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Biodiversity Assessment and Conservation in Lake Tanganyika

BIOSS FINAL TECHNICAL REPORT

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

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

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

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EXECUTIVE SUMMARY

1. Lake Tanganyika is one of the world's biodiversity 'hotspots'. Its diversity is threatened by the impact of human activity in the lake and its catchment. The Lake Tanganyika Biodiversity Project (LTBP) was conceived as a means of providing a regional framework for the management of the lake and protection of its biodiversity. The Biodiversity Special Study (BIOSS) provided technical advice to the project on techniques for biodiversity survey design and assessment and on current management approaches used for biodiversity conservation. We also undertook a range of training and capacity building activities in support of LTBP objectives.

2. The main aim of the BIOSS was to support the development of a strategic action plan (SAP) to manage Lake Tanganyika. The aim of the strategic action plan is "to provide for the regional management of Lake Tanganyika to enable the sustainable management of biodiversity and the livelihoods of present and future generations of lakeside communities."

   The specific objectives of the SAP that the BIOSS study addressed most directly were:
   - "Define and prioritise the management actions required to conserve biodiversity of Lake Tanganyika"
   - "Enable the Lake Basin Management Committee to provide guidance to the international community on the needs of the Lake Tanganyika region in terms of biodiversity conservation and sustainable use of resources".

   To achieve these aims the BIOSS had four key objectives:
   - Review current levels of biodiversity in Lake Tanganyika;
   - Identify the distribution of major habitat types, with particular focus on existing and suggested protected areas;
   - Suggest priority areas for conservation, based on existing knowledge and recommendations from other SS and supplemented by additional survey work where necessary; and,
   - Develop a sustainable biodiversity monitoring programme.

3. This technical report provides the results of research activities directed towards addressing these objectives. We review the concepts and processes that led to the choice of methodology, and validate that methodology (Chapter 2). We present a summary analysis of current knowledge about biodiversity relevant to conservation based on analysis of available secondary information (Chapter 3), and the results of surveys conducted by the BIOSS team from 1997-1999 (Chapter 4). These data are used to provide an improved basis for conservation decision-making (Chapter 5). We conclude with a summary of recommendations for approaches to conservation, management action, monitoring, and research priorities (Chapter 6). The report also provides an extensive bibliography (Chapter 7) and an archive for important data (Chapter 8).

4. Development of suitable survey approaches, yielding standardised protocols for comparative assessments of biodiversity, occupied a considerable part of the BIOSS programme. We paid attention to process considerations as well as the delivery of technical outputs in the form of survey data. Thus, we adopted practices that were implemented with the full participation of local scientists and technical assistants. Teams from Burundi, DR Congo, Tanzania and Zambia all participated in the design and testing of the survey methods. This has ensured a high level of ownership and understanding of the survey methodology, which sould ensure it is used in future survey activities.

5. Most taxa in the lake are not sufficiently well known taxonomically to form the basis for large-scale survey activities. The main techniques developed were therefore standardised protocols for sampling the very diverse fish community, as total biodiversity surrogates. Three fish-survey techniques were developed for the project, two SCUBA based techniques – Stationary visual census (SVC) and Rapid visual census (RVC) - and

standardised protocols for gillnet surveys. These techniques were carefully assessed for sampling bias, complementarity and minimum required sampling size. We also developed protocols for sampling molluscs. For future surveys that aim to characterise species richness in areas to be compared for conservation prioritisation we recommend the following minimum sampling sizes and combination of survey techniques:

- RVC – 40 replicates per survey stratum (e.g. area between 5 and 15 m depth);
- Gillnet – 60 night-time sets with 60m multimesh nets per survey area;
- Mollusc transects – 30 per survey stratum (chosen depth-habitat combination); and,
- The SVC technique may be more useful for monitoring surveys, as it covers less ground and takes longer, but may be more precise.

6. Estimates of species richness and diversity are sensitive to sampling size. 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.

7. Most of the work done in Lake Tanganyika prior to this project was not undertaken for the purposes of conservation planning so it is not standardised for this purpose. This inevitably limits its value in comparative analysis, or as baseline data to assess changes over time. This data does, however, provide a rich archival source, which, through the efforts of BIOSS in collating some of it into a relational database, is being made available to regional agencies as a powerful tool for conservation planning and research purposes.

8. Prior to the BIOSS study, 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). BIOSS developed a survey procedure and built up capacity to implement surveys that utilised regional expertise and minimised dependence on external inputs.

9. The habitat surveys 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, including emergent macrophytes, submerged macrophytes, stromatolite reefs, shell beds and all combinations of soft and hard subtrates. They do not necessarily provide the only or best examples of such habitat types, but have the advantage of existing conservation focus. Thus, the fundamental criterion for a protected area network – that it should contain good examples of all habitat types (and by inference the associated biota) – is fulfilled by the existing network.

10. The highest biodiversity, in terms of number of species, is situated in the sub-littoral zone (down to 40 m). We find that a high percentage of this biodiversity is ubiquitous in its distribution, but that there are limited number of taxa with spatially restricted distributions. 73% of described lacustrine fish (90% of species recorded in BIOSS surveys) were found in waters adjacent to existing national parks. A conservation strategy based primarily on maintaining and extending the functions of the existing terrestrial parks is therefore recommended.

11. Fish communities on rocky substrates are more diverse than those on sandy ones, and undisturbed or relatively pristine habitats support higher diversities than those areas close to population centres and subject to disturbance from fishing, pollution and sedimentation. These differences are also evidenct in comparing species richness measures. 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.

12. BIOSS 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. We therefore discuss additional strategies such as coastal zone management and integrated conservation and development.

13. 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 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.

14. LTBP had a strong technical focus, providing essential baseline information for the first management plan for the lake. The basis for scientific monitoring and underpinning of management has been established under LTBP, but the wider skills in communication, joint planning, co-operation between different ministries/disciplines and management are still required. Throughout our report, we have stressed the need to consider process issues as well as deliver technical outputs. If the international community still values this unique lake, we would recommend ongoing support that concentrates more on building the institutional capacity needed to ensure sustainable development of this biodiverse resource. We would also recommend a critical analysis of the costs and benefits of such conservation and explicit development of management approaches that will assist in ensuring that benefits of conservation flow to those who live around the lake, while the costs are borne by all who value it.

ACKNOWLEDGEMENTS

This report represents the written record of a considerable effort by a large number of people. Inevitably, only a sub-set of all these people have been involved in its production and appear as authors here.

Our greatest debt is to those team members who participated in the development of our survey methods and who went on to collect the data analysed in this report. They all had to put up with early attempts at surveying that looked good on paper, but didn't work under water. Their contribution to developing robust and repeatable methods that also generate worthwhile data is gratefully acknowledged. All have been involved in the authorship of other BIOSS reports. We would like to thank all the members of the BIOSS field survey teams:

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	ZULU Isaac	DoF – Mpulungu

When we began, our teams represented a wide range of levels of expertise in the techniques essential for carrying out this work. We had swimmers who didn't know how to identify fish, and fish experts who couldn't swim. Few of us were fully qualified divers with expertise in survey methods. We owe a dept to all participants in training activities and BIOSS workshops over the period 1997-2000. Those who shared their expertise, and the main roles they played, are given overleaf:

Name	Address	Main Roles
Simon Holden Crag Jones John Pearce	MRAG Ltd, 47 Prince's Gate, London SW7 2QA	Design, development and testing of Microsoft Access Survey and Literature databases
Pierre Ndamama	Universite du Burundi, B.P. 2700, Bujumbura, Burundi	Assistance with database queries in Microsoft Access
Dr Paul Tierney	Dept of Zoology, Trinity College Dublin 2, Ireland	Dive training and development of habitat survey protocols
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Dr Koen Martens	Royal Belgian Institute of Natural Sciences, Vautierstraat 29, B - 1000 Brussels, Belgium	Taxonomy and field identification of invertebrates
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Dr M.M. Gashagaza	National University of Rwanda, Faculty of Agriculture, BP 117 Butare, Rwanda	Taxonomy, ecology and field identification of fish
Dr Luc De Vos	National Museums of Kenya, Ichthyology Department, PO Box 406587,Nairobi, Kenya	Taxonomy and field identification of non-cichlid fish

Thanks must go the national park authorities in Mahale, Gombe, Rusizi and Nsumbu. The staff in each park were gracious hosts to the BIOSS survey teams. Their interest in the BIOSS field work illustrated a growing recognition of the value of the aquatic parts of their parks, which bodes well for future conservation efforts.

The coordination of training and research activities of people in different institutions, in four different countries takes considerable organisation. The excellent and enthusiastic support of LTBP's admininstrative team underpinned all our activities and made all the difference in the world. Therefore, we'd like to pay tribute to the contribution of Bahati Barongo in Kigoma, Mamert Maboneza in Bujumbura and Ritesh Bhandari in the Dar es Salaam office.

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1. INTRODUCTION

1.1 Lake Tanganyika and its biodiversity

Whereas most modern lakes were formed by glaciation within the last 12,000 years and have had a history of frequent water chemistry fluctuations and/or desiccation (Wetzel 1983), the African Rift Lakes are geologically long-lived. Dating back about 12 million years (Cohen et al 1993), Lake Tanganyika is the oldest of the African Rift Lakes, and behind Lake Baikal in Russia, it is the second-oldest and second-deepest lake in the world. Four countries bound Lake Tanganyika's 1,838 km perimeter: Burundi (controlling 9% of the coastline); Democratic Republic of Congo (administering 43% of the coastline); Tanzania (governing 36% of the coastline), and Zambia (claiming 12% of the coastline) (statistics from Hanek et al 1993). Lake Tanganyika drains a catchment area of about 220,000 km^2. It is fed by numerous small and two major influent rivers: the Rusizi draining Lake Kivu to the north, and the Malagarasi, draining Western Tanzania south of the Victoria Basin. Only a single outlet, the Lukuga River, drains Lake Tanganyika.

This ancient and nearly closed ecosystem harbours a remarkable fauna. While all of the African Great Lakes host world-famous species flocks[1] of cichlid fish, Lake Tanganyika, in addition to its species flocks of cichlid fish (250+ species), also hosts species flocks of noncichlid fish (145+ species) and invertebrate organisms[2], including gastropods (60+ species), bivalves (15+ species), ostracodes (84+ species), decapods (15+ species), copepods (69+ species), leeches (20+ species), and sponges (9+ species) among others (Coulter 1994). Lake Tanganyika, with more than 1,300 species of plants and animals is one of the richest freshwater ecosystems in the world. More than 600 of these species are endemic (unique) to the Tanganyika Basin and in many cases these taxa also represent endemic genera and sometime endemic families. With its great number of species, including endemic species, genera and families, it is clear that Lake Tanganyika makes an important contribution to global biodiversity.

One might expect that an abundance of species coexisting for a long period of time in a nearly closed environment would show interesting evolutionary patterns and behaviours. They do, including: species that are morphologically similar but genetically distinct, species that are genetically similar but morphologically distinct, species that are evolving robust armour in response to predation, species that diversified in jaw morphology in order to exploit every available trophic niche, and species that have adopted complex reproductive and parental care strategies, including nesting, mouth-brooding and brood parasitism (See Coulter (1991) for a review of these and other topics). With its numerous species exhibiting complex and derived patterns and behaviours, Lake Tanganyika is a natural laboratory for investigating ecological, behavioural and evolutionary questions.

While the cichlid species flocks of Lake Tanganyika are world famous, three non-cichlid species have drawn even more human interest. Two clupeid (sardine) species and *Lates stappersi* dominate the lake's biomass and constitute the target of the lake's artisanal and industrial fisheries. The sardine species, like their marine relatives, are small, numerous, short-lived and highly fecund. The *L. stappersi* is a large predator. The lake wide, annual harvest yields of these fish stocks has been estimated at 165,000 – 200,000 tonnes per year, volumes that translate into earnings of tens of millions of dollars (Reynolds 1999), making them an important part of the ecosystem and the economy.

In addition to being a global repository of biodiversity, Lake Tanganyika plays an important role in the economies of the riparian countries. Tanganyika is a source of fresh water for drinking and other uses. Fish provide a major source of protein in the local diet and the

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[1] Species flocks are groups of closely-related organisms which are endemic to a circumscribed area and possess great species richness compared to other occurences of the group elsewhere.

[2] These invertebrate species numbers are certainly significantly underestimated, as these groups in general have received relatively little attention from taxonomists and in addition, much of the Tanganyikan coast has not been adequately explored. Nonetheless, it is clear that invertebrates in other lakes do not show nearly these levels of diversity.

fishing industry, including harvesting, processing and marketing. Fishing-related occupations are a source of income and employment for more than 1 million people. Transport is another major industry on the lake, which serves as a super-highway connecting people and cargo within and between the riparian countries.

In spite of its importance to global biodiversity and to the economies of the region, Lake Tanganyika is threatened by several potentially disastrous environmental problems. These include: pollution from untreated industrial and domestic wastes, sediment pollution as a result of deforestation, and over fishing or fishing with inappropriate or destructive gears. Concern for Lake Tanganyika's future resulted in the First International Conference on the Conservation and Biodiversity of Lake Tanganyika in Bujumbura in 1991, where regional and international scientists gathered to discuss Tanganyika's riches and the burgeoning threats against it (Cohen, 1991). Ultimately these efforts resulted in the Global Environmental Facility (GEF) initiative for the "protection of biodiversity" through "a coordinated approach to the sustainable management of Lake Tanganyika." The Lake Tanganyika Biodiversity Project was funded by the United Nations Development Program (UNDP), executed by the United Nations Office of Project Services (UNOPS), and implemented by a UK-based consortium consisting of the Natural Resources Institute (NRI), the Marine Resources Assessment Group (MRAG), and the Institute of Freshwater Ecology (IFE).

1.2 The Convention on Biological Diversity and its implementation on Lake Tanganyika

1.2.1 The Convention on Biological Diversity

The Convention on Biological Diversity (CBD) was one of the outputs of the 1992 UN Conference on Environment and Development in Rio de Janeiro (UNEP, 1994). The CBD or 'Convention' is a commitment by the nations of the world to conserve biological diversity. Over 200 countries have signed the Convention, including Burundi, Democratic Republic of Congo, Tanzania, Zambia and the UK. All signatories recognise that biodiversity and biological resources should be conserved for reasons of ethics, economic benefit, and, in the long term, human survival. The objectives of the CBD are:

- Conservation of Biological Diversity
- Sustainable use of its components
- Fair and equitable sharing of the benefits arising out of the utilisation of genetic resources

The Convention has agreed the following definition of 'biodiversity', which is the broad definition used by the Biodiversity Special Study and Lake Tanganyika Biodiversity Project:

> "'Biological Diversity' means the variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems "
>
> (Article 2, Convention on Biological Diversity, UNEP, 1994)

The Convention recognises a very broad range of concerns linked to loss of biodiversity, and provides the policy and legal framework for national and international initiatives to conserve the world's natural resource systems. Glowka *et al.* (1994) provide a detailed overview of the articles of the Convention, and Allison (1998) reviews their relevance to LTBP.

1.2.2 The Global Environment Facility

The Global Environment Facility is a financial mechanism and policy instrument designed specifically to assist developing countries in meeting their obligations as signatories to international environmental agreements. Specifically, the GEF provides grants to assist developing countries to address environmental problems that transcend international borders in four areas: global climate change, pollution and overexploitation of international waters, destruction of biological diversity, and depletion of the ozone layer. It will also fund activities associated with preventing or reversing land degradation, providing this has an impact on one of this four focal areas.

GEF funds and programmes are administered both by the UN Environment Programme and the UN Development programme, thereby ensuring that both environmental and development issues are represented in its programmes and projects. The funding comes from the World Bank, which is also involved in administering the programme (for example, the Lake Malawi/Niassa GEF programme was implemented through the World Bank).

The GEF has a number of focal areas, within which are operational programmes that specify objectives related to areas identified as priorities for environmental management. The Lake Tanganyika Biodiversity Project was funded under the 'International Waters' programme, although it had clear links to the 'Biological Diversity' programme. The two operational programmes within these focal areas that are most relevant are 'Biodiversity of Coastal, Marine and Freshwater Ecosystems' and 'Waterbody-based programme'. A new focal area on 'The Land-Water Interface' is also relevant.

In formulating our contributions to the project, we have been careful to work as much as possible to the operational strategies specified by the GEF (see Allison, 1998).

1.3 LTBP Project goals and the Biodiversity Special Study

LTBP project goals were initially specified in the LTBP project document and Inception Reports (LTBP 1995, 1996). These goals have been modified as the GEF operational strategies have changed (Hodgson, 1997). The goals and objectives indicated here are taken from the 1997 Project Performance Evaluation Report (LTBP, 1997)

1.3.1 Project goal and purpose

> "The goal of the project is the protection of biodiversity in Lake Tanganyika. This will be achieved via the project purpose, which is to create a co-ordinated approach to the sustainable management of Lake Tanganyika. This in turn will be accomplished by increasing institutional capacity within the riparian states to monitor and manage threats to the lake."

It should be noted that the project purpose is stated in terms of a **process**, rather than an **output**: "to create a co-ordinated approach to management … by increasing institutional capacity". Scientists are generally less comfortable with the notion of 'process' and tend to focus on delivering outputs by the most efficient means possible (Shumway, 1999). In development work, it is recognised that outputs are linked very closely to process – in other words whether you achieve longer term, larger-scale goals depends as much on *how* you moved towards your goals as on *what* you produced (Cornwall, 1993; Mosse et al., 1998).

This report focuses mostly on outputs – the analysis of data on biodiversity distributions to inform conservation management. The BIOSS team, however, has been aware of the importance of process, so we have included some documentation of the rationale for our approach, and have reflected on our experience in developing and implementing this approach (see Chapters 2 and 6).

1.3.2 LTBP Project Objectives

The LTBP has six immediate objectives (LTBP, 1997):

- Establish a regional long-term management programme for pollution control, conservation and maintenance of biodiversity in Lake Tanganyika
- Formulate a regional legal framework for co-operative management of the lake environment.
- Establish a programme of environmental education and training for Lake Tanganyika and its basin.

- Establish tested mechanisms for regional co-ordination in conservation management of the Lake Tanganyika Basin.
- In order to produce a full Strategic Plan for long-term application, some specific studies need to be undertaken. These special studies will also add to the understanding of the lake as a whole, and in some cases, provide the baseline and framework for long-term research and monitoring programmes.
- The implementation and sustainability of the Lake Tanganyika Strategic Plan and incorporated environmental management proposals.

1.3.3 The Special Studies

Objective 5 of the LTBP project (Section 1.3.2) identifies the need for special studies to add to the understanding of the lake and provide the baseline and framework for long-term research and monitoring activities. The following table draws together the main objectives or aims of each of the other special studies.

Table 1.1 Special studies and their main aims

Special Study	Aims
BIOSS	*Four key objectives:* • review current levels of biodiversity in Lake Tanganyika; • identify the distribution of major habitat types, with particular focus on existing and suggested protected areas; • suggest priority areas for conservation, based on existing knowledge and recommendations from other SS and supplemented by additional survey work where necessary; and, • develop a sustainable biodiversity monitoring programme.
FPSS	*Two main aims:* • to understand the potential impact of different fishing practices employed in the littoral zone on fish biodiversity and • to understand the importance of these artisanal fishing practices to riparian communities
POLSS	*Main goal:* To identify the main sources of pollution, to determine where and how such pollution is negatively impacting biodiversity, and establish a monitoring programme for pollution in the lake.
SEDSS	*Aim* To understand the links between catchment factors which affect erosion (rainfall, vegetation, slope, soil etc.), to understand how and in what quantity these erosion materials are transported to the lake and to attempt to understand their impacts on the lake ecosystem.
SESS	*Principle tasks:* • to provide an understanding of current livelihood strategies and SE practices around the Lake and its catchment area, and • to suggest ways in which alternative livelihood strategies can be introduced while changes in current practices, which may be detrimental to biodiversity, are encouraged.

We have used a Venn diagram (Figure 1.1) to illustrate the relationship between the biodiversity study and each of the other special studies, and in turn the relationship between the studies and the other major components of the entire project, i.e. training, strategic action programme and the legal convention.

As can be deduced from the diagram, all project activities are designed with the overall aim of informing the Strategic Action Programme (SAP) for the management of Lake Tanganyika. Then in turn, the convention gives the ultimate authority for the SAP to be managed and implemented. The BIOSS is responsible for developing appropriate field methods for the assessment of impacts on biodiversity of Lake Tanganyika. These methods can then be applied in collaboration with other special studies in the assessment of the impact on diversity of pollution, sedimentation and fishing practices. A review of the current status of biodiversity in the lake (Allison *et al.,* 1996; Patterson and Makin, 1998) informed and guided the field programme and development of future activities.

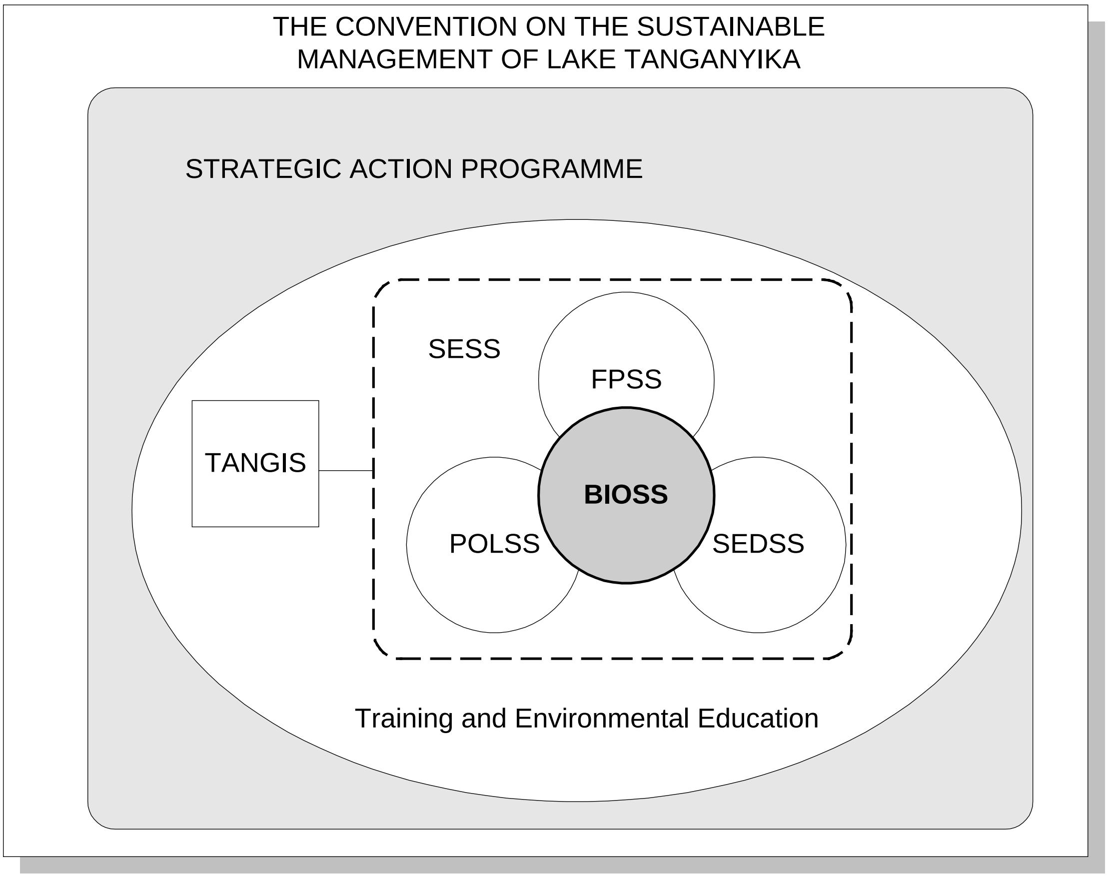

Figure 1.1 Venn diagram illustrating the relationship between BIOSS, the other special studies and other major components of LTBP

1.4 Aims and Objectives of BIOSS

The main aim of the BIOSS is to support the development of the strategic action plan (SAP) to manage Lake Tanganyika. The aim of the strategic action plan is “to provide for the regional management of Lake Tanganyika to enable the sustainable management of biodiversity and the livelihoods of present and future generations of lakeside communities.”

The specific objectives of the SAP that this study addresses most directly are:

- “Define and prioritise the management actions required to conserve biodiversity of Lake Tanganyika”
- “Enable the Lake Basin Management Committee to provide guidance to the international community on the needs of the Lake Tanganyika region in terms of biodiversity conservation and sustainable use of resources”.

To achieve these aims the BIOSS has four key objectives:

- Review current levels of biodiversity in Lake Tanganyika;
- Identify the distribution of major habitat types, with particular focus on existing and suggested protected areas;
- Suggest priority areas for conservation, based on existing knowledge and recommendations from other SS and supplemented by additional survey work where necessary; and,
- Develop a sustainable biodiversity monitoring programme.

Objectives 1, 3 and 4 would ideally have been carried out in close consultation with the other SS teams, but the desired level of integration was difficult to achieve in practice. Objective 3 in particular is perhaps best regarded as a cross-sectoral activity. This report's recommendations are thus framed largely in terms of biodiversity criteria for conservation prioritisation. These criteria were addressed during the Strategic Action Programme process, together with information on threats and feasibility of conservation supplied by other special studies.

This technical report provides the results of research activities directed towards addressing these objectives. We present a summary analysis of current knowledge about biodiversity relevant to conservation based on analysis of available secondary information (Chapter 3), and the results of surveys conducted by ourselves (Chapter 4) aimed at providing an improved basis for conservation decision making (Chapter 5). We also review the concepts and processes that led to the choice of methodology, and validate that methodology (Chapter 2). We conclude with a summary of recommendations for action, monitoring, and research (Chapter 6).

2. DEVELOPING A BIODIVERSITY ASSESSMENT STRATEGY FOR LAKE TANGANYIKA

The aims of this chapter are to provide an overview of the rationale and analysis that has informed our choice of methodology; to assess the sources of bias and error in the chosen sampling methods, and to provide an evaluation of the methods adopted. The output of this process is the data for information review and survey programmes analysed in Chapters 3 and 4. Those analyses, in turn, are used to inform options for conservation management (Chapter 5).

2.1 Assessing Biodiversity

The science of biodiversity assessment is new. The term ‘biodiversity’ did not come into common usage until the late 1980s (Wilson, 1989). To date, most biodiversity assessments for the purposes of conservation and resource management have taken place in terrestrial systems. Despite accumulating experience, procedures for biodiversity assessment in forests, grasslands etc are far from standardised, and vary according to objectives of the work, expertise and resources available, and the philosophy and approach of the teams doing the surveys (Jermy et al., 1995; Purvis and Hector, 2000). The terrestrial biologist therefore has a large range of techniques and approaches to choose from. These techniques have been evaluated and tested over the last decade. In aquatic systems there is much less experience of conservation-related biodiversity assessment surveys. The sciences of marine ecology and limnology provide sets of standardised procedures for sampling and analysis, but these have seldom been developed with biodiversity assessment in mind. When one considers the unique environments of the African Great Lakes, there is very little prior experience on biodiversity assessment. The LTBP and Lake Malawi Biodiversity Projects, both GEF projects with a goal of producing Lake Management Plans, are the first large-scale programmes to require extensive biodiversity assessments in this type of environment.

