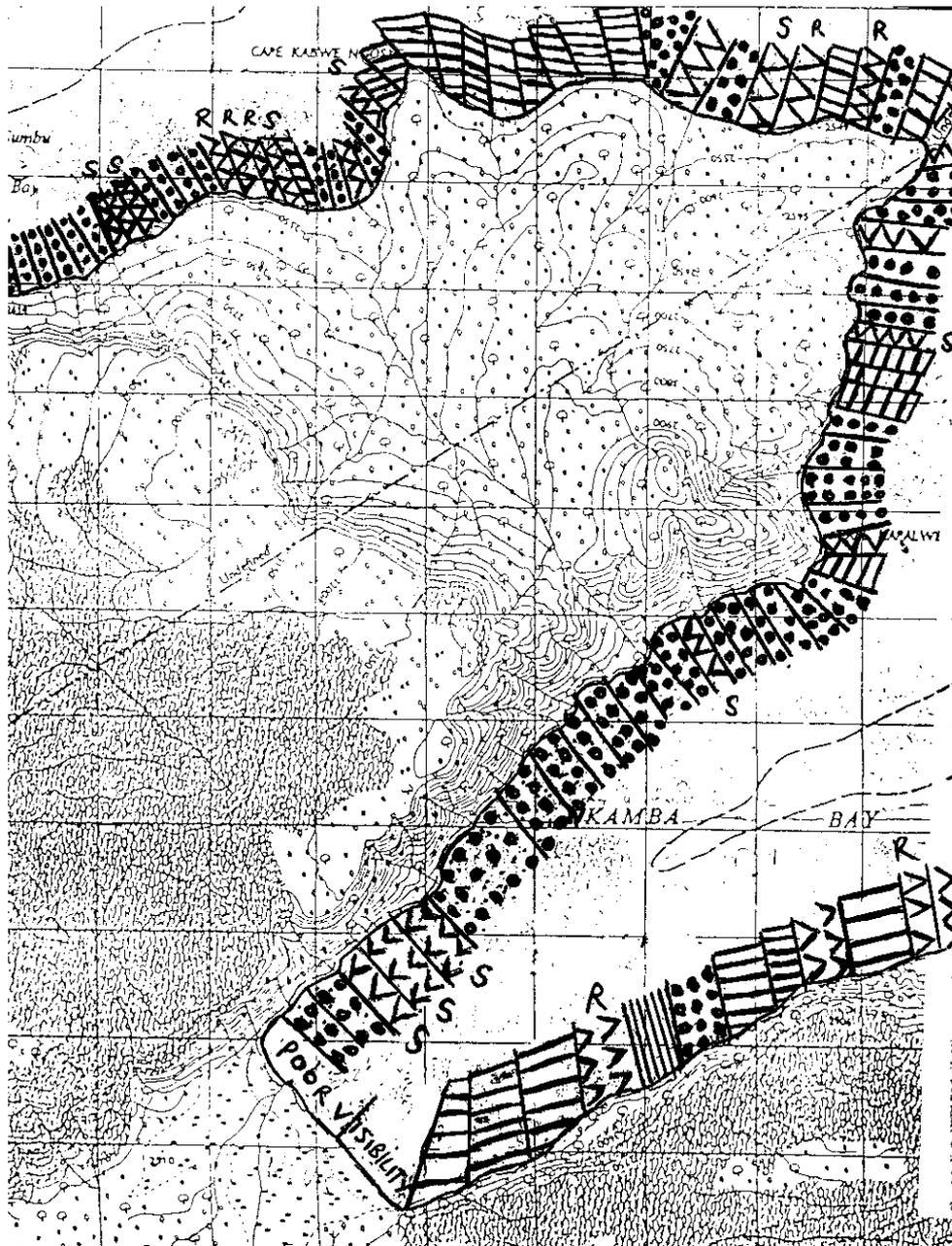


Figure 4.3 Map of BIOUS sampling sites in the South of the lake



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

Figure 4.4 Example field-map of a manta survey of habitats along a stretch of Zambian coastline in Nsumbu national park.

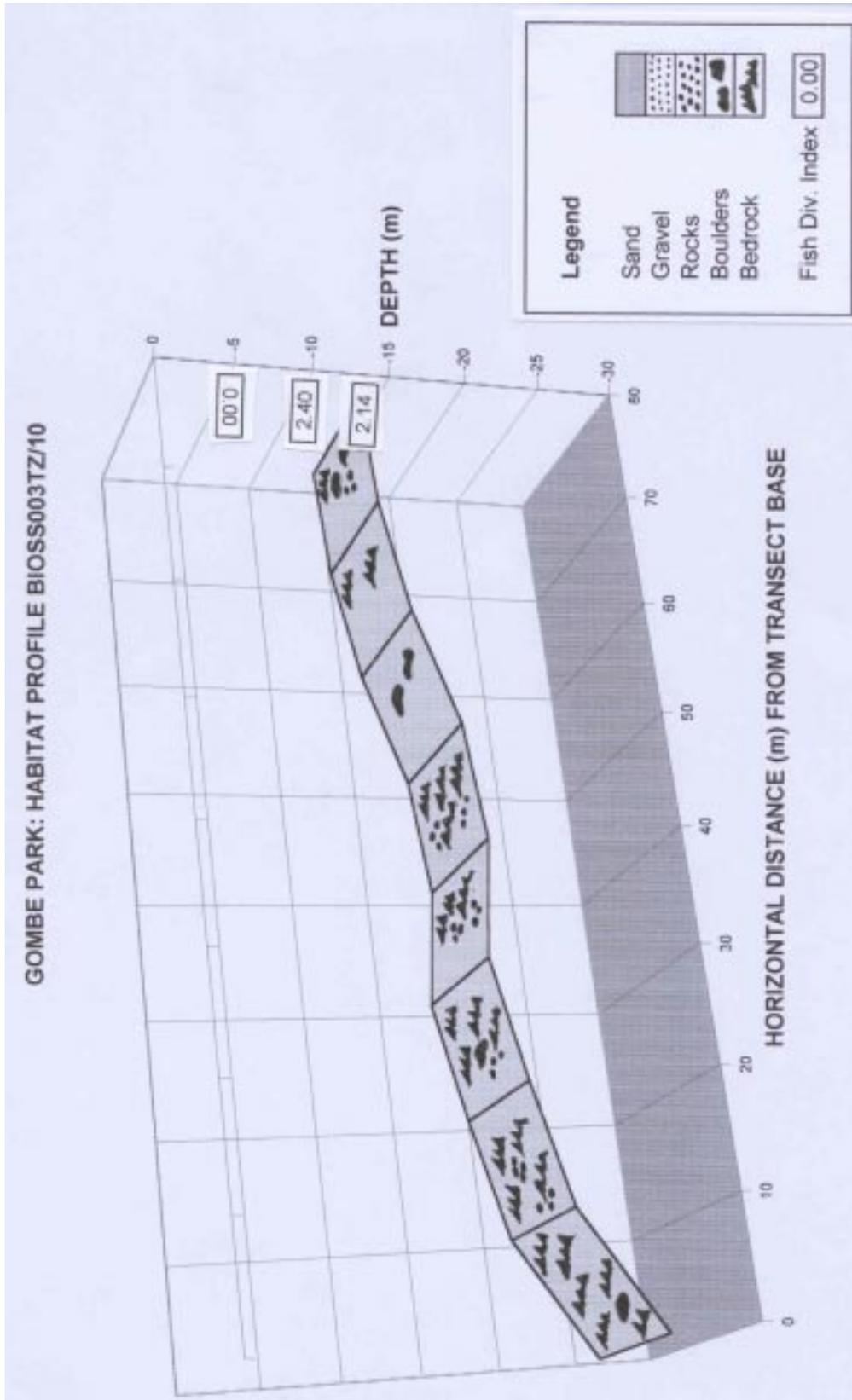


Figure 4.5 Results of a dive profile, taken from Gombe survey.

4.2.3 Fish diversity surveys

Fish surveys were used as a surrogate for total biodiversity surveys, to provide a measure of conservation values of existing or potential protected areas. The rationale for the focus on fish in biodiversity surveys is given in Section 2.5.2. Fish were surveyed using gillnets, and, where possible, direct observation by SCUBA using rapid and stationary visual census techniques (see Chapter 2).

In order to provide a basis for comparison of the extant fish diversity between areas, the data from fish surveys were used to calculate three measures of diversity: Species richness, Shannon-Weiner and Simpson's diversity indices.

Sampling bias (see Sections 2.8 –2.10) associated with each of the survey methods (gillnets, stationary visual census, rapid visual census) means that diversity indices and species richness need to be calculated separately across each survey method. Comparisons of diversity indices were only made where surveying used comparable methods.

For SVC, the three measures of diversity were calculated separately for each major habitat category (Rock-dominated, Sand-dominated, and shell bed substrates). Diversity measures were calculated within each national park area, and for defined areas surveyed outside parks.

For gillnets, species richness, Shannon-Weiner¹² and Simpson diversity indices (see Chapter 2) were calculated separately for day and night sets, within each national park area, and for defined areas surveyed outside parks. It was recognised early on that overnight gillnetting was preferable as it samples a greater proportion of the available fish community, including nocturnal fishes not sampled by other survey techniques, but night-time gillnetting was not always possible for security reasons. For this reason, not all sites surveyed can be compared directly. For certain sites in Zambia low numbers of replicate sets of day and night gillnetting made pooling of day and night sets desirable. Diversity indices and richness for these sites were not compared with others where only night or day gillnetting had taken place.

For RVC, only richness and relative abundance can be calculated. Separate analyses are made for the 0-4m and 5-15m depth bands, but habitat categories are not separated as RVC transects usually crossed a variety of habitats.

In order to obtain an estimate of total species lists for each major survey area for complementarity analysis (Chapter 5) data has been combined across survey methods, but the fact that comparable survey methods were not used in all areas must be noted in making such comparisons.

For SVC and gillnet survey data, statistical comparisons of diversity between areas were made using t-test type comparisons of Shannon-Weaver Diversity indices (Zar, 1991), with the Bonferroni approximation to correct for multiple comparisons. This increases the probability of type II errors (failure to identify significant difference), but maintains robustness with respect to type I error (finding a significant difference where none in fact occurs) and is thus statistically conservative.

The comparisons make it possible to identify if comparable habitats, surveyed with comparable methods and adequate sampling effort (all checked in Section 2) have significantly differing fish diversity in different parts of the lake. Mindful of the possibility of type II errors, we did not do a full comparison of all paired combinations of sites. We identified comparisons of interest in advance, and tested only these. Comparisons made included those between existing or proposed national parks, between adjacent impacted and less impacted areas (e.g. Rusizi NP and Bujumbura Bay), or between areas where habitats were similar (e.g. in the vicinity of river mouths on the E and W coasts of the lake, in Zambia).

¹² Note that all diversity indices were calculated using Log₁₀. It is now more usual to use Log_e, which tends to give indices >3 when applied to the present data. This is mentioned to avoid any concern that the diversity indices reported here seem unusually low.

Some of these comparisons must, however, be interpreted with caution, as they are based on variable sampling effort (Chapter 2). Diversity indices will be sensitive to sample size (Magurran, 1988). To explore the relationship between calculated diversity indices and sample size, we calculated diversity indices for one sample, then added replicate samples in random order and recalculated the index, until sampling was complete (i.e. all replicate samples included in the diversity index calculation). The calculations were based on 100 such randomisations, and were done using the EstimateS software (Colwell, 1997).

Species richness comparisons were made using a variety of estimators of richness from incomplete or variable sampling effort. All these methods are based on theoretical models of the patterns of relative abundance (or frequency of occurrence) of species in replicated samples (Coddington and Colwell, 1994). Most of the methods are applicable to species-abundance data, but some are also applicable to species presence-absence data (such as the RVC and mollusc transect data). Two of these models were used to explore the completeness of sampling effort, with the Clench model providing probably the more realistic fit to the observed species accumulation data (Chapter 2). The methods used were drawn from Colwell and Coddington (1994) and calculated using the EstimateS software package. S_{max} for each survey strata (defined by site, depth, substrate) is estimated from randomly-ordered samples, with more reliable estimates produced from larger sample sizes. This enables derivation of richness estimates from incomplete surveys, although the reliability of the estimates will vary. The procedure differs from the empirically fitted extrapolation curves used to estimate required sample size in Chapter 2.

Colwell and Coddington (1994) suggest that a range of species richness estimators be used, until more is known about the performance of each in specific circumstances (e.g. from assessment of how well the estimates perform against a well-sampled and known area). Henderson and Southwood (2000) suggest that the Chao incidence based estimator (ICE, detailed below) is emerging as a robust and cost-effective measure for fish surveys.

The following methods were used for SVC and gillnet:

- 1) The Michaelis-Menton (MM) model.

$$S(N) = \frac{S_{max} N}{B + N};$$

where $S(N)$ = number of species in each sampling event
 S_{max} = estimated species richness (a fitted constant)
 B = fitted constant
 N = number of sampling events

This asymptotic accumulation curve is mathematically equivalent to the Clench model (see Chapter 2) and is well-known as the Michaelis-Menten equation used in enzyme kinetics and there are therefore numerous ways of estimating the parameters and their statistical errors. For this analysis, we have used a maximum-likelihood estimator (see Colwell and Coddington, 1994). The EstimateS software offers two methods of calculating maximum-likelihood estimates of S_{max} . The first method (MMRuns) computes estimates for values for each successive group of samples (pooling level), for each randomisation run, then averages over randomisation runs. If there are individual samples that are much richer than others, randomisation runs that, by chance, add a rich sample early in the curve are likely to produce enormous estimates of richness. Thus MMRuns data are often rather erratic for small numbers of samples, even when 100 runs are randomised. The second method (MMMeans) computes estimates for each sample pooling level just once, from the mean species accumulation curves. Since this curve becomes quite smooth when many randomisations are averaged, the MM estimates are much less erratic. Because 'outlier' runs are thus suppressed, the MMMeans estimates are usually somewhat lower than for the MMRuns methods, for corresponding sample pooling levels, especially so from small sample sizes (Colwell, 1997). The choice, for small sample sizes is thus between smoothly systematic

underestimation, and erratic but unbiased estimation! We include both methods in this analysis.

2) ACE and ICE: Abundance and Incidence based Coverage Estimators (Chao and Lee, 1992; Colwell and Coddington, 1994; Colwell, 1997)

Chao and Lee (1992) developed a new class of estimators based on the statistical concept of 'sample coverage'. Coverage is the sum of the probabilities of encounter for the species observed, taking into account species present but not observed. This can be illustrated graphically (Figure 4.6) as a unit line broken into S segments with the length of each segment representing the true proportion formed by one of the S species found in the full set of samples (Colwell, 1997).

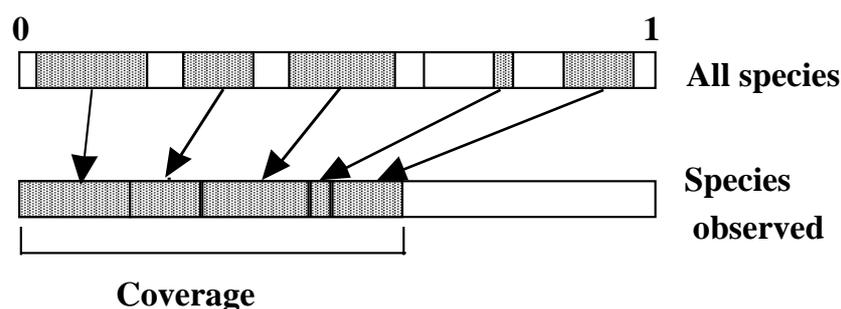


Figure 4.6 The theoretical principles behind coverage-based estimators of species richness. Shaded segments represent the species sampled, which will represent only part of the total species present. The sum of those segments is the coverage. (from Colwell, 1997).

These coverage-based estimators, known in the literature as 'Chao1' and 'Chao2' were found to consistently overestimate species richness, especially when sample numbers were low (Colwell and Coddington, 1994). This is due to the fact that most species richness samples contain data in which some species are very common and others are very rare. Recognising that in such cases all the useful information about undiscovered classes lies in the rarer discovered classes, the new Abundance-based Coverage Estimator (ACE) is based on those species with 10 or fewer *individuals in the sample*. The corresponding Incidence-based Coverage Estimator (ICE) is based on species occurring in 10 or fewer *sampling units*. The formulae for these estimators are rather complex, and the reader is referred to Colwell (1997: 18-20) for further explanation.

3) Incidence-based Jackknife (Jack1, Jack2) and Bootstrap (Boot) estimates

Species richness estimates can be made using the non-parametric statistical approaches known as jackknifing and bootstrapping (Smith and van Belle, 1984).

The first-order incidence-based jackknife estimator uses the number of species that occur in only one sample event (Q_1) and the number of sampling events (N) to estimate species richness (S_{max})

$$S_{max} = S_{obs} + Q_1 \left(\frac{N-1}{N} \right)$$

while the second order jackknife also includes the number of species that occur in two samples (Q_2):

$$S_{\max} = S_{\text{obs}} + \left(\frac{Q_1(2N-3)}{N} - \frac{Q_2(N-2)^2}{N(N-1)} \right)$$

The bootstrap estimator utilises the proportion of sampling events (N) containing each of k species (p_k) represented in the whole group of samples (e.g. Mahale rocky).

$$S_{\max} = S_{\text{obs}} + \sum_{k=1}^{S_{\text{obs}}} (1 - p_k)^N$$

For gillnet and SVC fish surveys, all the above seven estimators (MMRuns, MMMean, ACE, ICE, Jack1, Jack2, Boot) of total species richness (S_{\max}) were computed for each of the sampling strata (Area, substrate combination for SVC; Area, set-time for gillnetting), based on 100 randomisations of the original species-abundance and incidence data. These estimates of richness can be compared with total species lists generated from the literature and survey databases combined (Chapter 3).

For the RVC data, where there is no relative abundance data, only the four incidence-based estimators are used: ICE, Jack1, Jack2 and Boot.

The effect of sampling size on these estimates is illustrated for a sub-sample of the above analyses.

It should be noted that rarefaction curves and Coleman curves (used in Chapter 2 as a rough measure of sample heterogeneity) are not estimators of richness in the same sense as the estimators presented above. Whereas ICE and ACE, for example, estimate total species richness from samples, including species not discovered in any sample, rarefaction and Coleman curves estimate individual sample species richness from the pooled total species richness, based on all species actually discovered (Colwell, 1997).

There are no satisfactory formal statistical methods of comparing species richness estimates from different areas, given the uncertainties relating to which estimator is most applicable, and the unknown statistical properties of some of the estimators and their variances (Colwell and Coddington, 1994; Southwood and Henderson, 2000). We therefore restrict such comparisons to visual inspection of the ranges of values produced by these estimators for each of the surveyed areas.

4.2.4 Mollusc species richness

As part of an effort to expand the scope of biodiversity surveys, mostly limited to surveys of fish communities, preliminary surveys of mollusc species richness were undertaken in all the national parks and in Cameron Bay, Zambia, all sites in DR Congo, Gitaza, in Burundi and around Kigoma (see Table 4.1). For Nsumbu and Rusizi, only data from dredge-surveys was available, while for Gombe and Mahale, only data from diver-surveys was available. The data available for analysis comes from diver surveys in Gitaza, DR Congo and Mahale National park (see Chapter 2).