Most previous work on Lake Tanganyika’s biota falls within five major categories: fisheries biology, biological limnology, basic taxonomy and systematics, evolutionary biology, and behavioural and descriptive ecology; Coulter’s (1991) classic book integrates all five categories. There is some recent work on discussion of appropriate conservation measures for Lake Tanganyika (Coulter and Mubamba, 1993; Pendleton and Van Breda, 1994; Cohen, 1994; Coulter, 1999), but this work, which is laudably concerned with highlighting conservation issues, has not been in a position to back up the various claims made with standardised, comparable data sets.

Biodiversity assessment draws from the professional and academic traditions of all these sciences, but also adds elements from applied quantitative ecology and conservation biology. Particularly relevant are recent literatures on assessing adequacy of sampling effort, means of summarising biodiversity data for comparative analysis, and the use of complementarity analysis for reserve planning and design (reviewed in Coddington and Colwell, 1994; Margules and Pressey, 2000 and Southwood and Henderson, 2000; Chapter 13).

2.2 Determining information needs: an objectives-driven approach

From the BIOSS objectives we identified certain key questions that required analysis of existing data, and the collection of new data:

- How is biodiversity distributed within the lake?
- Is there any evidence for change in biodiversity distribution over recent time (e.g. last 50 years), possibly associated with anthropogenic disturbance of the lake environment?
- If biodiversity needed protecting, which areas would you protect?

In developing a methodology for biodiversity assessment, a fundamental question is how much do you need to know about biodiversity in order to manage or conserve it successfully? In addressing this question, we have been guided by two observations:

1. Biodiversity in Lake Tanganyika is increasingly threatened.

If it is accepted that threats to biodiversity are increasing (Cohen, 1991; Cohen *et al.*, 1996; Coulter and Mubamba, 1993; Coulter, 1999), this is justification enough for conservation action. We know the direction of change, and there is consensus that it is not a favourable one. The problem is therefore one of finding a way to reverse the change. Dealing with the causes of extinction and resource degradation is more important than documenting the process precisely. Ideally, a sound scientific understanding of the nature and rate of change supports incisive and cost-effective intervention, but too often, the effort needed to provide this understanding delays action until it is too late.

2. *Information is needed to help choose from a set of possible responses to the threats to biodiversity.*

Sufficient information must be available to choose a suitable course of action for conservation if resources are not to be squandered tackling low-priority problems. Conservation action needs to address three main issues:

- What are the most important or valuable areas, habitats or species to conserve?
- What are the most threatened areas, habitats or species?
- What conservation actions are most easily achievable and have least adverse development impacts?

The Transboundary Diagnostic Analyses carried out in 1998 and 2000 (LTBP, 1998; 2000) sought to prioritise conservation actions on the basis of these three broad criteria.

BIOSS addresses mainly the first of these conservation-related issues: which areas, habitats and species are most valuable in conservation terms? Pollution, Fishing Practices and Sediments special studies have identified the nature and degree of threats to the lake's biodiversity. Socioeconomics and Environmental Education special studies have addressed mechanisms, and (at least qualitatively) social and economic costs and feasibility of threat-mitigation and conservation action. Together, these studies informed the SAP.

With the above two observations in mind, the BIOSS strategy has been to combine analysis of existing information on the distribution of biodiversity in Lake Tanganyika with surveys of areas identified as being potential candidates for conservation. These are mainly areas where conservation action is likely to be least costly, in social and economic terms, and where institutional and administrative structures are already in place to facilitate conservation activities. The areas that best fulfil these criteria are those within, or adjacent to, existing terrestrial national parks – Rusizi delta in Burundi, Gombe Stream and Mahale Mountains in Tanzania, and Nsumbu National Park in Zambia. Survey activities were thus targeted at these areas, with additional work in areas known to be threatened, such as those in the vicinity of the Lake's major human settlements – Bujumbura, Kigoma, Mpulungu and Uvira. The areas we surveyed are indicated in Figure 2.1.

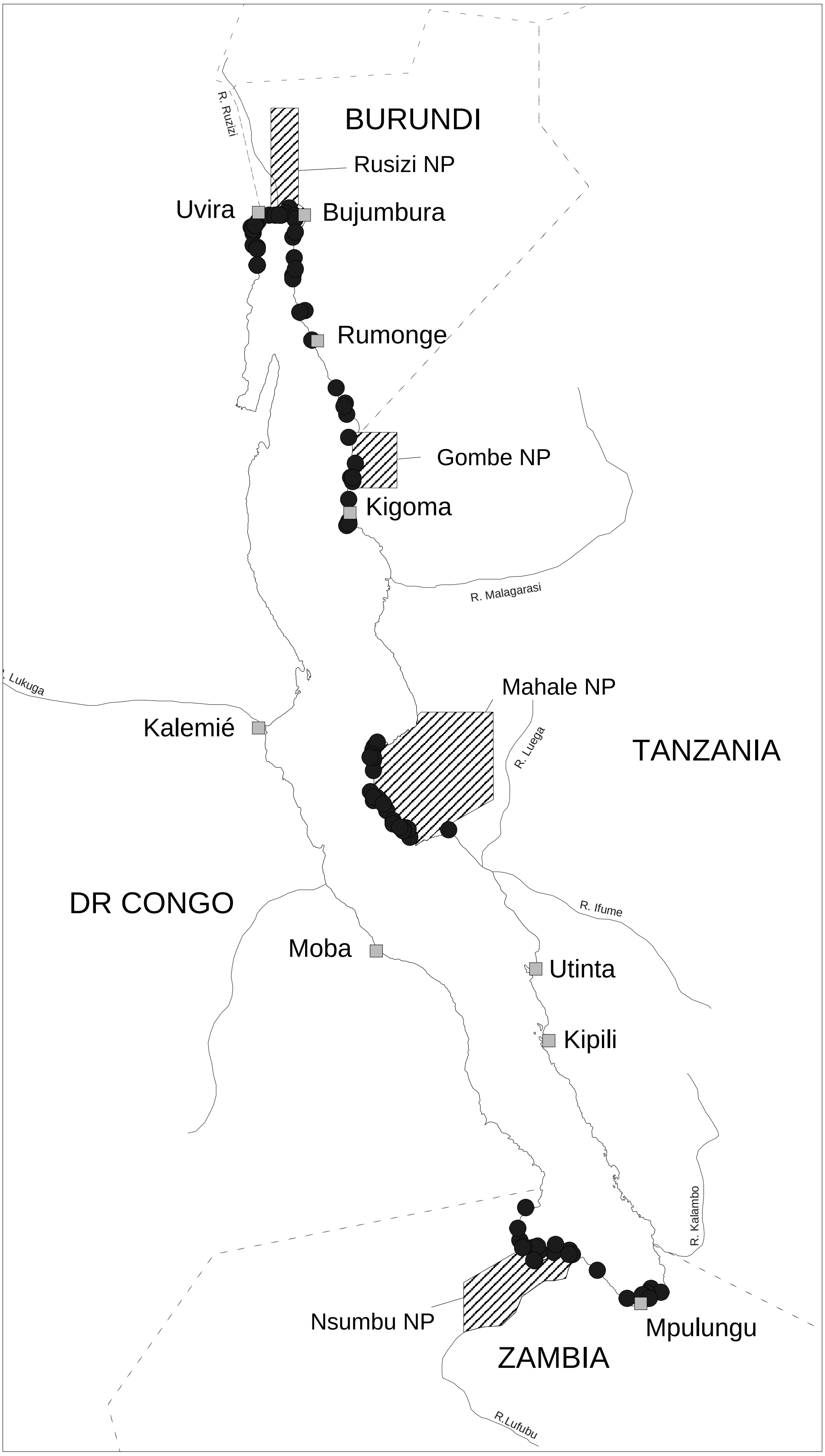

Figure 2.1 Map locating all BIOSS survey sites

2.3 Information review and organisation

The first part of any biodiversity programme is to review existing information: its quality, availability and relevance to conservation. Answers are required to the most basic questions about the lakes' biodiversity:

- Which are the most diverse areas?
- Where are the major barriers to species distributions, or to gene flow between populations of species?
- Which species are associated with which habitats?
- Which species distributions or abundances have changed due to environmental degradation or unsustainable resource use?

2.3.1 Baseline review and 'Literature Database'

A literature-based baseline review was used to provide an initial overview of the type of information available (subsequently published under editorship of Patterson and Makin, 1998). The baseline review revealed that much of the available information was in the form of scattered observations from exploratory collecting expeditions and notes from the aquarium fish trade. There was little published survey work that adhered to basic ecological survey principles (e.g. Sutherland, 1996). This is not a criticism of previous work – it was undertaken with different objectives in mind – but an indication that most of the published literature can provide only species 'presence' data. Absence can only be inferred if adequate and comparable sampling was undertaken by all surveys. Subject to errors in identification, failure by some authors to identify collecting or sampling areas precisely, and the limited distribution of survey effort, the data do provide species-distribution maps that can be analysed to infer 'hotspots' with reference to criteria such as endemism, higher-taxon diversity and range limitations.

There are, however, some datasets that have been designed specifically to assess species distributions and relative abundances (the most common components of biodiversity indices) for comparative purposes. There is an extensive database on the lake's pelagic fisheries (reviewed by the FAO/FINNIDA Lake Tanganyika Research Project), a historical data series of gillnet catches in Nsumbu Bay, Zambia (Coulter, 1991), surveys of the impact of sediments on littoral fish, ostracods and molluscs in the northern part of the lake (Cohen et al., 1993; Alin et al., 1999), and a series of fish surveys, also in the northern part of the lake (Ntakimazi, 1995, CRRHA[3]).

It became obvious that a useful analytical synthesis of this information could only be achieved through creation of a relational database. The 'literature database' (Pearce and Holden, 1999) was designed to be sufficiently flexible to include even the most anecdotal of information, but to provide sufficient structure to allow analysis of recorded species by location, major habitat groupings, trophic guilds and year and method of survey. Details of database structure are given in the SOP[4] document (Allison *et al* 2000), together with procedures for its management and update within the region. It was specifically designed to be updated and used beyond the life of the current project, with no further input from outside the region except for the usual courtesy (and legal obligation under Articles 17 and 18 of the Convention on Biological Diversity) for foreign scientists to supply riparian country institutions with publications resulting from work done in the region. After initial data entry in London to help develop the structure, subsequent data entry was co-ordinated by Prof. G. Ntakimazi in Bujumbura, Burundi. Preliminary analysis of information collated to date is given in Chapter 3 of this report.

Procedures for analysis, updating and maintenance have been developed, and are detailed in the SOP document (Allison *et al.,* 2000). The database was an ambitious activity for BIOSS to undertake in addition to a regional field programme, both in terms of the scale of the task and the technical skills required. As a result, at the close of BIOSS Professor Ntakimazi in

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[3] CRRHA – Centre Regional de Recherche en Hydrobiologie Applique

[4] Standard Operating Procedures for BIOSS

Burundi and MRAG in London jointly maintain the master database. Much of the relevant literature is located in Bujumbura, while the technical support for the analysis and development of the database is carried out from London. It is hoped that the considerable training needed to ensure the database can be sustained in the region will be a component of the future stages of the LTBP project.

2.3.2 The survey database

A second relational database, also programmed in Microsoft Access, was established to manage survey data generated by the BIOSS special study and subsequent monitoring activities (Jones, 1999). The survey activities and database procedures were designed to provide for continued survey activities in the lake, and to be sufficiently flexible to allow addition of new methods for other taxonomic groups once knowledge of their basic taxonomy and ecology is sufficient to allow their inclusion.

Each national team was responsible for updating the database with information on surveys conducted within their national waters. The database has the facility for each country to send regular updated national data files to a central location, where a master copy of a regional (whole-lake) database will be maintained. The updated regional database should then be returned to each riparian country. Further details on database structure and procedures are given in the BIOSS SOP where procedures for updating both national and a master regional database have been implemented are also described.

As with the literature database, the technical knowledge is insufficient to maintain this system in the region. Therefore, a similar arrangement whereby MRAG and Professor Ntakimazi continue to jointly maintain the survey database has been established. The analyses presented in this report are based on data held in these two databases. Both databases are linked to LTBP's Geographical Information System, TANGIS (Mills *et al.,* 1999).

2.4 Analysis of institutional capabilities, costs and logistical feasibility of biodiversity assessment

Conservation is a management activity. Institutions carry out management activities. The nature and scope of any conservation-related activity will, in part, be determined by institutional capability. A strong institutional capability for conservation research is more useful if it is allied to a capacity to act on research recommendations (Allison, 1998). An assessment of institutional capability is therefore an important pre-requisite to developing a biodiversity research, monitoring and management programme within LTBP.

Institutions may be formal - government agencies, research organisations, universities, schools, NGOs etc. - or they may be informal and traditional - village committees or co-operatives of resource users. Institutions can also be described as the social 'norms, standards and practices' that define or determine human activities (Ostrom, 1990). Cultural traditions, religions, and social networks and hierarchies are all forms of human institutions. All could provide a focus for involvement of conservation-related activities. Recent conservation practice in sub-Saharan Africa and elsewhere has been directed towards working more with informal, 'local' or 'community' institutions, especially in wildlife, forest and fisheries management (McNeely, 1995; Pinkerton and Weinstein, 1995; Western and Wright, 1994).

The technical special studies (Biodiversity, Pollution, Sediments) have, however, focused most of their activities on formal institutions. It is the formal institutions that have been involved in research for management, and that have been the focus of training and institutional capacity-building activities. The GEF have been criticised for a bias towards these formal institutions (Edwards and Kumar, 1998). Within the wider LTBP project, there has been awareness of the need to involve communities and other informal institutions, (Roland and Trudel, 1998). These types of institution have been involved in the project, most frequently in the training and environmental education component, socio-economic study and to some degree the fishing practices species study.

The capabilities, resources and needs of the formal institutions with a potential role in conservation research and management in the Lake Tanganyika catchment were assessed in 1996 (Allison *et al,* 1996). The assessment was conducted through visits to lake-shore laboratories and the offices of government institutes involved in water, land, fisheries and wildlife/environmental resources management. Key research institutes, including the Universities of Dar es Salaam and Zambia, were also visited. As well as obtaining profiles of professional staff and their interest and ability to participate in the project, the visit assessed requirements for equipment, technical support and specialist training. This assessment was used to determine a strategy for developing the research and monitoring capabilities required as a basis for improved conservation planning and action.

Institutional capability to undertake biodiversity assessments was limited. This is not surprising – there was no previous institutional mandate to undertake this type of work. One of LTBP's main functions was to 'mainstream' biodiversity issues in the mandate of relevant government departments, in order to assist the riparian countries from fulfilling their obligations as signatories of the Convention on Biological Diversity. BIOSS strategy has therefore been to involve the relevant institutions in the development of methods for biodiversity survey and monitoring, and assist these institutions in developing teams that could realistically be expected to function given the constraints identified.

The main participating institutions are indicated in Table 2.1. These are the institutions from which BIOSS survey team members were drawn directly. A full list of individuals and institutions involved in the BIOSS special study in consultative, administrative and training roles is given in the acknowledgements (page IV).

Table 2.1 National institutions participating in BIOSS

Country	Institution
Burundi*	University of Burundi, Department of Biology, Department of Mathematics and Computer Sciences, Bujumbura
	Departement de L'eau, Peche et Pisciculture
	Institut National pour l'Environment et Conservation de la Nature (INECN)
Democratic Republic of Congo	Centre Recherche Hydrobiologie, Uvira.
Tanzania	Tanzania Fisheries Research Institute, Kigoma
	Tanzania National Parks Authority, Gombe and Mahale
Zambia	Department of Fisheries, Mpulungu

*Two members of the BIOSS team are graduates of the University of Burundi, and are currently working as secondary school teachers, but continue to be available for biodiversity survey work, through the University Biology Department.

All institutions, to a greater or lesser extent, operated under conditions of inadequate government funding, geographical isolation, lack of access to scientific resources, limited number of qualified senior staff, uncertain security situation and poor infrastructure. In institutional development, it is important to distinguish between weaknesses and constraints. Weaknesses are those factors that the project expects to be able to address. Constraints are factors beyond the remit and control of the project. Lack of skills relevant to biodiversity surveys and lack of scientific equipment are weaknesses that can, and were, addressed by BIOSS. Staff recruitment policy in government institutions, geographical isolation, and national security situations are examples of constraints beyond the capability of the project to address.

Sustainable projects are those that address weaknesses, but take account of, and attempt to function within existing constraints. Unsustainable strategies are those that use external resources and personnel to bypass local constraints temporarily. Our strategy was to identify both strengths and weaknesses in institutional capability, then build on strengths (e.g. knowledge and experience of fish taxonomy, identification, behaviour and ecology) and to address identified institutional weaknesses, such as lack of appropriate training and basic equipment. We assumed that constraints such as limited funding and low levels of senior staff recruitment and retention would continue to operate beyond the life of the project, and designed programmes that would not require these issues to be addressed.

2.5 Biodiversity Assessment

2.5.1 Survey Design

Previous experience of biological surveys in the lake by BIOSS team members (e.g. Ntakimazi, 1995, Alin *et al*., 1999) and some standard techniques such as gillnetting, provided initial guidance for survey design. We determined that there was a requirement for improved survey methodology that took account of both standard ecological census procedures (e.g. Sutherland, 1996) and the information requirements of biodiversity conservation planning (Jermy *et al*, 1995; Groombridge and Jenkins, 1996).

Given the size of the task, several key decisions had to be made. We have already alluded to the need to direct survey activities towards answering conservation-related questions. This led us to choose a strategy of prioritising surveys of existing and proposed protected areas. The highest species diversity in the lake is found in the littoral and sub-littoral (Coulter, 1991; Brichard, 1989; Cohen, 1994). It is also the littoral and sub-littoral zone that is most directly impacted by land-based human activity (e.g. domestic waste disposal, sewage-pollution, soil erosion). The choice of the sub-littoral for survey activities also allowed the use of direct observation census methods using SCUBA techniques. This has two advantages: first, complex habitats and substrata can be sampled; second, survey activities can be non-destructive, thereby setting an example of biodiversity concern.

Not all areas are amenable to SCUBA survey – crocodiles, low visibility and pollution can all make SCUBA-based surveys dangerous, unpleasant and, worse still, inefficient from the sampling point of view. These areas were therefore surveyed using remote techniques: gillnetting, grab sampling and dredging.

Not all taxa can be surveyed, and it is common for biodiversity surveys to be based on small sub-sets of total diversity (see Section 2.5.2). The criteria and rationale for choice of ‘total biodiversity surrogates’ is also given in section 2.5.2.

The overall survey design adopted during the period of the BIOSS special study is indicated below. A detailed explanation of all components of the methodology is given in the BIOSS standard operating procedures (edited by Allison *et al*., 2000, with contributions from all BIOSS team members; this document is referred to as the BIOSS SOP from now on). The methods continue to evolve, and it will be possible to add further taxonomic groups and procedures to the basic template of activities outlined in Table 2.2 (see BIOSS SOP for details).

Table 2.2 Outline of main components of biodiversity assessment surveys conducted by BIOSS survey teams between 1997 and 2000

	TARGET	TECHNIQUE	OUTPUT
PRELIMINARY	Expedition planning	Collation and assessment of large scale topographical maps	Delineation of survey area.
DIVING SAFE **SCUBA TECHNIQUES CAN BE USED**	Habitat	Manta Board Survey	Maps of coastal topography, land form and land use, and littoral zone (sub- and supra-) habitats to maximum depth of 10 m
		Habitat profiles: SCUBA	Fine-scale habitat map (25 m x 5m strip for each profile)
	Species	Mollusc census: SCUBA then snorkel shallows	Mollusc species or genus richness data for depths 15 - 0m
		Stationary visual fish census: SCUBA	Fish species richness, abundance and diversity index data in 10 m diameter cylinders at 15, 10 and 5 m depth
		Rapid Visual Census: SCUBA then snorkel shallows	Fish species richness data for 15 minute transects at each of four depths (15, 10, 5, 0). Likely to include patchily distributed, rarer and diver-wary species missed by stationary visual fish census, as it covers a larger area. No abundance data recorded, but relative rarity can be calculated
		Multi-mesh survey gillnets set before dusk (1700) and retrieved after dawn (0800)	Fish species richness, relative abundance and diversity, to complement visual census data.
DIVING UNSAFE **DO NOT ENTER THE WATER**	Habitat	Manta with crocodile box	Maps of coastal topography, land form and land use, and littoral zone (sub- and supra-) habitats to maximum depth of 10 m
		Grab samples and echo sounder	Survey of soft substrates (sand and silt)
	Species	Mollusc dredging	On hard shelves, replaces mollusc survey
		Gill nets	Day and night (as above) replaces stationary visual census.
		Grab	Survey of benthic invertebrates – planned in future

2.5.2 Choosing indicator groups or 'total biodiversity surrogates'

Biodiversity inventories are seldom, if ever, based on sampling the entire biota. Even if all biota were sampled, what attributes of that biota should be measured? Biodiversity includes the diversity of genetic composition, form and function of organisms, as well as the diversity of their interactions. Identifying the species names of all the organisms in a region is measuring just one aspect of biodiversity.

Biodiversity surveys in terrestrial systems tend to focus on vegetation types, and on groups that are well-known or easily identified, such as birds, mammals and amphibians (Jermy et al, 1995). Aquatic biodiversity surveys have tended to focus on habitat mapping (Moran et al., 1989; UNEP/AIMS, 1993), and on surveying conspicuous flora and fauna such as macroalgae (Sutherland, 1996), fish (Karr, 1981; Fausch et al; 1990; Toham and Teugels, 1999) and macroinvertebrates (Resh, 1994, Chessman, 1995).

It is important to distinguish between two separate uses of the word 'indicator' in biodiversity assessments. The traditional use of the term is in talking about taxa that are taken to be particularly sensitive or indicative of some form of perturbation, such as pollution. A more recent usage is in talking about a sub-set of total diversity that can be used to give an indication of what differences in total (usually species) diversity might be. For example, one might use the diversity of cichlid fish as an 'indicator' for total biodiversity. For this latter use, we will use the term 'total biodiversity surrogate' (TBS) rather than 'indicator'.

Guidelines have been developed to assist the choice of suitable taxa for use as surrogate measures of total biodiversity and as indicators for impacts such as pollution and sedimentation (see SOP Section 3). The features that both indicators and total biodiversity surrogates should ideally possess are reported in Table 2.3.

Table 2.3 Features of potential total biodiversity surrogate taxa

Indicator or TBS Groups should be:

- Taxonomically well-known so that populations can be reliably identified and named;
- Biologically well-understood;
- Easy to survey (e.g. abundant, non-cryptic) and manipulate experimentally;
- Widely distributed at higher taxonomic levels (e.g. order, family, genus) across a large geographic and habitat range;
- Diverse and include many specialist taxa at lower taxonomic levels (i.e. species, subspecies) which would be sensitive to habitat change;
- Representative of distribution and abundance patterns in other related and unrelated taxa;
- Actually or potentially of economic importance.

On the basis of these criteria, the groups chosen as total biodiversity surrogates for the purposes of comparative biodiversity assessments in this report are the fishes and mollusca. There is a good level of expertise in the region on fish identification, and a capability in mollusc identification has recently been developed through BIOSS and LTBP training and survey activities (West and Michel, 2000). BIOSS has also organised basic training and materials for identification of other invertebrate groups to higher taxon levels (Martens, 1997), and this expertise has been applied in determining the impact of sediments on invertebrates (Irvine, and Donohue, 1999; Irvine, et al, 2000), but invertebrate taxonomy and sampling methods are not yet sufficiently well known to implement in broad-scale biodiversity survey activities.

2.5.3 Habitat mapping

Much modern conservation is based on the premise that to conserve species and communities of interest, you need to sustain the habitat (biotic and abiotic processes and features) that supports these species and communities. One basic BIOSS objective was therefore to ensure that all identified habitat types are represented in the existing or any proposed network of protected areas. Operational definitions of 'habitat' are given in the BIOSS SOP.

Habitat characteristics and known environmental gradients determine biotic community structures. Surveys need to be stratified by the major habitat-related variables. From the practical surveying point of view, habitats therefore need to be mapped before selection of sampling localities.

Rapid, broad-scale mapping techniques in aquatic environments typically involve some form of remote sensing, such as side-scan sonar, which can differentiate hard and soft substrata. The equipment requirements are relatively modest, but nonetheless prohibitively expensive when contrasted with the operating budgets of most of the riparian institutions. Instead, a method used extensively for mapping major features of reef systems, 'manta boarding' (Moran *et al*., 1989; UNEP/AIMS, 1993), was adopted to rapidly produce maps of areas surveyed by the present project. This method involves towing an observer, riding a plywood board and equipped with mask and snorkel, at slow speed behind a small boat. The observer notes characteristics of the substrate type. The technique is detailed in the SOP (Section 4). This is the first application of this technique in a freshwater ecosystem.

The Manta technique provided broad-scale habitat maps, covering the sub-littoral (3-10 m depth usually) at a rate of 15 km per day. The data could quickly be transcribed to maps in the field, for use as a decision tool to stratify and select sampling locations for surveys of biota (see SOP for methodology).

Within each substrate strata identified by the Manta technique, habitat-depth profiles were conducted perpendicular to the shoreline, usually from depths of 25 m up to 5 m, although this was dependent on bottom topography and slope. The habitat profiling technique was developed from adaptations of line intercept and point intercept transect methods, adapted by coral reef biologists from techniques used for botanical surveys in terrestrial environments (Kershaw, 1957; Greig-Smith, 1961; Sullivan and Chiappone, 1993; UNEP/AIMS, 1993; Rogers *et al.,* 1994). With the exception of submerged macrophyte beds, the biotic components of the habitat (substrate) are unlikely to be so strongly linked to depth in Lake Tanganyika, *within the depth range sampled*. Algal productivity in aufwuchs and episammic communities will of course be related to light intensity and therefore depth, but productivity maxima may occur at considerable depth in this clear lake (Hecky, 1991). Retrospective analysis of changes in fish and mollusc community structure by depth for each major habitat type should allow this to be differentiated.

The importance of physical habitat (principally substrate) in determining what species are found at a locality is frequently stressed in the Lake Tanganyika literature (Patterson and Makin, 1998, for review). The main concern regarding human threat, sedimentation, is based on the premise that sediments smother the rocky littoral habitats that support the highest biodiversity (Cohen *et al*., 1993; Alin *et al*., 1999). The methodology adopted in this study allows individual SCUBA fish and mollusc census surveys to be linked to local habitat characteristics. Although considerable detail on substrate and habitat characteristics has been collected, until large numbers of samples are analysed, or monitoring is able to detect fine-scale habitat change, linking these fine-scale features to fish and mollusc community structure will be difficult. For the purposes of this analysis, we have grouped data within very broad habitat categories, defined by depth strata and predominant substrate type (Section 2.7)

2.5.4 Survey methods for fish

Three methods of fish survey were developed, tested and deployed over the period 1997-2000: gillnet surveys, and two types of SCUBA diver surveys: stationary visual census, and rapid visual census. Detailed protocols for application of these techniques are given in the SOP (Section 5).

2.5.4.1 Gillnet surveys

Gillnet surveys were used either as the sole sampling method in areas where diving was not possible, or to complement diver-surveys. Gillnets were usually set before dusk and hauled after dawn, although some daytime gillnetting was also done, both for comparative purposes, and also where security problems and the possibility of theft prevented night-time deployment.