Calculation and comparison of species richness was carried out using the four incidence based richness estimators (ICE, Jack1, Jack2 and Boot) detailed in section 4.2.3, calculated using the 'EstimateS' software package (Colwell, 1997)

4.3 Results

4.3.1 Characteristics of sub-littoral habitats

This report presents an overview of the extensive mapping activities undertaken by BLOSS. More detailed reports on habitat issues are given in each of the protected area reports (see Appendix 8.1 for list of BLOSS documents).

Fundamental to any attempt to conserve species in situ are efforts to conserve the habitats in which they are found. In a strategy centered on protected areas, the basic requirement is that each identified habitat type, with its characteristic assemblage of species, should be represented in the protected area network.

The distribution of habitat types is also important for conservation. Long stretches of homogenous habitat allow interchange of species within large geographical areas, while areas composed of a mosaic of small patches of different habitat may restrict interchange with similar habitats nearby but separated by other habitat types. Long stretches of rocky coastline may support diverse assemblages of species, but the community composition may be similar along the whole stretch of coast, while a coast consisting of rocky headlands separated by sandy bays may support a number of discrete communities of species with very limited geographical distributions (Brichard, 1989 and Cohen, 2000).

Thus, for conservation purposes, the relevant habitat characteristics are representation, distribution and quality. Our mapping exercises have concentrated on the first two, with habitat quality being difficult to assess within the scope of BLOSS surveys. Habitat quality issues were investigated as part of other special studies (Sediments and Pollution), and would ideally have been integrated with BLOSS surveys, but the different approaches taken by each special study did not allow this level of integration. Surveys did take account of obvious features of habitat quality (e.g. sediments coating rocks, turbidity, major pollution sources etc), but no formal measures of turbidity or presence of contaminants were made.

Table 4.2 shows the proportion of each habitat type recorded in the shallow sub-littoral zone (2-10 m approximately) adjacent to existing protected areas. In three of the parks (Mahale, Gombe, Nsumbu), all the major habitat types (sandy, rocky and mixed sand/rock) are well represented. Mahale and Nsumbu are clearly dominated by rock and mixed rocky substrates, while at Gombe there is a preponderance of sandy habitat. At all three parks the majority of these habitats were found to be relatively pristine. Specialised habitats (shell-beds, emergent macrophyte stands, stromatolite reefs) are also represented in the aquatic zones adjacent to national parks. Extensive shell beds were identified in the southern part of Mahale National Park, Tanzania and the north-western part of Nsumbu National Park, Zambia. Stromatolite reefs are also found near both the northern and southern boundaries of Mahale. Submerged macrophytes occur in small patches in sandy substrates in Nsumbu, Mahale and Gombe.

Though supporting a more restricted range of habitats, Rusizi National Park is particularly important, since it incorporates habitats not well represented elsewhere in the protected area network including: large emergent macrophyte stands, a major river delta with associated muddy substrates and turbid, nutrient-rich waters. Similar habitats are to be found at the other extensive delta, where the Malagarasi River enters Lake Tanganyika on the Tanzanian shore.

The other areas in which surveys were conducted by manta technique contained substrate types broadly similar to those found adjacent to the national parks. Thus from a habitat perspective extending the parks network to include them would add little to the range of habitat types protected, though it would of course help to conserve the species within those areas. This is particularly the case for Nsumbu, where extending the park to cover the deltas of the rivers that form the current park boundaries (Lufubu and Chisala) may significantly add to the species represented within the park. (see Section 4.2.2)

Table 4.2 The proportion of each major substrate-type recorded by Manta-board surveys in the waters adjacent to national parks, in kilometres and as a percentage of protected area shoreline

Survey area*	Substrate type											
	Rock		Gravel		Sand		Mixed		Mixed rock		Mixed sand	
	(km)	(%)	(km)	(%)	(km)	(%)	(km)	(%)	(km)	(%)	(km)	(%)
Gombe	4.8	24.5	-	-	10.7	54.9	4	20.5	-	-	-	-
Mahale	25.2	42	0.6	1	12	20	12.6	21	6	10	3.6	6
Nsumbu	34	44	1	1	18	23	2	3	13	17	9	12
All areas	64	40.9	1.6	1	40.7	26	18.6	11.9	19	12.1	12.6	8.1

*Owing to the poor visibility and density of crocodiles and hippopotami Rusizi national park was not sampled by manta tow technique. However, subsequent sampling for molluscs by dredge confirmed that soft substrates (sand, silt, mud) predominate

While manta-board surveys of the shallow sub-littoral indicated that all major fringing habitats were present within the existing protected area, such surveys provide little indication of the distribution of habitat types in deeper water. While in deeper water there are fewer habitat-structuring features (emergent vegetation, submerged macrophytes and stromatolites will all disappear), the different combinations of rock and sand and bathymetric profile will all affect the structure of biotic communities.

A summary of dive profiles from Mahale National Park (Table 4.3) indicates that although hard substrates make up more than 80% of the areas surveyed at 5 m depth, they make up only 7% of areas surveyed at 25 m. Stretches of coastline that are classified by Manta Survey as being rocky thus cannot be assumed to be so at greater depth. This is also true of Gombe, where a mixed littoral zone consisting mostly of cobbles gives way to steep sand slopes. Deep diving outside the survey programme established that below these sand slopes, at >40m depth, there are areas of steep, heavily calcified bedrock.

Table 4.3 Composition of substrate by depth for the 11 sites in Mahale NP, Tanzania, for which complete habitat profiles were recorded

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

In Nsumbu, where depth-habitat profiles were taken by grab-sampling due to crocodile risks. Indications are that depth profiles were more uniform, with areas having soft substrates in shallow water also having soft substrates at depth, and the same for rocky areas.

The areas around the extreme North of the Lake – Uvira, Rusizi and Bujumbura Bay – are almost all soft-substrate areas, although in the shallow littoral (0-2m) around Uvira, areas of cobble and boulder substrates are found. This area's substrates are characteristic of the areas around river deltas, and in this case are heavily influenced by the sediment cone of the Rusizi River. Further south on both the Burundi and Congo coasts (Burundi South, Gitaza, Pemba, Bangwe, Luhanga) the lakebed in the littoral zone becomes rockier. At Luhanga, the substrates are 80-90% bedrock at all depths between 0 and 25m, while at Pemba, bedrock gives way to large boulders in the deeper samples.

When examining the distribution of major habitat types within the larger areas surveyed (e.g. the four maps, which together cover Mahale coastline, Figure 4.7 and Figure 4.8¹³), the pattern of this largest scale patchiness can be described.

¹³ These maps were kindly produced by Anne Jackson (NRI) using the link between the BLOSS database and TANGIS. These illustrate the potential of these management tools to assist planning and conservation in the lake.

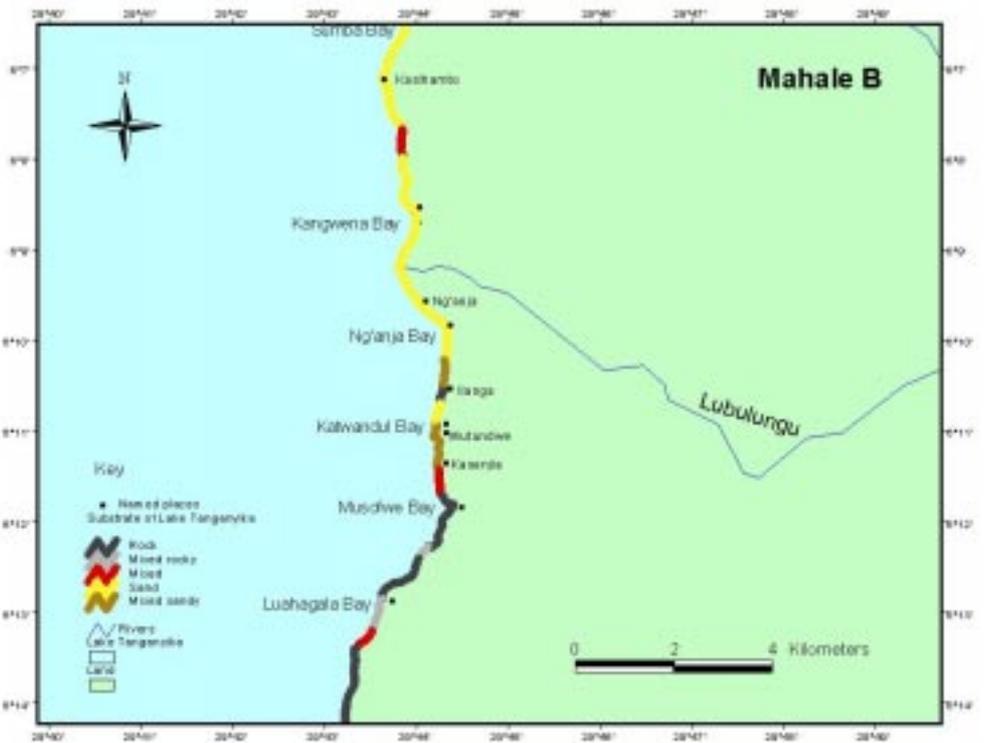
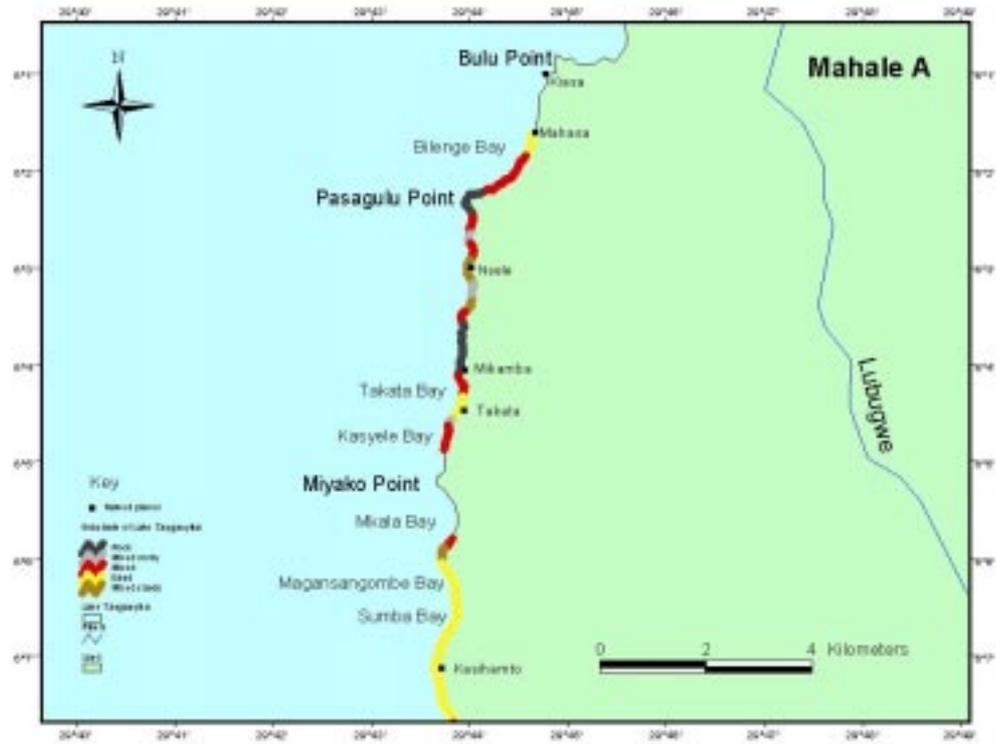


Figure 4.7 Littoral zone substrate categories from Manta-board surveys, Mahale NP (maps A and B)



Figure 4.8 Littoral zone substrate categories from Manta-board surveys, Mahale NP (maps C and D)

In Mahale, for example, there is an extensive, relatively unbroken sandy area around the Lubulungu River and an extensive rocky area between Luahagala Bay (map B: Figure 4.7) and Luahagala point (map C: Figure 4.8). Elsewhere, Rocky, mixed and sandy substrates alternate along short segments of the coastline. It is this mosaic of habitat patches that are thought to provide barriers to species dispersal, and hence the conditions for micro-allopatric speciation in the cichlids that is thought to maintain the high levels of diversity and of spatially-restricted taxa, whether at the level of species, sub-species or sub-population (Cohen 2000, West 1997, and Cohen and Johnston, 1987).

Missing from the current surveys was a rigorous analysis of habitat quality, for reasons discussed elsewhere. Subjective visual inspection determined that the habitats surveyed in the existing protected areas were in general pristine and there were few indications of human disturbance. In Gombe, Mahale and Nsumbu, much of the adjacent land area was covered mostly by natural forest and there was no evidence of excessive sedimentation deposition, although with the small size of Gombe, influences from the adjacent deforested catchments may be felt at the park boundaries. There was no evidence of eutrophication or discernible sources of pollution aside from a limited amount of domestic waste emanating from the administrative and tourist camps in the parks. A more exact assessment of the state of the aquatic habitats would however require direct observation, measurement of turbidity and water quality analysis, as well as comparison with areas known to be impacted. Linking habitat quality with its impact on biodiversity remains a considerable challenge in habitats of this complexity, and in communities having such high levels of diversity and such patchy distributions.

4.3.2 Fish diversity indices from gillnet and stationary visual census

Gillnet and Stationary Visual Fish Census techniques both provide species-relative abundance data suitable for the calculation of standard diversity measures, such as the Shannon-Weaver and Simpson indices.

Calculated Shannon-Weaver diversity indices from gillnet surveys range from 0.87 to 1.50 (Table 4.4). The highest values come from Mahale and Nsumbu night-set gillnets, and the lowest from day-set nets in the DR of Congo. The range of values is quite small, partly because the calculations used Log_{10} , instead of the more usual Log_e . Although the differences in diversity indices are small, the calculated variances are also small, due to the relatively large sample sizes. Note that calculating the diversity index of individual samples and averaging the individual values to create an average and standard error for a larger area is not valid, as diversity indices are not normally distributed numerical variables, but are in fact a weighted sum of frequency distributions.

Simpson indices vary from 3.5 to 26.1, with the highest values also being from Mahale and Nsumbu National Parks (Table 4.4) and the lowest from the sites in the DR of Congo. In general, the two diversity indices show similar order of diversity of sites, indicating that either can be used as a broad indicator of relative diversity. The advantage of the Shannon-Weaver index is that there is a validated statistical procedure for testing differences between indices (Zar, 1996). The test is restricted to paired comparisons, which can lead to type II errors (increasing probability of incorrect rejection of the null hypothesis of no significant difference, the more paired comparisons are made among a group of samples). This is minimised by adjusting the significance level of each paired comparison by the number of comparisons made among each set of samples (the Bonferroni approximation). The results of this analysis are presented in Table 4.5.

Table 4.4 Species richness and diversity indices from gillnet surveys

Country	Location	Sets (M)	S _{obs}	n	Shannon H'	Variance (H')	Simpson 1/D
Day-time sets							
Burundi	Rusizi	23	45	1087	1.249	0.00023	11.49
Burundi	Bujumbura Bay	12	44	4425	1.266	0.00004	13.08
DR Congo	Uvira	24	36	1115	0.872	0.00035	4.32
DR Congo	Pemba/Luhanga/Bangwe	10	38	322	0.965	0.00182	3.45
Tanzania	Gombe	13	46	659	1.188	0.00047	9.15
Zambia	Cameron Bay	3	40	274	1.385	0.00056	17.80
Zambia	Nsumbu NP	16	71	2460	1.398	0.00010	16.04
Night-time Sets							
Burundi	Rusizi	18	56	1019	1.405	0.00021	17.45
Tanzania	Mahale NP	20	99	2190	1.629	0.00011	26.21
Zambia	Mpulungu Area	27	57	2600	1.173	0.00014	7.55
Zambia	Kalambo and Lunzua	12	53	1044	1.223	0.00035	8.38
Zambia	Chikonde	6	44	469	1.312	0.00041	14.21
Zambia	Lufubu and Chisala	16	86	2154	1.354	0.00010	11.29
Zambia	Nsumbu NP	18	70	1829	1.424	0.00018	13.72
Zambia	Katoto, Kasakalawe, Kapembwa	9	54	544	1.428	0.00039	18.00
Day and night combined							
Zambia	Mpulungu	30	59	3481	1.121	0.00011	7.03
Zambia	Kalambo and Lunzua	15	54	1077	1.246	0.00034	8.75
Zambia	Nsumbu NP	66	96	4289	1.497	0.09545	18.28
Zambia	Chikonde	8	49	795	1.376	0.00028	15.29
Zambia	Katoto, Kasakalawe, Kapembwa	11	57	670	1.421	0.00033	17.65
Sets = number of standard 60 m gillnets set, S _{obs} = total number of species recorded (a measure of species richness), n = total number of fish sampled.							

Two-tailed tests are used for most comparisons in Table 4.5, where the hypothesis is that the sites differ in their diversity. For day-night comparisons, examination of the data suggests that day-time samples are less diverse, and this is tested with a one-tailed t-test. A one-tailed t-test is also used for comparison between adjacent impacted and unimpacted sites, with the hypothesis that the unimpacted site has higher biodiversity.

The following conclusions can be drawn from this comparison of diversity indices based on analysis of gillnet catches (Table 4.4 and Table 4.5):

- Diversity indices for the two areas where adequate day-night comparisons are available (Nsumbu NP, Zambia and off Rusizi NP, Burundi) are significantly higher for night-time samples. This is backed up by species richness in the case of Rusizi, but not for Nsumbu, where comparable sampling effort by day and night sampled 70 species by night and 71 species by day.

Table 4.5 Bonferroni-adjusted paired comparisons (t-tests) between Shannon-Weaver diversity indices of fish sampled with gillnets (from Table 4.4)

Paired comparisons - Night-time gillnets							
Site 1	Site 2	d.o.f	t	Prob level	Critical t (2-tailed)	Sig level	Sig?
1) National Parks							
Rusizi	Nsumbu	18	-3.245	0.0167	2.878	0.01	Y
Rusizi	Mahale	198	-22.708	0.0167	2.602	0.001	Y
Nsumbu	Mahale	189	-25.494	0.0167	2.602	0.001	Y
2) Zambian Rivers, E and W coasts							
Kalambo/Lunzua	Lufubu/Chisala	501	-8.338	0.05	1.965	0.001	Y
3) Unimpacted/impacted, Zambia							
Katoto etc	Mpulungu	216	16.215	0.05	1.653	0.0005	Y

Paired comparisons - same site, day/night							
Site 1	Site 2	d.o.f	t	Prob level	Critical t, (1-tailed)	Sig level	Sig?
Rusizi day	Rusizi night	4	-36.455	0.05	2.353	0.0001	Y
Nsumbu day	Nsumbu night	253	-3.054	0.05	1.651	0.0025	Y

Paired Comparisons, daytime gillnets							
Site 1	Site 2	d.o.f	t	Prob level	Critical t (2-tailed)	Sig level	Sig?
1) National Parks							
Gombe	Rusizi	158	-3.926	0.0167	2.607	0.01	Y
Nsumbu	Rusizi	298	-5.551	0.0167	2.592	0.01	Y
Nsumbu	Gombe	400	-3.205	0.0167	2.588	0.01	Y
Site 1	Site 2	d.o.f	t	Prob level	Critical t, (1-tailed)	Sig level	Sig?
2) Unimpacted/impacted, Congo and Burundi							
Pemba etc	Uvira	209	2.430	0.05	1.653	0.01	Y
Rusizi	Bujumbura	703	-1.227	0.05	1.647	0.20	N

d.o.f = degrees of freedom, see Chapter 2 for equation to calculate
t = calculated value of students' t-distribution
Prob level = Bonferroni-adjusted significance level at which individual comparisons are made, overall significance level of 0.05 is maintained.
Sig level = significance level of calculated t (from t-distribution tables)
Sig? = decision made on significance; Y = Yes, N = No. Comparison is taken as significant if Sig. Level > Prob. Level (Bonferroni-adjusted).

- Comparison of the SW diversity indices of fish fauna in the existing national parks indicate, for night-set gillnets, that significant differences in SW index occur between the three parks for which data are available (Mahale > Nsumbu > Rusizi). For the day-time gillnet data, Nsumbu>Rusizi>Gombe, although Rusizi and Gombe have similar species richness (45 and 46 species respectively).
- Night-time gillnet samples from the pollution-impacted Mpulungu harbour area (Zambia) had significantly lower diversity indices than those from adjacent areas (Katoto etc), although similar numbers of species were recorded in the two catch series (57 for Mpulungu; 54 for Katoto etc.). The comparison of species richness is, however, confounded by unequal sample sizes (27 net sets for Mpulungu; 9 for Katoto etc.).
- Gillnet surveys taken near the mouths of rivers adjacent to Nsumbu NP (Lufubu and Chisala) had higher species richness and diversity indices than the rivers entering the lake from the Eastern part of the Zambian catchment (Kalambo and Lunzua area). The

difference in species richness is marked (86 spp for Lufubu and Chisala with 53 from Kalambo and Lunzua).

- Daytime gillnet samples from pairs of impacted/less impacted sites show significant differences (Pemba-Luhanga SW Diversity Index > Uvira), but are based on limited sample sizes. Diversity indices from Rusizi and Bujumbura Bay do not show significant differences.

The same analysis for data from stationary visual census indicates broadly comparable patterns but, overall, slightly lower values. Shannon-Weaver diversity indices range from 0.23 to 2.53 but both these values - for sandy substrates at Pemba, Bangwe, Luhanga (Congo) and Cameron Bay (Zambia) - are outliers. The former is a likely underestimate due to limited sample size ($N=2$), the latter possibly due to encounter of a large, single-species shoal of fish during survey activities.

Both Simpson and Shannon-Weiner diversity indices are known to be more sensitive to the presence of large number of individuals of a few species than to small numbers of individuals of many species (Magurran, 1988). This is evident in the fact that species represented in samples by a single individual do not contribute to the sum of frequencies used to calculate these indices, as $\text{Log}(1) = 0$. This bias may account for the unusually high value of diversity index for the Cameron Bay (Sand) sample, where a large shoal of *Stolothrissa tanganicae* was encountered during the surveys (Table 4.6). Typically, such 'vagrant' species are excluded from surveys of this type.

Table 4.6 Species richness and diversity indices from stationary visual census surveys.

	Location	Substrate	Sample events (M)	n	S _{obs}	Diversity Indices		
						Shannon H'	Variance (H')	Simpson 1/D
Burundi	Burundi south	Rock	3	426	22	1.117	0.00034	9.741
	Burundi south	Sand	4	429	6	0.447	0.00049	1.947
	Gitaza	Rock	3	1143	26	1.031	0.00024	6.245
DR Congo	Pemba, Luhanga, Bangwe	Rock	21	5128	61	1.115	0.00010	5.508
	Pemba, Luhanga, Bangwe	Sand	2	45	4	0.229	0.00411	1.319
	Uvira	Rock	4	160	21	1.127	0.00096	9.467
	Uvira	Sand	21	1643	34	0.857	0.00024	4.141
Tanzania	Gombe	Rock	13	9795	54	1.129	0.00003	7.880
	Gombe	Sand	18	5957	55	1.075	0.00006	6.567
	Kigoma	Rock	9	446	26	1.061	0.00049	7.897
	Kigoma	Sand	3	153	9	0.678	0.00097	3.681
	Mahale	Rock	25	5139	82	1.470	0.00006	14.355
	Mahale	Sand	19	65	59	1.210	0.00012	8.109
	Mahale	Shell	2	3188	4	0.587	0.00018	3.756
Zambia	Cameron Bay	Rock	4	780	42	1.191	0.00043	8.364
	Cameron Bay	Sand	2	11046	5	2.587	0.00128	1.008
	Katoto etc	Rock	10	1697	71	1.133	0.00032	6.861
	Katoto etc	Sand	5	630	28	0.918	0.00051	5.033

Sample events = number of SVC samples completed
S_{obs} = total number of species recorded (a measure of species richness)
n = total number of fish sampled.

Values for Simpson's index range from 1.0 for Cameron Bay (Sand) to 14.4 for Mahale (Rock). The lowest Simpson's (D) value is for the same data as the highest Shannon-Weaver index, but this value is an outlier, for reasons given above. Apart from this site, the two indices rank the other sites in similar order of diversity.

Paired comparisons are made among the rocky sites sampled by SVC, the sandy sites and sites where both rock and sand were adequately represented in samples (Table 4.7)

Table 4.7 Bonferroni-adjusted paired comparisons (t-tests) between Shannon-Weaver diversity indices of fish sampled with gillnets (from Table 4.6)

Site 1	Site 2	d.o.f	t	critical t, two tailed	Sig. Level	Sig?
1) Paired comparisons - Rocky sites						
				(p = 0.005)		
Pemba etc	Gombe	2244	-1.801	2.878	0.01	N
Pemba etc	Kigoma	285	2.703	2.602	<0.001	Y
Pemba etc	Mahale	477	-59.716	2.602	<0.001	Y
Pemba etc	Katoto	795	-1.203	2.815	>0.5	N
Gombe	Kigoma	391	3.184	2.823	0.002	Y
Gombe	Mahale	1122	-61.099	2.813	<0.001	Y
Gombe	Katoto	1379	-0.193	2.812	>0.5	N
Kigoma	Mahale	339	-19.735	2.825	<0.001	Y
Kigoma	Katoto	48	-5.479	2.943	<0.001	Y
Mahale	Katoto	1087	20.979	2.813	<0.001	Y
2) Paired comparisons - Sandy sites						
				(p = 0.0083)		
Uvira	Gombe	141	1.746	2.735	0.1	N
Uvira	Mahale	117	-2.850	2.695	0.01	N
Uvira	Katoto	33	9.818	2.887	<0.001	Y
Gombe	Mahale	17	-16.850	3.005	<0.001	Y
Gombe	Katoto	489	7.420	2.745	<0.001	Y
Mahale	Katoto	228	14.911	2.716	<0.001	Y
3) Rock-Sand comparisons						
				(p = 0.0167)		
Gombe rock	Gombe sand	1147	10.197	2.385	<0.001	Y
Mahale rock	Mahale sand	16	33.231	2.688	<0.001	Y
Katoto etc rock	Katoto etc sand	73	15.757	2.427	<0.001	Y
d.o.f = degrees of freedom, calculated by equation in Chapter 2 t = calculated value of students' t-distribution Bonferroni-adjusted significance level at which individual comparisons are made is reported in brackets above each set of comparisons; overall significance level of 0.05 is maintained. Sig level = significance level of calculated t (from t-distribution tables) Sig? = decision made on significance; Y = Yes, N = No. Comparison is taken as significant if Sig. Level > Prob. Level (Bonferroni-adjusted).						

The paired samples suggest the following conclusions:

- The fish diversity of rocky sites in Mahale NP is significantly higher than that of all other rocky sites sampled by SVC, with differences among other sites being less consistent.
- Mahale NP also has significantly higher sandy-area diversity than most other sites sampled. The exception, surprisingly, is the low species-richness Uvira area.
- All rock-sand comparisons in the same area indicated highly significant differences in diversity, with the rocky areas being, unsurprisingly, more diverse.

All the above diversity indices and their comparisons will be affected by differences in sampling size and 'completeness' (see Chapter 2). By examining the calculated diversity index from 100 randomisations at each step in the species-accumulation process, we can determine the number of sampling events required to ensure unbiased, stable estimates of diversity indices. In order to do this, we selected eight well-sampled areas (>16 samples) to examine how calculated diversity indices changed as additional samples were added, until all samples at that site were included – the basis for calculating the diversity indices presented in Table 4.5 and Table 4.7. These sensitivity analyses are presented in Figure 4.9.

For the Shannon-Weaver index, a clear and stable pattern of increase to asymptote is shown for all samples. The sensitivity analysis suggests that surveys based on less than 15-20 sampling events are likely to seriously underestimate diversity indices. This applies to several of the values reported in Table 4.5 and Table 4.7, so that comparisons among sites where sampling was limited must be interpreted with caution.

One of the few datasets allowing direct comparison between sampling methods are those from the uniformly sandy Uvira, where both gillnetting and SVC surveys were undertaken. Shannon-Weaver indices for Uvira gillnet and SVC surveys show very close correspondence in both absolute value and their sensitivity to number of samples. Gillnet samples taken in most other locations will integrate both sandy and rocky substrates, perhaps explaining why diversity indices from gillnets tend to be slightly higher than for SVCs in the corresponding areas (Table 4.5 and Table 4.7).

For gillnetting, there seems to be a tendency for values of Simpson's index to continue to increase at large sampling sizes, while the values from SVCs stabilise at much smaller sample sizes. The reason for this is not known, but the observation may be worth considering when considering the use of Simpson's index derived from the two methods to compare diversity between areas.

In general, the Shannon-Weaver diversity index appears to perform better. It is both more stable at lower sample sizes and maintains rank-order differences in diversity from relatively low sample sizes onwards. This means that if all sites were undersampled, the results in terms of diversity ranking would be unaffected, although if some sites were fully sampled and others not, this would of course affect the rank ordering. The Simpson index is less stable, with rank order of calculated diversity changing as sample size is increased. We would recommend use of the Shannon-Weaver in preference to the Simpson index for comparisons of diversity between sites.

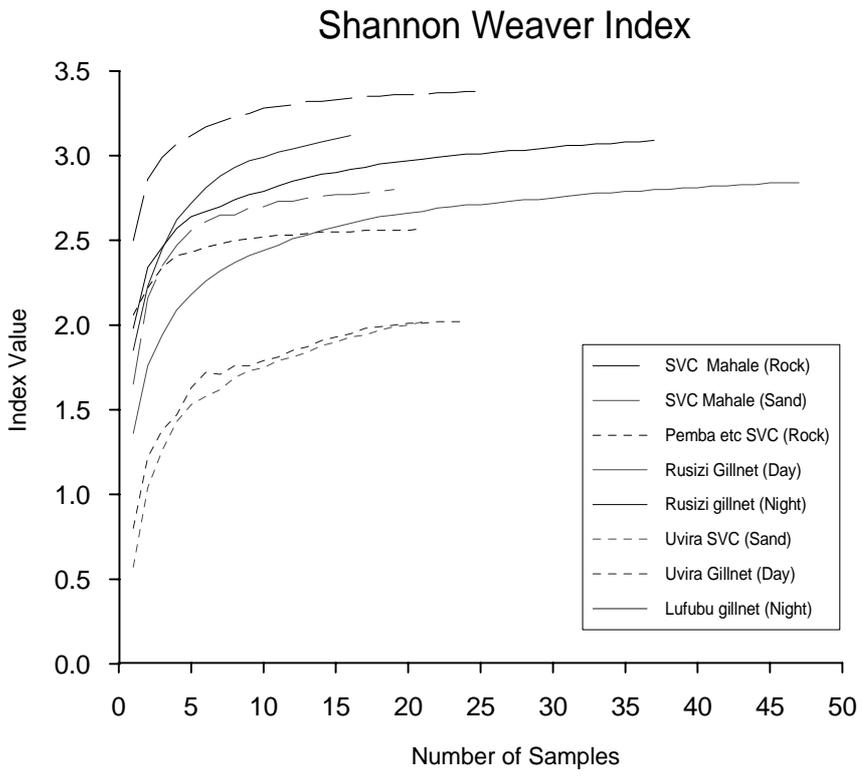
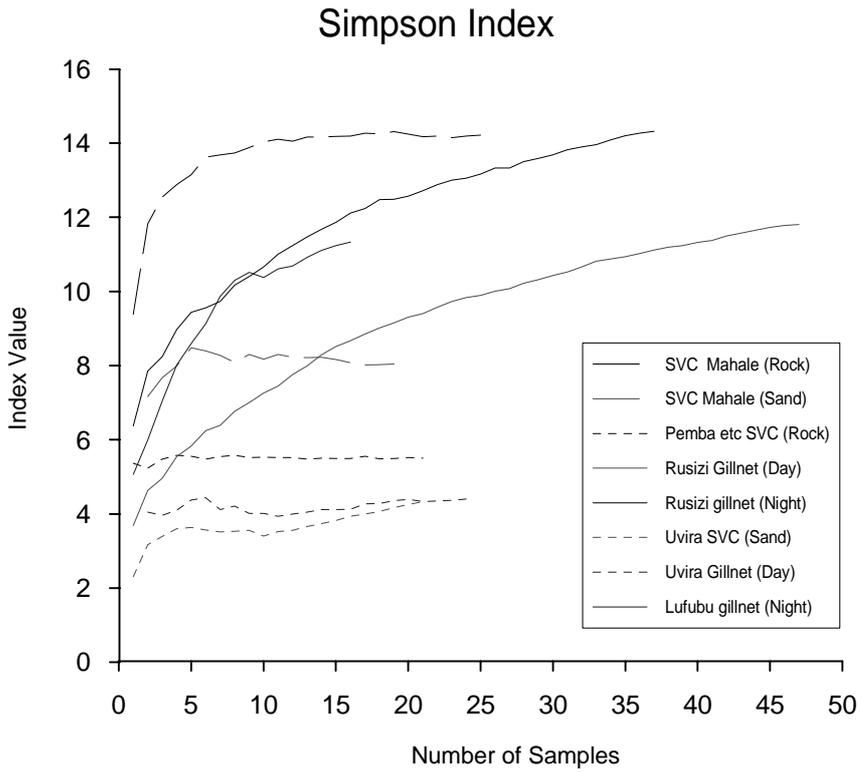


Figure 4.9 Sensitivity of diversity indices to sample size, based on 100 randomisations of sample order.

4.3.3 Fish species richness

Fish species richness estimates (S_{max}) were calculated separately for SVC, Gillnet and RVC surveys. For SVC and Gillnet surveys, both abundance and incidence-based methods were used, while for RVC, only incidence-based methods were appropriate as the data did not reflect relative abundance.

Estimates of species richness from SVC surveys are summarised in Table 4.8. Apart from outliers and areas that are clearly undersampled, the values all fall within a reasonable range (usually within 10-15 species) and differences in diversity index are also reflected in differences in estimated species richness, with Mahale (Rock) producing the highest estimates. The estimates will always exceed observed species richness, except at very large sample sizes (functionally equivalent to infinite sampling effort).

Table 4.8 Fish species richness estimates (S_{max}) from the stationary visual census (SVC) technique. Outlying estimates are given in brackets.

				S_{max} Estimates						
Area	Subs	N	S_{obs}	MMRuns	MMMean	ACE	ICE	Jack1	Jack2	Boot
BURUNDI										
Burundi South	Rock	3	22	49	38	24	40	30	33	26
Burundi South	Sand	4	6	12	13	(6)	(32)	10	12	8
Gitaza	Rock	3	26	35	34	27	36	33	35	29
DR CONGO										
Pemba etc	Rock	21	61	68	67	62	68	71	70	66
Pemba etc	Sand	2	4	6	10	5	15	6	6	5
Uvira	Rock	4	21	(158)	52	22	41	31	35	26
Uvira	Sand	21	33	(92)	53	35	47	45	50	39
TANZANIA										
Gombe	Rock	13	54	73	68	54	68	69	75	61
Gombe	Sand	18	55	90	77	58	96	80	94	66
Kigoma	Rock	9	26	43	40	27	50	38	47	32
Kigoma	Sand	3	9	18	24	11	35	14	16	11
Mahale	Rock	25	82	89	88	88	101	101	108	91
Mahale	Sand	19	60	82	76	64	71	75	77	68
Mahale	Shell	2	4	4	6	4	7	5	5	5
ZAMBIA										
Cameron Bay	Rock	4	35	63	61	37	61	49	56	42
Cameron Bay	Sand	2	5	5	9	5	11	7	7	6
Katoto etc	Rock	10	48	65	62	48	58	60	63	54
Katoto etc	Sand	5	28	47	(102)	32	(79)	44	53	35

N = number of sampling events (replicates)

S_{obs} = number of species actually sampled

MMRuns = Michaelis Menton estimator based on averaging individual randomisation runs

MMMean – Michaelis Menton estimator based on mean species sample curve

ACE = Abundance-based Coverage Estimator

ICE = Incidence-based Coverage Estimator

Jack1 = Incidence-based 1st order jackknife estimate

Jack2 = Incidence-based 2nd order jackknife estimate

Boot = Incidence-based bootstrap estimate

The Bootstrap and ACE estimators tend to produce the lowest S_{max} estimates, while ICE and Jack2 tend to yield the highest. Jack 1 and MMMeans are intermediate, while MMRuns

tends to be unstable as it will be sensitive to the appearance of unusually rich single samples early on in the sample-order randomisation process.

Estimates from gillnet surveys (Table 4.9) show a similar pattern in the values yielded by the different estimation techniques. Of note are the very high estimates of species richness for the Lufubu/Chisala rivers bordering Nsumbu NP in Zambia, which are similar to those for Mahale NP in Tanzania.

Table 4.9 Fish species richness estimates (S_{max}) from gillnet surveys. Outlying estimates are given in brackets.