The gillnets used were 60m length multi-mesh monofilament survey nets, comprising twelve 5 x 1.5 m panels in mesh sizes of 8, 10, 12.5, 16.5, 18.5, 22, 25, 30, 33, 38, 45 and 50 mm half-mesh size. Nets were set parallel to the shore at a depth of approximately 10 m, during the night. Day-time sets were made at 5, 10 and 15 m. The difference was due in part to logistical reasons (gillnet surveying had to fit in with other survey activities), and in part to the observation that a set before dusk, hauled after dawn, caught fish that moved diurnally within the depth ranged sampled. A 10 m sample therefore provided an integrated catch for depth 5-15 m. Catches were recorded by number of individuals and weight per species, to provide relative abundance data for calculation of diversity indices and description of fish community structure.

2.5.4.2 Stationary visual census

Stationary visual census (SVC) provides data on the relative abundance and diversity of sub-littoral fish species. SVC data was collected in conjunction with habitat profile dives, at depths of 5, 10 and 15 m. At each depth, a 'cylinder' of the water column, to a height of 5 m above the lake bottom, and diameter 15 m (lakebed area = 177 m^2, volume = 884 m^3) was surveyed for a 15 minute time period at each depth. Fish were identified to species and an estimate of the abundance of each species was recorded. The data allow an estimate of population density for each species to be computed. The method is developed from Bohnsack (1986), and is most suited to the survey of relatively immobile smaller species.

2.5.4.3 Rapid visual census

Rapid visual census (RVC) was also carried out at each of 5, 10 and 15 m, with some snorkel-surveys in the immediate littoral (0-1.5 m). Each RVC consisted of a 15 minute transect parallel to the shore, conducted by a pair of divers. The transect is divided into five 3-minute intervals, and the time-interval in which each species was first seen is recorded. A species seen in the first time-interval is given a score of '5', those seen in the second time-interval are given a score of '4', etc. Assuming that the more abundant species will tend to be seen soonest, the scores, when averaged across transects, can give an indication of relative abundance (although this has not been analysed for this report). The method is modified from Jones and Thompson (1978), and is intended to cover a wider area than is possible with the SVC, thus recording more mobile or less abundant species, including larger fishes.

2.5.5 Mollusc census methods

Survey for molluscs were done either by diver or using a naturalists' dredge where diving was not possible. Heterogeneity of habitats made quantitative, replicable methods of diver survey transects difficult to implement, and qualitative time-standardised search methods were employed instead, to give presence-absence data derived from known sampling effort.

2.5.5.1 Mollusc transects using SCUBA

Initially, searches were carried out at 25, 15, 10 and 5m, following dive profiles, but this was later changed to 15, 10, 5 and littoral (0-2 m), to fit in with the SCUBA fish census procedures. Searches were conducted for 10 minutes at each depth, and the identity of all species found recorded. Specimens were taken for on-shore identification where doubts over identity existed. Smaller species found in sandy substrates were also collected by sieving sand through 1 mm mesh drum sieves. Sieved samples were retained in plastic sample-jars for sorting on shore.

Exact search procedures carried out by each pair of divers at each depth were chosen according to substrate types encountered (Table 2.4).

Table 2.4 Procedures for sampling molluscs on diver-transects

Habitat Category	Diver 1 Tasks	Diver 2 Tasks
Non Sandy (all types of rock and gravel)	Search rocks/gravel for 5 minutes	• Search rocks/gravel for 5 minutes
Mixed	Search all micro habitats for 5 minutes	• Search all microhabitats for 2½ minutes • 1 x sieve sample from the sandy habitat during remaining 2½ minutes.
Sandy	Search for 5 minutes for larger molluscs	• 2 x sieve samples during 5 minute period
These operations were performed at each depth. The tasks were carried out on one side of a transect line for a total of 5 minutes and then repeated on the other side of the transect line. The total time spent sampling at each depth is therefore 10 minutes.		

It must be borne in mind that this was the final protocol developed from previous experience, and that some of the samples were taken with earlier, evolving methodology. There is therefore some possibility of a lack of replicability between samples from earlier and later mollusc sample transects.

2.5.5.2 Mollusc dredge sampling

At locations where diving was not possible a 'naturalists dredge' was used to sample for molluscs. This technique could only be employed in areas where soft substrates were identified, as the dredge is ineffective and easily damaged on rocky substrates. Substrate type was first identified along a transect at the target sampling depth, using grab samples. The dredge was deployed from a boat positioned at the start of this transect and towed at slow speed along the transect for approximately 60-100 m

2.6 Metrics and measures of biodiversity

Measuring diversity presents philosophical and well as practical difficulties. Strictly, a measure of 'biodiversity' would be given not in terms of the number of different 'things' (species, habitats *etc.*), but in the total 'difference' or 'variability' (Zeide, 1997). The loose definition of biodiversity has hindered the development of widely accepted measures, and it is now acknowledged that what is measured must be tailored to the needs and circumstances of individual studies, perhaps to the detriment of wider comparative analysis (Purvis and Hector, 2000). We have adopted two of the most common approaches to 'measuring' biodiversity: diversity indices, and taxonomic (species) richness and related measures such as richness of endemic species. These are only two of many potential measures or indices of biodiversity, that include approaches aimed at the genetic, taxonomic, morphological, functional and ecosystem levels (Solbrig, 1991; Harper and Hawksworth, 1994; Gaston, 1996). Some alternative approaches, that we believe have potential utility for conservation-related work, are described in Section 2.12.

The immediate objective of the biodiversity survey data analysis is to use estimates, or measures, of biodiversity to compare the diversity of different areas. In this report, we use these estimates to compare between areas surveyed for possible inclusion, or retention, in a protected area network. The methodology, however, can be applied to any situation where a comparative approach is needed, e.g. comparing diversity of fished and un-fished beaches, sedimented or un-sedimented rocky habitats *etc*. The estimates may also be used to establish comparative estimates for similar habitat types in different parts of the lake (e.g. Gombe, Mahale, Nsumbu). Some comparison with previous surveys may also be possible for certain taxa, to examine changes in diversity over time.

Uses, biases, advantages and disadvantages of various diversity measures applied to biodiversity data are given in Magurran (1988), Solbrig (1991), Zar (1996), Colwell (1997), Mouillot and Lepretre (1999) and Southwood and Henderson (2000; Chapter 13). The methods chosen are based on review of these sources, and references therein.

2.6.1 Species richness

For surveys where data on abundance or relative abundance is NOT collected, the only summary statistics that can be produced are estimates of species richness. This is simply the number of species collected for a given level of sampling effort.

The advantages and disadvantages of species richness as a measure are given in Table 2.5.

When using species richness estimates to compare between areas, habitat categories or sampling methods, we first checked that sampling effort had been adequate. Methods for assessing the adequacy of sampling effort are given in Section 2.8.

Table 2.5 Advantages and disadvantages of species richness as a measure of biodiversity

Advantages	Disadvantages
An integral measure of several elements of biodiversity	Loss of information regarding species identity and no information on ecological structure and function
Relatively easy to survey, measure (taxonomic difficulties permitting!) and explain to non-specialists	No information on relative abundance of species
Comparable to existing data from literature and previous surveys	Comparability depends on adequate sampling effort in all cases

2.6.2 Calculating and comparing diversity indices

There are many different types of diversity index, but they all incorporate measures of both the number of taxa (e.g. species) and some measure of the number of individuals of each species in the sample. None of the indices available are ideal, and all were developed for purposes other than biodiversity assessment. Despite these reservations, it is still useful to calculate diversity indices as a summary measure, provided they are not calculated across different sampling methods, or across defined taxonomic groups. Diversity indices are also sensitive to sample size, tending to stabilise when sampling effort is adequate (Colwell, 1997) and so comparisons of diversity indices from incomplete or inadequate sampling must be avoided. Methods for assessing the adequacy of sampling effort are given in Section 2.8.

At present, the appropriate survey data to calculate diversity indices on are fish from gillnets and stationary visual census data (separately). The most common index is variously known as the Shannon, Shannon-Weaver, or Shannon-Weiner index:

$$H' = \sum_{i=1}^{k} p_i \log p_i$$

where k = the number of species and p_i is the proportion of the total number of individuals sampled in each of i species. Log_{10} was used in all calculations presented in this report. The Shannon-Weiner diversity index was calculated directly from the sample size (n) and frequency f of each species i:

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

H' is known to be an underestimate of the diversity of the sampled population, however, this bias decreases with increasing sample size.

Diversity indices are not normally distributed measurements, and cannot be compared statistically using standard parametric inferential methods. Comparisons of diversity indices between two or more different sites were made using a test similar to the well known t-test (Zar, 1996). The t value is the difference between the two calculated diversity indices divided by the standard error of the difference:

$$t = \frac{H_1' - H_2'}{s_{H_1' - H_2'}}$$

The standard error of the difference is the square root of the difference between the variances of each diversity index:

$$s_{H_1^{'}-H_2^{'}} = \sqrt{s_{H_1^{'}}^2 - s_{H_2^{'}}^2}$$

The variance of each diversity index is calculated from:

$$s_{H^{'}}^2 = \frac{\sum (f_i \log f_i)^2 - (\sum f_i \log f_i)^2 / n}{n^2}$$

The appropriate degrees of freedom are calculated from:

$$v = \frac{(s_{H_1^{'}}^2 - s_{H_2^{'}}^2)^2}{\frac{(s_{H_1^{'}}^2)^2}{n_1} + \frac{(s_{H_2^{'}}^2)^2}{n_2}}$$

In all cases the null hypothesis tested is that the two diversity indices are the same, and the alternative hypothesis is that they are different. Two-tailed hypotheses, using the 95% confidence level were used unless specified otherwise. There is no multi-sample test to compare diversity indices, so multiple paired comparisons were done using t-tests, with the significance level of individual comparisons being adjusted by the Bonferroni approximation, at some risk of committing type II errors (incorrect acceptance of the null-hypothesis), which is statistically conservative (Zar, 1991). *H'* is insensitive to the presence of a few individuals of rare species in large samples. It is, however, sensitive to large differences in abundance. It is therefore useful to use other diversity indices to analyse whether inferred differences are consistent, or may be adversely affected by this type of bias. We also calculated Simpson's index, which measures the increase in the number of species per individual sampled:

$$D_v = \sum_{i=1}^{k} \frac{1}{p_i^{\,2}}$$

Both indices perform well for a variety of underlying distributions, and for small sample sizes. Recent simulation analyses have indicated that Simpson's index is least biased and Shannon-Weaver shows the smallest residual variance (Mouillot and Lepretre, 1999). All diversity index calculations and statistical comparisons were done in EXCEL spreadsheets, in order to familiarise BIOSS participants with the use and analysis of this type of data. Several software packages are now available to perform most of these calculations, and the 'EstimateS' package (Colwell, 1997) can also be used to examine the sensitivity of the indices to sample size.

2.6.3 Alpha, beta and gamma diversity, and rarity and endemism.

The diversity of samples all from the same community is usually referred to as alpha diversity. All the diversity indices and species richness measures mentioned above are estimates of alpha diversity. The difference in diversity between different areas or communities is known as beta diversity (Solbrig, 1991). The procedures for testing differences between areas, given above, are indirect measures of beta diversity. Gamma diversity measures the extent to which ecological counterparts occur as allopatric replacements throughout comparable habitat type, across a geographical transect (e.g. from north to south in the lake).

Beta and Gamma diversity become important when we begin to think about conservation strategies and the notion of complementarity when considering the design of conservation areas. We have also used the notion of complementarity when making a preliminary assessment of the use of more than one survey technique to overcome selectivities and biases associated with all available methods (see below)

When considering relative conservation values of different areas, it would be usual to also examine available information on endemism, rarity, and metapopulation dynamics. Endemism is of less relevance in the Lake Tanganyika case, as levels of endemism are so high (>90% in all our samples). Rarity is not sufficiently well known to use as a criterion, and information on metapopulation dynamics is generally more relevant to conservation of individual species than of habitats or ecosystems. Its relevance to Lake Tanganyika may be in identifying intra-lacustrine distribution patterns that are common across taxa – only if this is demonstrated can population-level information be brought be bear in conservation planning (see Chapters 3 and 5).

2.7 Habitat categories for data analysis

Following recent trends in conservation research and management, we adopted a habitat-driven survey approach. There are likely to be large differences in species compositions and diversity between samples taken across known environmental gradients – substrate type and depth. For all comparative analyses, and for investigation of survey bias and the enumeration of minimum required sample sizes, all survey data were therefore initially dis-aggregated by depth and by substrate category.

The manta and profile habitat survey protocols (see SOP) allowed for collection of quite detailed habitat features (e.g. granulometry of sand, presence of particular small-scale features such as crevasses in bedrock substrate, etc.). At present, survey activity has not been extensive enough to produce sufficient replicate samples within habitat categories differentiated to such a fine scale. Prior to analysis, therefore, we have used manta and profile data to reclassify habitats on the basis of the dominant physical substratum.

In areas where diver-surveys were possible, we recognise five major physical substrate/habitat categories: shell beds, rock, mixed-rock, mixed-sand and sand. The profile and manta data record the percentages of these major categories. The percentages of each substrate that define the boundaries of each category are indicated in Figure 2.2.

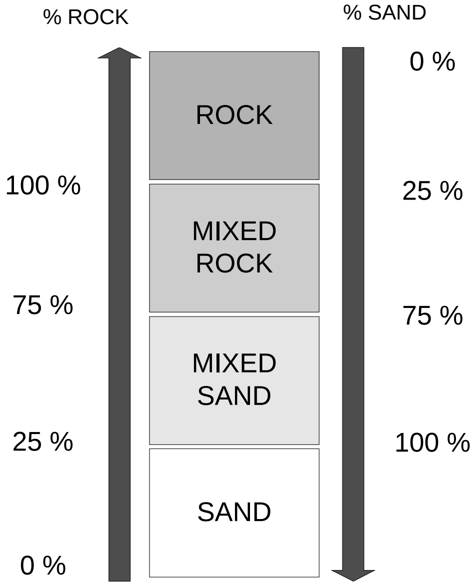


Figure 2.2 Major substrate-based habitat classifications. 'Rock' includes boulders, bedrock and cobbles. 'Sand' includes all grades of soft substratum from mud to fine gravels.

The rationale for choice of these boundaries and for this restricted range of habitats, defined purely in terms of physical substrates is as follows:

- The presence of rocks in a sand or soft substrate has a greater ecological effect than the presence of some sand in a predominantly rocky habitat.

- Mixtures of rocks, boulders, cobbles and shells effectively function as a hard substrate, and were therefore classified as either rock (if no soft substrates present) or mixed-rock. The type of rock (bedrock, boulders etc) and other features (crevices, overhangs etc) were recorded in the original profiles, but insufficient data on biota is available to investigate associations with these more detailed features of the habitat.

- All diving transects were from depths of 5m or greater, therefore habitats characteristic of the littoral fringe, such as pebble or cobble substrates and emergent macrophytes (reed beds) were not present in the main fish surveys. Some mollusc surveys and RVC fish surveys were, however, conducted in the littoral fringe. Littoral fringe substrates are accommodated within the classification scheme indicated above.

- Submerged macrophyte stands were not common in the areas surveyed, and are recorded as a secondary characteristic associated with sand and mixed-sand substrates.

- Shell beds occur overlaying soft substrates (sand, mud). Where shell beds occur, they are normally extensive, flat areas. The shells normally form dense layers, so that the substrate in normally uniform – i.e. it was usually recorded as 100% shell. There is a distinctive fish community associated with these *Neothauma* shell beds, so we have classified this as a separate habitat category.

- Analysis of frequency distributions of % substrate compositions indicated that divers tended to record these to the nearest 10% (multiples of 10 were twice as frequent as multiples of 5). It is likely that accuracy of visual estimation of substrate % cover is to within 10-20%.

- Preliminary analyses of fish-species assemblages based on these habitat classifications indicated that there were few differences in species between rock and mixed-rock substrates (Table 2.6). Very few samples fell within the mixed-sand classification. For the purposes of this report, we have therefore further reduced the above habitat categories to 3 broad littoral habitats: Rock-dominated and mixed (>10% rock), Sand-dominated (<10% rock) and shell beds. The proportion of sand/rock in the matrix may well affect community structure, but until large datasets are built up that will allow fine-scale analysis of the change in community structure associated with small differences in substrate composition, such changes will not be readily detectable.

Table 2.6 Fish species found uniquely in each of three broad substrate categories, Mahale National Park.

Rock	***n***	**Rock (mixed)**	***n***	**Sand**	***n***
Lates mariae	11	*Neolamproogus fasciatus*	5	*Neolamprologus tetracanthus*	40
Gammatotria lemairei	5	*Petrochromis macrognathus*	4	*Xenotilapia spilopterus*	22
Simochromis babaulti	5	*Aethiomastacembelus cunningtoni*	3	*Xenotilapia boulengeri*	20
Julidochromis tanscriptus	4	*Ctenochromis horei*	2	*Lamprologus ocelatus*	14
Spathodus erythrodon	4			*Lamprologus signatus*	10
Julidochromis ornatus	3			*Neolamprologus boulengeri*	10
Acapoeta tanganicae	2			*Neolamprologus ocellatus*	10
Neolamprologus olivaceous	1			*Neolamprologus wauthioni*	10
Tropheus duboisi	1			*Neolamprologus brevis*	8
				Neolamprologus meeli	6
				Neolamprologus ornatipinnis	6
				Asprotilapia leptura	5
				Neolamprologus chrystyi	5
				Neolamprologus hecqui	5

Rock	***n***	**Rock (mixed)**	***n***	**Sand**	***n***
				Plecodus multidentatus	5
				Lamprologus ornatipinnis	4
				Neolamprologus leleupi	4
				Petrochomis trewavasae	4
				Petrochromis orthognathus	4
				Ectodus descampsi	3
				Neolamprologus moorii	3
				Aulonocranus dewindti	1
				Telmatochromis vittatus	1

The category mixed-sand contained no species unique to that substrate. Species unique to Rock and mixed-rock are based on few individuals (*n*) and are likely to have arisen by chance. To increase within-category sample sizes, we pooled all ‘rock’ and ‘mixed-rock’ and all ‘sand’ and ‘mixed-sand’ substrates for subsequent analysis.

- For molluscs, the relationship between species presence and substrate characteristic is obviously very close. We therefore retained the four categories indicated in Figure 2.2, plus the shell bed category, although this resulted in the loss of some information from substrate-depth category combinations with sample sizes too small to use for further analysis.

- For areas where diving was not possible, we can only distinguish between three categories: soft and hard substrates and shell-beds. These were determined from surface inspection in shallow depths, and by grab sampling in deeper waters.

- The depth-range sampled by SCUBA was also rather narrow. Samples of fish by SVC and RVC at 5, 10 and 15m did not show consistent major differences in species composition within habitat categories (Appendix 8.2). Habitat categories were unevenly distributed with depth, despite habitat-based stratification by Manta. This is because substrates at 2-10 m (the depth range of the Manta surveys) did not often correspond with substrate characteristics in deeper waters. Some elements in the habitat-depth sampling matrix therefore consist of very few samples. To increase sample sizes for statistically valid comparisons, and given the high similarity indices between samples taken at different depths, samples were pooled across the depth range 5-15 m. This will increase within-sample variance, which in turn makes comparisons between areas statistically conservative. Pooling across depths is also justified in terms of the objectives of the study – there is no possibility in protecting areas of certain depth and not others, so there is no need to establish fine-scale depth differences for the purposes of this study, although they may be ecologically interesting.

2.8 Determining required sample sizes

In order to compare richness and diversity of fish or molluscs between sites, we need to know if our sampling effort was sufficient to include the majority of species (or at least a known proportion for the likely total diversity). In either case, we are able to use species-accumulation curves to ‘correct’ for differences in sampling adequacy. We will therefore be able to distinguish true differences in richness from under sampling-induced bias.

Before samples were compared to assess relative diversity of different areas, or across habitat gradients, we determined whether sample sizes within each sub-set of data were adequate. Graphical plots of cumulative species encountered against cumulative sample area will reach an asymptote when all available species in that area/habitat (that are susceptible to the survey method) have been sampled. While these plots provide a useful preliminary impression, their form may be greatly affected by the order in which the samples are added to the cumulative curve. To get round this difficulty, we plotted species accumulation curves based on 100 randomisations, using the ‘Estimates 5.0’ software (Colwell, 1997).

Visual inspection of ‘smoothed’ species accumulation curves provides a useful first impression of whether or not sampling has been adequate, but further analysis is also possible. We have fitted asymptotic models to the species accumulation curves generated by

100 randomisations of the observed species-abundance data for each set of samples. These models are used to:

1. measure within-inventory efficacy and completeness;
2. obtain estimates of species richness that are based on a standardized measure of sampling effort (making possible valid comparisons between areas sampled to a different extent - see Chapter 4) and
3. provide estimates for the minimum sampling effort required to reach a satisfactory level of census completeness (Moreno and Halffter, 2000).

For each of the sampling techniques used (SVC, RVC, gillnetting, mollusc transects, mollusc dredging), we generated species accumulation curves using ‘Estimates 5.0’. We then used the non-linear regression module in the statistical package SPSS (v 9.0) to fit two asymptotic models to the data.

The linear dependence model is based on the assumption that the number of species collected decreases linearly as sampling effort increases:

$$S_n = a/b[1 - \exp(-bn)];$$

where n is a measure of sampling effort (for SVC, number of stationary census ‘events’;, for RVC, number of 15 minute transects; for gillnets, number of gillnet sets; for mollusc transects, number of searching events), S_n is the predicted number of species in the n^{th} sample, and a and b are fitted regression constants (Colwell and Coddington, 1994). The number of samples required to include a given proportion (q) of the species in the vicinity liable to be sampled by each technique is given by:

$$n_q = -1/b\ln(1-q) \quad \text{(Moreno and Halffter, 2000).}$$

We set q as 0.9, considering sampling effort that censused 90% of the extant fauna to be adequate (theoretically, infinite effort would be required to guarantee all species were sampled).

The Clench model (e.g. Moreno and Halffter, 2000) assumes that the probability of adding species to the list decreases with the number of species already recorded, but increases over time:

$$S_n = an/(1+bn)$$

For the Clench model, the number of samples required to include a given proportion (q) of the species is given by:

$$n_q = q/[b(1-q)] \quad \text{(Moreno and Halffter, 2000).}$$

For both the linear dependence and Clench models S_{max}, the predicted species richness with infinite sampling effort, is given by *a/b*. These two models are likely to predict the upper and lower bounds of the likely true species richness of a site. The estimates of minimum sampling effort required to sample a predetermined proportion of total species present are therefore also likely to represent upper and lower bounds of estimates. The model parameter estimates and goodness of fit statistics are given in Appendix 8.3: Table 8.3, Table 8.4, Table 8.5 and Table 8.6.

2.8.1 Sampling effort for fish stationary visual census (SVC)

For the SVC, the basic unit of sampling is a single cylinder of 15 m diameter and 5 m height above the substrate, surveyed for 15 minutes. Sampling effort was expressed in terms of accumulated sampling events. This can readily be translated into area or volume sampled. Separate analyses were done for each geographical area, with samples from Sand/ mixed-sand, rock /mixed-rock and shell-bed substrates done separately within each area. There are some samples where data on substrate composition is not available due to the mismatch between the profile dives for habitat characterisation and the fish survey activities. This was generally where depth profiles were of shallow gradient, so that divers starting a profile at 20 or 25 m did not reach the 5 or 10 m sample stations for the stationary visual fish census. This means that some samples were excluded from calculations of optimal sampling size and species richness and diversity for each substrate type. The data from these excluded samples is, however, included in generating total species lists for each sampled area and comparing total recorded species for conservation prioritisation purposes (Chapter 5).

The SVC technique was not used much in Burundi, and sample sizes did not provide adequate basis for estimating total species richness, nor even for determining which model of sample species accumulation curve is more appropriate (Figure 2.3). Three or four sample dives per locality/substrate combination is clearly inadequate, yet is fairly typical of previous diver-surveys used to compare species richness between areas (e.g. Alin et al, 1999). The rocky habitats of the Pemba, Luhanga, Bangwe area and the sandy habitats in the vicinity of Uvira (both in the DR of Congo) were more intensively sampled using this technique, and show a clearly asymptotic pattern (Figure 2.3). Asymptotic models predicting the effects of additional sampling can therefore be fitted with greater confidence.

Although more than 15 diver SVC surveys of fish were undertaken on both rocky and sandy sites at Gombe, species accumulation curves had not yet levelled off, implying greater sampling effort would be needed (Figure 2.4). For the very diverse rocky areas of Mahale, continued slow increase in species is seen, even though more than 25 SVC surveys were undertaken. In the case of both sandy and rocky substrates in Mahale, the Clench model, which predicts a continued slow increase in species sampled as sample size increases, appears to provide the most realistic fit (Figure 2.4). There are no statistical criteria for separating the fit of the Clench and Linear dependence models (r^2 >0.99 in most cases – see Appendix 8.3, Table 8.3) but that is mostly because much of the data are from the steep part of the species-accumulation curve, where both models provide a similar fit. It is in their behaviour in reaching an asymptote that the two models reveal a crucial difference. This difference has considerable ramifications for predictions of ‘true’ species richness, and of the minimum sampling size required to estimate an acceptable proportion (90% is chosen in this study) of that richness.

The SVC technique was also used only occasionally in Zambia, where many sites cannot be dived because of the risk posed by crocodiles. Only for the rocky sites in the Katoto area were sample sizes sufficiently large to estimate species richness and minimum required sampling size with any confidence (Figure 2.5).

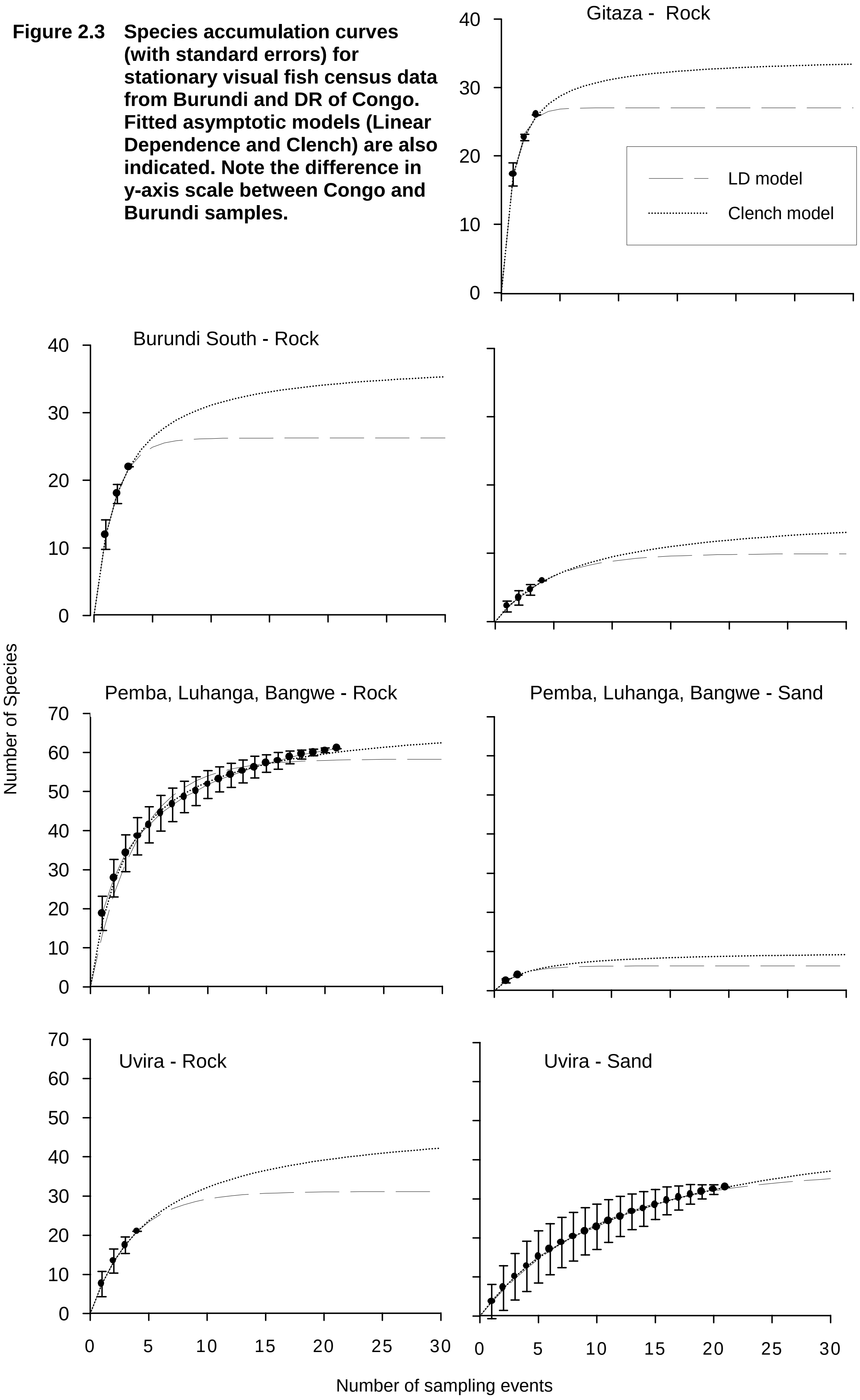
Table 2.7 indicates that some areas were adequately sampled (>90% of estimated total species present in the areas sampled), while other areas were under sampled. It is clearly seen that it is difficult to recommend a single minimum required sampling size, as this varies with location and substrate.