				S_{max} Estimates						
Area	Set-time	N	S_{obs}	MMRuns	MMMean	ACE	ICE	Jack1	Jack2	Boot
BURUNDI										
Bujumbura Bay	Day	18	45	52	51	48	51	54	57	49
Bujumbura Bay	Night	2	31	41	(74)	42	(109)	43	43	37
Rusizi	Day	47	59	65	65	64	67	71	77	64
Rusizi	Night	37	72	79	78	83	83	88	99	79
DR CONGO										
Pemba etc	Day	14	43	67	59	52	60	58	65	50
Uvira	Day	24	36	63	51	48	58	53	68	43
TANZANIA										
Mahale	Day	4	23	84	64	32	73	36	43	29
Mahale	Night	23	101	119	116	113	127	128	138	114
ZAMBIA										
Cameron Bay	Day	6	40	(149)	(92)	47	64	58	66	49
Chikonde	Night	7	49	71	68	53	63	64	70	56
Kalambo	Night	12	52	78	73	57	86	74	88	62
Katoto etc	Night	9	54	(96)	80	62	75	73	79	63
Lufubu	Night	16	86	136	129	94	127	119	136	101
Mpulungu	Day	3	16	23	(98)	26	(93)	25	30	20
Mpulungu	Night	27	57	65	64	63	76	74	80	65
Nsumbu NP	Night	44	70	88	84	77	81	86	90	78

N = number of sampling events (replicates)
 S_{obs} = number of species actually sampled
 MMRuns = Michaelis Menton estimator based on averaging individual randomisation runs
 MMMean – Michaelis Menton estimator based on mean species sample curve
 ACE = Abundance-based Coverage Estimator
 ICE = Incidence-based Coverage Estimator
 Jack1 = Incidence-based 1st order jackknife estimate
 Jack2 = Incidence-based 2nd order jackknife estimate
 Boot = Incidence-based bootstrap estimate

The RVC data provide only incidence-based estimates of richness, but these estimates generally appear to be fairly consistent among the different methods used (Table 4.10). For Uvira 5-15m samples, for example, estimated richness are 19-21 species, while the rockier and less impacted Pemba/Bangwe/Luhanga sites have an estimated 65-76 species, and Mahale 0-15 m has an estimated 113-138 species.

Table 4.10 Incidence-based fish species richness estimates (S_{max}) from rapid visual census (RVC) surveys. Outlying estimates are given in brackets

Area	Depth range (m)	N	S_{obs}	ICE	Jack1	Jack2	Boot
BURUNDI							
Burundi South	0 to 3	4	26	48	38	43	32
Burundi South	5 to 15	16	51	67	69	79	59
Gitaza	0 to 3	2	19	(65)	26	26	23
Gitaza	5 to 15	11	41	44	46	43	45
DR CONGO							
Pemba etc	0 to 3	7	36	63	51	60	43
Pemba etc	5 to 15	18	65	73	76	74	71
Uvira	0 to 3	4	15	26	21	23	18
Uvira	5 to 15	44	19	20	21	21	20
TANZANIA							
Kigoma	0 to 3	3	16	27	21	23	19
Kigoma	5 to 15	9	32	47	44	50	38
Mahale	0 to 3	20	77	94	95	100	86
Mahale	5 to 15	69	105	117	123	134	113
ZAMBIA							
Katoto etc	0 to 3	8	40	44	46	48	43
Katoto etc	5 to 15	19	54	67	69	80	61

<p>ICE = Incidence-based Coverage Estimator Jack1 = Incidence-based 1st order jackknife estimate Jack2 = Incidence-based 2nd order jackknife estimate Boot = Incidence-based bootstrap estimate</p>
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In comparing the richness estimates in the above tables with the values derived from the total species lists generated from the literature and survey databases combined (Chapter 3), it is important to note that the estimators will partly be determined by the number of species susceptible to the particular sampling gear. Thus, small, sessile species living near the bottom may be present but not liable to capture by gillnets. Larger predators may have a very low probability of encounter in a spatially and temporally restricted SCUBA survey, but a very high probability of capture in a gillnet. It should also be noted that the lists in Chapter 3 will include a wider depth-band than was sampled in this study, so that lower estimates do not necessarily reflect underestimation of what was present in the area sampled and liable to capture by the sampled method used.

A comparison of the ranges of observed and estimated species richness for each technique, against all recorded species from the same area (Table 4.11) indicates that the richness estimates fall close to the range of previously recorded species for each area, with underestimates usually being found where it was only possible to use one technique (e.g. only night-time gillnetting in Nsumbu NP, where diving the rocky areas may have yielded many species unlikely to be caught in gillnets).

These findings reinforce the contribution the current surveys make to comparative surveys of fish diversity in Lake Tanganyika and provide adequate justification for the pooling of sampling methods to give as definitive a list of currently known species-distributions as is currently available.

Table 4.11 Observed and estimated fish species richness in the major national park and defined survey areas, by survey technique.

Area	Gillnets (nights)		Gillnets (days)		SVC (Rocky)		SVC (Sandy)		RVC (0 - 3 m)		RVC (5 - 15 m)		Total recorded species	
	S _{obs}	S _{max} estimates (range)	S _{obs}	S _{max} estimates (range)	S _{obs}	S _{max} estimates (range)	S _{obs}	S _{max} estimates (range)	S _{obs}	S _{max} estimates (range)	S _{obs}	S _{max} estimates (range)	BIOSS Surveys ¹⁴	BIOSS + previous surveys ¹⁵
Rusizi	72	78-99	59	64-77	-	-	-	-	-	-	-	-	80	105
Pemba etc	-	-	43	50-67	61	62-71	*	5-15	56	43-63	65	71-76	82	-
Gombe	*	*	*	*	54	54-75	55	58-96	-	-	-	-	94	62
Mahale	101	113-138	*	*	82	88-108	60	64-82	77	86-100	105	113-134	128	160
Nsumbu	70	77-90	-	-	-	-	-	-	-	-	-	-	91	99

S_{max} estimates ranges exclude outliers.

The areas presented in this table are those included in or adjacent to existing national parks, plus an area in DR Congo that has been suggested as a national park. The areas and techniques chosen represent well-sampled areas, with estimates of diversity likely to be reliable.

- indicates that this sampling technique was not used at this locality

* indicates that the sampling was limited and any estimates of species richness are likely to be unreliable and are hence not reported here.

¹⁴ From all gear types and sampling methods combined (From Table 5.2)

¹⁵ From all previous surveys taking place including the recent BIOSS surveys (From Table 3.7).

In order to evaluate the effect of sample size on the richness estimates given in Table 4.8 - Table 4.11 we examined calculated estimates based on 100 randomisations of the observed species-samples for 1 sample, 2, 3... n samples, with n being the total number of sampling events in each strata. We illustrate the effect of sampling size on the richness estimates presented in the above tables by selecting four well-sampled locations of differing species richness for each of the three sampling techniques (Figure 4.10, Figure 4.11 and Figure 4.12)

It is evident that sample size greatly affects the estimates of species richness. Thus, although the theoretical advantage of such estimates is that they enable comparison of areas sampled to different extent, and of undersampled areas, in practice the estimates themselves are sensitive to the degree of under sampling.

The different estimates behave in different ways as sample-size is reduced. The ICE estimator tends to shoot up at very small sample-sizes (2-4 sampling events), before stabilising quite rapidly (5-10 samples) and then changing little in value. It tends to stabilise even before species-accumulation curves have reached a clear asymptote (See Figure 4.11: Rusizi daytime gillnetting). This, plus the fact that it does not require abundance estimates (only incidence) makes it potentially the most useful and cost-effective estimator of species richness. Its estimates tend, however, to be much higher than the corresponding Abundance based Coverage Estimator (ACE).

MMRuns is the least stable estimator, and its use should be avoided. It seems particularly erratic for data from Sandy substrates, where the nature of the sampling is such that most samples will yield few species, while one or two may be species rich (isolated rock or patch of macrophytes encountered). MMMeans, by contrast, performs almost as well as ICE, and yields similar estimates of species richness. The fact that two estimators based on the same equation but fitted to the data in slightly different ways give such different performance underlines the importance of careful, informed choice of analytical method when undertaking this sort of analysis.

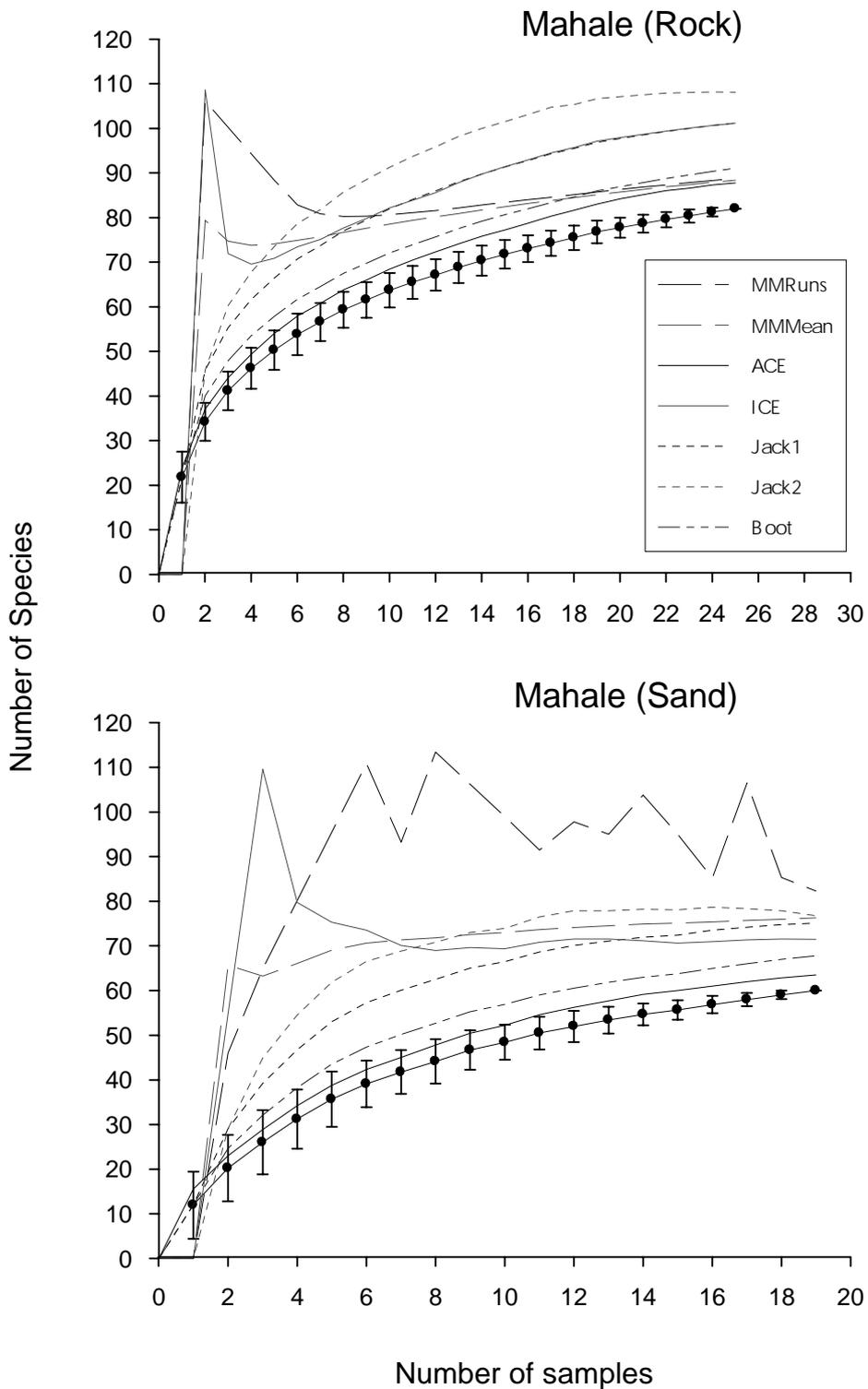
The Jackknife, Bootstrap and ACE estimators tend to shadow the species-accumulation curve, and are therefore sensitive to sample size. Where the species-accumulation curve has not reached an asymptote, then neither will the estimators have stabilised. This makes them less useful than ICE and MMMeans as a way of deriving species richness estimates from under-sampled areas, or from surveys consisting of widely different sampling effort, as is the case with this survey.

Our final recommendation for fish surveys is therefore the ICE and MMMeans estimators; with the caveat that they cannot be applied to survey strata with less than 10 replicate sampling events.

Of the three sampling methods, the RVC surveys appear to give the most consistent estimates of species richness, and are therefore preferred to SVC surveys where SCUBA diving is possible. Where it is not, gillnetting is an adequate replacement.

Figure 4.10 Relationship between number of replicate SVC sampling events and S_{max} estimates: (a) Mahale and (b) Democratic Republic of Congo

a) Mahale NP, Tanzania



b) Democratic Republic of Congo

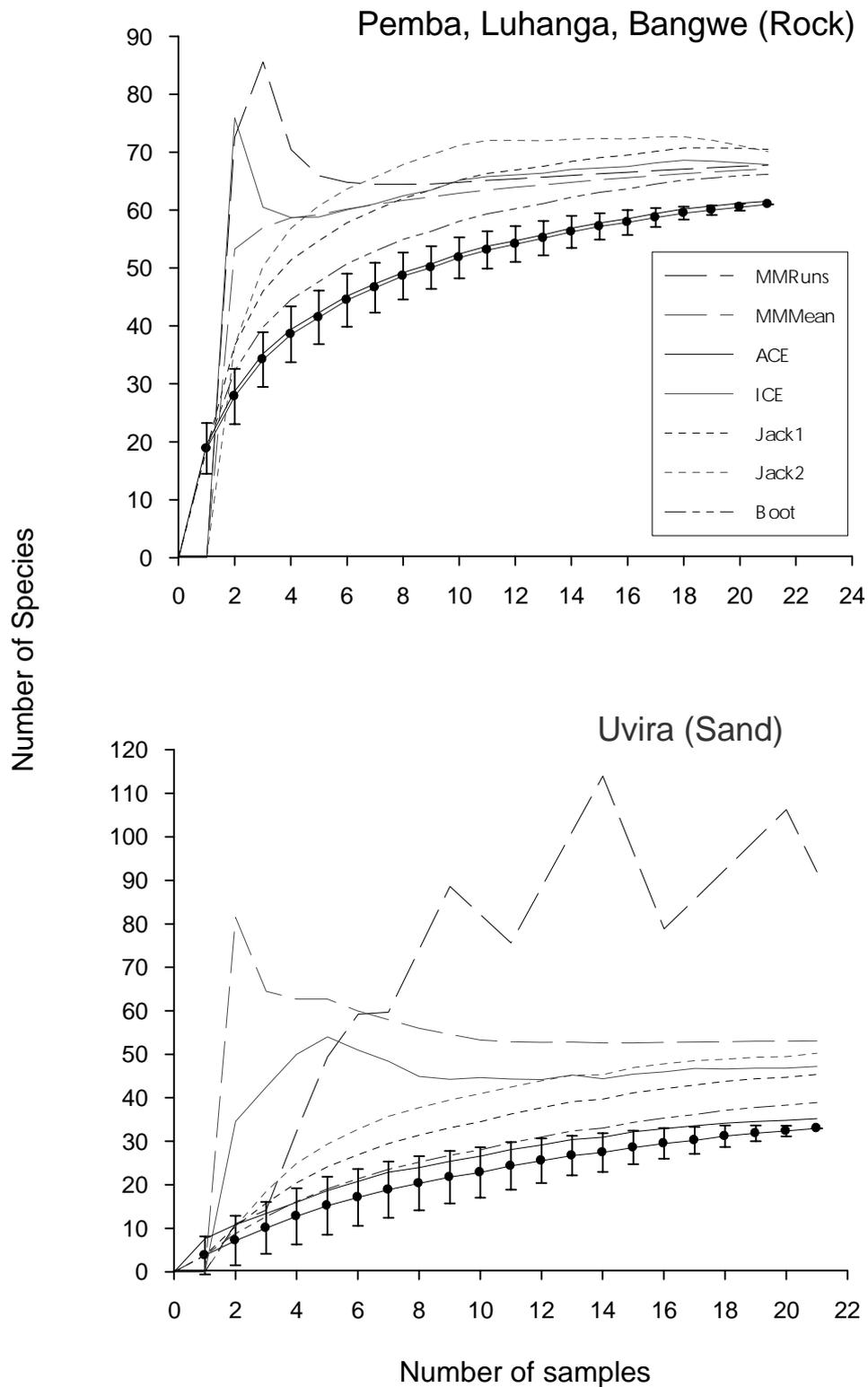
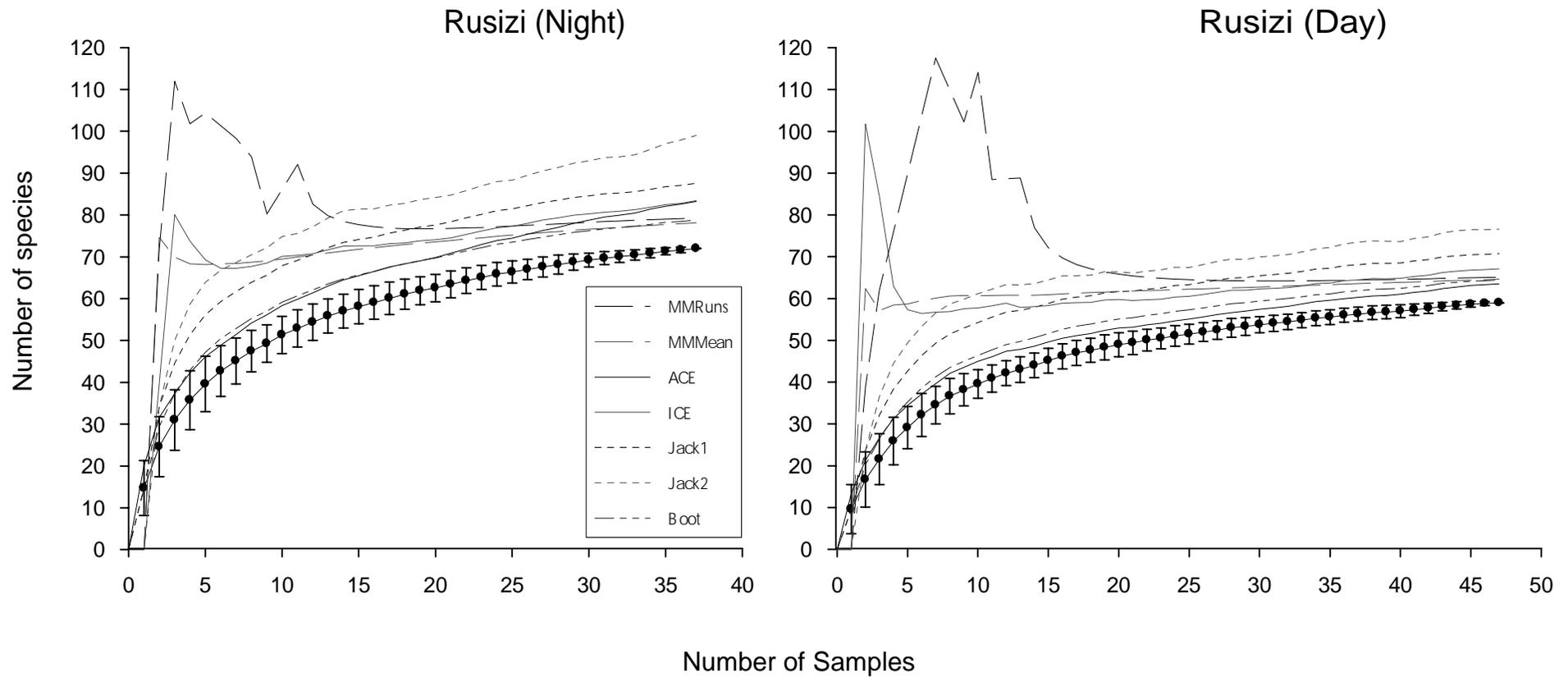