In general, sandy substrates require equal or greater sampling effort to rocky and mixed habitats in the same areas. This may seem surprising at first, given that they have generally lower species richness. However the sand-dwelling species are more mobile, and often schooling. This means that probabilities that additional samples will yield additional species can be high.

The two asymptotic models used to extrapolate ‘true’ species richness from partially sampled populations perhaps represent upper and lower bounds of these estimates. Minimum required sampling sizes estimated from the linear dependence model vary from 2 to 20 samples (mean = 9), while estimates from the Clench model vary from 9 to 120 (mean = 47).

The linear dependence model suggests that, while Mahale, Gombe, Gitaza and some of the sites in DR of Congo were adequately sampled, other areas dived in Burundi and Zambia were under sampled, as were the sandy areas at Pemba, Luhanga, Bangwe, and rocky areas at Uvira (DR of Congo). The Clench model seems to predict very high species richness and therefore suggests that insufficient replicate samples were taken with the SVC technique at all sites. The predictions of the Clench model are not strongly supported by comparison of our sampling with the total recorded species in the lake (Table 5.5). BIOSS surveys have, in aggregate, sampled over 80% of recorded lacustrine fish species. This suggests that the Clench model overestimates species richness and overestimates the number of samples required to census the fish populations. For the areas that were better sampled, however, the pattern of species accumulation would suggest that the Clench model may be more appropriate. Given this rather contradictory evidence, we suggest that future sampling should be based on at least 20 SVC samples per survey strata until species-accumulation curves become better known and defined.

Figure 2.3 **Species accumulation curves (with standard errors) for stationary visual fish census data from Burundi and DR of Congo. Fitted asymptotic models (Linear Dependence and Clench) are also indicated. Note the difference in y-axis scale between Congo and Burundi samples.**



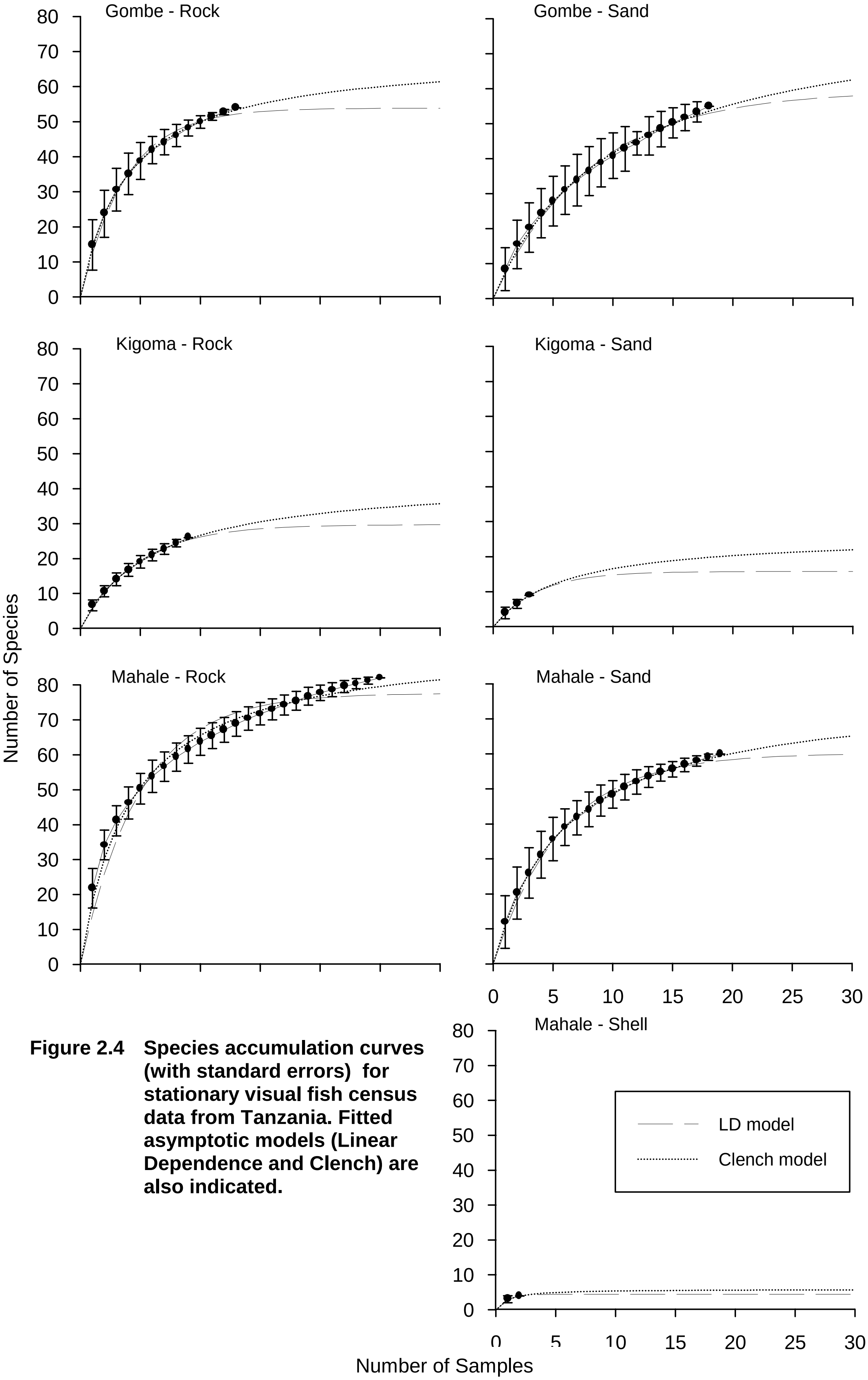


Figure 2.4 **Species accumulation curves (with standard errors) for stationary visual fish census data from Tanzania. Fitted asymptotic models (Linear Dependence and Clench) are also indicated.**

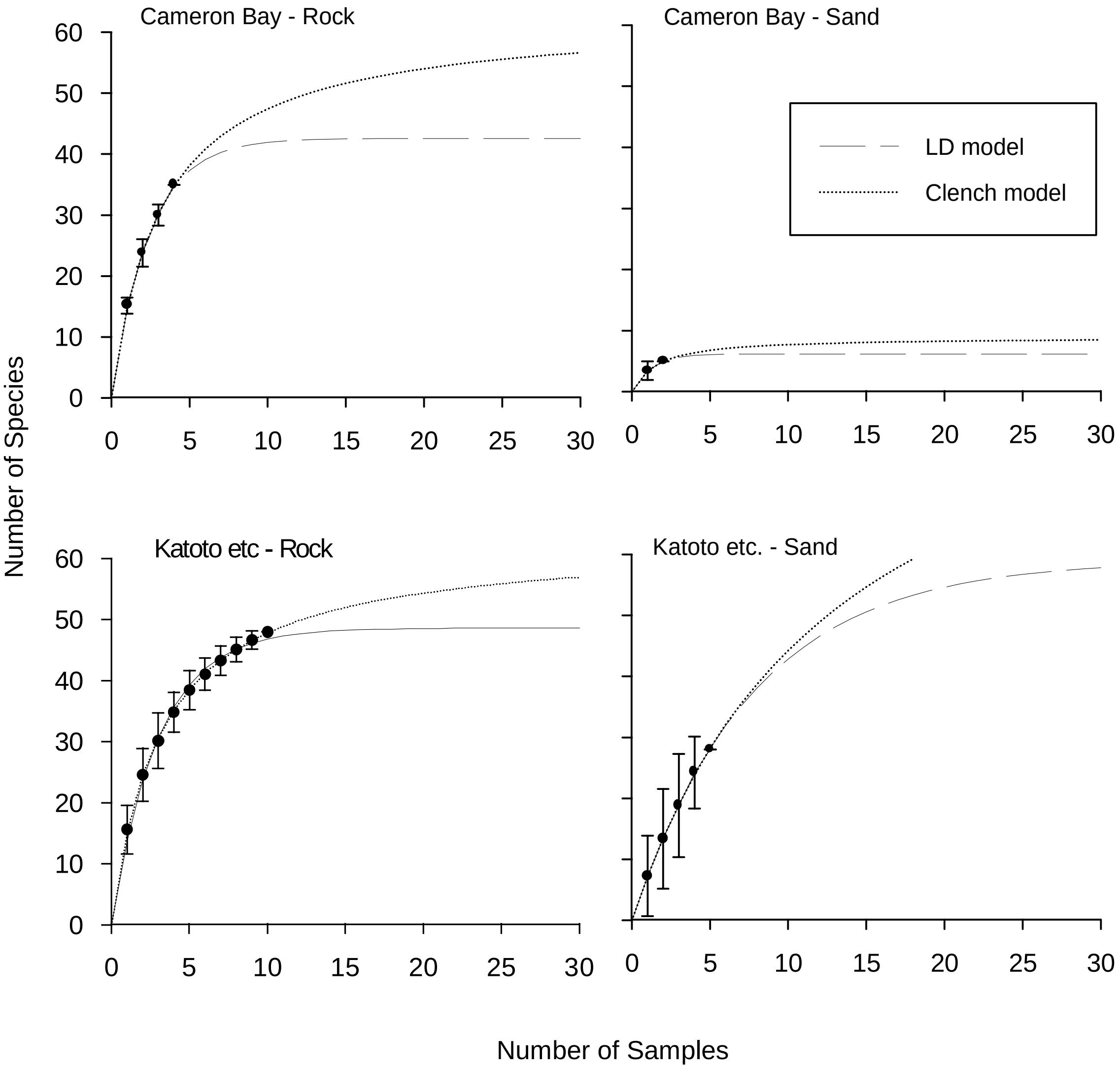


Figure 2.5 **Species accumulation curves (with standard errors) for stationary visual fish census data from Zambia. Fitted asymptotic models (Linear Dependence and Clench) are also indicated**

Table 2.7 Analysis of sampling adequcy for stationary visual census of fish species, using two asymptotic models (see text for details)

				Linear Dependence Model			**Clench Model**		
Area	Substrate	N	S_{obs}	S_{max}	S_{obs}:S_{max} (%)	N_{req} (90% S_{max})	S_{max}	S_{obs}:S_{max} (%)	N_{req} (90% S_{max})
BURUNDI									
Burundi South	Rock	3	22	26	84	4	38	58	20
Burundi South	Sand	4	6	10	60	10	16	37	63
Gitaza	Rock	3	26	27	96	2	35	75	9
DR CONGO									
Pemba etc	Rock	21	61	58	105	9	69	88	28
Pemba etc	Sand	2	4	6	63	5	10	39	28
Uvira	Rock	4	21	31	67	8	50	42	50
Uvira	Sand	21	33	37	89	23	53	62	116
TANZANIA									
Gombe	Rock	13	54	54	100	9	69	78	35
Gombe	Sand	18	55	60	92	19	83	66	90
Kigoma	Rock	9	26	30	87	11	43	60	55
Kigoma	Sand	3	9	16	57	8	26	34	52
Mahale	Rock	25	82	78	106	11	93	89	37
Mahale	Sand	19	60	60	100	13	78	77	54
Mahale	Shell	2	4	4	89	2	6	68	9
ZAMBIA									
Cameron Bay	Rock	4	35	43	82	5	63	56	29
Cameron Bay	Sand	2	5	6	81	3	9	56	14
Katoto etc	Rock	10	48	49	99	7	63	76	29
Katoto etc	Sand	5	28	59	48	18	103	27	120

N = number of SVC samples, S_{obs} = observed number of species in those samples, S_{max} = estimated species richness, N_{req} = the number of samples that would be required to sample 90% of the estimated species present. Note that estimates of S_{max} and S_{obs}:S_{max} are rounded to the nearest integer but that the calculations of have been made with the original un-rounded estimates.

2.8.2 Sampling effort for rapid visual census (RVC)

For the RVC, the basic unit of sampling is a single linear transect, defined in terms of time (15 minutes), rather than distance covered. Sampling effort was expressed in terms of cumulative number of sampling transects, but this could readily be converted to cumulative sampling time or estimated area if required. Samples were not grouped by substrate, as the RVC sampling frequently integrated across substrate types, so no meaningful separation could be made. This will add to the variance and tend to over-estimate the required minimum sampling effort for the area as a whole.

Because the RVC technique was applied in both the shallow sub-littoral (5-15 m) and the littoral fringe (0-3 m), whereas the SVC technique was used only for 5-15m, we analysed these two depth bands separately. Four transects were also done in the 16 to 25 m depth band as part of survey activities in Zambia, but limitations of bottom-time (and air supply) for no-stop SCUBA diving probably preclude routine surveys at this depth and beyond. This data is not included in the analysis. Species accumulation curves with fitted asymptotic models are given in Figure 2.7, Figure 2.8 and Figure 2.9.

Figure 2.7 Species accumulation curves (with standard errors) for rapid visual fish census data from Burundi. Fitted asymptotic models (Linear Dependence and Clench) are also indicated

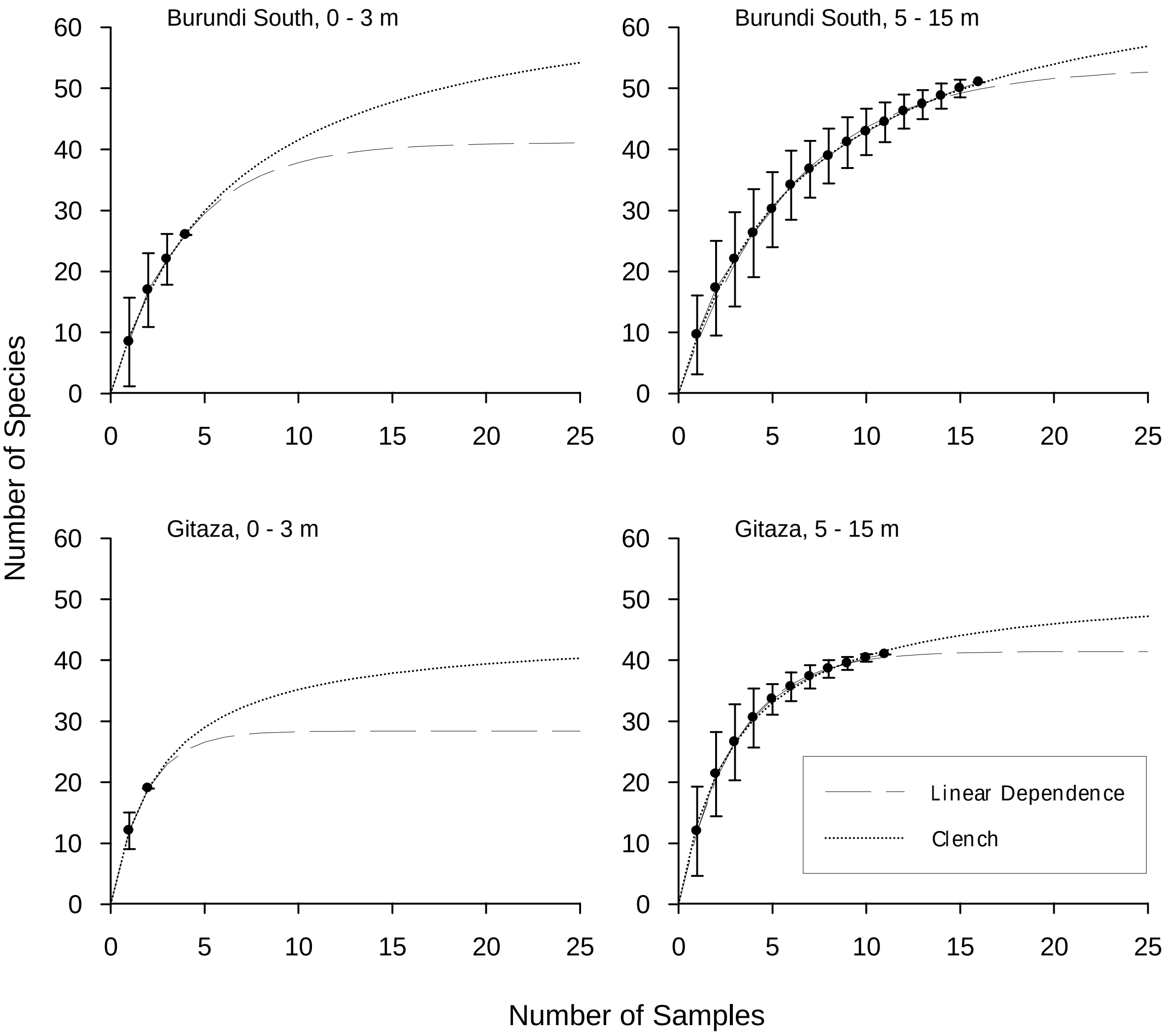


Figure 2.8 **Species accumulation curves (with standard errors) for rapid visual fish census data from DR Congo and Zambia. Fitted asymptotic models (Linear Dependence and Clench) are also indicated. Note the different X and Y axis scales for DR Congo and Zambia.**

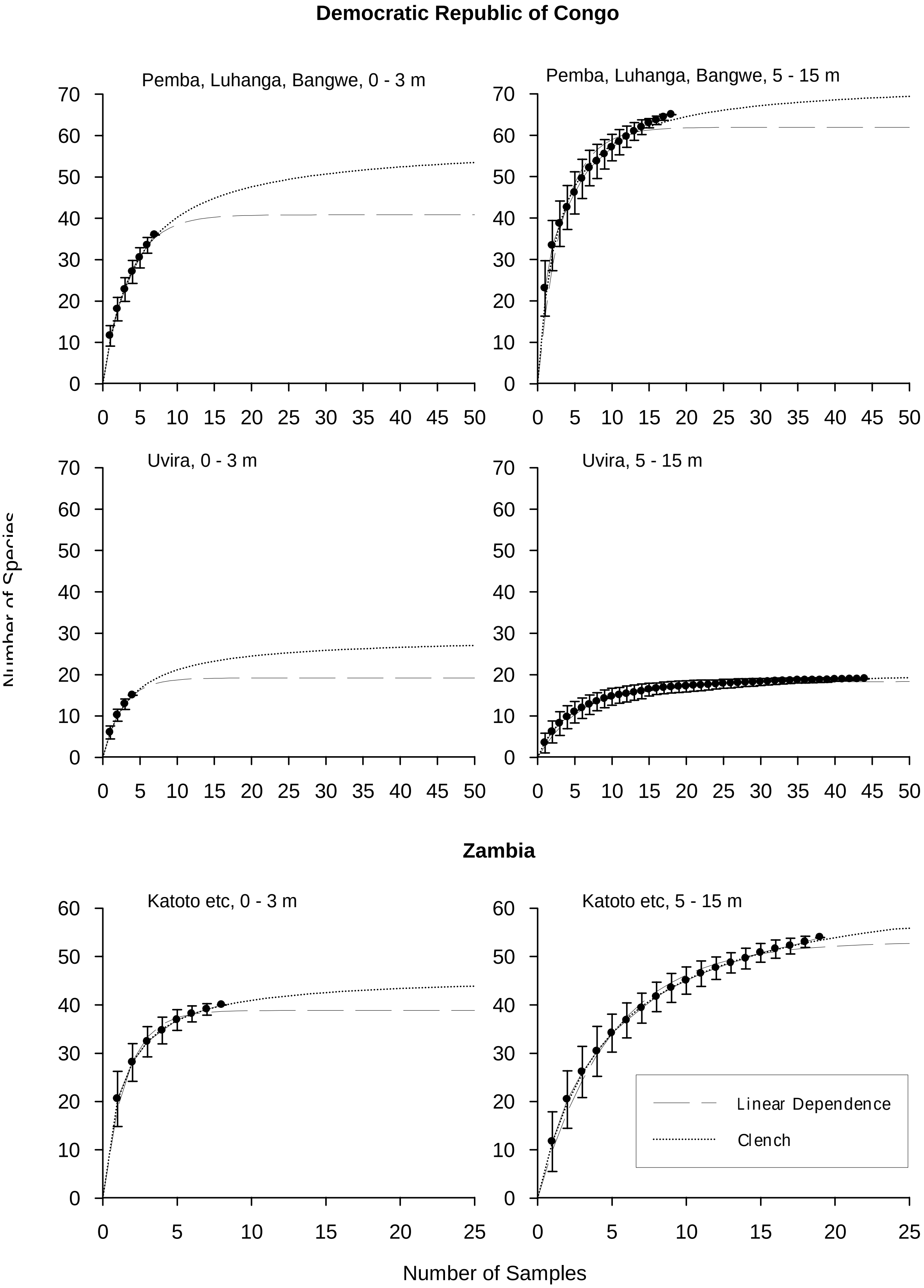


Figure 2.9 **Species accumulation curves (with standard errors) for rapid visual fish census data from Tanzania. Fitted asymptotic models (Linear Dependence and Clench) are also indicated. Note the different X and Y axis scales for Mahale and Kigoma. This is done for clarity of presentation.**

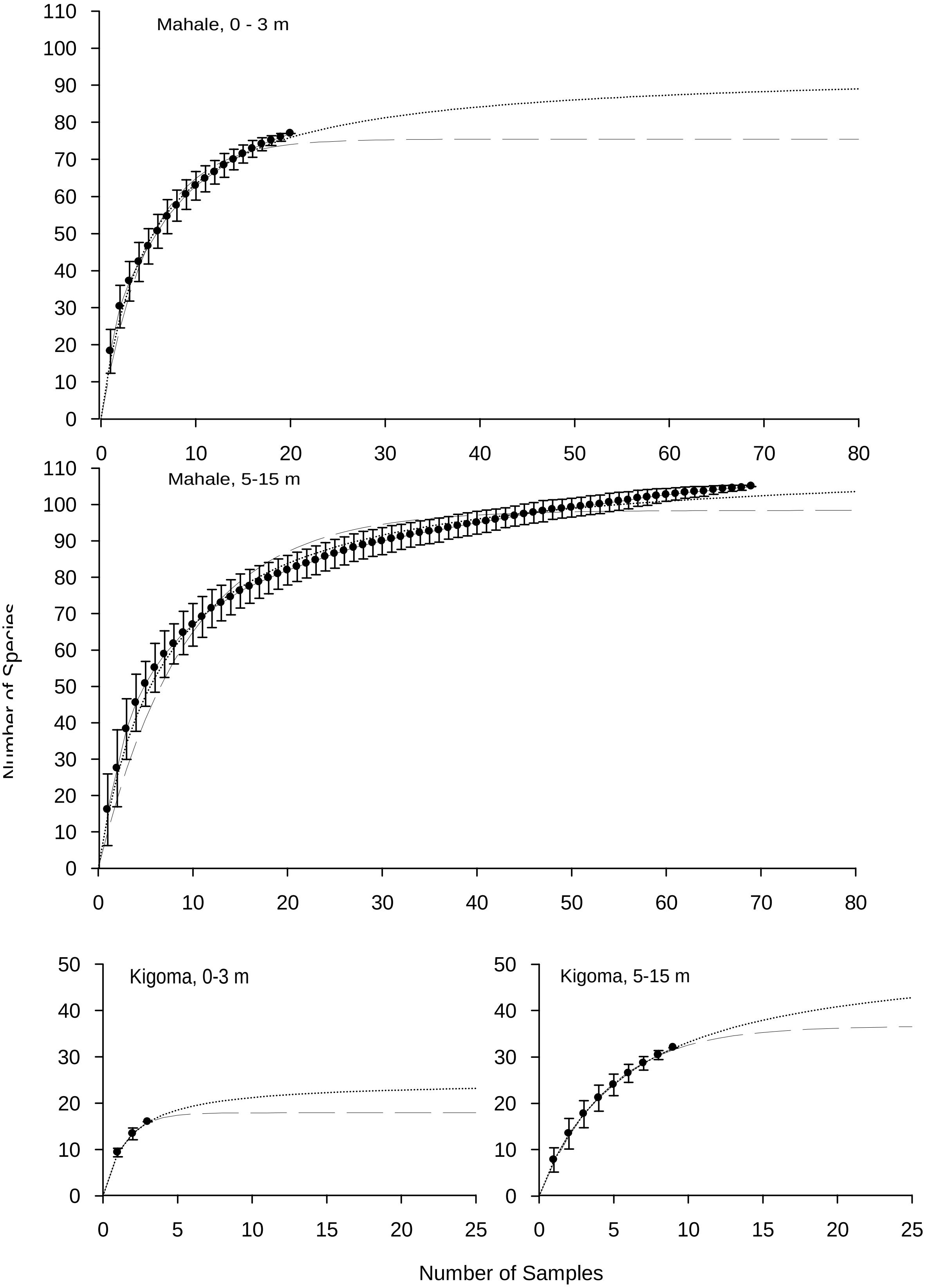


Table 2.8 Analysis of sampling adequacy for rapid visual census (RVC) of fish species, using two asymptotic models (see text for details)

				Linear Dependence Model			Clench Model		
Area	Depth range (m)	N	S_{obs}	S_{max}	S_{obs}:S_{max} (%)	N_{req} (90% S_{max})	S_{max}	S_{obs}:S_{max} (%)	N_{req} (90% S_{max})
BURUNDI									
Burundi South	0 to 3	4	26	41	63	9	68	38	57
Burundi South	5 to 15	16	51	53	96	14	73	70	62
Gitaza	0 to 3	2	19	28	67	4	45	42	24
Gitaza	5 to 15	11	41	42	99	7	53	77	27
DR CONGO									
Pemba etc	0 to 3	7	36	41	88	8	58	62	40
Pemba etc	5 to 15	18	65	62	105	8	73	89	24
Uvira	0 to 3	4	15	19	78	6	29	52	34
Uvira	5 to 15	44	19	18	103	14	21	90	41
TANZANIA									
Kigoma	0 to 3	3	16	18	89	3	25	65	15
Kigoma	5 to 15	9	32	37	87	11	53	60	54
Mahale	0 to 3	20	77	75	102	12	94	82	44
Mahale	5 to 15	69	105	98	107	21	113	93	62
ZAMBIA									
Katoto etc	0 to 3	8	40	39	103	4	46	87	11
Katoto etc	5 to 15	19	54	53	102	11	67	81	43

N = number of RVC samples, S_{obs} = observed number of species in those samples, S_{max} = estimated species richness, N_{req} = the number of samples that would be required to sample 90% of the estimated species present. Note that estimates of S_{max} and S_{obs}:S_{max} are rounded to the nearest integer but that the calculations of have been made with the original un-rounded estimates.