Figure 4.11 Relationship between number of replicate gillnet sampling events and S_{max} estimates: (a) Rusizi and (b) Uvira and Lufubur/Chisala

a) Rusizi, Burundi



b) Uvira, DR of Congo and Lufubu/Chisala, Zambia

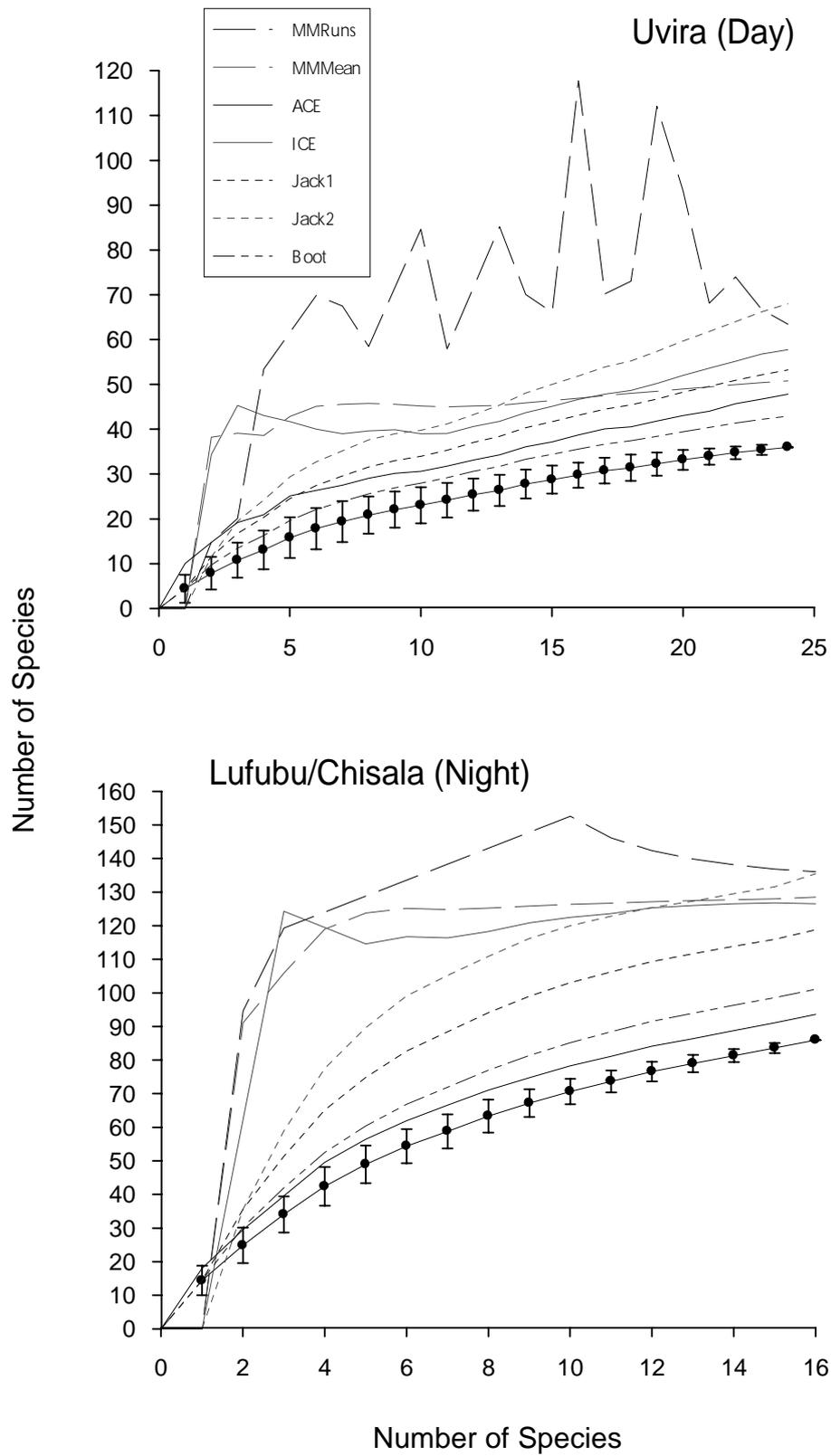
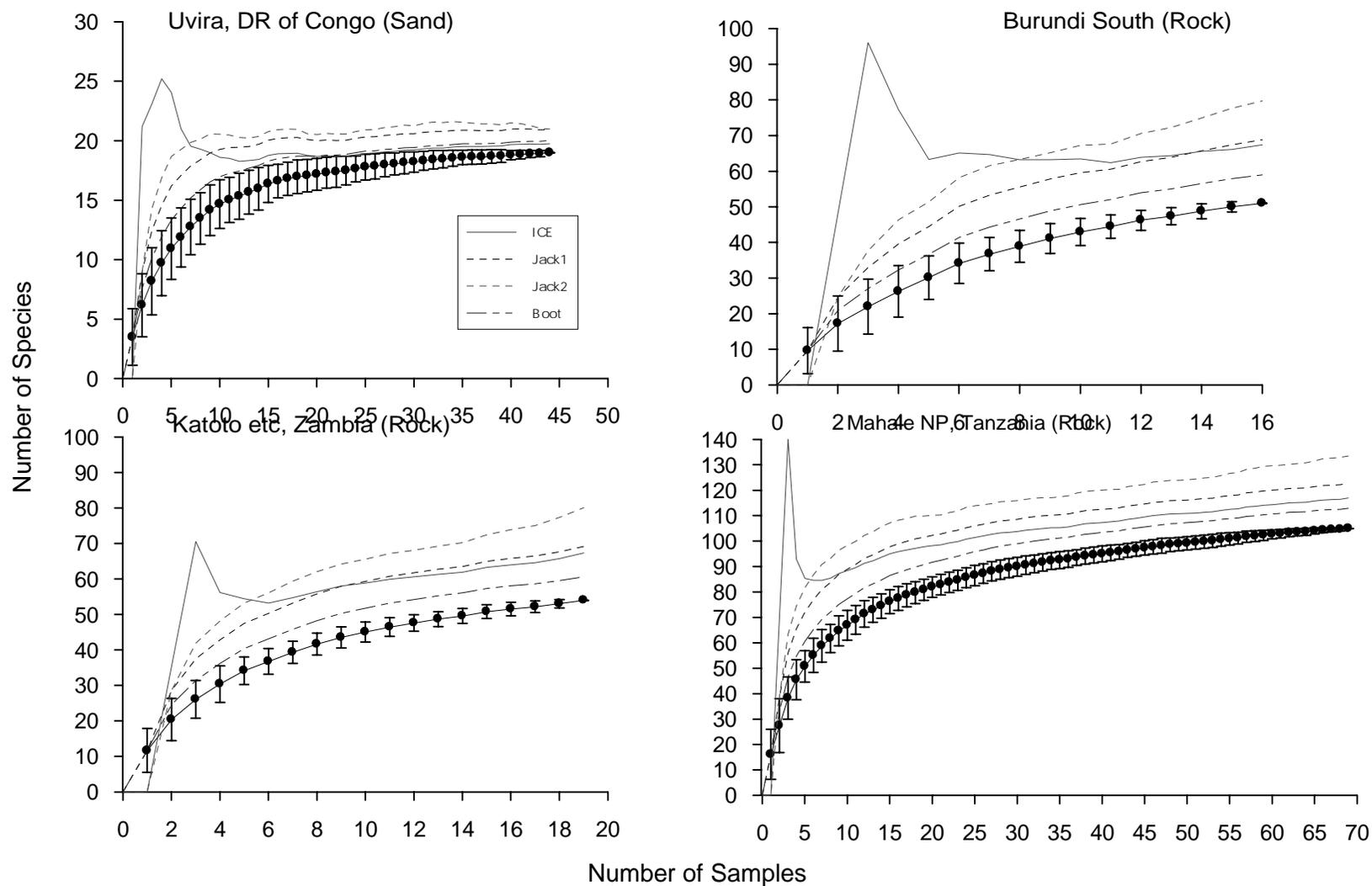


Figure 4.12 Relationship between number of replicate RVC sampling events and S_{max} estimates



4.3.4 Mollusc species richness

Mollusc species richness estimates were generated from four incidence-based methods, despite some limited sample sizes for individual survey strata (depth, substrate, area combinations). The four estimates of species richness (S_{max}) show fairly good agreement for most samples (Table 4.12).

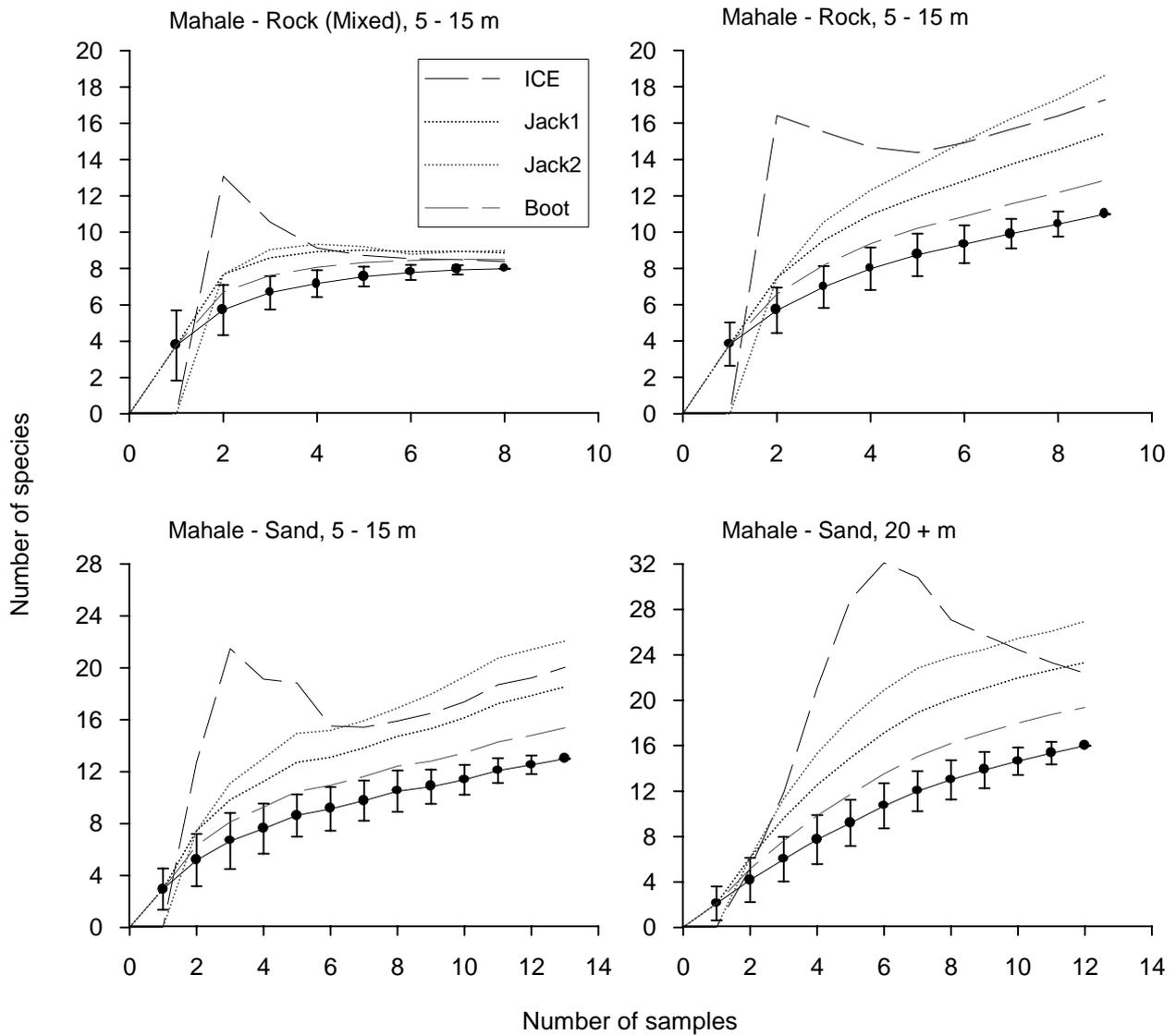
Table 4.12 Incidence-based species richness estimates (S_{max}) for molluscs

Area	Depth (m)	Substrate	N	S_{obs}	S_{max} estimates			
					ICE	Jack1	Jack2	Boot
BURUNDI								
Gitaza	5 to 15	Sand	4	6	7.3	7.5	7.5	6.8
DR CONGO								
Pemba etc	5 to 15	Sand	3	4	6.0	5.3	5.7	4.7
Pemba etc	5 to 15	Rock	4	9	11.3	11.3	11.1	10.3
Pemba etc	5 to 15	Mixed (Rock)	5	8	10.2	10.4	10.4	9.3
Uvira	5 to 15	Sand	3	7	(0.0)	11.7	14.0	9.1
Uvira	5 to 15	Mixed (Sand)	4	8	10.3	10.3	10.8	9.1
TANZANIA								
Mahale	5 to 15	Sand	13	13	20.0	18.5	22.1	15.4
Mahale	5 to 15	Mixed (Rock)	8	8	8.4	8.9	9.0	8.5
Mahale	5 to 15	Rock	9	11	17.3	15.4	18.7	12.9
Mahale	> 20 m	Sand (Mixed)	4	5	16.3	8.0	9.7	6.3
Mahale	> 20 m	Sand	12	16	22.4	23.3	27.0	19.4
Mahale	> 20 m	Shell	5	10	(92.8)	17.2	22.6	13.0
ICE = Incidence-based Coverage Estimator Jack1 = Incidence-based 1 st order jackknife estimate Jack2 = Incidence-based 2 nd order jackknife estimate Boot = Incidence-based bootstrap estimate								

Estimated richness for Mahale tend to be higher than for other areas, particularly those taken from sandy substrates and deeper water (20+ m, not sampled elsewhere). In general, the Bootstrap estimates are lower than the other methods. The first and second-order Jackknife estimates are either similar, or the Jack2 estimates are higher. ICE estimates often fall within the range of Jackknife estimates. The ICE estimator is occasionally unstable, with spurious estimates produced for two of the samples (Uvira, Sandy, 5-15 m and Mahale, Shell bed 20+m)

Analysis of the sensitivity of the estimates to sampling size indicates that Jackknife and Bootstrap estimates increase steadily with increasing sampling size (Figure 4.13). Their behaviour when a survey strata has been fully sampled is not known, although the Mahale mixed-rock sample, where a clear asymptote is reached, indicates that these estimates may stabilise and decrease slightly as an asymptote is reached. The ICE estimator is quite unstable at low sample-sizes (<5 in most cases), but appears to stabilise quite rapidly. Richness estimates in Table 4.12 must therefore be treated as provisional, once again illustrating the importance of adequate sampling size.

Figure 4.13 Sensitivity of species richness estimators to sample size. Examples illustrated are from mollusc surveys in Mahale NP. Plot symbols indicate observed species accumulation curves and standard deviations (based on 100 randomisations in sample ordering).



4.4 Discussion and Conclusions

It has been established that the areas adjacent to the existing terrestrial protected areas, whether they are currently protected as aquatic zones or not, contain the full range of littoral habitat types. They do not necessarily provide the only, or best examples of such habitat types, but have the advantage of existing conservation focus, as will be discussed in Chapter 5. Habitats within protected areas vary in the nature and scale of the main structural features of the habitat. While Rusizi is mainly soft-sediment both horizontally and vertically, Gombe is strongly structured vertically, with littoral zone cobbles and sand giving way to steep sandy slopes above deep rock substrates. Nsumbu's rocky habitats are concentrated in part of the Eastern part of the park only, and where rocky areas are found, these tend to dominate the littoral profile at all depths. In Mahale, a rocky littoral often gives way to sand or shell-bed at depth, and horizontally, the coastline is broken into alternating small patches of sand, mixed and rock habitat. Thus a range of both habitat type and patch structure is incorporated in the existing parks network.

Diversity indices for fish are broadly consistent with expectations – with the communities on rocky substrates being more diverse than those on sandy ones, and undisturbed or relatively pristine habitats supporting higher diversities than those areas close to population centres and subject to disturbance from fishing, pollution and sedimentation. These differences are also evident in comparing species richness measures, and indeed analysis of diversity indices adds little to the analysis of species richness, as others have recently pointed out:

“The Shannon-Weiner index should in general be regarded as a distraction, rather than an asset, in ecological analysis.”

Southwood and Henderson (2000), p 478.

This is an important conclusion in that much sampling effort is wasted in quantifying relative abundance. There are now several procedures for estimating species richness that do not rely on relative abundance data, and the pursuit of diversity indices can probably be abandoned for broad-scale survey activities of the type presented here, in favour of rigorous estimation of species richness. Diversity indices may continue to be useful for monitoring programmes, where these indices can provide evidence of systematic change in selected indicator groups. The requirements for relatively large sample sizes to obtain unbiased estimates is, however, a potential problem for monitoring programmes, which need to be fairly rapid, frequent and of low cost if they are to be sustainable.

Estimates of species richness and diversity are sensitive to sampling size, with some estimation procedures being more sensitive than others. We recommend use of Shannon-Weiner estimates of diversity in preference to Simpson's index as it gives more consistent results from undersampled areas. We also recommend Chao's Incidence-based Coverage Estimator (ICE) and the Michaelis-Menton (Means) estimation procedures for species richness, although the former is unstable for very small sample sizes (<5 replicates of most techniques). No reliable extrapolation of likely species richness can be made from such limited samples by any method, and extrapolations from such samples are likely to be unreliable.

Species number is often a straightforward measure for comparing diversity between samples collected in similar fashion. If the comparison is to be made between samples that differ in sampling effort, then estimates can be made of total species richness, S_{max} , and these can be compared. Different models may prove to be more effective for different groups of organisms or different environments, since the shape of a species accumulation curve depends upon the patterns of relative abundance among species sampled (Colwell and Coddington, 1994). Colwell and Coddington advocate testing against known samples (e.g. well sampled areas) and seeing which fits best – then using that model. This is what has been done in this survey, but once again, there is no escape from inadequate sampling: if sampling effort is insufficient to demonstrate an asymptote in species accumulation curves, then estimates of total richness will tend to be too low. The exceptions appear to be ICE and MMMMeans, which can stabilise

to provide reasonable estimates at sample sizes where the species-accumulation curve is still in its steeply rising phase.

It is important to note once again that minimum required sampling sizes to give reliable assessment of diversity indices and richness differ markedly between sites. In general, the higher the species richness and the greater the within-strata heterogeneity in richness and relative abundance, the higher the required sampling effort.

The analysis confirms the high diversity of the waters off existing parks, and highlights other areas, such as Pemba, Bangwe, Luhanga, in Congo, and Lufubu and Chisala in Zambia which are potentially rich sites. The latter are river mouth areas adjacent to Nsumbu National park, and may be worthy of some form of protection, perhaps as a park buffer zone. These conservation options are discussed further in the next chapter.

5. BIODIVERSITY CRITERIA FOR CONSERVATION PLANNING

5.1 Introduction

The main objective of the BLOSS surveys was to gather data that could be analysed to provide recommendations for a conservation strategy for Lake Tanganyika. In this chapter we use the results of the surveys to compare areas in terms of their conservation value. In Chapter 4 we measured diversity in terms of fish and mollusc species richness and where possible calculated diversity indices from the fish data. However, species richness and diversity are not necessarily the most important biodiversity criteria on which to base a conservation strategy. It is also important to consider levels of endemism, habitat specificity, restricted range and rarity and intensity of threat in different areas. We have already suggested that endemism is less relevant a criteria for comparative assessment within Lake Tanganyika, as the vast majority of taxa surveyed are endemic. Habitat specificity, range restrictions, rarity and intensity of threat are all important parameters, but information on them is currently rather sparse. We have attempted to collate information on range restrictions in Chapter 3, based on analysis of secondary data. Habitat specificities could be analysed in future, but are likely to require larger datasets than we have been able to assemble to date. High degrees of habitat specificity with resultant range restrictions are likely to be applicable only for habitats of restricted spatial extent or occurrence, such as shell beds, stromatolite reefs, submerged macrophyte stands and major river deltas. Given these caveats, we believe that an analysis based on species richness and such distribution information as exists is a useful starting point to inform conservation management.

In recommending areas that are valuable in conservation terms we have been limited to using biodiversity-based criteria. We acknowledge, however, that a wide variety of factors will influence decisions on how best to safeguard biodiversity and that the criteria used for conservation planning can vary dramatically depending on who sets the conservation priorities. Donor agencies, conservation or development NGOs and governments will often approach this issue from different perspectives, and their priorities can vary between conserving the maximum number of species to managing species and habitats for sustained income generation at national or local level (Reid *et al.*, 1993). Consequently, in planning for conservation, scientific recommendations are invariably modified by social, economic and political imperatives (Margules and Pressey, 2000).

BLOSS has based its conservation strategy advice mainly in terms of protected areas. This reflects the original LTBP project document, which went as far as to specify the creation of additional National Parks, as well as strengthening the management of existing ones. We have attempted to identify the areas of greatest diversity and sought to establish which combination of these would give the greatest level of protection to Lake Tanganyika's biodiversity. It is recognised however, that protected area status is only one option, and that a wider approach to lake management is likely to be critical if the strategy is to be successful. Additional strategies are discussed later in this chapter, and in Chapter 6.

5.2 Biodiversity Hotspots, Surrogacy and Complementarity

Owing to the complex nature of biodiversity and the difficulties associated with conducting All-Taxa Biodiversity Inventories (ATBI) (Kaiser, 1997), we have to accept incomplete knowledge and use partial measures of biodiversity in estimating the relative conservation value of different areas (Margules and Pressey, 2000). So in common with much recent work in biodiversity assessment and conservation planning, BLOSS has utilised the concepts of 'biodiversity hotspots' and 'surrogacy'. These were originally predicated on the basis that spatial patterns of species richness coincide across different taxonomic groups. Therefore, by identifying an area of high diversity (hotspot) for one or a few indicator taxa (the surrogates), one could predict high levels in diversity for all other taxa in that same area.

The term 'biodiversity hotspot' was first used by Myers (1989) to describe relatively small areas containing large numbers of endemic species, which he suggested would conserve larger numbers of species, if protected, than areas of similar size elsewhere. Since then the

term has been applied to a wider range of biodiversity criteria including; species richness, endemism as well as rare or threatened species, but is most commonly used to refer to areas of high species richness. In the context of Lake Tanganyika the usefulness of the 'hotspots' concept has been questioned. Cohen (1994) supports the view that clusters of populations of certain taxa in the lake may function as metapopulations and thus may be subject to fluctuations in size and frequent patch extinctions, even under natural conditions. He suggests that long-term biodiversity assessments and paleoecological studies would confirm the degree to which current diversity hotspots are ephemeral and consequently the feasibility of basing conservation strategies upon them is questioned. Nevertheless, as Coulter (1999) states, the need for measures to protect Lake Tanganyika's biodiversity is pressing and the extent to which conservation action can await long-term studies and prolonged debate is arguable, since they often lead to a "limbo of planning paralysis". Conservation is also a human activity, and must operate within time-scales relevant to human society. A 50-year planning horizon may seem woefully short-term in the context of the geological and evolutionary history of Lake Tanganyika, but is a long time in the context of Africa's current political economy.

The surrogacy concept is also open to question. A number of studies conducted in both temperate and tropical areas have shown that species-rich areas frequently do not coincide for different taxa, (Prendergast *et al.*, 1993; Van Jaarsveld *et al.* 1998; Howard *et al.* 1998). Van Jaarsveld *et al.* (1998) also found a lack of coincidence between hierarchical levels and felt this underscored the value of sound species related distribution data for conservation planning, while Prendergast *et al.* (1993) observed that many rare species do not occur in the most species rich areas. None of these studies sampled taxa from aquatic ecosystems extensively, but they do suggest that caution be exercised in selecting priority biodiversity conservation areas on the basis of one or a few taxonomic groups.

In some studies, as an alternative to surrogacy, taxon ratios have been calculated between various taxonomic groups at 'reference sites' and then applied to similar sites elsewhere (Colwell and Coddington, 1994). However this was not possible for BIOSSE given the lack of sufficient data on taxonomic groups other than fish and molluscs. Such analyses may be possible using the literature database in the future when collating all known species-location data.

Nevertheless, Howard *et al.* (1998) and Prendergast *et al.* (1993) also demonstrate that though individual hotspots may not correspond across taxa, a set of areas in which one or two major taxa are well represented can also represent diversity in other unrelated taxa. Thus, if a protective network is established for an all-embracing taxon or taxa, a large proportion of other taxa will be protected as well. The key element in this approach is complementarity analysis, which assesses different areas not merely on the basis of their species richness, but on how well they complement one another biologically. As Howard *et al.* (1998) point out, any site selection approach that encompasses most of the diversity in one taxon is likely to include a diversity of habitats, thus capturing a large proportion of the diversity of other taxa as well.

In order to answer the question of which areas to conserve in order to maintain the most biological diversity, we have build on our analysis of species richness using complementarity analysis, since it is an efficient method for maximizing the number of species protected in the smallest area. (Reid, 1998).

5.3 Methods

5.3.1 Habitat-based analysis of conservation value

Habitat maps were examined to ascertain if all habitat types were included in the protected areas network. Habitat types were defined at both local and topographical scales (Table 5.1). A combination of primary survey data from BIOSSE surveys, and more general and descriptive information from secondary sources, and from BIOSSE team members' knowledge of the lake, was used to categorise substrates, and to provide an overview of the major habitats included

in each area identified by Cohen (1991) and in baseline reviews (Patterson and Makin, 1998) as being of potential conservation interest.

5.3.2 Comparison of areas using fish and mollusc species richness and endemism

Total species lists, which cut across depth, habitat types and sampling methods were produced for each of the areas surveyed. The areas were then placed in rank order from highest to lowest species richness. This approach does not take into account potential biases and the impact of under sampling either in terms of limited effort or use of limited methods of sampling. Such considerations have been analysed in earlier chapters and are brought to bear in interpreting the output of pooled-sampled richness comparisons. In addition the proportion of endemic species recorded among the fish and mollusc species found at each site were calculated as percentages.

5.3.3 Comparison of sites using complementarity

As mentioned in section 5.2 this method uses the total species list for each area to derive smallest combination of areas that includes all species recorded in our surveys. Expressed most simply; the procedure we carried out identified the species content of existing reserves, then selected further sites in stepwise fashion in order to add areas that contribute the greatest number of new species.

- Step one: select the area with the most species not found in any of the other survey areas (Area 1). This will not necessarily be the area with the longest species list.
- Step two: Add the area with the most number of species not found in Area 1 (Area 2)
- Step three: Add the area with the most number of species not found in Area 1 or 2.
- Step four. Continue adding sites in the same manner until there are no sites with different species recorded.

At each step cumulative number of species represented by the selected sites is also calculated as a total and as a percentage of all the species recorded for Lake Tanganyika.

An important property of complementarity is that it is recalculated for all unselected areas as each new area is added to the set of areas. This takes into consideration the fact that the contribution of an area to the number of species included in the notional network is dynamic and that some or its entire species might be represented as a result of the selection of other areas. (Margules and Pressey, 2000). When establishing a protected area network, it is more efficient to begin with survey area containing the most species found nowhere else (as outlined above), thereby adding areas so as to provide greatest marginal gain with each new area. However, when investigating the options for extending an existing network, as on Lake Tanganyika, it may be more logical to use the combined species list from all the protected areas as a start point. Conscious that we were seeking to enhance an existing set of national parks and yet wanting to gain a sense of how each area contributed to protecting fish and mollusc species, we carried out analysis using both methods.

5.4 Results

5.4.1 Comparison of sites using habitat maps

Table 5.1 shows the proportion of each habitat type recorded in the waters adjacent to existing protected areas. In three of the parks (Mahale, Gombe, Nsumbu), all the major habitat types (sandy, rocky and mixed sand/rock) are well represented. Mahale and Nsumbu are clearly dominated by rock and mixed rocky substrates, while at Gombe there is a preponderance of sandy habitat. At all three parks the majority of these habitats were found to be relatively pristine. Specialised habitats (shell-beds, emergent macrophyte stands, stromatolite reefs) are also represented in the aquatic zones adjacent to national parks. Extensive shell beds were identified in the southern part of Mahale National Park, Tanzania and the north-western part of Nsumbu National Park, Zambia. Stromatolite reefs are also found near both the northern and southern boundaries of Mahale.

Though supporting a more restricted range of habitats, Rusizi National Park is particularly important, since it incorporates habitats not well represented elsewhere in the protected area network including: large emergent macrophyte stands, a major river delta with associated muddy substrates and turbid, nutrient-rich waters. Similar habitats are to be found at the other extensive delta, where the Malagarasi River enters Lake Tanganyika on the Tanzanian shore. As with the Rusizi, the Malagarasi delta is subject to intense fishing effort. Unlike the Rusizi, however, the delta itself is unprotected and is now home to numerous villages and their inhabitants. Nevertheless, whereas the Rusizi has no protection from threats originating in its wider basin, the likelihood of negative impacts emanating from the catchment of the Malagarasi could be reduced as a result of the recent designation of Malagarasi-Muyovozi Wetlands as a Ramsar site. A comparative study of the two important systems would be useful to ascertain the full extent of the biodiversity they support and inform decisions on how best to conserve it.

Table 5.1 Manta tow: the proportion of each substrate recorded in the waters adjacent to national parks, in kilometres and as a percentage of protected area shoreline

Survey area*	Substrate type											
	Rock		Gravel		Sand		Mixed		Mixed rock		Mixed sand	
	(km)	(%)	(km)	(%)	(km)	(%)	(km)	(%)	(km)	(%)	(km)	(%)
<i>Gombe</i>	4.8	24.5	-	-	10.7	54.9	4	20.5	-	-	-	-
<i>Mahale</i>	25.2	42	0.6	1	12	20	12.6	21	6	10	3.6	6
<i>Nsumbu</i>	34	44	1	1	18	23	2	3	13	17	9	12
<i>All areas</i>	64	40.9	1.6	1	40.7	26	18.6	11.9	19	12.1	12.6	8.1
*Owing to the poor visibility and density of crocodiles and hippopotami Rusizi national park was not sampled by manta tow technique. However, subsequent sampling for molluscs by dredge confirmed that soft substrates (sand, silt, mud) predominate												

The other areas in which surveys were conducted by manta technique contained substrate types broadly similar to those found adjacent to the national parks. Thus from a habitat perspective extending the parks network to include them would add little to the range of habitat types protected, though it would of course help to conserve the species within those areas.

The species assemblages associated with these habitats are representative, in terms of overall diversity and ecosystem structure, of communities in similar habitats elsewhere in the lake. And each area does support some unique species, but overall the difference in species composition between areas is limited. The reed beds areas of the Rusizi Delta provide important nursery grounds for fish of commercial importance and perform the important function of trapping some sediment. This is an area of low endemism, but high diversity among non-cichlid fish species, including a number of migrants between the lake and river.

5.4.2 Comparison of areas using fish and mollusc species richness

Table 5.2 and Table 5.3 give the total number of species, genera and families recorded for fish and molluscs in each survey area, as well as placing those sites in rank order according to the level of representation at each taxonomic level. Mahale is clearly the richest area at all levels for both fish and molluscs, with markedly fewer species being recorded at the next richest areas, which for the most part are also areas adjacent to existing national parks. In general high species diversity is mirrored by high diversity at genus and family level. The exception is the Lufubu and Chisala river mouths, which recorded 40% fewer species than Mahale but the same number of families. The reasons for this remain unclear since similar results were not obtained from other river mouth areas such as the Rusizi Delta and the Kalambo and Lunzua rivers.

Some of the variation in taxonomic richness between areas can be ascribed to differences in sampling effort. Some survey areas were sampled less intensely than others, or with only one sampling method, often for security or logistical reasons. It seems likely therefore that certain

sections of the lakeshore, notably the survey areas in northern DR Congo, would yield more species if sampled with similar intensity to the protected areas. This should be borne in mind when considering the ranking in Table 5.2 and Table 5.3.

Table 5.2 Survey areas with rank order of richness in fish species, genera and families (uncorrected for differences in sampling intensity)

Country	Survey Area	Species		Genera		Family	
		Total	Rank	Total	Rank	Total	Rank
Burundi	Rusizi NP	80	5=	48	4	9	4=
	Bujumbura Bay	44	14	34	12=	7	10=
	Gitaza	62	10=	39	10	7	10=
	Burundi South	80	5=	43	5=	8	7=
DR Congo	Uvira Area	71	9	42	7=	8	7=
	Pemba/Bangwe/Luhangwa	82	4	40	9	8	7=
Tanzania	Gombe NP	94	2	49	3	9	4=
	Kigoma Area	38	16	26	15	5	14=
	Mahale NP	128	1	54	1	11	1=
Zambia	Kalambo/Lunzua	50	13	34	12=	6	13
	Chikonde	43	15	25	16	5	14=
	Mpulungu Area	62	10=	38	11	9	4=
	Lufubu/Chisala	75	7	43	5=	11	1=
	Katoto/Kapembwa/Kasakalawe	74	8	42	7=	7	10=
	Nsumbu NP	91	3	51	2	11	1=
	Cameron Bay	54	12	28	14	4	16

Table 5.3 Survey areas in rank order of richness in mollusc species and genera

Country	Survey Area	Species		Genera	
		Total	Rank	Total	Rank
Burundi	Rusizi NP	1	9	1	9
	Gitaza	25	2	15	1=
DR Congo	Uvira Area	9	8	7	7
	Pemba/Bangwe/Luhangwa	17	3	10	4=
Tanzania	Gombe NP	16	4=	11	3
	Mahale NP	26	1	15	1=
Zambia	Katoto/Kapembwa/Kasakalawe	10	7	5	9
	Nsumbu NP	16	4=	10	4=
	Cameron Bay	11	6	9	6

5.4.3 Comparison of areas using fish and mollusc endemism

The total number of endemic fish species recorded in each survey area is listed in Table 5.4, together with the percentage all species in each area which were endemic. As can be seen the great majority of taxa recorded are endemic, the average percentage across all areas being 96.3%. In all the survey areas where mollusc sampling was conducted the levels of endemism were 100%. From this we have concluded that endemism is a less relevant a criteria for comparative assessment than species richness and therefore we have not considered it further in our analysis.

Table 5.4 Proportion of endemic fish species recorded by survey area

Country	Survey Area	Endemic species	
		Total	%
Burundi	Rusizi NP	75	93.8
	Bujumbura Bay	38	86.4
	Gitaza	61	98.4
	Burundi South	78	97.5
DR Congo	Uvira Area	68	95.8
	Pemba/Bangwe/Luhangwa	80	98.8
Tanzania	Gombe NP	91	96.8
	Kigoma Area	38	100
	Mahale NP	122	96.1
Zambia	Kalambo/Lunzua	48	96
	Chikonde	43	100
	Mpulungu Area	59	95.2
	Lufubu/Chisala	70	93.3
	Katoto/Kapembwa/Kasakalawe	73	98.6
	Nsumbu NP	86	94.5
	Cameron Bay	54	100

5.4.4 Comparison of sites using complementarity

Complementarity analysis based on species richness was carried out for both fish and mollusc data as outlined in Section 5.3.3. In the analysis of fish data (Table 5.5) Mahale National Park was selected first since it has the greatest number of unique species not found elsewhere in our surveys. Although not the next most species rich area, Rusizi has the largest number of species not found in Mahale (highest complementarity to Mahale) followed by the other two lakeside national parks, Nsumbu and Gombe. The results indicate that the waters off the four existing national parks include at least 73% of known fish species from the lake, and almost 90% of species recorded by this survey.

The addition of both the river mouth areas adjacent to Nsumbu (Lufubu and Chisala) and rocky areas in northern Congo (Pemba, Luhanga, Bangwe) adds only 6 more species to the total, and with each area subsequently included the number of species added dwindles further. There is no reason to assume that this trend would not be true for other areas outside the scope of our survey. Each new area that is added to the protected area network is only likely to uniquely include one or two species not found elsewhere. Even significant additions to the protected area network will, therefore, only add marginally to the species officially protected and are unlikely to ensure the survival of the small proportion of fish taxa that have spatially limited distributions.

Table 5.5 Complementarity analysis, fish species richness

Country	Area	Cumulative total Species	Cumulative % of surveyed species represented	% of total species recorded from lake
Tanzania	Mahale NP	128	64.6	52.7
Burundi	Rusizi	157	79.3	64.6
Zambia	Nsumbu NP	169	85.4	69.5
Tanzania	Gombe	178	89.9	73.3
Zambia	Lufubu/Chisala	184	92.9	75.7
Congo	Pemba/Luhanga/Bangwe	187	94.4	77
Congo	Uvira	190	96	78.2
Burundi	Bujumbura Bay	193	97.5	79.4
Zambia	Mpulungu	195	98.5	80.2
Zambia	Kalambo/Lunzua	197	99.5	81.1
Burundi	Burundi South	198	100	81.5
ALL	ALL	198	100	81.5

Approximately 243 species of fish are known from the lake (up to 100 additional species are found in the catchment, but not the lake). Of these, 198 (81.5%) were recorded in the present survey.

It should be noted that these analyses are based on LTBP/BIOSS sampling data only, but could be repeated with the addition of earlier data (CHRAA, ECOTONES etc), where sample sizes were larger in some cases.

In contrast our analysis of the mollusc data showed that the area with the most unique species (Gitaza), which would normally be selected first, was outside the existing protected areas network. However, since we are concerned with the extent to which areas would add species to the current parks network we carried out our analysis on the 4 national parks before determining the degree of complementarity of the other survey areas (Table 5.6).

Table 5.6 Complementarity analysis, mollusc species richness

National Park	Cumulative total species	Cumulative % of surveyed species represented	% of total species recorded in the lake**
Nsumbu National Park	16	35.6	23.9
Mahale Mountains National Park	31	68.9	46.3
Gombe Stream National Park	34	75.6	50.7
Rusizi	34	75.6	50.7
Gitaza	41	91.1	61.2
Pemba, Luhanga, Bangwe	43	95.6	64.2
Katoto, Kapembwe, Kasakalawe	44	97.8	65.7
Uvira	45	100	67.2

** Currently, 52 species of gastropod and 15 species of bivalve have been described in the lake, although taxonomic work continues.