Although RVC data from the 5-15 m depth band Burundi South and Gitaza were sufficient to identify a reasonably narrow range for the likely total species richness, under sampling at the 0-3 m depth band means that extrapolations are rather unreliable (Figure 2.7), thus leading to unreliable estimates of minimum required sample sizes (Table 2.8) and difficulty in determining which asymptotic model provides the best fit to the randomised species-accumulation curve.

Examination of the better-sampled areas in samples from the DR of Congo and Zambia (Figure 2.8) indicates that the Clench model may provide the best fit to the observed species-accumulation curves for the Rapid Visual Census technique as well. This is confirmed by examination of the species-accumulation curves from Mahale (Figure 2.9), where the Clench model provides a better fit even in the steeper part of the species accumulation curve.

RVC surveys (Table 2.8) generally recorded slightly higher species numbers than SVC surveys (Table 2.7) probably because they covered larger areas and included larger and more mobile species, but perhaps at the expense of smaller, cryptic species. According to the Linear Dependence model, an average of 9 RVCs are usually adequate to sample 90% of estimated total species present (Table 2.8), sometimes fewer, depending on richness and patchiness of the survey area. According to this model, most areas were sampled adequately by the BIOSS team. Once again, the Clench model estimates much higher required sample sizes (11-62, averaging 38). If this model is accepted, then only Pemba, Bangwe and Luhanga, Uvira and Mahale were adequately sampled for the depth range 5-15m. By pooling samples taken at 5, 10 and 15 m we increased sample size but probably also increased variance. For the 0-3 m snorkel-based RVCs, sampling sizes were smaller (generally one snorkel survey for each 3 dive surveys at 5-15m). Future surveys should aim to carry out at least 10 RVCs per survey strata, and, if the Clench model is more accurate, 40 RVC transects would be more likely to ensure that an adequate proportion (90%) of the fish species present were recorded. Once again, this number will vary with species richness and habitat heterogeneity, and will therefore be difficult to fix in advance.

2.8.3 Sampling effort for gillnetting

For gillnet samples, it was not always possible to standardise setting time, as gillnetting was often conducted alongside other survey activities. In theory, one could correct for differences in sampling time assuming that gillnets set for longer caught more fish (and therefore were likely to sample more species). The assumption is that there is a linear relationship between the time the gillnet is in the water and what it catches. This assumption may not be valid (Minns and Hurley, 1988), so we have tested it using data from gillnets set overnight in Mahale: times in the water varied due to survey logistics, but showed no significant relationship with catches (Figure 2.10).

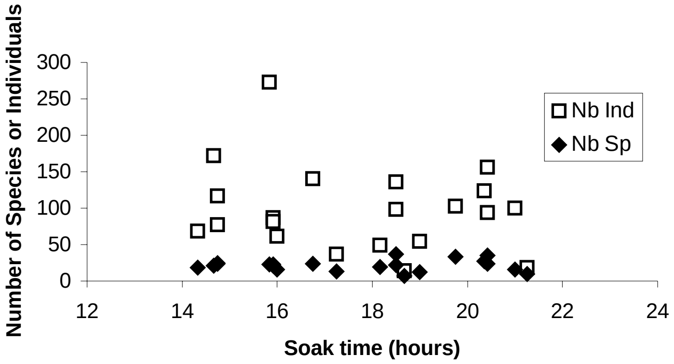


Figure 2.10 **Scatter plot of soak times against the number of species and individuals caught in gillnets set overnight within Mahale National Park, based on 21 sets.**

There is no significant (linear) relationship between set time and total catch (r^2 = 0.04, F = 0.764, $P_{1,19}$ = 0.39) or set time and number of species sampled (r^2 < 0.001, F = 0.01, $P_{1,19}$ = 0.91) so we assume that the shortest time of setting (14 hours) exceeds the ‘saturation time’ for the net, and treat each set as being equivalent replicate samples.

For Rusizi, nets were set consistently at 1700 and hauled at 0800 (15 hours). Mahale net sets can be treated as equivalent sampling units, as can nets set in other locations, which covered similar time periods. Daytime gillnet sets in Rusizi were always done for the same time (0900 – 1500; 6 hours), so no test of the effects on soak time against catch could be performed. The shorter time that nets set in the daytime were fished for may account, at least in part, for their lower catches, in terms of both species and individuals. The minimum ideal sampling time for adequate representation is thus yet to be determined.

Having ascertained that catches were not closely related to soak times, we use a ‘gill net set’ as our standard sampling unit. Attempts were made to standardise the setting times as 15 hrs overnight and six hours during the day for surveys conducted elsewhere. These units of sampling effort are obviously applicable only to the net configurations used in our programme, and future surveys using different gear should recalibrate minimum sampling effort required.

We plotted species accumulation curves in order to assess the number of replicate sets of gillnets needed to sample all fish vulnerable to gillnetting in an area. Separate analyses were done for gillnets set during the day, and overnight, using data from surveys conducted along the Burundi, Congo, Tanzanian and Zambian coast.

This analysis addresses the question: how much gillnetting effort is needed to sample the fish community adequately, and does this differ between night and day, or between areas (as a function of patchiness and/or diversity)? This can be answered by finding out how much cumulative effort is needed before no new species are found in successive gillnet samples. The number of species caught in each set is recorded, and the cumulative species calculated by checking the number of new species added by each successive net set. Each sub-set of data was selected, and successive individual net sets were added to the data-set at random. One hundred such randomisations were performed, using the Estimates 5 Software (Colwell, 1997).

The data come from a mixture of planned, intensive surveys of particular areas (e.g. Uvira, Rusizi, Mahale, Nsumbu) and more opportunistic and sporadic deployment during training and exploratory surveys. The latter tend to suffer from under sampling (see individual graphs in Figure 2.11, Figure 2.12, Figure 2.13).

Quite large gillnet samples were taken in the northern part of the Lake (Burundi and DR Congo), even with limitations on night-time gillnetting imposed by the security situation. Day/night comparison based on similar sample sizes is possible in Rusizi, where it is clear that night-time netting gives higher estimates of species richness (Figure 2.11). Even for well-sampled areas, the curves have not reached a clear asymptote. Instead, the Clench model, with its continued gradual rise is estimated species richness, seems to fit the data best. This implies that there are relatively large numbers of rare or infrequently encountered species, and good estimates of total richness can only be made with very large sample sizes. This is well illustrated for Mahale (Figure 2.12), where after 23 gillnet sets the species accumulation curve had still not reached an asymptote.

Gillnetting was an important sampling method in Zambia, where diving opportunities are severely constrained by threats from crocodile and hippo attack. Although a good range of areas were sampled in Zambia, the low sample size leads to uncertainty over predicted asymptotic species richness (Figure 2.13). It is clearly seen that the shorter the observed species-accumulation curve, the greater divergence there is between predicted species richness extrapolations from the two asymptotic models. This further illustrates that extrapolation tools, while they can be useful to gain preliminary estimates of species richness, are no substitute for a well-replicated sampling programme.

Figure 2.11 Species accumulation curves (with standard errors) for gillnet survey in Burundi and DR Congo waters. Fitted asymptotic models (Linear Dependence and Clench) are indicated.

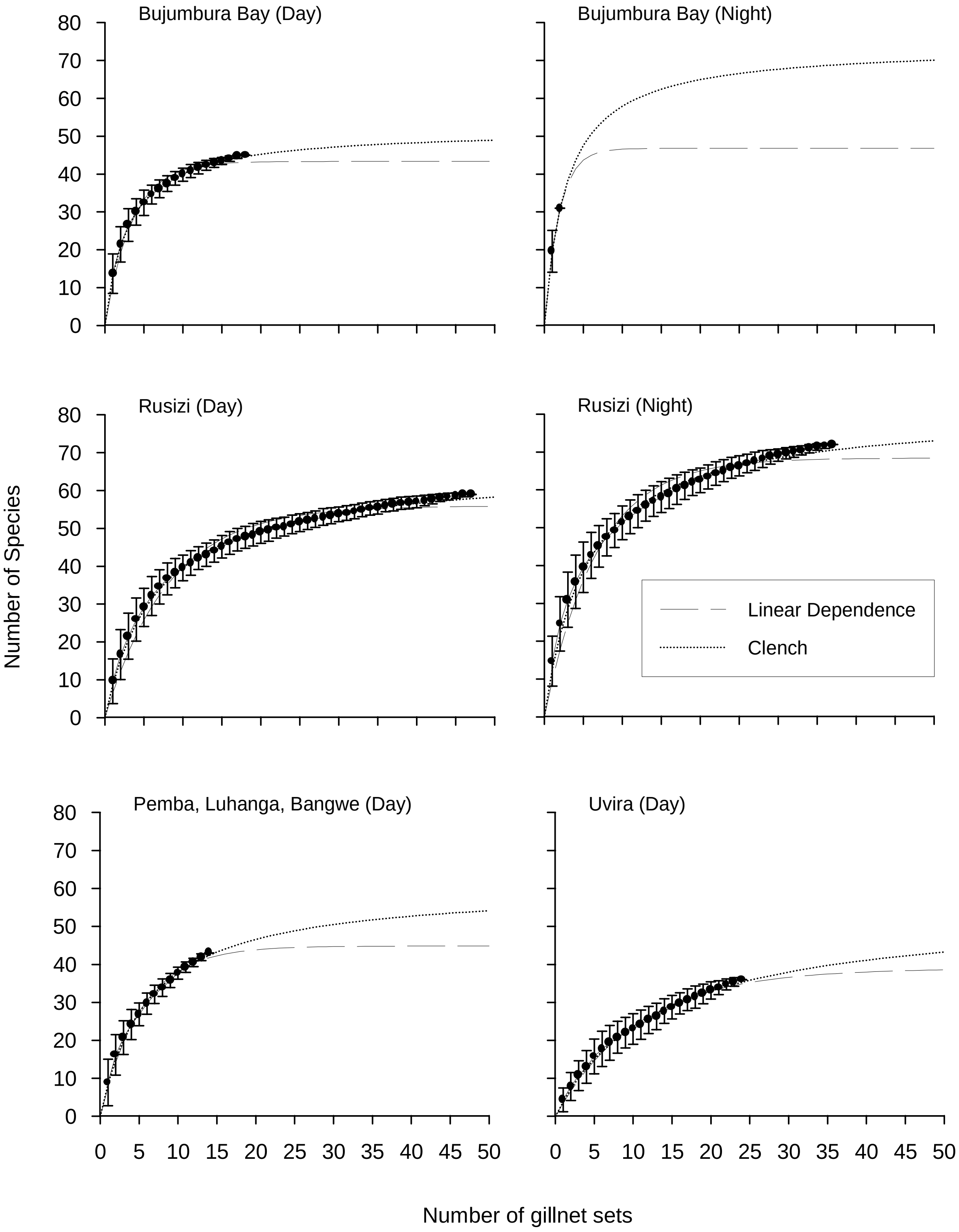


Figure 2.12 Species accumulation curves (with standard errors) for gillnet survey in Mahale National Park, Tanzania. Fitted asymptotic models (Linear Dependence and Clench) are indicated.

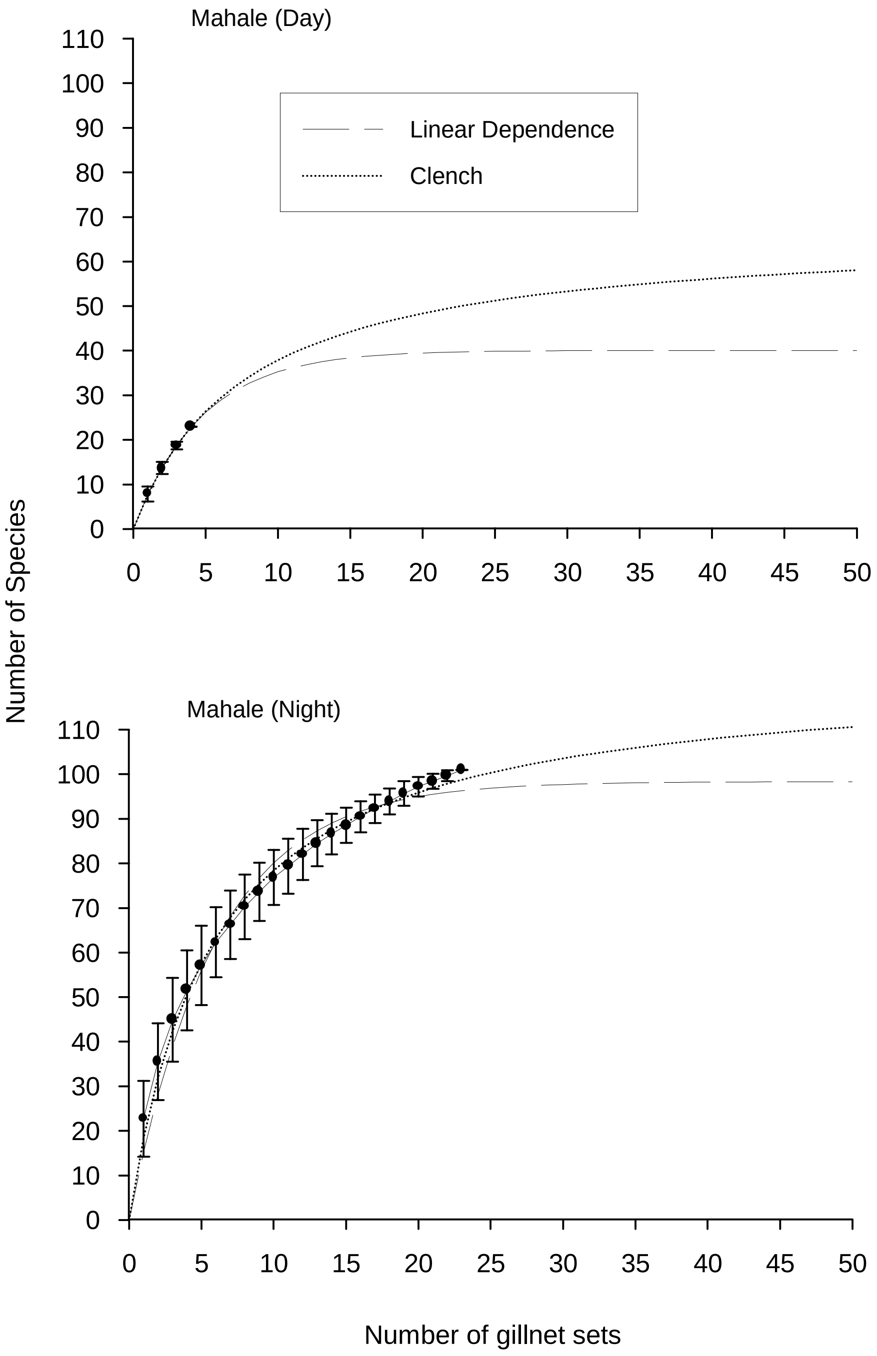


Figure 2.13 **Species accumulation curves (with standard errors) for gillnet surveys in Zambian waters. Fitted asymptotic models (Linear Dependence and Clench) are indicated. Note the Y-axis for the Lufubu sample is on a different scale to the rest (0-110 species, instead of 0-90)**

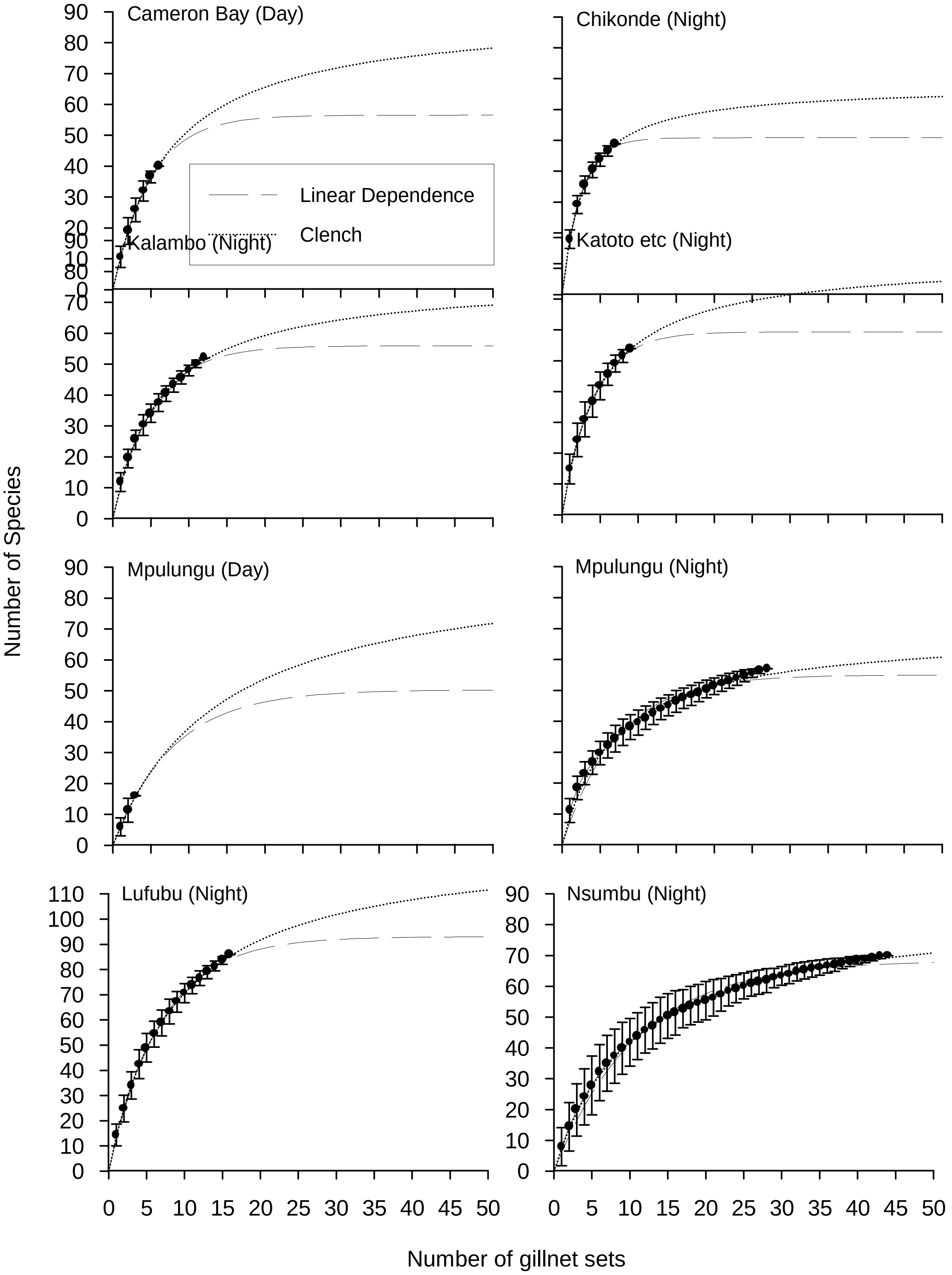


Table 2.9 Analysis of sampling adequacy for gill net sampling of fish species, using two asymptotic models (see text for details).

				Linear Dependence Model			Clench Model		
Area	Set-time	N	S_{obs}	S_{max}	S_{obs}:S_{max} (%)	N_{req} (90% S_{max})	S_{max}	S_{obs}:S_{max} (%)	N_{req} (90% S_{max})
BURUNDI									
Bujumbura Bay	Day	18	45	43	104	8	52	87	26
Bujumbura Bay	Night	2	31	47	66	4	74	42	25
Rusizi	Day	47	59	56	106	19	66	89	60
Rusizi	Night	37	72	69	105	15	81	89	49
DR CONGO									
Pemba, Luhanga, Bangwe	Day	14	43	45	96	12	61	71	55
Uvira	Day	24	36	39	92	24	55	66	118
TANZANIA									
Mahale	Day	4	23	40	58	11	67	34	69
Mahale	Night	23	101	98	103	14	132	77	51
ZAMBIA									
Cameron Bay	Day	6	40	57	70	11	90	58	66
Chikonde	Night	7	49	51	96	6	68	72	24
Kalambo	Night	12	52	56	93	12	78	67	56
Katoto etc	Night	9	54	59	92	9	83	65	44
Lufubu	Night	16	86	93	92	16	130	66	76
Mpulungu	Day	3	16	50	32	18	92	17	129
Mpulungu	Night	27	57	55	104	16	69	82	62
Nsumbu NP	Night	44	70	69	102	25	86	81	95

N = number of gillnet samples, S_{obs} = observed number of species in those samples, S_{max} = estimated species richness, N_{req} = the number of samples that would be required to sample 90% of the estimated species present. Note that estimates of S_{max} and S_{obs}:S_{max} are rounded to the nearest integer but that the calculations of have been made with the original un-rounded estimates.

N.B. The daytime set at Katoto etc is excluded (N = 2) as both fitted models failed to reach an asymptote.

Estimates of sampling size required to capture 90% of the total estimated species richness are given in Table 2.9. Once again, the Linear Dependence model suggests most areas were adequately sampled, except for those where six samples or fewer were taken. An average of 13 samples are required to capture 90% of estimated species, with a range of 2 – 25 for the individual site and set-time combinations. The Clench model again provides much higher estimates for required sample sizes, ranging from 9 to 129 and averaging 60. The Clench model suggests that in the areas where most of our sampling took place – the main survey areas – we sampled between 70 and 90% of estimated total fish species.

Areas represented by a single gillnet set are not included in this analysis: they are night-time sets at Gitaza, Burundi (15 species, 10 of which were represented by a single specimen) and Kigoma, Tanzania - (7 species, 3 'singletons') and day-time sets at Kalambo (11 species, 6 singletons) and Chikonde, Zambia (2 species). We have also excluded from the set of graphs all site and set-time combinations with less than four replicate samples, as extrapolations from such small sample sizes are unreliable.

The results of the analysis of sampling adequacy presented in Table 2.9, Figure 2.11, Figure 2.12 and Figure 2.13 suggest that, with the gillnets used, a fairly large number of replicate sets should be set to ensure reasonable estimates of richness. Once again, the estimated required sample size is variable by area, and differs markedly according to which model is chosen to represent the best extrapolation of the likely consequence of additional sampling in terms of probability of sampling additional species. In most cases where sampling was adequate, the Clench model does appear to fit the species distributions better as the asymptote is approached (although the difference in fit is not statistically significant in any case, with r^2 values usually >0.99 for both models – see Appendix 8.3: Table 8.5). If the Clench model is accepted as being preferable, then future surveys should employ at least 60 gillnet sets per location, with required sample-sizes for areas like Nsumbu possibly being as high as 95 (Table 2.9). These estimates are of course specific to the gillnets used in this programme, and must be recalculated for each gear-type used – another incentive for moving towards standardisation of sampling methodology between surveys.

2.8.4 Sampling effort for molluscs

Sampling for molluscs was done by both SCUBA and dredge techniques. Dredging was not very successful, probably owing to the small mouth of the naturalist's dredge and the relative patchy distributions of sand-dwelling molluscs. Dredging was carried out only at Rusizi and Nsumbu. Dredge sampling effort data is not considered further here. Standardised mollusc searching events constitute the sampling unit for SCUBA surveys.

As the mollusc sampling was evolving as identification skills were developed and protocols refined, sample sizes were generally small. When making decisions on how to treat the dataset, i.e. whether to pool or subdivide data on the basis of substrate and/or depth we drew on field observations from BIOSS surveys as well as previous sampling expeditions (K. West). Therefore, samples from each locality are subdivided by the five main substrate categories: sand, mixed (sand), mixed (rock), rock, and shell beds. In addition, depth categories were assigned based on broad subdivisions of the littoral zone (0m, 5-15m, >20m), which seem to correspond to species depth zonation (West, 1997). As a result the number of replicates for each substrate depth-locality combination is rather low (Table 2.10).

Sample-species accumulation curves were plotted for each location-depth-substrate category combination for which three or more replicate transects were available (Figure 2.14 and Figure 2.15). The mollusc sampling protocols were developed after much trial-and-error, and had to await the development of a capacity to identify them within the BIOSS team. This capacity developed as one of us (K. West) specialising in Lake Tanganyika molluscs was able to join the field teams in training and survey activities, and to produce field identification materials (West et al 2000). Molluscs thus tended to be under sampled, as illustrated in Figure 2.14. In the case of the sandy habitat at Uvira, no levelling off of the species accumulation curve was evident after 3 transects. Many depth-substrate-locality combinations had between 0 and 2 samples only, and are not analysed here.

Mahale NP was rather better sampled, and several depth-habitat-substrate categories provide sufficient replicate transects to fit models to species accumulation curves. Many of these curves do not, however, approach the estimated total species richness within the sampling effort applied (Figure 2.15). Only the mixed (Rock) sample at Mahale reaches a clear asymptote. This is indicative of a high degree of patchiness (and therefore uncertainty in whether or not additional species will be found in additional sample transects). For sandy substrates, it also reflects low density of the more conspicuous species.

Table 2.10 Number of replicate transects for mollusc species in each sampling strata (area, depth band, substrate category)

Country	Area	Substrate	Depth (m)	N
Burundi	Gitaza	Mixed rock	0	1
	Gitaza	Mixed rock	>20	2
	Gitaza	Mixed sand	>20	2
	Gitaza	Rocky	>20	1
	Gitaza	Sandy	>20	1
	Gitaza	Mixed sand	5 to 15	2
	Gitaza	Mixed rock	5 to 15	2
	Gitaza	Rocky	5 to 15	2
	Gitaza	Sandy	5 to 15	4
				17
DR Congo	Pemba, Luhanga, Bangwe	Rocky	0	2
	Pemba, Luhanga, Bangwe	Mixed rock	5 to 15	5
	Pemba, Luhanga, Bangwe	Rocky	5 to 15	4
	Pemba, Luhanga, Bangwe	Sandy	5 to 15	3
	Uvira	Mixed sand	0	2
	Uvira	Rocky	0	1
	Uvira	Rocky	5 to 15	1
	Uvira	Mixed sand	5 to 15	4
	Uvira	Sandy	5 to 15	3
				25
Tanzania	Mahale	Rocky	0	1
	Mahale	Mixed sand	>20	4
	Mahale	Sandy	>20	12
	Mahale	Shell	>20	5
	Mahale	Mixed rock	>20	2
	Mahale	Shell	5 to 15	1
	Mahale	Mixed rock	5 to 15	8
	Mahale	Rocky	5 to 15	9
	Mahale	Sandy	5 to 15	13
				55
Total samples:				**97**

Figure 2.14 Species accumulation curves (with standard errors) for mollusc diver-transect surveys in Burundi (Gitaza) and DR Congo (all other sites). Fitted asymptotic models (Linear Dependence and Clench) are also indicated.