The proportion of the total number of species in the lake found in the waters adjacent to the protected areas is clearly much less than for fish. The discovery of a number dead shells of species previously recorded off Rusizi National Park, suggests that further sampling would increase the species total for that area. A further 11 species were found at sites unconnected with the national parks bringing the proportion of known lake species recorded by BIOSS to 64.1%. The sites in the Gitaza area (Burundi) supports the second highest species richness (25 species) of any survey area and if included to the protected areas network would add a further 7 species, in other words over 10% of all the species so far recorded in the lake. It therefore constitutes an important centre for mollusc diversity in Lake Tanganyika.

For the analysis above we grouped gastropods and bivalve molluscs together. However out of the 45 mollusc species recorded by our surveys only 3 were bivalves. If the two groups are considered separately then it emerges that only 20% of bivalve species found in Lake Tanganyika were recorded by our surveys and those are all represented in the extant national

parks. Conversely 80.8% of all gastropod species were recorded by BLOSS. Of those 59.6% are afforded a measure of protection by the current system of national parks, which would rise to 73% with the inclusion of Gitaza.

5.5 Discussion

5.5.1 Conservation options

As stated in the introduction to this chapter we have based our recommendations for conservation strategy on biodiversity criteria: habitat representation, species richness and complementarity. We recognise that other biodiversity criteria could be considered in future surveys (see Section 2.11) and that rarity, endemism, range restrictions, metapopulation dynamics, temporal stability of species richness, functional diversity and higher-taxon diversity could all add to the efficiency with which protected area networks are selected. This all becomes rather theoretical (and frankly unnecessary) if other criteria that determine conservation options are of overriding importance. We have also already acknowledged the importance of other factors in formulating conservation strategies such as the nature and extent of the threats, feasibility, social and economic costs of implementation. It is usual to include this information in any assessment of conservation options. However the extent of our data in these areas is very limited and therefore we are only able to make a preliminary evaluation of these criteria.

Complementarity analysis of BLOSS survey data has given an indication of the extent to which the biodiversity of Lake Tanganyika is represented in the existing protected area network. We know that 81.5% of all fish species and over 50% of all molluscs [almost 60% of Gastropods] species known to exist in the lake are found in the waters adjacent to the national parks and that the vast majority of these species are endemic to the lake basin. This suggests a significant proportion of the diversity across a number of taxa is currently afforded some measure of protection. Complementarity analysis has also identified some areas presently unprotected which if managed for conservation would provide significant extra protection for Lake Tanganyika's biodiversity. Whether these areas are superior to other un-surveyed areas in this respect obviously cannot be answered until the whole lake has been surveyed. Given the extent of current surveys, the principal question is what is the best strategy for conserving the biodiversity within the areas outside parks that have been identified as of biodiversity conservation value? Should they be added to the protected area network or are there alternative options, which would achieve this goal more effectively?

5.5.2 Threats

Detailed assessment of the threats to biodiversity is crucial for making effective decisions on the scheduling and location of conservation action (Margules and Pressey, 2000), particularly, since the factors which have led to high rates of speciation in Lake Tanganyika may also render species more vulnerable to such threats (Cohen, 1994). Data on the major threats to biodiversity has now been collated for Lake Tanganyika, but was not available until a very late stage in the project, and consequently we are unable to integrate it fully in this document. Regrettably therefore there is little specific information in this report on where and how the major threats, sedimentation, pollution and over-fishing, are likely to impact on Lake Tanganyika's biodiversity. This serves to underline the importance of integrating the objective and work-plans at an early stage in project implementation. The general picture that emerges is that much of Lake Tanganyika supports fairly pristine habitats, with the major threats remaining fairly localised in and around the larger centres of human population. However with increasing pressure on natural resources driven by high rates of population growth within the lake catchment area, the impacts of these threats are likely to become more widespread and increase in severity (Patterson, 2000; Bailey-Watts *et al.*, 2000; Lindley, 2000).

5.5.2.1 Sedimentation

The LTBP Sedimentation Special Study (SedSS) concluded that erosion is a serious problem in certain areas of the Lake Tanganyika catchment, due to deforestation and inappropriate

farming practices. This has resulted in a large increase in suspended solids entering the lake compared to historical rates of input. A complex array of factors affects the distribution sedimentation and its horizontal transport within the lake is not yet well understood. Nevertheless, evidence from SedSS research suggests that littoral sites within 10 km of the point of discharge of medium sized catchments (approx. 50 km² – 4,000 km²) are most at risk (Patterson, 2000). Significantly however, in a study conducted in and around Gombe National Park, rates of sedimentation were found to be an order of magnitude lower in pristine environments, where the catchment area was protected, than in impacted areas (Nkotagu and Mwambo, 2000)

LTBP research into the direct impacts of sedimentation on the biodiversity of the lake has been limited and the results are incomplete. However, paleolimnological work carried out by SedSS suggests that, when disturbance in an area is very high and total sedimentation is increasing, diversity is invariably low and communities are dominated by species tolerant of high sediment loading. Similarly sediment-addition field experiments conducted on rocky habitats demonstrated a negative impact from sedimentation on gastropod populations (interpretation of the results for fish populations are not yet concluded). In contrast, research into the effects of sediments on chironomid faunas did not identify significant impacts on diversity or species composition (Patterson, 2000).

In an earlier study on sedimentation effects on fish, mollusc and ostracod populations in Lake Tanganyika, Alin *et al.* (1999) found that diversity was generally negatively correlated with disturbance level. One of the most likely reasons for this is simplification of the habitat structure as cracks and crevices filled up with mud and sand. This left fewer refugia from predation for many species and their juveniles and a reduction in available habitat area for cryptic and nocturnal species. Furthermore, they point out that many Lake Tanganyika fish species are substrate spawners and therefore excessive sediment deposition on the substrate may adversely affect reproductive success of fishes.

They also argue that as benthic productivity on rocks exceeds that on sand, a reduction in the area of rocky substrate could possibly have magnified effects on diversity and abundance at higher trophic levels. Moreover, the same patchy habitat distribution combined with the tendency to habitat specificity and stenotopy that stimulated speciation, may also enhance susceptibility to extinction, as distance between neighbouring populations is increased by habitat destruction and fragmentation and opportunities for re-colonisation are likewise restricted.

As yet, it is difficult to determine what the precise effects of increased sediment deposition will have on different taxonomic groups since, because of varying characteristics, these groups will have different response thresholds to perturbation. In time however, this is likely to lead to greater habitat homogeneity in the littoral-sublittoral zones of the lake, as rocky substrates are inundated with soft substrates, resulting in a corresponding fall in species diversity (Alin *et al.*, 1999)

5.5.2.2 Pollution

The work conducted by Pollution Special Study (PoISS) suggests that Lake Tanganyika is currently relatively unaffected by pollution, in spite of the fact that industrial and domestic waste is never treated before being emitted into the lake. In general the lake waters remain oligotrophic and PoISS inventories of industrial pollution, water quality analysis and phytoplankton studies suggest that pollution is not currently damaging water quality or altering food webs. This is principally because, at their current low levels, pollutants are rapidly diluted on entering the lake (Bailey-Watts *et al.*, 2000).

The exceptions to this overall assessment are the major lakeside urban centres. In Kigoma Bay there is a discernible trend towards eutrophication and in Bujumbura Bay the quantity of industrial contaminants being emitted into the lake is cause for concern. Furthermore, the high rate of population growth within the catchment area is likely to lead to an increase in pollution, which could have serious long-term consequences for the ecological health of the lake. This is particularly alarming given that Lake Tanganyika has an average residence time

of 440 years and a flushing time of 7000 years, so the process of amelioration could span generations (Bailey-Watts *et al.*, 2000).

Little work has been conducted on the effects on biodiversity of different types of pollution. Alin *et al.* (1999) felt that eutrophication, might favour some species, but could also lead to reduced population sizes and local extinction of others. They also suggest that surplus nutrient influx and biological oxygen demand may contribute to increased bacterial production and lead to anoxic conditions near the substrate-water interface at depths much shallower than the oxycline. Furthermore, industrial and domestic pollution may have led to a reduction in species richness and changes in community composition in locations such as Bujumbura and Mpulungu harbours (Pers. Comm. Ntakimazi and Mwape).

5.5.2.3 *Over-fishing*

The Fishing Practices Special Study (FPSS) has reported that many diverse littoral and sub-littoral fish communities adjacent to areas of high population settlement are subject to heavier fishing pressure than previously thought. These inshore fisheries are complex, as they are multi-species, multi-gear (more than 50 gears have been identified by FPSS) and involve both artisanal and subsistence fishermen, so it is difficult to assess their full impact. Nevertheless, the cumulative off-take is estimated to be considerable (Lindley, 2000). FPSS noted the importance of the pelagic fishery to many small-scale artisanal fishermen, predicting that the effect of a failed pelagic fishery would be to increase pressure on the coastal zone through greater reliance on littoral fish resources and land for agriculture (Cowan and Lindley, 2000).

The indirect effect of over-fishing is that it decreases the resilience of fish populations thus rendering them more vulnerable to environmental change (Lauck *et al.*, 1998). Sanyanga *et al.*, (1995) surmised that Cichlids in Lake Kariba were particularly vulnerable to intense fishing pressure because many species guard their nests or mouth brood thereby investing in a strategy of high survival rates but low fecundity. Likewise, many fish populations of Lake Tanganyika may lack resilience owing to their low fecundity, small population size, stenotopy and limited distribution range (Cohen, 1994)

National Parks (see next section) provide a potential means of limiting the impacts of fishing on biodiversity. Two of the terrestrial national parks have an aquatic zone – Mahale and Nsumbu. In both cases fishing is prohibited, and though resources available for enforcing this are small, it appears that illegal exploitation is limited (pers. Comm. park staff Mahale and Nsumbu National Parks). Though the area adjacent to Gombe is not officially protected, beach seining is banned and the issuing of gillnetting licences is at the discretion of park authorities. Owing to the short length of the shoreline few resources are required to enforce these controls and therefore the fishing intensity is low (pers. comm. D. Sellanyika). The waters off Rusizi National Park are not protected and are heavily fished. More detail on the status of each of the National parks is given in Table 5.7.

5.5.3 *Protected areas as a conservation tool*

5.5.3.1 *Positive aspects of protected areas*

The two principal functions of reserves are to sample or represent the biodiversity of the systems in which they occur and they should separate this biodiversity from processes that threaten it (Margules and Pressey, 2000). From the analysis conducted so far, Lake Tanganyika's protected area network clearly contributes significantly to fulfilling the first requirement. To what extent it satisfies the second requirement is less clear. The large body of literature concerning aquatic reserves is almost exclusively concerned with marine systems and areas where management for fisheries is the guiding factor. Nevertheless, many of the issues concerning the effectiveness of marine reserves are pertinent to the conditions in Lake Tanganyika.

Aquatic reserves are widely held to provide a buffer from potential threats that increases the chances of sustainability of the communities within their boundaries (Mangel, 2000) principally

through direct habitat protection (Williams, 1998). The current status of parks in Lake Tanganyika would appear to support this view. All of them offer a substantial degree of protection to the catchment adjacent to the lakeshore. This means the vegetation is largely undisturbed and consequently sedimentation remains at natural levels (Nkotagu and Mwambo, 2000). In addition the restrictions placed on human activities within the park combined with their remoteness from major centres of human habitation (with the exception of Rusizi National Park) reduces their vulnerability to pollution. Though in reality aquatic parks remain vulnerable to pollution threats since their boundaries provide no physical barrier to pollutants, which may originate from far beyond the borders of the park, contaminating the waters within it.

Parks also potentially provide protection from human exploitation of aquatic resources, which in the case of Lake Tanganyika takes the form of fishing. Studies of marine reserves suggest that where fishing is excluded fish biomass increases (Roberts, 1995; Walls, 1998;), and as a consequence the production of eggs and larvae increases (Williams, 1998). There is also some evidence for higher catches in adjacent fishing areas as juvenile and adult fish move out of refuges in response to increased crowding and competition (Roberts and Polunin, 1991; DeMartini, 1993; Attwood and Bennett, 1994; Williams 1998). Lauck *et al.*, (1998) goes as far as to state that owing to the insurance offered by an effective reserve system, the exploited areas can probably be fished somewhat more intensively than would be desirable in the absence of the reserve. The extent to which this is applicable to Lake Tanganyika is questionable, since aside from the pelagic species of clupeids and *Lates* sp., many fish species in the lake are highly stenotopic and have restricted ranges and are unlikely to be effective in restocking exploited areas. It is therefore likely that the most important function of protected areas in terms of their effect on fish resources will probably be limited to those associated with the reduction of mortality on one portion of a much larger population of fishes highlighted by Idechong and Graham (1998) in their studies of small marine reserves in the Ngerukewid Islands of Palau.

In only two of the parks, Mahale and Nsumbu, are the adjacent waters immediately included in the park boundaries. In both cases fishing is prohibited, and though resources available for enforcing this are not extensive, it appears that illegal exploitation is limited (see section 5.5.2.3). More detail on the status of each of the National parks is given in Table 5.7.

5.5.3.2 *Problems associated with protected areas*

Our results show that the existing parks on Lake Tanganyika encompass significant species diversity and provide a measure of protection within their boundaries. But protected areas in isolation do not guarantee effective biodiversity conservation. They have inherent features which limit their effectiveness and they remain vulnerable to a variety of environmental and anthropogenic threats.

Whilst reserves might contain a significant number of species they do not necessarily contain viable populations of those species. Biogeography theory asserts that bigger reserves are more robust, that they should preferably be close together and, in any case, be linked by habitat corridors. In reality many constraints, often political and socio-economic, prevent such guidelines being applied. At best, where the area available for protection is limited, choices may have to be made between a few large reserves or a combination of smaller reserves that together are more representative of the region's biodiversity but individually are less effective for the persistence of some species (Margules and Pressey, 2000). Small reserves are more susceptible to losing their species if they become remnants of natural habitat surrounded by a hostile habitat, as a result of increasing and intensifying human activities (Folke *et al.*, 1996).

Water is an efficient medium for the transport of dissolved nutrient, sediments, pollutants and both juvenile and adult organisms. Consequently, irrespective of size, no aquatic protected area is immune to negative impacts, which originate off-site and sometimes at considerable distance in linked habitats, whether land based, atmospheric or aquatic (Williams, 1998; Horrill *et al.*, 1996). The waters adjacent to Rusizi illustrate this. The major threats to their diversity originate in the Rusizi basin and are not mitigated by the small area of the delta, which is currently protected. Nor would extending the park boundary into the lake itself

enhance the protection from threats originating in the wider basin, though it might reduce the impact of the present intensive fishing effort.

When assessing the advantages or disadvantages of National parks, however, it is important to look beyond exclusively ecological or conservation factors. Effective management of protected areas requires a level of resource allocation, which few developing nations are able to provide given the many pressing demands on their often limited resource base. Consequently parks are invariably understaffed and under-funded, with the result that often inadequately trained staff have neither the equipment nor logistical capability to implement management plans properly. This is clearly demonstrated on Lake Tanganyika by the minimal policing effort of aquatic zones conducted in Mahale and Nsumbu National Parks. In the case of Mahale illegal fishing is currently maintained at low levels, not by the activities of the park authorities, but by the lack of security for fisherman given the proximity of the conflict in DR Congo. Similarly, the enforcement capability of the park rangers at Nsumbu is negligible (they have no boats) and the most vigorous policing is conducted by staff from the two tourist lodges located in Nkamba Bay. Resource allocation is also determined by political will and protected areas must enjoy political support at high levels if they are to succeed (Pearson and Shehata, 1998). Rusizi National Park in Burundi is an example of a protected area, which has suffered from a lack of political will to maintain its integrity. Pressure from a variety of sources including cattle grazing and urban development, has led to a decision by the government to downgrade its status from national park to nature reserve and reduce its size drastically from 8,000 to an estimated 5,000 ha (Pers. comm. West).

Amongst advocates of national parks there has been a tendency to extol their potential value in socio-economic terms. In reality however, biodiversity conservation is often at odds with socio-economic aspirations of local stakeholders, and this leads to a policy of containment (Few, 2000). Understandably the establishment of protected areas generates deep resentment in communities that find themselves excluded from resources to which they have traditionally had access, which in turn undermines the viability of those protected areas (Horrill *et al.*, 1996).

There is therefore an urgent need for realistic assessment of the value of National Parks to local people and development through ecotourism. Coulter and Mubamba (1993), Cohen (1994) and Coulter (1999) all assume that parks will benefit local people, as well as conservation. Worldwide, the evidence suggests the contrary; the benefits of protected areas accrue internationally, while the costs are borne locally (Wells, 1992). A cursory glance at the visitor figures for the existing terrestrial parks, and budgets and employment registers for those parks is enough to show that an ecotourism boom is unlikely without radical change in the present political and regional economy.

“[The] majority of protected areas have limited tourism potential due to lack of infrastructure, difficulty of access, political instability, ineffective marketing, or simply the absence of spectacular or readily-visible natural features”.

Wells, 1992, p240.

Even the most enthusiastic of Lake Tanganyika's advocates for development-through-ecotourism must recognise some features of the Lake's protected areas from the above description! See Table 5.7, Table 5.7, Table 5.8, Table 5.9, Table 5.10 and Table 5.11. They will also recognise that these shortcomings are not easily addressed. The implications are clear: the main beneficiaries for protected area management in Lake Tanganyika are international, and the costs of developing parks that will attract visitors will be considerable. If park regulations forbid any fisheries exploitation, then effective implementation of such regulations would yield zero benefits locally. An example from that of Lake Tanganyika is that of Nsumbu National Park, Zambia, where local fishermen are excluded from exploiting the parks resources in the interests of safeguarding the tourism industry founded on sport fishing, and yet enjoy negligible benefits from tourism. We cannot therefore, in all conscience, recommend the diversion of much-needed development funding from national budgets towards an economic development strategy based on eco-tourism support. If the international community wishes to support protection, models similar to that for Gombe,

where research funding supports conservation of a forest enclave, must be sought. The costs of such management must be borne internationally.

5.5.4 Preliminary SWOT analysis of existing and proposed National Parks

A preliminary analysis of the 'Strengths, Weaknesses, Opportunities, and Threats' of the Lake's existing and proposed protected areas was undertaken by a team of Burundian, Congolese, Zambian and Tanzanian scientists and National Parks ecologists, in Kigoma in February 2000. The analysis was loosely based on the 'SWOT' model commonly applied to institutional analysis in management science (Armstrong, 1986). We adapted the SWOT framework to present key information on:

- biodiversity and conservation attributes of the parks (loosely based on 'Strengths');
- assessment of feasibility of conservation action (a combination of Strengths and Weaknesses);
- current threats to biodiversity (Threats);
- potential for ecotourism development or other direct or indirect benefit of biodiversity conservation (Opportunities).

The results are summarised in Table 5.7 to Table 5.11. We recognise that such an analysis would ideally be conducted with a range of stakeholders participating in the process. It serves to highlight the need for a stronger information base upon which to make recommendations for park planning and management.