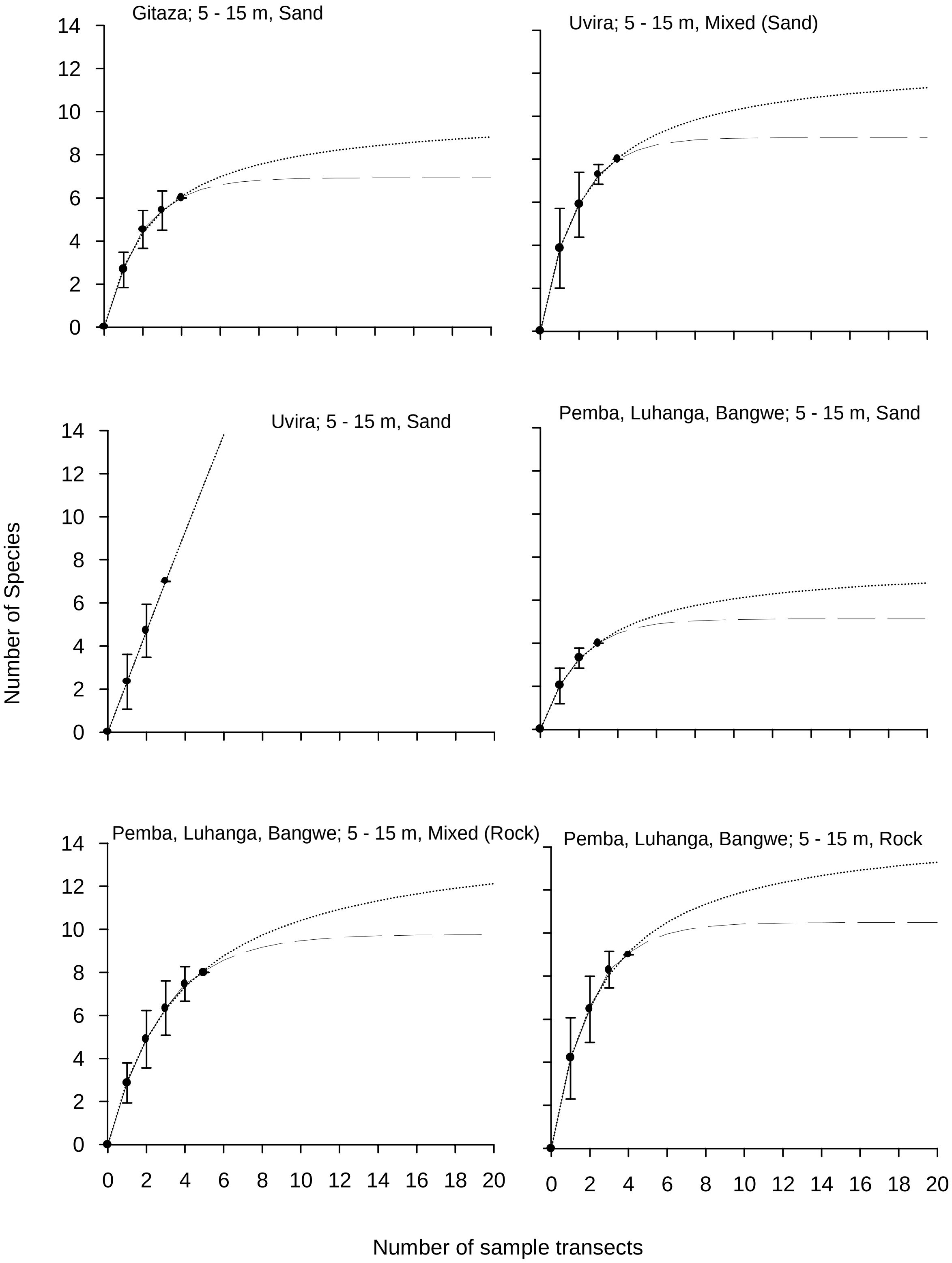
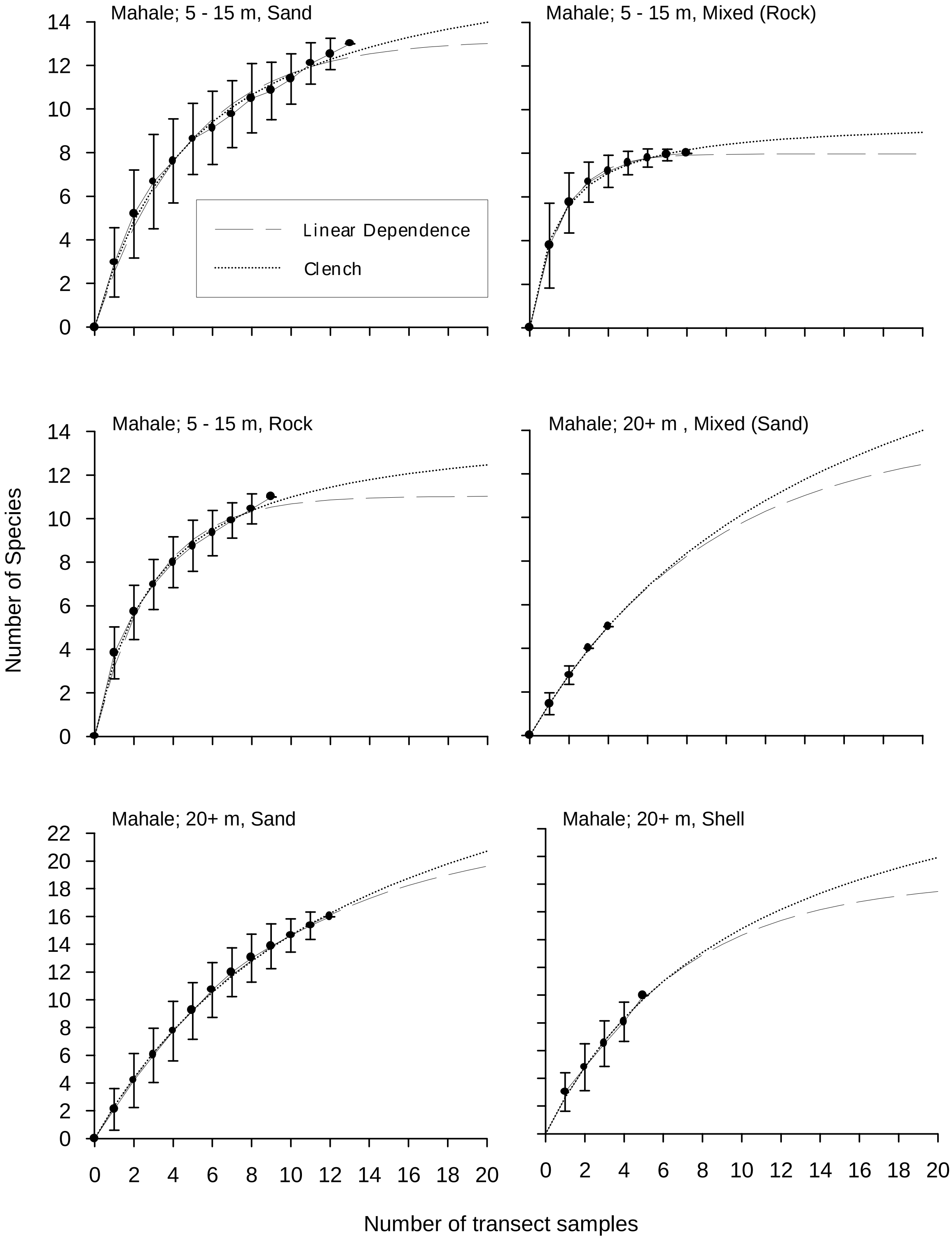


Figure 2.15 Species accumulation curves (with standard errors) for mollusc diver-transect surveys in the sub-littoral zone of Mahale National Park. Fitted asymptotic models (Linear Dependence and Clench) are also indicated. The Y-axis for the 20+ m sample from the sand and shell bed substrates has been plotted on a different scale for clarity.



Estimates of mollusc species richness are investigated in Chapter 4 (along with fish species richness estimates), however it is evident that relatively few species can be expected in surveys of the type undertaken, compared to fish surveys (Table 2.11). This means that relatively small differences in estimated species richness will have a large impact on calculated minimum sampling size required to census 90% of species present. Bearing this in mind, it is evident that for most sites, the present survey under sampled the extant mollusc diversity. According to the Clench model (which appears to fit the species accumulation curves better than the linear dependence model), some 20 to 35 transects for each sampling strata would be required to provide a strong probability of including 90% of the species present.

There is clearly a need for more intensive mollusc surveying, but there remain difficult sampling problems in dealing with the sand/rock matrix, and with species that vary in size by orders of magnitude, necessitating combined visual and mechanical sorting sampling techniques. There is also an element of learning involved in this type of survey work, where experienced workers can often find many more species than inexperienced ones, through development of a ‘search image’ and knowledge of micro distribution patterns and habitat preferences.

Table 2.11 Analysis of sampling adequacy for diver transect surveys of gastropod molluscs, using two asymptotic models (see text for details)

					Linear Dependence Model			Clench Model		
Area	Depth (m)	Substrate	N	S_{obs}	S_{max}	S_{obs}:S_{max} (%)	N_{req} (90% S_{max})	S_{max}	S_{obs}:S_{max} (%)	N_{req} (90% S_{max})
BURUNDI										
Gitaza	5 to 15	Sand	4	6	7	86	5	10	60	23
DR CONGO										
Pemba etc	5 to 15	Sand	3	4	5	78	5	8	52	25
Pemba etc	5 to 15	Rock	4	9	10	86	5	15	60	23
Pemba etc	5 to 15	Mixed (Rock)	5	8	10	82	7	15	55	35
Uvira	5 to 15	Mixed (Sand)	4	8	9	89	4	13	63	20
TANZANIA										
Mahale	5 to 15	Sand	13	13	13	99	11	18	74	47
Mahale	5 to 15	Mixed (Rock)	8	8	8	100	4	10	83	13
Mahale	5 to 15	Rock	9	11	11	100	7	14	76	28
Mahale	> 20 m	Sand (Mixed)	4	5	14	36	21	25	20	145
Mahale	> 20 m	Sand	12	16	22	72	21	35	45	127
Mahale	> 20 m	Shell	5	10	18	55	15	30	33	96

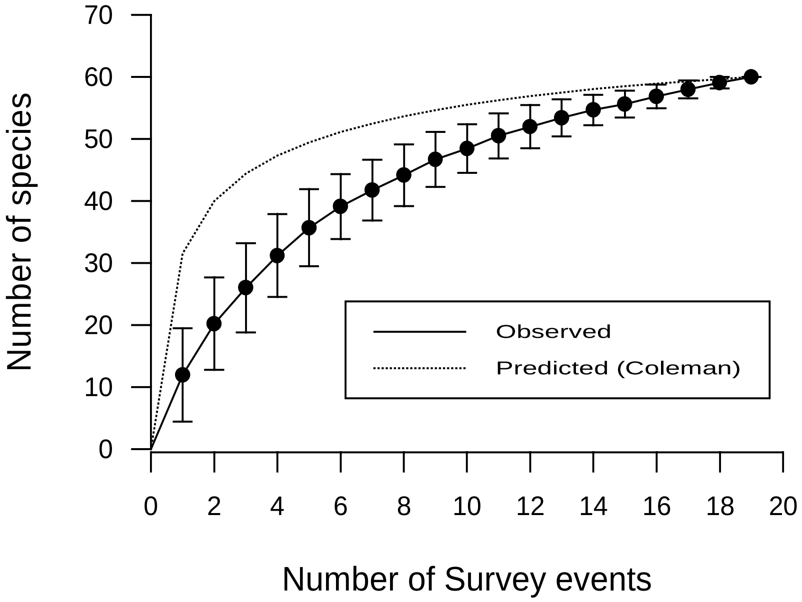
N = number of SVC samples, S_{obs} = observed number of species in those samples, S_{max} = estimated species richness, N_{req} = the number of samples that would be required to sample 90% of the estimated species present. Note that estimates of S_{max} and S_{obs}:S_{max} are rounded to the nearest integer but that the calculations of have been made with the original un-rounded estimates.

N.B. – the sample from Uvira, 5-15 m, Sand, is excluded from the analysis as both models failed to reach an asymptote at realistic species numbers

2.9 Assessing sample heterogeneity

One of the key factors in determining potential bias in the estimates of species richness from incomplete or under sampled datasets is in assessing whether the sample groupings are reasonably homogenous.

a) Stationary visual fish census, sandy substrates, Mahale National Park



b) Stationary visual fish census, rocky substrates, Mahale National Park

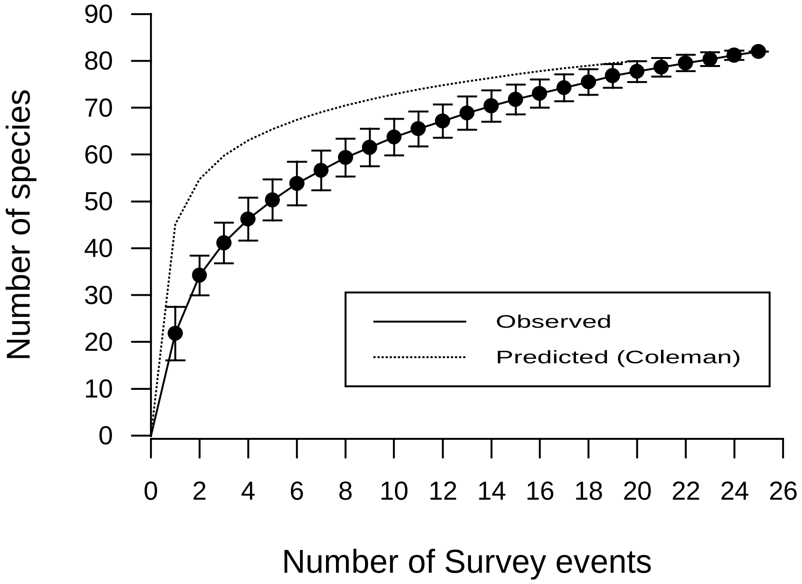


Figure 2.16 Comparison of observed species-sample accumulation curves (based on 100 randomisations of the data, with standard deviations) and calculated Coleman or 'random placement' curves.

One way to examine the level of homogeneity is to compare the empirical mean randomised species accumulation curve with the curve expected if the individuals in all samples pooled had been randomly assigned to the samples. If this expected curve rises significantly more steeply from the origin than the mean empirical curve, then the empirical samples are more heterogeneous in species composition than sampling error, alone, can account for (Colwell and Coddington, 1994).

Figure 2.16 illustrates that there is more heterogeneity in the datasets than can be accounted for by random error variation alone. There is an important trade-off to be made in all analyses, between differentiating samples within known environmental gradients (depth, substrate type or habitat) and between accumulating sufficient samples to provide a reasonable analysis of total richness within a locality. Ideally, we would have large sample-sizes within each depth-substrate combination. In practice, we have had to pool samples across broad habitat categories and depth ranges to make any evaluation of minimum required sampling sizes and estimated total species richness. We have to accept a reduction in precision in estimates of species richness, and a reduction in our ability to elucidate links between specific habitat types and fish and mollusc communities. For fish, we have pooled to a greater extent than for molluscs, because habitat-species assemblage relationships are more likely to be very strongly coupled in benthic invertebrates than in the more mobile fish species.

As samples accumulate, through future surveys, it should be possible to reduce the amount of pooling, and obtain more reliable estimates of true species richness by extrapolating from data sets of greater homogeneity. Certainly it is desirable **not** to pool across known environmental gradients whenever possible. However, given that the primary objective here is not to carry out ecological studies of species-habitat association, but to provide preliminary estimates of species richness of large areas for conservation planning purposes, pooling to increase sample sizes for each area is justifiable.

2.10 Testing for complementarity and bias in different sampling techniques

2.10.1 Fish Sampling methods

Every fish survey method will be subject to bias (Perrow *et al.,* 1996). If the results of sample surveys are to be used comparatively, then the extent and nature of bias must be investigated. This can be done by simple comparative analysis of the species compositions of different survey techniques used in the same area.

Two types of qualitative comparison are employed here as a preliminary analysis. First, we computed lists of species caught uniquely by each survey method employed (gillnet-day, gillnet-night, SVC, RVC) and calculated simple similarity indices:

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

Where *a* = number of species in sample A, *b* = number of species in sample B and *c* = number of species common to both *A* and B.

A high similarity index indicated that the use of either survey method would include most species present, a low similarity index would indicate that it was necessary to use both methods to survey the fish population adequately. This gives an indication of the types of fish that could be missed in surveys that do not employ the full range of techniques, but is sensitive to the appearance of rare or infrequent species, and assumes comparable sampling effort.

Second, we created a list of the 10 most abundant species recorded by each quantitative survey method (gillnet-day, gillnet-night, SVC). By comparing which species are most abundant in each survey method, we could gauge whether different techniques were sampling different sections of the same fish community.

2.10.2 Comparing gillnet catches by day and night, Rusizi

Night time-gillnets tended to catch more species than daytime set gillnets (Figure 2.11, Figure 2.12 and Figure 2.13: Table 2.9). In Rusizi, for example, 59 species were recorded from 23 hauls in the daytime, while 18 hauls sampled 72 species at night. Although it must be noted that daytime soak times for the gillnets were lower than during the night (a total of 138 hours in the day, 270 at night), we have established that there does not appear to be a relationship between soak time and catch rates in terms of either species or number of individuals caught, within the range of soak times used in this survey programme (Figure 2.10).

The number of species caught uniquely by day or night is low compared with the total diversity, so there is a relatively high Krebs similarity index (0.83, see Table 2.12). Of the 14 species caught uniquely at night several are nocturnally active catfish or deepwater cichlids that move into the shallows to feed at night (*Auchenoglanis, Bathybates, Hemibates, Benthochromis, Synodontis, Chrysichthys,* etc ...). The list of species caught only during the day is shorter (only 4 species). Their presence only during the day is likely to be by chance, with the possible exception of *Perissodus microlepis*, which feeds by attaching other fish, tearing off a piece of flesh or scales, and may favour daylight to help it hunt.

Table 2.12 Species caught uniquely in day and night set gillnets, Rusizi, Burundi, synthesised from all sets

	DAY Number of sets=23 Total species recorded =59		**NIGHT Number of sets = 18 Total species recorded =72**
1	*Chrysichthys brachynema*	1	*Astatoreochromis straeleni*
2	*Lestradae perspicax*	2	*Auchenoglanis occidentalis*
3	*Perissodus microlepis*	3	*Bathybates graueri*
4	*Xenotilapia burtoni*	4	*Benthochromis tricoti*
		5	*Chrysichthys platycephalus*
		6	*Cyathopharynx furcifer*
		7	*Enantiopus melanogenys*
	Similarity index = 0.83	8	*Hemibates stenosoma*
		9	*Neolamprologus mondabu*
		10	*Neolamprologus tetracanthus*
		11	*Petrochromis fasciolatus*
		12	*Plecodus paradoxus*
		13	*Synodontis multipunctatus*
		14	*Trematocara nigrifrons*
One sampling unit = 60 m multimesh gillnet set overnight (15 hours) or during the day (6 hours).			

While there may be over 80% over lap between day and night catches, the most striking difference between day and night samples is in the structure of catches (Figure 2.17). The most abundant species in the daytime catches (*Boulangerochromis microlepis*) does not feature among the dominant species in night-time catches. *Lates* species are similarly common in night-time catches but not in daytime ones. However five species feature in the 'top ten' most abundant species in both day and night catches (Figure 2.17). From this we can conclude that night-time gillnetting is slightly more effective and is likely to add nocturnal and crepuscular species, while retaining most species caught during the day. We therefore recommend that gillnetting for species richness estimation be carried out by night where possible.

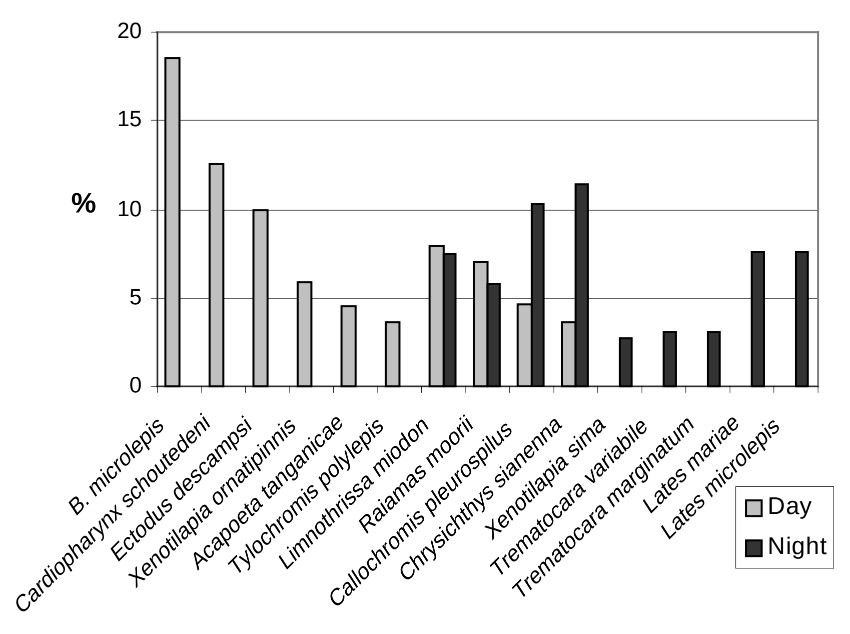


Figure 2.17 The ten most abundant species represented in day and overnight gillnet samples from Rusizi

2.10.3 Comparison of gillnet, SVC and RVC samples from Mahale National Park

As it was not possible to sample all sites with the same methods, and as ultimate species lists are compiled from combinations of sampling methods, it is of interest to establish biases and complementarities between different sampling methods. We use the survey of Mahale National Park to explore the selectivity of different methods, as Mahale was comprehensively surveyed over a short time period using all three main fish sampling techniques – SVC, RVC and gillnetting.

It is evident that gillnets sample fish normally found in deep water but feeding at night in the shallows (*Bathybates sp, Chrysicthys sp, Trematocara sp, Tanganykallabes*). These are not seen in daytime dive-surveys in shallow water (Table 2.13). The lists of species seen uniquely by SVC and RVC methods are not obviously differentiated from one another (and indeed similarity indices between these two methods are high). Thus it would appear that the most efficient sampling strategy would be to combine gillnetting with either SVC or RVC, and that there is little advantage to be gained by using both SVC and RVC in the case of Mahale, as both recorded almost the same number of species (103 and 104).

Four of the ten most abundant species in gillnet catches also occur among the most abundant diver counts in the SVC method (Figure 2.18). The differences probably reflect differences in behaviour, with more mobile and predatory species being preferentially selected by gillnets, while static and cryptic species tend to be better sampled by careful visual census, such as in the SVC technique. The two techniques are therefore complementary, and the closest approximation to actual species richness can be achieved by using both techniques with sufficient replicates to ensure most species vulnerable to sampling by each method is included in any census.

It should be noted that the continuing slow accumulation of species seen in the species-abundance curves may represent species that are not efficiently sampled by one or other method, rather than being rare. Thus, an area that is apparently under sampled by both gillnets and SVC may be adequately sampled by the combination of the two methods.

Table 2.13 Species recorded uniquely in rapid visual census (RVC), stationary visual census (SVC) and night-set gillnets (GILL), Mahale, March-April 1999.

	RVC Number of transects = 108 Total species recorded = 104		**SVC** Number of surveys = 78 Total species recorded = 103		**GILL** Number of sets = 29 Total species recorded = 96
1	*Aethiomastacembelus cunningtoni*	1	*Altolamprologus calvus*	1	*Batybates graueri*
2	*Aethiomastacembelus platysoma*	2	*Caecomastacembelus ophidium*	2	*Batybates horni*
3	*Barbus sp*	3	*Neolamprologus falcicula*	3	*Batybates leo*
4	*Cæcomastambelus frenatus*	4	*Neolamprologus niger*	4	*Batybates vittatus*
5	*Julidochromis ornatus*	5	*Oreochromis tanganicae*	5	*Benthochromis tricoti*
6	*Julidochromis tanscriptus*	6	*Telmatochromis caninus*	6	*Callochromis macrops*
7	*Neolamprologus olivaceous*	7	*Xenochromis hecqui*	7	*Chrysichthys brachynema*
8	*Petrochromis ephippium*			8	*Chrysichthys platycephalus*
9	*Spathodus erythrodon*			9	*Chrysichthys sianenna*
10	*Telmatochromis burgeoni*			10	*Cyprichromis nigripinis*
11	*Xenotilapia papilio*			11	*Hyppopotamyrus discorhynchus*
			Similarity indices: RVC/SVC = 0.85 SVC/GILL = 0.71 GILL/RVC = 0.68	12	*Limnothrissa miodon*
				13	*Petrochromis sp(red)*
				14	*Phyllonemus filinemus*
				15	*Synodontis eurystomus*
				16	*Tanganicallabes mortiauxi*
				17	*Trematocara caparti*
				18	*Trematocara marginatum*

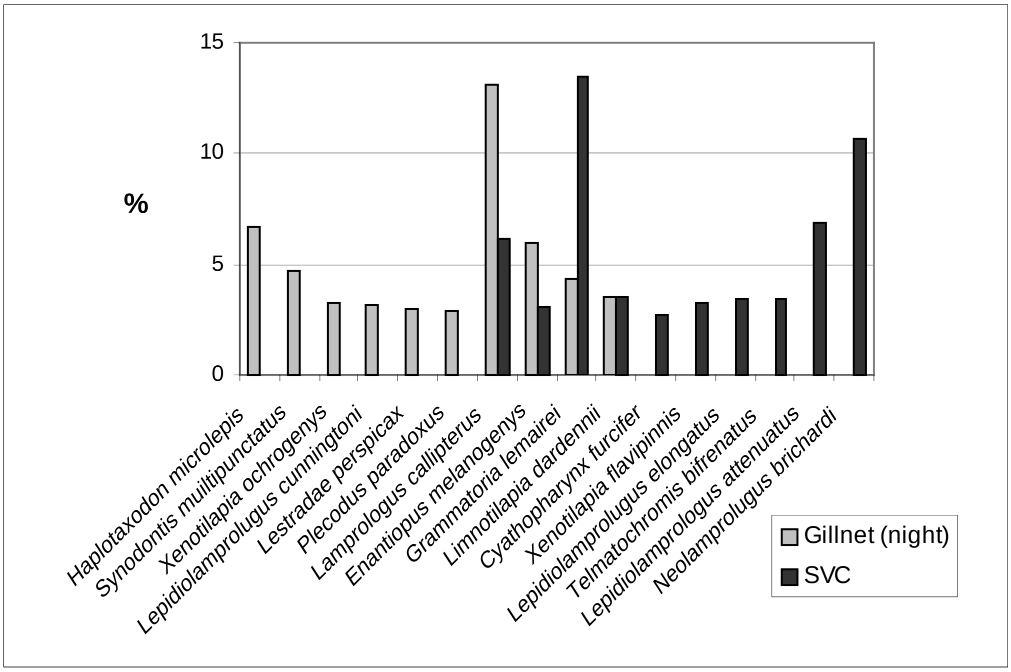


Figure 2.18 The ten most abundant species in gillnet and SVC surveys, Mahale Mountains National Park

2.10.4Mollusc sampling methods

Because we experimented with dredging relatively late in our program, there was insufficient data to compare species richness as a function of survey method (dredging or diving). However, surveys completed in Zambia allow comparison between the sampling efficiency of divers and dredging. These comparisons are limited to soft substrate surveys, as dredging was not attempted (and is generally not feasible) on hard substrates where the equipment can get caught or torn. A comparison of which soft-substrate-dwelling molluscs were found in Zambia by each method provides a first insight into the relative selectivities of each method.

Table 2.14 Soft-substrate-dwelling mollusc species lists found in Zambia by diving and by dredging

Diving	Dredging
	Bathanalia howesi
	Caelatura spp
	Limnotrochus thomsoni
Neothauma tanganyicense	*Neothauma tanganyicense*
Paramelania minor	
	Syrnolopis lacustris
	Syrnolopsis minuta
	Tanganyicia neritinoides
Tanganyicia rufofilosa	*Tanganyicia rufofilosa*

Interestingly, dredging recovered three very small species (*Tanganyicia neritinoides* and the two *Syrnolopsis* species) while divers did not recover any small species. Dredging may be a more efficient way of surveying small molluscs as the dredge 'samples' a much larger area than divers do when they sieve sediment.

Dredging recovered more species from soft substrates than divers. Unfortunately, because we did not dredge and dive at the same locality, we cannot know for sure if this is a function of disjunct distribution patterns. Future studies should dredge and dive at the same locale to eliminate this variable and test whether the two methods do recover similar taxa.

2.11 Evaluation of biodiversity assessment methods

In this chapter, we have highlighted the questions we set out to answer and the strategy we adopted to collect the data necessary to answer them. We have given an overview of the philosophy that guided our approach, and an overview of the process of developing a methodology for biodiversity assessment that takes into account survey objectives, institutional and human resource capacity and the practical realities of fieldwork on Lake Tanganyika.

We have also tested and compared our methods to enable us to account for biases in different techniques, and to assess, and provide guidance on, the minimum sample sizes required for valid comparative studies. This preliminary analysis and testing was also necessary to define sub-sets of data on which to base subsequent analyses.

We conclude that not all our sampling has been adequate to provide reliable estimates of species richness for all sites sampled. We would argue, however, that we have achieved good coverage of our main sampling areas, including the four proposed and existing National Parks, and at least three areas considered adversely impacted by pollution and sedimentation (Uvira, Bujumbura Bay, Mpulungu). The strength of this study is that it has attempted to investigate the sampling requirements for biodiversity assessment. It has shown that such requirements are highly variable, depending on the structure of communities, patchiness of the habitat and on the species richness itself.

The type of species-accumulation curve represented by the Clench model is most typical of large areas of high biodiversity. It assumes that the probability of adding species to the list decreases with the number of species already recorded , but increases over time (or sampling effort). Soberón and Lorente (1993) recommend this model for larger areas than those where the linear dependence model would be applied, or for taxa for which the probability of adding new species will increase as more time is pent in the field. The Linear Dependence model is perhaps better suited to sampling a known diversity of species in a relatively small study area or habitat. This does suggest that to gain reliable estimates of total species richness will require very extensive sampling programmes at each location to be compared. Data from casual collecting visits such as those undertaken by earlier studies are therefore unlikely to represent useful estimates of species richness.

These analyses are preliminary, and much further refinement is possible, particularly in the calculation of different similarity indices between fish communities found at different combinations of depth, substrate type, sampling method and location of sampling. We hope that the availability of the data in the region will stimulate scientists in the participating institutions to undertake further, more refined analyses. In particular, we recommend the calculation of quantitative measures of similarity, such as the Merista-Horn index, now greatly facilitated by the availability of appropriate software for this type of analysis (e.g. Pisces Conservation Ltd, Species Diversity and Richness II, 2000). This will allow objective decisions to be made on whether it is best to pool samples across known environmental gradients in order to increase sample size, or to accept under sampling and use model extrapolations of species richness for comparative purposes.

Although we have made considerable progress towards identifying biases and uncertainties in sample surveys, there is more work to do in this area, and future surveys will need to take into account the findings of our work on minimum required sample size and effort. The present survey results are confounded to some extent (but it is a quantifiable extent) by the limitations of differing and sometimes inadequate sampling size. It has also been impossible to eliminate sampling biases, for example in the use of non-comparable sampling methods between areas where diving was or was not possible. All survey activities that aim to sample across habitat types and species groups will be confounded by these difficulties (which is why comparative all taxa biodiversity inventories are almost impossible to achieve). We hope that the experiences detailed here will aid the design of future surveys, where adequate sample size and comparable methodology can be allied to carefully focused and defined survey aims to improve the quality of information available for management decision-making.

A particularly useful feature of this analysis, not previously undertaken in Lake Tanganyika, is our use of species accumulation curves to give measures of the completeness of our biodiversity surveys. This allows a comparison of species richness between localities, and provides an assessment of trade-off of increased sampling cost and effort versus returns in the form of additional information (Henderson and Southwood, 2000).

2.12 Alternative methods of biodiversity assessment

The methods of assessment chosen by this study are the conventional species-based approaches used in many such surveys. This is despite well-known concerns with the definitions of species, and species concepts themselves (e.g. Mishler and Donoghue, 1982; Turner, 1999; Wheeler and Meier, 2000), a growing consensus that species diversity is not the most important diversity-related attribute of an ecosystem (Bengtsson, 1998; Schwartz et al 2000) and a move away from species-based conservation practice to broader focus on environmental conservation (Pickett et al., 1997).

The choice of conventional species-based measures of diversity has both advantages and disadvantages. The main advantages are that the results will be comparable with past and future surveys of the same type, and the survey outputs are likely to be broadly acceptable to administrators impressed by long lists of Latin names, and scientists reassured by the legitimacy these names confer.

The disadvantage of using conventional taxonomic-based measures of biodiversity is that the limited knowledge of formal taxonomy of Lake Tanganyika organisms, and the scarcity of specialists in possession of that knowledge, was always going to constrain the number of taxonomic groups that could be chosen for survey. The most extensive previous surveys have sampled three groups: fishes, molluscs and ostracods (Cohen *et al.,* 1993; Alin *et al.,* 1999), whereas we have only sampled fishes and molluscs. At present, there is insufficient taxonomic expertise among riparian nationals to include ostracods in routine surveys. In short, there were few options for acceptable 'total biodiversity surrogates', and an 'all taxa biodiversity inventory', although of potential scientific interest, would not have been feasible nor useful in management terms (Kaiser, 1997).

Increasing the level of taxonomic knowledge in Lake Tanganyika was one potential BIOSS objective (it was never an LTBP objective), but was difficult to achieve on a time-scale relevant to meeting the project's needs to develop advice for management within its 5 year lifespan. BIOSS achieved something in this field: there is now a cadre of 23 research scientists and technicians in the institutions of all the riparian countries with the ability to identify a high proportion of the lake's fish and mollusc species. This is an improvement on the situation before the project, when perhaps 10 scientists on the lake (mostly in Burundi and Congo, with some knowledge in Zambia) could identify fish, and none could identify molluscs. There are also 20 qualified scientific divers, who have amassed considerable experience of quantitative underwater survey techniques. These skills could be built on when extending surveys to new taxonomic groups in future.

Even this expanded scientific capability is limited when faced with the size of the lake and the diversity of its biota. The limitations of conventional, formal species-based survey approaches was appreciated early on in the project and other, more radical, methods of assessing relative biodiversity and conservation value were proposed at the time. These suggestions included approaches commonly used in major biodiversity projects elsewhere:

1. The use of non-specialist technicians as 'parataxonomists' to distinguish morphologically 'recognisable taxonomic units' (Oliver and Beattie, 1993; 1996a; 1996b) for sorting large samples. Expert time is expensive and there is not enough time and experts available to carry out the large amount of routine sample processing required of comparative biodiversity surveys. Trials with insect species showed that with a few hours training, non-specialist technicians and students performed with 87% accuracy compared to formally trained taxon-specialists (Oliver and Beattie, 1993). This level of accuracy may be inadequate for the production of a definitive monograph, but is likely to suffice for purposes of conservation management, where error variances and bias associated with sampling techniques are likely to over or under-estimate species richness by greater margins. Most major biodiversity projects in rainforests, where the task of species identification is at least as complex as Lake Tanganyika, make extensive use of veritable armies of parataxonomists (Tangley, 1990; Cranston and Hillman, 1992; Kaiser, 1997).

2. Participatory biodiversity assessment and monitoring. Fishermen generally have a great deal of non-scientific or 'indigenous knowledge' about fish species. Given the diversity of fishing methods in use in all habitats of the lake (Lindley, 2000) there is a strong probability that there are some fishermen in the lake who, between them, could identify the majority of fish species. A distinguished African Great Lakes scientist recently highlighted that many of his early scientific descriptions and ecological insights into cichlid fish in Lake Malawi were based on observations grounded in local knowledge (Fryer, 1999). Colonial-era scientists seemed to make greater use of local knowledge than subsequent fishery experts have done. Worthington, who visited Lake Victoria in 1927 to carry out biological research in support of fisheries development, narrates:

> "In addition to the fish themselves, I became deeply interested in the indigenous native fishing methods and was surprised at their variety….adapted to what was a clear understanding of the fish themselves."
>
> "The Luo fishermen we employed had a better eye for a species than we had and pointed out that the "ngege", as served for breakfast in Nairobi, was in fact new to science"
>
> pp 659-660 in Worthington (1996)

Involving fishermen and other lakeshore people in biodiversity assessment and monitoring has other advantages besides being a cost-effective use of existing information. It minimises the requirements for expensive expert input; it involves resource-users, who have a larger stake in the future of the resources than any government official or visiting scientist; and it serves to maintain dialogue and build co-operative understanding between resource users, researchers and resource managers. The importance of using indigenous understanding of natural resource systems to assess, manage and monitor natural resources, including biodiversity (e.g. Hellier *et al.,* 1999), is now widely recognised (see a review by Sillitoe, 1998) beyond the boundaries of ethnobotany where it has long been a legitimate research method (Martin, 1995). The perils of ignoring indigenous ecological understanding, and the price of 'expert arrogance' are legitimate targets for criticism in much recent writing on environmental conservation in developing countries (Brokenshaw *et al*., 1980; Agrawal, 1995).

3. The use of higher-taxon approaches. If the hierarchical taxonomic classification system has any objective validity, then it is obvious that higher levels of taxa provide integrative summaries of diversity within each level of classification. Thus, in principle, any level of taxonomic classification can be chosen for comparative analysis. By convention, the species level is chosen, but where identification to species is not possible, it is common to use higher-taxon approaches. There is some experience indicating that correlation between diversity at different taxonomic levels can be established (Balmford *et al* 1996), although this is likely to be highly variable (Gaston and Williams, 1993; Williams and Gaston, 1994; Prance, 1994; Anderson, 1995). Balmford *et al*. (1996) found that using woody plant genera and families, rather than species, yielded comparable estimates of relative conservation value of tropical forest, for 60-85% less cost that a species-based survey. Exploration of area-specific relationships between generic or family-level diversity and species diversity would be worthwhile. It may be possible to use a much wider range of taxa, for lower sample processing effort, if the principle of higher-taxon comparisons proves acceptable. Biotic indicators of ecosystem health (which should be related to diversity) in aquatic systems are usually based on identification of macroinvertebrates to higher taxonomic levels, such as genus or family (Chessman, 1995; Hilsenhoff, 1988).

4. Rapid assessment techniques. In recognition that the task of determining a conservation strategy is urgent in areas where biodiversity is both threatened and poorly known or difficult to survey, a number of techniques for rapid assessment of conservation value have been developed (reviewed in Groombridge and Jenkins, 1996). These techniques, which employ some of the approaches outlined above, vary in their data requirements, cost, and suitability for application for different purposes and at different spatial scales. The methodology developed here is most closely related to the 'Rapid Assessment Programme', developed by Conservation International for surveys of poorly known areas using 'surrogate' or 'indicator' groups identified to species level by small teams of national and international experts (See Table 3.2 in Groombridge and Jenkins, 1996,). These surveys are then used to assess conservation value by assuming a relationship between these 'indicator' groups and total diversity and habitat quality. The main drawbacks of the methodology are the reliance on specialist taxonomic expertise (beyond standard field identification skills) and the assumptions made about relationships between indicator diversity and total diversity.

Other rapid assessment methods include Conservation Biodiversity Workshops, Conservation Needs Assessments, Gap Analysis and Biodiversity Information Systems (Groombridge and Jenkins, 1996). Some of these methods do not require additional survey work, and aim to make best use of existing information, including socio-economic data that can be overlooked by biodiversity specialists. The BIOSS studies included elements of these procedures, particularly in its work towards setting up Biodiversity information systems. The Transboundary Diagnostic Analysis and Strategic Action Programme processes contributed elements of the Conservation Needs Assessments approach, and Cohen's (1991) International Conference on the Conservation and Biodiversity of Lake Tanganyika provided an exemplary illustration of the Conservation Biodiversity Workshop approach.

When aired at the start of the present project, many of the above suggestions for formalised 'rapid' techniques of assessment met with considerable scepticism from scientists familiar with Lake Tanganyika. We maintain that the realities of practical conservation work and the need to deliver relevant and timely advice to policy makers remain compelling reasons for open-minded consideration of these techniques for future surveys.

We stress that the choice of assessment strategy has been a learning process for all of us involved in this study, and that we are satisfied that we have made good decisions over methodology, and that we have validated our chosen methods to produce useful data. We also recognise, however, that the quantity and range of data has been limited by the need to satisfy scientific criteria (international taxonomic standardisation, comparison with work done by scientists from outside the region) that are not closely related to the immediate project objectives. We offer these insights into less conventional approaches to biodiversity assessment to encourage those involved in future surveys to consider all options seriously. Such consideration should be based on adequate research of available alternatives and explicit consideration of relevant management goals. Groombridge and Jenkins (1996) provide an accessible introduction to the range of techniques that have been applied by others working in remote tropical locations of exceptional biodiversity interest, with limited resources and poorly known flora and fauna.

Our remaining concern is that, while we have a valid scientific methodology for biodiversity survey that meets the needs of the present project and is within the current capabilities of the riparian institutions, there is no backup method should the current capability change, due to staff changes, equipment failure or lack of funds. SCUBA diving demands specialist equipment, expertise and levels of funding that are high relative to local institutions' research budgets. Some of the methods proposed above are more robust and sustainable.

2.13 Summary

Chapter 2 has detailed the rationale, process and methodology developed for assessing biodiversity in Lake Tanganyika for the purposes of conservation and management planning. These analyses are intended to demonstrate that great care must be taken in designing and analysing simple species richness data. Assessing and quantifying bias is an important and neglected step in the analysis. In this case, it has pointed to a number of shortcomings with the present data set. These are principally that the 'completeness' of surveys is highly variable, and that it has been necessary to compare richness between areas sampled by pooling different techniques. It is not possible to correct completely for these problems. Although estimates of how many species remain unsampled can be (and have been) made, it is obviously not possible to identify which species they are. This remains a problem when undertaking complementarity analysis (Chapter 5). At this stage it is only possible to add a note of caution to such comparisons, and to urge those undertaking future surveys for comparative biodiversity analysis to take such considerations seriously. Despite these remaining problems, we believe that the present analysis complements and adds significantly to the more qualitative surveys previously undertaken. A summary of these previous surveys is reported in the next chapter.

For future surveys that aim to characterise species richness in areas to be compared for conservation prioritisation we recommend the following minimum sampling sizes and combination of survey techniques:

- RVC – 40 replicates per survey stratum (e.g. area between 5 and 15 m depth)
- Gillnet – 60 night-time sets with 60m multimesh nets per survey area
- Mollusc transects – 30 per survey stratum (chosen depth-habitat combination)

The SVC technique takes a similar amount of time to RVC, but covers less ground and samples a similar number or fewer species, with few that are unique (not found in RVC or gillnets). Its advantage is that it allows abundance to be estimated, so diversity indices can be calculated. However diversity indices are not necessarily more useful than species richness estimates for conservation prioritisation exercises, and are often calculated merely because it is traditional and relatively straightforward to do so, rather than for any directed purpose (see Chapter 4).

3. AN ASSESSMENT OF LARGE-SCALE DISTRIBUTION OF BIODIVERSITY IN LAKE TANGANYIKA

3.1 Introduction

The surveys undertaken by BIOSS during the LTBP project represent one of the first attempts at quantitative, replicable and standardised surveys of components of the Lake Tanganyika biodiversity. These surveys were specifically designed to carry out comparative estimates of richness and diversity of fishes and molluscs. These surveys are therefore used as the primary source of advice for conservation planning (Chapters 4 and 5). There is, however, an extensive body of prior information on the biota of Lake Tanganyika, dating back to the late 19th Century (reviewed in Coulter, 1991). This body of literature (and some archived but unpublished data) provides an important complementary source of information. It has three important direct contributions to the work carried out by LTBP, as it provides:

- a historical record of survey activity and species distributions;
- additional information on spatial distributions; and,
- the only sources of information on taxa and environments not surveyed by the present project.

Most of the work done in Lake Tanganyika prior to this project was not undertaken for the purposes of conservation planning so it is not standardised for this purpose. This inevitably limits its value in comparative analysis, or as baseline data to assess changes over time. The previous work on Lake Tanganyika's biota falls mainly into four categories:

- Fisheries-related studies, mainly on the offshore pelagic fish community (summarised by LTR, 2000).
- Collecting expeditions for studies in alpha taxonomy and systematics (authors such as Poll, 1956 and Boulenger, 1920).
- Sample surveys for evolutionary studies (including molecular genetics for sub-specific studies, and fossil species for palaeological approaches).
- Studies in behavioural ecology (mostly work by Japanese research teams, summarised in Kawanabe, Hori and Nagoshi, 1997 and frequently reported in short abstracts under the title of: Ecological and Limnological Study on Lake Tanganyika and its Adjacent Regions).

This data provides a rich archival source, which, through the efforts of BIOSS in collating some of it into a relational database, is being made available to regional agencies for conservation planning and research purposes. Of the many possible uses to which this database can be applied, we choose to present in this report only those relevant to the aims and objectives of BIOSS. The analyses presented are therefore aimed at generating species lists for national biodiversity inventories and identifying major intra-lacustrine distribution patterns that will inform the choice of conservation strategy. We also aim to produce species lists from National Park areas, to compare with and supplement the standardised surveys described in Chapters 2 and 4. These can then be used for parks inventories, and for assessment of future survey requirements.

3.2 Methods

To date, information from 143 reference sources have been entered into the literature database, including the dataset generated by the BIOSS field programme. While the database has the capacity to include data from all species, the priority taxonomic group for data entry were the fishes. Over 13,000 individual "species at a specific location" data have been entered and are drawn on for this analysis. As many of the data entered were not collected for this purpose, some judgement is required to distil the relevant data for entry. For example, determining the latitude and longitude for a species location described as "offshore locality in southern Burundi". Also many of the surveys record only presence data, which is important to consider when interpreting the output of the database. In addition to location data, the database stores information on diet categories, length, habitat categories, depth, survey description and timing for each species as well as full reference details of the literature sources.

The database has the facility to update and retain changes in species names and can also record the full range of common names used for a single species. This information is critical to keep track of taxonomic revisions and is in line with world-wide databases being developed to record species with important conservation status (for example the WCMC Animals Database and the IUCN Red List of Threatened Animals).

Several key datasets are not included as yet. Dr Kelly West supplied key mollusc data, namely her PhD, masters and SIAL surveys, but unfortunately this could not be entered in time for this analysis. The mollusc data collected during the survey field programme of BIOSS have been incorporated. The CRRHA[5] project (1992-1995) collected a great deal of fish location and habitat data along the Burundian and Congo coast using gill nets and diving. This type of data is incredibly valuable, supporting the aims of the database by providing a standardised source of species location information for planning and research. However, the data are coded and collated into tables in various project reports and unfortunately presentation in this format is inaccessible. Ideally these types of data could be made available to the lake-wide management body in an electronic format with explanatory notes, and then with some reformatting be imported relatively easily. These are a few examples of the huge wealth of data on Lake Tanganyika, which provides an incredible potential resource for planning and management.

During database development, a set of standard reports was included to allow users unfamiliar with the database software (Access) to interrogate the data. These reports were a preliminary set, developed before the more detailed analysis for this chapter. The established reports are as follows:

- fish species lists by reference, location (named site) and habitat category
- references for a single species, location or habitat category
- locations for a single species, reference or habitat category
- list of fish species at a depth
- depths recorded for all species
- list of species by diet category
- list of diet categories recorded for fish species
- full lists of all species, fish, cichlids, non noncichlid fish, bivalves, and ostracods
- list of all fish found only in the north, south, middle basins and those found in all three, i.e. circumlacustrine species

As noted in the introduction, this chapter focuses on a narrower set of issues and so additional queries have been developed to provide data for this analysis. These queries have yet to be built into the database and so, unfortunately remain unavailable to the non-Access user. However, it is hoped that building this latest set of reports into a user-friendly format will be part of the next project planned for the implementation of Lake Tanganyika's strategic action programme.

The database has been specifically developed to link with TANGIS, which is the GIS (geographical information system) system that was developed within LTBP. However, more technical work is required to fully integrate the database into TANGIS. Therefore, to generate maps for this report, we linked the database to another mapping programme (Mapinfo).

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[5] CRRHA – Centre Regional de Recherche en Hydrobiologie Applique

The following analyses have been generated from the literature database to support this chapter.

- Map showing location of surveys included in the database.
- Map showing the location of different types of surveys used for the fishes, i.e. gill nets, scuba techniques and seine nets.
- Total species (fish) lists by country
- List of species (fish, molluscs) recorded exclusively in each country
- Total species (fish) lists by each of the three basins (north, middle, south) and those found in all three, i.e. circumlacustrine
- Total species (fish and molluscs) list for the waters off each national park (Rusizi, Gombe, Mahale, Nsumbu)
- List of species (fish and molluscs) recorded exclusively in each park, i.e. not found in any of the other parks
- List of fish species not recorded in waters adjacent to any of the four national parks – their locations illustrated on a map

An important point to note is that the results presented in this chapter draw from the literature database as it stands at the close of BIOSS, and the database does not include all available literature on Lake Tanganyika. As has been noted elsewhere in BIOSS reports (standard operating procedures, final outputs report, database documentation) this database will improve in its value as a planning and research tool the more data are entered and reviewed. It is important to understand that the database will never be 'completely final' for that 'ultimate' analysis we would all like. The database will always lag behind the ongoing clarification of the taxonomy of Lake Tanganyika's species, new papers and reports awaiting publication, data entry of existing literature, the huge wealth of data currently stored in researcher's notebooks and other sources not easily accessible[6]. Therefore, interpretation of the database's output must recognise that results will be a function of the data entered and its quality.

At times when significant analysis needs to be completed (for example, when the strategic action programme for Lake Tanganyika is reviewed), a decision has to be made to cease data entry and the data "cleaned' and queried". Such a process has happened at the close of BIOSS: entry of data from the literature has been stopped, electronic data from the BIOSS survey programme and the Ecotones survey (kindly provided by Dr Ntakimazi) were imported. A process of sorting and checking the data entered has occurred with a flurry of long distance email exchanges between England, Burundi and America. Despite all efforts, it may be expected that Lake Tanganyika's taxonomic experts will be able to correct some of the detail presented here and the authors would be very grateful for any feedback, which would be used to update the database.

In conclusion, the aim of this chapter is not to present definitive results, rather to illustrate the power of the database to deal with disparate, complex data that were collected for other purposes and yet still provide us with insights into the wider picture of Lake Tanganyika's biodiversity.

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[6] The task of maintaining and continuing the data entry is onerous, given the extent and diversity of literature on Lake Tanganyika's biodiversity. Unfortunately, at the close of LTBP funding to support the ongoing data entry is not certain. It is hoped that this will be seen as a priority in all future work and that bodies with a stake in Lake Tanganyika such as the lake-wide committee initiated under LTBP, international researchers and relevant national institutions will allocate appropriate support to its continued development.

3.3 Results

3.3.1 Location data

The following maps indicate where various surveys taken place on Lake Tanganyika.
Figure 3.1 shows the location of all surveys currently entered into the database. Note that a single dot on the maps may represent a single species-location datum or a more intensive survey that provided many species-location data at that site.

As survey details are entered into the database, we have also produced maps showing where different types of surveys have been carried out. This should help identify areas that have been under sampled by specific methods and hopefully guide future work. The survey types illustrated here include: gill net surveys (Figure 3.2), seines nets (Figure 3.3), and scuba work (Figure 3.4).

With the exception of the Congolese coast and the southern most section of Tanzania (south of Kipili) the lake is remarkably well surveyed. The fish in waters adjacent to the national parks, the coast close to Bujumbura, Uvira and Mpulungu have been intensively surveyed with gill nets (reflecting BIOSS survey locations), while the remainder of the lake's coastline awaits such investigation. The use of seine nets to sample the fish is more widespread and scattered. The pattern of scuba surveying mirrors the map of all survey types, being concentrated on national parks and highlighting the coasts of DR Congo and Tanzania south of Kipili as those areas that remain under sampled.