Table 5.7 Current status and viability of the aquatic zones in Mahale National Park

MAHALE MOUNTAINS NATIONAL PARK, TANZANIA	
Biodiversity Criteria	
<i>Aquatic species</i>	Flagship species: fish – Tropheini and Lamprologini tribes, <i>Petrochromis spp.</i> Species richness: high
<i>Aquatic habitats</i>	Sandy, rocky and mixed (sand and rock) habitats well represented throughout park. <i>Neothauma</i> shell beds at Sitolo, Mabilibili and Busisi bays. Stromatolites at Nsele.
<i>Other</i>	Terrestrial fauna: Mahale supports 9 species of Simian (including Chimpanzee), more than any other park in Tanzania.
Reason for conservation	Supports the highest aquatic diversity of any lakeside protected area.
Type and level of threat	Fishing only potential threat. Fishermen from Kalilani and Sibwesa fishing villages fish illegally within park at northern and southern boundaries respectively. Central areas of park too far for local fishermen. Formerly illegal fishing by Congolese was extensive, now disrupted by conflict in DRC.
Feasibility	
<i>Legal status</i>	Well established; the park extends 1.6 km into lake.
<i>Costs/benefits to local community</i>	Costs; ongoing, denial of access to fish resources. Benefits; current limited opportunities as safari guides and camp staff potentially expanded by introduction of sport fishing.
<i>Enforcement</i>	Insufficient TANAPA manpower and equipment for adequate policing of the aquatic park. Not possible to mount regular patrols by boat. If active protection were confined to a 200 – 300 m band adjacent to shore task would be made easier
Tourism Potential	
<i>Infrastructure</i>	Transport: plane; Arusha to Mahale boat; Kigoma to Mahale (journey time 6-10 hrs) no vehicle roads within the park – walking only. Facilities: accommodation and catering very basic
<i>Attractions</i>	Lakeside scenery and beaches. Abundance of species favoured as sport fish. Water visibility ideal for underwater viewing of aquatic fauna.
<i>Market</i>	Currently trekking, chimp watching. Opportunities for attracting sport fishermen as yet untapped. Potential for snorkelling and scuba diving limited by ubiquitous threat from hippos and crocodiles. High fish diversity could attract paying research scientists and aquarium collectors.
<i>Security</i>	Currently uncertain; occasional bandit activity along coast and park has been used as a refuge for Congolese combatants

Table 5.8 Current status and viability of the aquatic zones adjacent to Rusizi National Park

RUSIZI NATIONAL PARK, BURUNDI	
Biodiversity Criteria	
<i>Aquatic species</i>	Flagship species: Fish - <i>Polypterus spp</i> and <i>Protopterus aethiopicus</i> Species richness: High. Particularly rich in non-cichlid species. Includes river to lake to river migrants such as <i>Alestes macrophthalmus</i> and <i>Raiamas spp.</i>
<i>Aquatic habitats</i>	Delta and riverine; reed beds, lagoons, large rivers and floodplain Littoral; sand with some rocks. Offshore; shallow shelf area, 2 km to reach deep water.
<i>Other</i>	Birds; migrant and resident Vegetation; flood plain
Reason for conservation	Protection of distinctive habitats that provide spawning and nursery grounds for many fish species including commercially important pelagics – <i>Lates sp</i> , <i>Boulengerochromis microlepis</i> , <i>Limnothrissa miodon</i> .
Type and level of threat	Population pressure around Gatumba village (100,000 people) now a suburb of Bujumbura. Fishing; intensive in lake and lagoons, none in river due to hippos, crocodiles and the strong current. Agriculture and industry; land purchase and encroachment for enterprises and access to grazing. Land loss has occurred with support of Ministry of Agriculture. Potential environmental threats from Lake Kivu 150 km away.
Feasibility	
<i>Legal status</i>	Current boundary is the land/water interface, therefore no protection for adjacent aquatic areas. Recommended; the creation of an “Aquatic Management Area” with seasonal exclusion (March – May and November – December) of fishing out to 1km, to cover main fish spawning periods. DRC part of Rusizi delta should be designated as zone where agricultural or industrial activities prohibited or controlled.
<i>Costs/benefits to local community</i>	Costs; any restriction of access to fish stocks in the delta and littoral areas would involve considerable costs to local communities. Benefit; potential expansion of pelagic fisheries through the protection of spawning and nursery grounds
<i>Enforcement</i>	Protection of the park by INECN ineffective. Clear delineation of park boundaries would help. Under present security conditions enforcement fisheries regulations is very difficult. Participatory management by local farming/fishing communities will be essential in future strategies
Tourism Potential	
<i>Infrastructure</i>	Transport: road; easy access from Bujumbura boat; no special boat tours from city to delta and river. Facilities: limited, no visitors centre or information leaflets, wooden viewing towers
<i>Attractions</i>	Currently the bird life, crocodiles and hippos. Water unsafe for aquatic sports and visibility too poor for diving or snorkelling. Alternative to a conventional park could be creation of a zoological garden, intensively managed and stocked with a variety of mammal species.
<i>Market</i>	Predominantly expatriates working in Bujumbura. Some overseas ornithologists visit as part of East African tour.
<i>Security</i>	Currently a major deterrent to visitors both from Burundi and overseas.

Table 5.9 Current status and viability of the aquatic zones in Nsumbu National Park

NSUMBU NATIONAL PARK, ZAMBIA	
Biodiversity Criteria	
<i>Aquatic species</i>	Flagship species: fish – <i>Lates spp</i> , <i>Boulengerochromis microlepis</i> , <i>Citharinus gibbosus</i> . Species richness: high
<i>Aquatic habitats</i>	Predominantly sandy, but rock and mixed (sand and rock) habitats also well represented. <i>Neothauma</i> shell beds between Nsumbu village and Nundo Point.
<i>Other</i>	Terrestrial: four of the “big five” mammals present in the park but in low densities. Iyendwe Valley a wetland of international significance borders on the park.
Reason for conservation	The protection of high levels of aquatic biodiversity and maintenance of fish stocks for sport fishing based tourism.
Type and level of threat	Pressure on park resources increasing owing to growing population on north western side of park due to influx of refugees from the Congo war. Fishing; limited seasonal beach seine and gill net fishing authorised near Nsumbu village; Some poaching in Nkamba Bay.
Feasibility	
<i>Legal status</i>	The park aquatic zone extends 1.6 km into lake. Some demarcation disputes particularly in Nkamba Bay. Could be resolved if the boundary ran across the mouth of the bay from Nundo Pt to the Nangu Peninsula.
<i>Costs/benefits to local community</i>	Costs; ongoing for local communities through loss of potential fishing areas. Benefits; the tourist lodges employ local villagers as domestic staff and both game and fishing guides.
<i>Enforcement</i>	The Parks and Wildlife Service is understaffed and poorly equipped. They rely on local or DoF boats for transport. Policing of aquatic areas is driven and largely executed by tourist lodge management, who are often honorary game rangers, with support from parks staff. Park management may improve with the formation of the Zambian Wildlife Authority
Tourism Potential	
<i>Infrastructure</i>	Transport; plane from Kasama or Lusaka to Kasaba Bay Lodge and onward to other lodges by boat, road from Kasama to Nkamba Bay dry season only. Facilities; luxury accommodation and facilities are available at the tourist lodges. It is also possible to stay at basic chalets provided by the park authorities.
<i>Attractions</i>	Game viewing. Species prized as sport fish. Fishing competitions organised by tourist lodges.
<i>Market</i>	Sport fishermen, wildlife enthusiasts. Lake Tanganyika competes with Lake Kariba, which is much closer to other popular attractions with better infrastructure such as Victoria falls and Lower Zambezi National Park. Minimal potential for dive or snorkelling tourism exists due to very high crocodile populations. Paying research scientists and collectors for the aquarium trade.
<i>Security</i>	Good, but is vulnerable to repercussions from war in DRC.

Table 5.10 Current status and viability of the aquatic zones adjacent to Gombe National Park

GOMBE NATIONAL PARK, TANZANIA	
Biodiversity Criteria	
<i>Aquatic species</i>	Flagship species; fish – <i>Cyphotilapia frontosa</i> Species richness: high
<i>Aquatic habitats</i>	Rocks, cobbles and sand in shallow littoral zone. Rock at about 40 m depth.
<i>Other</i>	Terrestrial fauna: chimpanzee
Reason for conservation	Park founded to preserve the habitat for a remnant population of chimps. The principal impetus for continued protection provided by research activities of the Jane Goodall Institute. Protection of littoral zone would ensure preservation of fish nesting sites in the extensive areas of sandy shoreline.
Type and level of threat	Fishing; some line fishing and gillnet fishing occurs inshore. Currently fishermen have access to shore but numbers much reduced due to banning of beach seining. Sedimentation; potential threat from deforestation on eastern boundary due to increasing population pressure.
Feasibility	
<i>Legal status</i>	Park boundary is 100 m inland of lakeshore. Recommended that fishing with bottom gear is prohibited within 200-300 m of shore. Line fishing should be allowed to continue within this zone.
<i>Costs/benefits to local community</i>	Costs; effects of ban on beach seining continue to impact on nearby fishing communities. Further restrictions on bottom fishing would not increase costs significantly because TANAPA currently issue very few licences. Benefits; at present this is confined to limited employment generated by chimp research and tourism. The extent to which current and future restrictions on fishing in the littoral zone will lead to an improvement in offshore fishery is not yet known.
<i>Enforcement</i>	Because the park shore is short (16 km) and linear, a modest increase in TANAPA resources would probably provide adequate protection for the littoral zone. TANAPA is keen to establish an aquatic buffer zone to reduce disturbance for primates or the possible introduction of human borne diseases
Tourism Potential	
<i>Infrastructure</i>	Transport; boats from hotels in Kigoma. Facilities; accommodation is simple but adequate.
<i>Attractions</i>	Chimp watching is the reason that visitors come to the park. Additional attractions are the pleasant beaches and clear water which are free from crocodiles and hippos. The number of tourists permitted in the forest at any one time is limited, therefore snorkelling could provide an alternative activity for groups are waiting their turn.
<i>Market</i>	Primate enthusiasts. As research is the primary focus for the park, there has been a deliberate policy of limiting visitor numbers.
<i>Security</i>	Good

Table 5.11 Current status and viability of the aquatic zones adjacent to Pemba, Luhanga and Bangwe

PEMBA, LUHANGA, BANGWE, Democratic Republic of CONGO	
Biodiversity Criteria	
<i>Aquatic species</i>	Flagship species: fish - Pemba; <i>Tropheus duboisi</i> (Red colour-morph). Luhanga; <i>Neolamprologus leleupi</i> Species richness: high
<i>Aquatic habitats</i>	Rocky, flanked by sandy beaches.
Reason for conservation	The need to conserve sites of aquatic diversity in the northern part of DRC shore and as an important study site for scientist based out of CRH. These sites could provide a vehicle for increasing environmental awareness of local population.
Type and level of threat	Fishing; minimal – not suitable for gillnets due to sharply sloping rocky substrate. Intensive beach seining carried out on adjacent beaches. Fishing collection for aquarium trade. Sedimentation; deforestation at Luhanga and Pemba Increasing population pressure particularly at Bangwe village.
Feasibility	
<i>Legal status</i>	Currently there is no formal protection of the aquatic zone or the land adjacent to it. Formal park protection is not necessary. All three locations could be declared “Sites of Special Scientific Interest” (SSI) in order to highlight their conservation importance. Intervention is required to reverse increase in sediment load. A reforestation programme led by local NGO, is recommended.
<i>Costs/benefits to local community</i>	Costs; these would be minimal. Benefits; the SSIs would act as focus for reforestation.
<i>Enforcement</i>	No formal enforcement is required. The aim would be to conserve through increased awareness of conservation importance.
Tourism Potential	
<i>Infrastructure</i>	Transport; the road link from Uvira is good. Facilities; accommodation is available for 9 people at CRH, Uvira.
<i>Attractions</i>	Diving; visibility is good, there are no crocodiles or hippos. Scientific research; the sites are ideal for the study of rocky substrate aquatic communities and are close to the newly refurbished CRH facilities.
<i>Market</i>	Research scientists, expeditions conducted by organisations such as Earthwatch or Frontier, expatriates from Bujumbura dive club.
<i>Security</i>	Security; at present this severely restricts the activities that can be carried out at these sites.

The analysis indicates that all the riparian parks possess significant biodiversity and conservation attributes with regard to both their terrestrial zones and the adjacent littoral waters. Mahale and Gombe are important refuges for remnant populations of primates and in particular Chimpanzees, which have been the focus of considerable research effort. Indeed it is arguable that Gombe National Park owes its continued existence to the ongoing research activities of the Jane Goodall Institute. Rusizi National Park supports an internationally renowned population of resident and migratory birds. The BioSS survey programme has shown that the existing parks network offers a measure of protection to a wide spectrum of underwater habitats and a substantial proportion of the fish and mollusc species of lake, among them many flagship species such as the Tropheini, Lamprologeni and *Petrochromis* species. The Rusizi National Park and its adjacent waters are particularly important in that they contain habitats and species not well represented in other national parks.

With the exception of Rusizi, whose status is currently being downgraded, all the parks enjoy a long standing and well established legal status. Nevertheless they are all subject to threats posed by increasing population pressure on their boundaries, both in terms of habitat destruction (tree felling) and poaching of both terrestrial and aquatic fauna. At present they are all ill-equipped to meet such threats, through lack of equipment, manpower and funds to support conservation and enforcement activities. The fact that the levels of impact on their resources is not greater is due to external factors such as the instability in DR Congo and the remoteness of park hinterlands from human populations and, in the case of Nsumbu, the policing activities of tourist lodge staff.

Currently costs of national parks are borne almost entirely by the communities on their borders, who are denied access to the resources within - notably fish - which they traditionally enjoyed. What benefits accrue from the existence of the parks are usually felt internationally or at least away from parks themselves. The benefits to local people are minimal and amount to very limited employment opportunities as tourist lodge and camp staff, as well as safari and fishing guides. Nor is there any discernable potential for growth in the tourism industry. Lake Tanganyika and its shoreline boasts considerable attractions in terms of scenery and wildlife above and below the water. Nevertheless, the current status of infrastructure and facilities means that it is unlikely to attract tourists away from other well-established tourist locations in the region. Furthermore, the current instability in the region and well-publicised security incidents have probably acted as a deterrent to would-be visitors. Until these problems are resolved it is difficult to envisage an expansion of the tourist industry around the lake. Even if it were to take place, there is no reason to assume that local communities will benefit from such activities any more than they do in the vast majority of wildlife tourism operations in Sub-Saharan Africa.

5.5.5 Alternatives to protected areas

Protected areas can play an important role in preserving biodiversity, but are not in themselves sufficient to solve the problem of biodiversity loss (Folke *et al.*, 1996). Furthermore analysis of BIOSS survey results tells us that while each area sampled supports unique species, these unique species make up a very low proportion of total species richness in each area, and it would be impossible to guarantee protection of all species without protecting a very high percentage of the whole coastal zone. In other words, expanding the protected area network significantly will add only marginally to the species officially protected. This together with the difficulties associated with establishing and maintaining an effective protective area network, suggests a lower level of protection, aimed at larger areas of coast, will be most appropriate for ensuring survival of the small proportion of those taxa that have spatially limited distributions. The argument for a conservation strategy, which operates beyond the boundaries of national parks, is least weight by the fact that the role of biodiversity in the functioning of ecosystem performance is not limited to protected areas. Conservation should seek to maintain levels of biodiversity that will guarantee the resilience of ecosystems wherever possible (Folke *et al.*, 1996).

This can be achieved through adoption of a Coastal Zone Management (CZM) Strategy, which has as its core an established protected areas system that contains a large proportion of representative habitat types and species (Horrill *et al.*, 1996). CZM however embraces a

more multiple use and integrated management approach and acknowledges that both consumptive and non-consumptive natural resource use can be compatible with conservation (Williams, 1998). Acceptable uses and sustainability levels must be determined, based on best available knowledge, and implemented in cooperation with the different economic sectors in accordance with long-term conservation interests. This requires a highly flexible approach to management.

A key element of CZM is the zoning of areas according to their conservation importance, the degree of threat to them, and requirements for human development. This system of zoning sets out the type of coastal development permitted in specific areas, in order to prevent it threatening littoral biodiversity. CZM would aim to minimise conflicts between different coastal zone uses, and to locate developments according to a predetermined plan as opposed to the haphazard development, which is characteristic of many regions, including Lake Tanganyika, at present. This process can also provide a means of mitigating the negative effects on biodiversity engendered by past-unplanned development.

The CZM approach provides appropriate levels of protection to specific habitats in a more cost effective manner than management that relies on an extensive protected areas network. It recognises the need to combine the management of near-shore waters with adjacent terrestrial zones at the same time as taking into account human-development needs in both these areas. Clark (1998) provides a basic introduction to the tools and approach of CZM.

One component of CZM could be the devolvement of responsibility for management of certain areas of the lake to lakeside communities. One of the main reasons for the poor success of government initiatives to conserve biodiversity is lack of community involvement, yet many subsistence fishers in tropical regions live in discrete communities that have some degree of control, either legal or traditional, over adjacent waters. This provides an appropriate basis on which communities can be encouraged and empowered to manage their own marine resources with a far more modest requirement for resources than for national reserves (King and Faasili, 1998).

Community fisheries management has been initiated on Lakes Malawi and Chiuta in the early 1990s in Malawi - a process that has involved changes to rights of access, the assumption of limited legal authority by communities and the introduction of a system of positive incentives for conservation (Sholtz *et al.*, 1998). Scientific input, in the form of research and monitoring, has been an integral part of such schemes and vital to their success. Partnerships of this type, between government science, monitoring and policy-making capacity, and local management and enforcement capacity, are known as co-management systems, and are being widely promoted in fisheries and resource management around the world (e.g. Jentoft and McCay, 1995).

It can also be argued that, rather than focusing attention on areas with the highest diversity, the goal of a conservation strategy should be to identify the major social and economic forces that are currently driving the loss of biological diversity and to create incentives to redirect those forces. This process would involve reducing the differences between the value of biological diversity to the private individual and to society as a whole and would be facilitated by developing institutions, policies and patterns of human consumption and production that work in sympathy with ecosystem functions and processes (Folke *et al.*, 1996).

5.5.6 Conclusion

As pressure on Lake Tanganyika's resources increases with population growth, threats to the lake's biodiversity are likely to increase in intensity and effective conservation measures will be essential if the integrity of aquatic ecosystems and the ecological services they provide are to be maintained. The existing system of national parks contributes significantly to protection of biodiversity in Lake Tanganyika, including representation of all the main aquatic habitat types and a high proportion of fish and mollusc species. But the parks are isolated, constitute only a fraction of the coastline and there are no guarantees that the populations that they support would be viable if surrounded by hostile environments. The feasibility of achieving a more comprehensive level of protection through an extension of the present parks network is

highly questionable for the reasons outlined above. For this reason we have highlighted the alternative of a Coastal Zone Management strategy, which combines the goals of biodiversity conservation with development and stakeholder participation. Few (2000) goes even further when he calls for a fundamental shift to an approach which starts with the presumption of continued human access and the exploration of means to conserve biodiversity within those parameters.