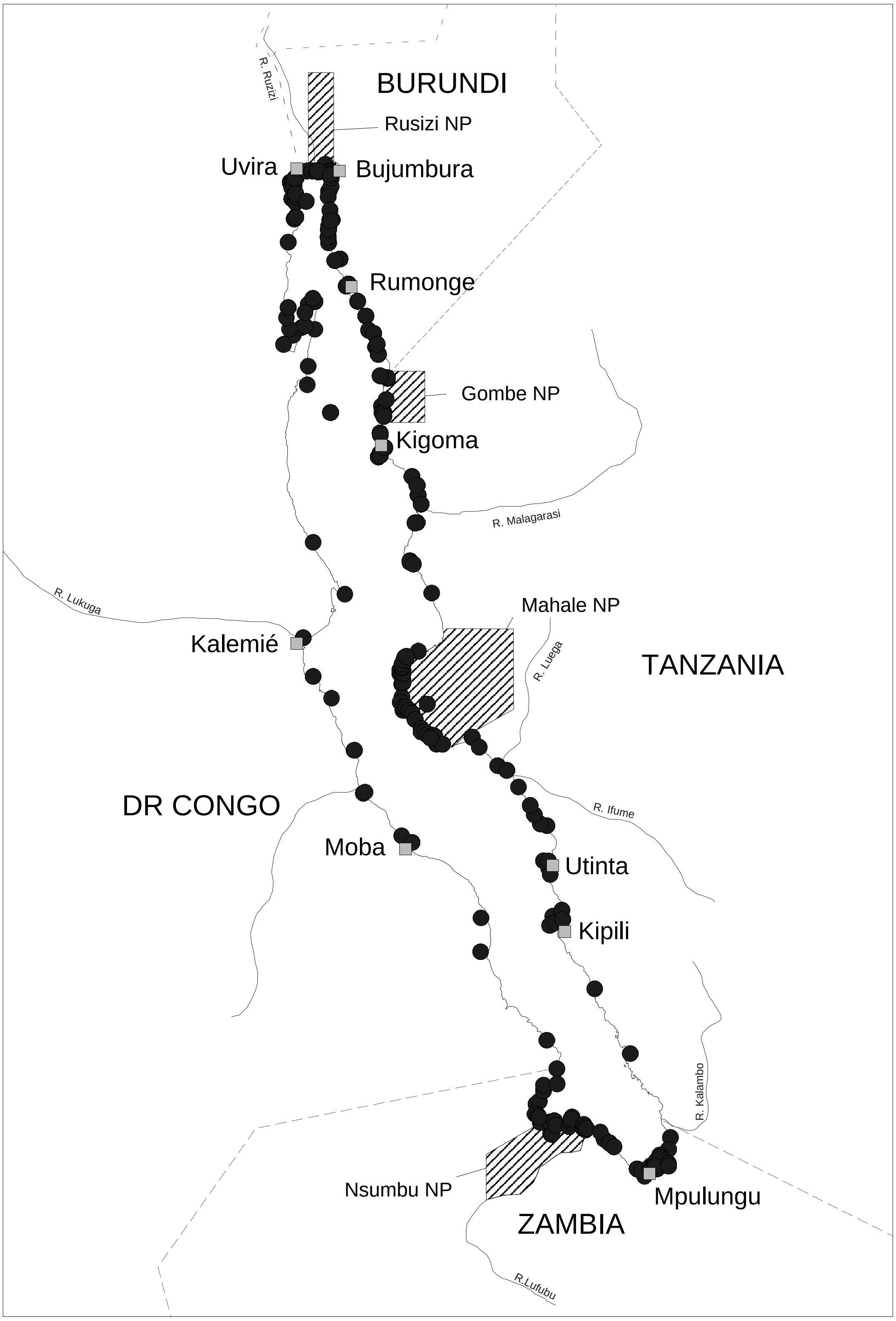

Figure 3.1 **Map showing location of surveys conducted on Lake Tanganyika (source Literature database)**

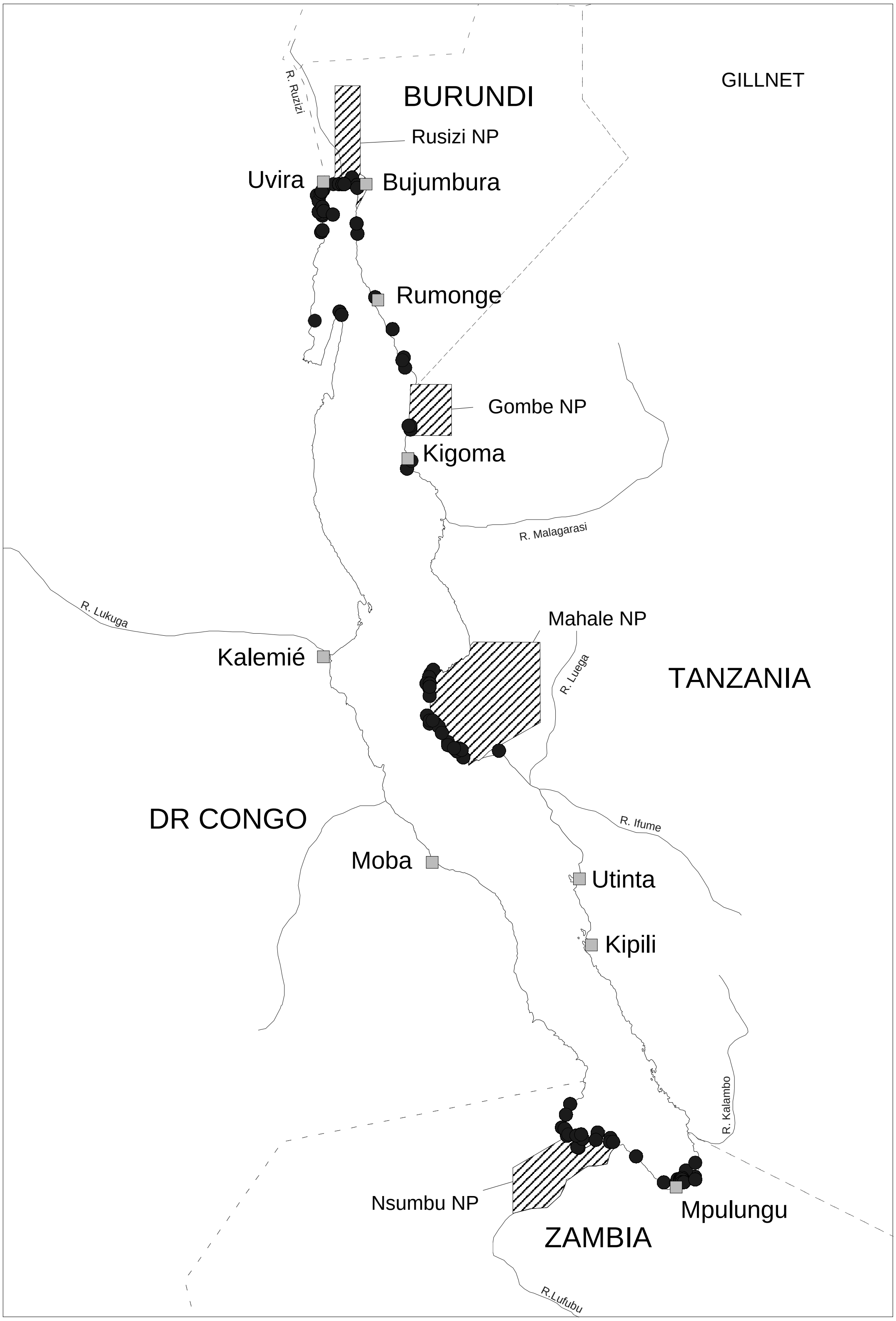

Figure 3.2 Map showing location of gill net surveys on Lake Tanganyika (source Literature database)

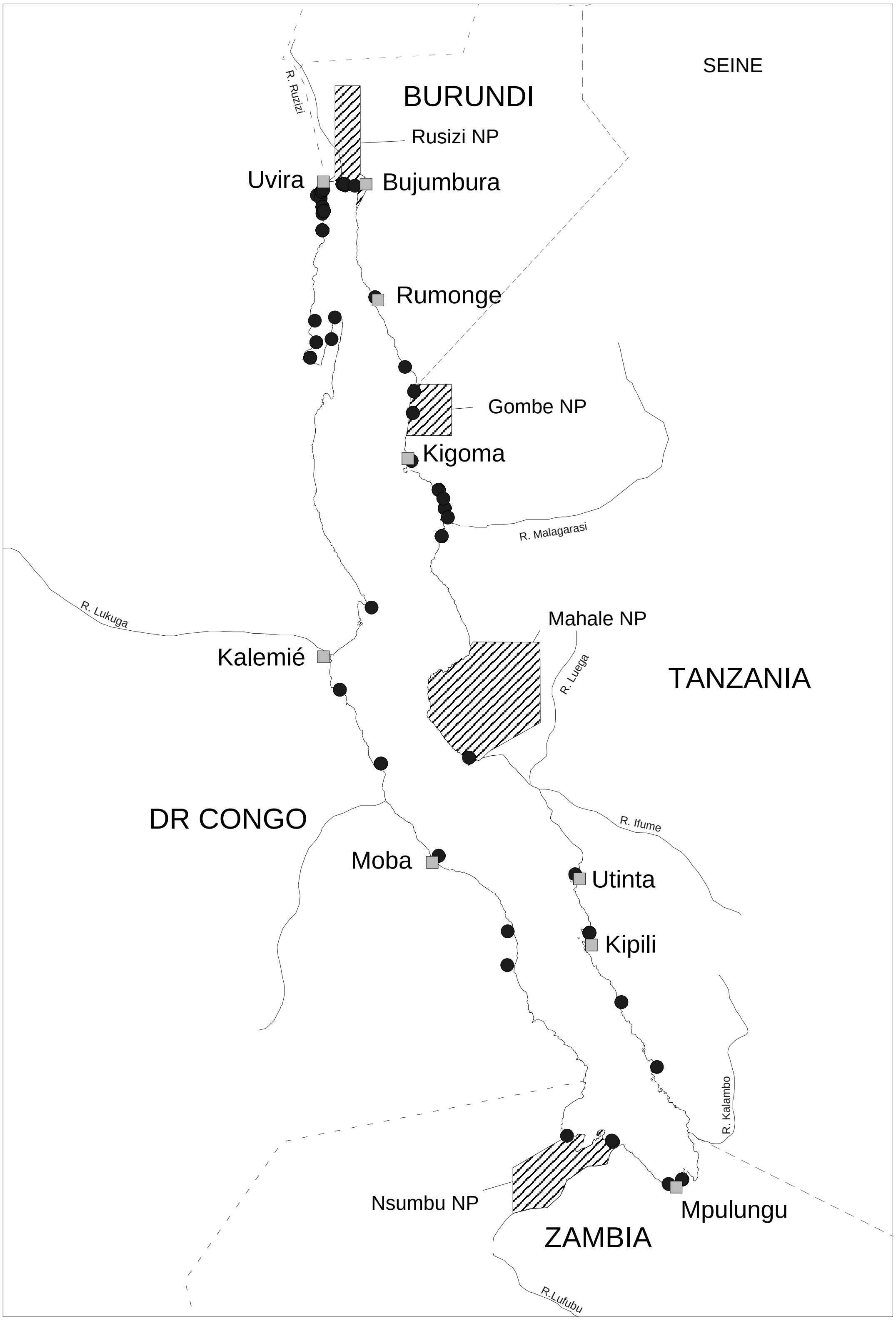

Figure 3.3 Map showing location of seine net surveys on Lake Tanganyika (source Literature database)

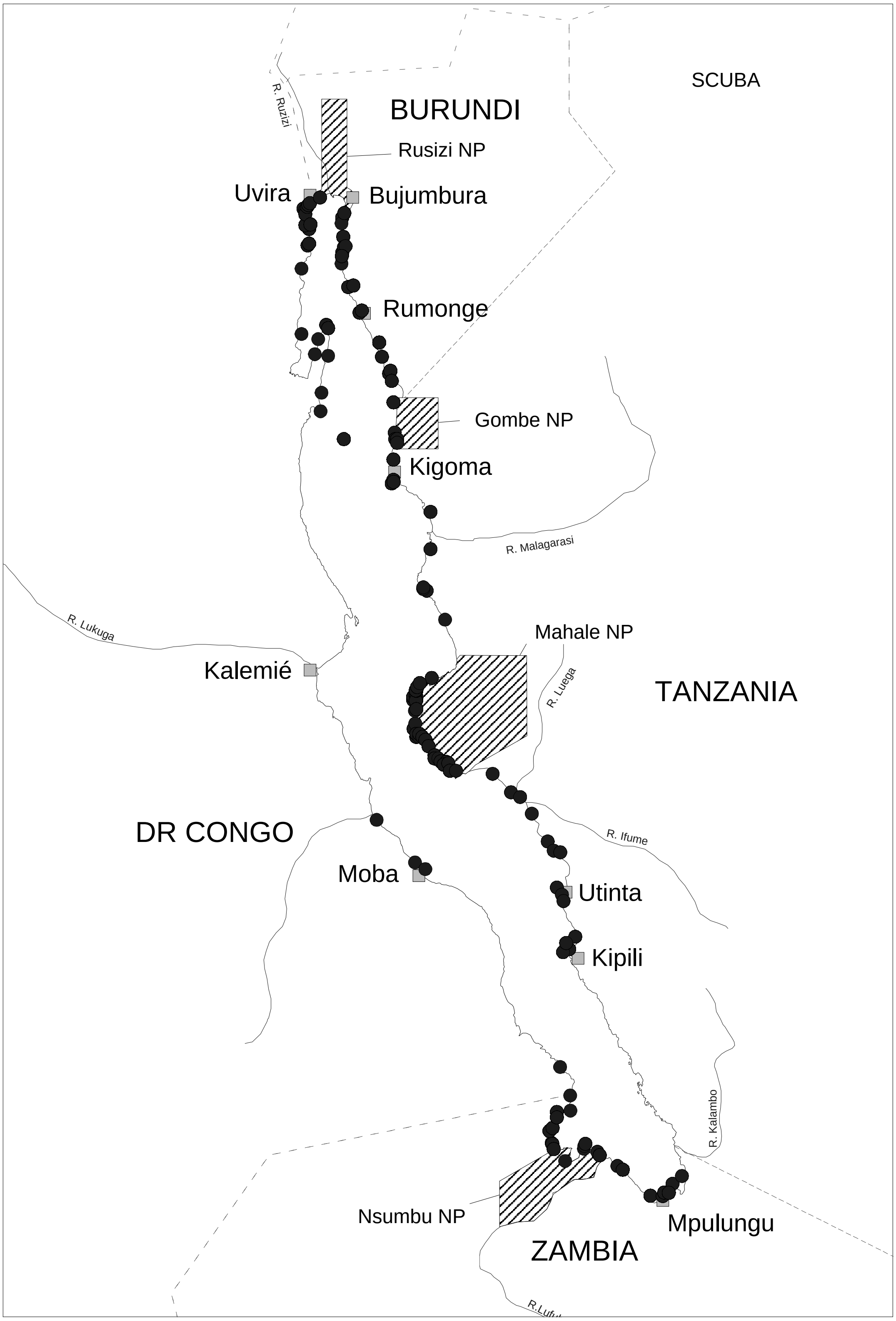

Figure 3.4 Map showing location of surveys using scuba on Lake Tanganyika (source Literature database)

3.3.2 Lists of fish found in each basin

Three intra-lacustrine basins are recognised in Lake Tanganyika, we drew from the bathymetric map presented in Coulter (1991) to define their boundary co-ordinates for analysis in the literature database. Analysis on this level provides the first gross assessment of the overall distribution of fish in the lake. The prompt for this level of assessment was that if, for example, 90% of fish species were confined to a single basin this would require a different management strategy than if we found 90% of fish were found in all basins, i.e. circumlacustrine.

Results are presented in Table 3.1. The literature database indicates that the largest percentage of fish species, 79%, is found to be circumlacustrine, i.e. found in one or more of the three basins. The middle basin is the poorest, with the south and north having 8 and 12% of the total respectively. Note that the total species included in this analysis (263) is less than the 287 fish noted in Coulter (1991) and the 330 species recognised in DeVos and Snoeks (1994). This represents the number of species that have corresponding 'basin' data entered into the database.

Table 3.1 Number of fish species recorded uniquely in each basin of Lake Tanganyika

Basin	**Number of species**	**% of total**
North	32	12
Middle	3	1
South	22	8
Circumlacustrine	206	79
Total with location data	263	100

De Vos and Snoeks (1994) report that 75% of littoral (i.e. excluding the six pelagic species) non-cichlids found in the lake (i.e. not in associated tributaries and marshes) are circumlacustrine. The data presented here doesn't differentiate between the lake proper and associated water bodies; however, 56 of the 85 non-cichlid species included in this analysis are found to be circulacustrine (66%)[7]. A higher proportion of non-cichlid species (37%) do not have basin data associated with them when compared to information on the cichlids (6% have no basin data) and so are not drawn on in this analysis. This probably reflects the focus on cichlid literature in Bujumbura during data entry: future work will have to redress this imbalance. De Vos et al (1994) note that further collecting work is required to further complete a list of all noncichlids: they prioritise the tributaries of the western and south-eastern coast of the lake.

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[7] Note that the database has a function to differentiate species locations between the lake and its associated water bodies, however this has not been fully utilised to date.

Table 3.2 Fish species found exclusively in south, north or middle basins (species endemic to Lake Tanganyika in bold)

Family	North basin (32))	Middle basin (3)	South basin (22)
Anabantidae	*Ctenopoma muriei*		
Bagridae	***Lophiobagrus aquilus***		
	Phyllonemus brichardi		
Characidae	***Brycinus rhodopleura***		*Bryconaethiops boulengeri*
	Micralestes stormsi		
Cichlidae	***Astatoreochromis straeleni***	***Tropheus annectens***	*Astatotilapia stappersii*
	Astatoreochromis vanderhorsti		***Baileychromis centropomoides***
	Ctenochromis benticola		***Cunningtonia longiventralis***
	Neolamprologus boulengeri		***Greenwoodochromis bellcrossi***
	Neolamprologus falcicula		***Haplochromis paludinosus***
	Neolamprologus finalimus		***Lepidiolamprologus kendalli***
	Neolamprologus longicaudatus		***Lepidiolamprologus nkambae***
	Oreochromis leucostictus		*Neolamprologus cylindricus*
	Oreochromis niloticus eduardianus		***Neolamprologus leloupi***
	Simochromis margaretae		*Neolamprologus mustax*
	Spathodus marlieri		***Telotrematocara macrostoma***
	Trematochromis schreyeni		***Trematocara caparti***
	Xenotilapia nasutus		***Tropheus kasabae***
			Xenotilapia lestradii
Clariidae			*Clarias ngamensis*
Cyprinidae	*Barbus altianalis altianalis*	***Barbus taeniopleura***	
	Barbus caudovittatus	***Labeo dhonti***	
	Barbus serrifer		
	Barbus somerini		
	Barbus urostigma		
	Chelaethiops minutus		
	Raiamas salmolucius		

Family	**North basin (32))**	**Middle basin (3)**	**South basin (22)**
Distichodontidae	*Distochodus sexfasciatus*		
Mastacembelidae	***Afromastacembelus plagiostomus***		
	Afromastacembelus tanganicae		
	Caecomastacembelus flavidus		
	Caecomastacembelus zebratus		
Mochokidae	*Synodontis benthicola*		*Synodontis polystigma*
			Synodontis serratus
			Synodontis unicolor
Mormyridae			*Marcusenius stanleyanus*
			Mormyrops deliciosus
Polypteridae	*Polypterus ornatipinnis*		*Polypterus endlicheri congicus*

3.3.3 National lists for fish

National species lists are important for countries to be able to produce reasonably regularly. Particularly where they carry an international obligation to report under treaties such as CBD, and Ramsar as well as submitting accurate data to the IUCN hosted Red List of Threatened Species.

National lists of fish species have been generated by the database at the close of BIOSS. The full lists are given in Table 8.7, Appendix 8.4. The total number of fish recorded for each country is presented in Table 3.3.

Table 3.3 Number of fish species recorded by the database in each country

Country	Number of species	Length of coastline (km)
Burundi	192	165
DR Congo	175	790
Tanzania	192	662
Zambia	205	221

Taking the length of coastline into account, and drawing from the maps of survey sites (Figure 3.1) both DR Congo and Tanzania have been under sampled and should be targeted in future work.

Nakaya (1993) generated a national list of fish species for Zambia: recording a total of 140 species, excluding rivers. All species listed by Nakaya are included in the list generated by the literature database. The balance of families is very similar in both national lists, with cichlids dominating – 78% of the Nakaya list and 73% of the literature list. An additional three families are included in the literature database list, as follows: Citharinidae (single species); Cyprinidae (three species) and Tetraodontidae (a single species). The same author, with some colleagues also surveyed Burundian waters and generated a national list (Takahashi et al, 1995). Once again the literature database picks up the 76 species listed (82% cichlids) and adds more. A larger number of families are included in the literature database list, although are represented with few individual species as follows: Anabantidae (one species); Characidae (six species); Clariidae (three species); Clupeidae (two species); Distichodontidae (one species); Malapturidae (one species); Mormyridae (one species) and Protoperidae (one species).

Table 3.4 lists the number of fish species per family that are found in each country. The figures in bold indicate where one family contributes more than 5% to the overall total. As might be expected, the pattern is fairly standard among all countries: cichlids represent the majority of fish species found (68 – 73 %), with only one to three other families contributing >5% to the total national lists.

Drawing from the national species lists generated by the database, it is possible to identify species found exclusively in each of the riparian countries[8]. From the current dataset, a total of 49 fish species were found to be exclusive to one of the four countries, the numbers in each are as follows: Tanzania (6); Zambia (17); DR Congo (7); and, Burundi (17). While the high number of species found exclusively in Burundi and Zambia will reflect the intensity of aquatic survey work completed in these countries they also highlight the diversity of fish in their waters. These species are listed in Table 3.5.

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[8] Data were extracted from the database and this analysis was completed in an Excel spreadsheet using the 'vlookup' function

Table 3.4 Number of species per family recorded in each riparian country

Family	Burundi		DR Congo		Tanzania		Zambia	
	no. spp	%	no. spp	%	no. spp	%	no. spp	%
Anabantidae	1	1%						
Bagridae	**13**	**7%**	**11**	**6%**	**10**	**5%**	**12**	**6%**
Centropomidae	4	2%	4	2%	4	2%	4	2%
Characidae	6	3%	1	1%	4	2%	5	2%
Cichlidae	**131**	**68%**	**127**	**73%**	**138**	**72%**	**149**	**73%**
Citharinidae					1	1%	1	0%
Clariidae	3	2%	4	2%	4	2%	4	2%
Clupeidae	2	1%	2	1%	2	1%	2	1%
Cyprinidae	**11**	**6%**	5	3%	7	4%	3	1%
Cyprinodontidae	2	1%	2	1%	2	1%	2	1%
Distichodontidae	1	1%						
Malapteruridae	1	1%	1	0%	1	1%	1	0%
Mastacembelidae	**9**	**5%**	**10**	**6%**	8	4%	5	2%
Mochokidae	6	3%	6	3%	7	4%	**10**	**5%**
Mormyridae	1	1%	1	1%	1	1%	3	1%
Polypteridae					2	1%	2	1%
Protopteridae	1	1%	1	1%			1	0%
Tetraodontidae					1	1%	1	0%
Totals	192	100%	175	100%	192	100%	205	100%

Table 3.5 National lists of fish species found exclusively in each country (species endemic to Lake Tanganyika in bold)

Family	Zambia (17)	Burundi (17)	Tanzania (6)	DR Congo (7)
Anabantidae		*Ctenopoma muriei*		
Bagridae		***Lophiobagrus aquilus***		***Phyllonemus brichardi***
Characidae	*Bryconaethiops boulengeri*	***Brycinus rhodopleura***		
		Micralestes stormsi		
Cichlidae	*Astatotilapia stappersii*	***Astatoreochromis straeleni***	***Neolamprologus leloupi***	*Neolamprologus longicaudatus*
	Baileychromis centropomoides	***Astatoreochromis vanderhorsti***	***Spathodus erythrodon***	***Trematochromis schreyeni***
	Cunningtonia longiventralis	*Neolamprologus boulengeri*		***Tropheus annectens***
	Greenwoodochromis bellcrossi	*Neolamprologus falcicula*		
	Haplochromis paludinosus	*Oreochromis leucostictus*		
	Lepidiolamprologus kendalli	*Xenotilapia nasutus*		
	Lepidiolamprologus nkambae			
	Neolamprologus mustax			
	Telotrematocara macrostoma			
	Xenotilapia lestradii			
Clariidae	*Clarias ngamensis*			
Cyprinidae		*Barbus altianalis altianalis*	***Barbus taeniopleura***	***Barbus urostigma***
		Barbus caudovittatus	***Labeo dhonti***	
		Barbus serrifer		
		Barbus somerini	***Varicorhinus leleupanus***	
		Raiamas salmolucius		
Distichodontidae		*Distochodus sexfasciatus*		
Mastacembelidae		***Afromastacembelus plagiostomus***		***Afromastacembelus tanganicae***
				Caecomastacembelus zebratus
Mochokidae	*Synodontis polystigma*	*Synodontis benthicola*		
	Synodontis serratus			
	Synodontis unicolor			
Mormyridae	*Marcusenius stanleyanus*			
	Mormyrops deliciosus			
Polypteridae	*Polypterus endlicheri congicus*		*Polypterus ornatipinnis*	

3.3.4 National lists for molluscs

Similar analysis was completed for the molluscs, and the complete national lists are presented in Table 3.6. The total number of species recorded in each country is as follows: Tanzania, 29; Zambia, 24; Burundi, 28; and, DR Congo, 18.

These results are very preliminary as this analysis only draws on data collected during the BIOSS field programme; mollusc data from other sources has yet to be entered into the database. Moreover, mollusc sampling from BIOSS is geographically limited to intensive studies at one or two sites in each country and broad and rapid surveys of portions of the Burundian, Tanzanian and Zambian coasts (as indeed are other investigations). However, these BIOSS lists are included here to provide some baseline data of molluscs sampled in each country as the study closed. It is interesting to note that the numbers of species found in each country are not vastly different, though the coastlines are quite variable in length. This will reflect differences in BIOSS sampling effort. Most of the species in Burundi were found over the course of two years of periodic surveys at a single site. More than 75 km of Tanzanian coastline was surveyed for molluscs, but the great majority of these were single survey events. A total of 30 species were recorded by BIOSS, representing less than half the 80 mollusc species that have been previously recorded in the Tanganyika Basin. Much mollusc survey work remains to be done.

Table 3.6 Complete national lists for mollusc species (from BIOSS surveys only), with species exclusive to one country indicated in bold.

Family	Tanzania	Zambia	Burundi	DR Congo
Mutelidae	*Mutela spekei*		*Mutela spekei*	*Mutela spekei*
			Spathopsis anceyi	
Unionidae	*Caelatura spp*	*Caelatura spp*	*Caelatura spp*	
	Pseudospatha tanganyicensis			
Thiaridae	*Anceya giraudi*	***Bathanalia howesii***	*Anceya giraudi*	*Anceya giraudi*
	Bridouxia giraudi	*Bridouxia giraudi ***	*Bridouxia giraudi*	*Bridouxia giraudi*
	Lavigeria grandis	*Bridouxia leucoraphe ***	*Bridouxia leucoraphe*	*Bridouxia leucoraphe*
	Lavigeria paucicostata	*Bridouxia praeclara ***	***Bridouxia ponsonbyi***	*Lavigeria grandis*
	Lavigeria nassa	*Lavigeria grandis*	*Bridouxia praeclara*	*Lavigeria sp A*
	Lavigeria sp A	*Lavigeria paucicostata*	*Lavigeria grandis*	*Lavigeria sp C*
	Lavigeria sp B	*Lavigeria sp A*	*Lavigeria sp A*	*Lavigeria spp*
	Nov. gen n.sp	*Lavigeria sp B*	*Lavigeria sp C*	*Nov. gen n.sp*
	Nov. gen spinulosa	*Limnotrochus thomsoni*	*Martelia tanganyicensis*	*Nov. gen spinulosa*
	Paramelania crassigranulata	*Nov. gen n.sp*	*Mysorelloides multisulcata*	*Paramelania imperialis*
	Paramelania imperialis	*Nov. gen spinulosa*	*Nov. gen n.sp*	*Reymondia horei*
	Paramelania iridescens	***Paramelania minor***	*Paramelania imperialis*	*Reymondia minor*
	Reymondia horei	*Reymondia horei*	*Paramelania iridescens*	*Spekia zonata*
	Reymondia minor	*Reymondia minor*	*Reymondia horei*	***Syrnolopsis gracilis***
	Reymondia tanganyicensis	*Spekia zonata*	*Reymondia minor*	*Syrnolopsis lacustris*
	Spekia zonata	*Syrnolopsis lacustris*	*Reymondia tanganyicensis*	*Syrnolopsis minuta*
	Stormsia minima	*Syrnolopsis minuta*	*Spekia coheni*	*Tanganyicia neritinoides*
	Syrnolopsis lacustris	*Tanganyicia neritinoides*	*Spekia zonata*	
	Syrnolopsis minuta	*Tanganyicia rufofilosa*	*Stormsia minima*	
	Tanganyicia neritinoides		*Syrnolopsis lacustris*	
	Tanganyicia rufofilosa		*Syrnolopsis minuta*	
			Tanganyicia neritinoides	
Viviparidae	*Neothauma tanganyicense*	*Neothauma tanganyicense*		

3.3.5 Protected areas lists for fish

Chapter five of this report deals in detail with the BIOSS surveys of the national park waters and provides the analysis, which informed the recommendations on conservation of aquatic biodiversity we made to the strategic action plan. However, by compiling full species lists from the literature database we can draw on a wider source of data as other researchers have recorded species in these waters. We have not used this full dataset for the conservation prioritisation exercise as the literature data are drawn from an extensive time period, and may not therefore reflect current diversity in the parks.

The references drawn on for each park are as follows:

Mahale National Park

- BIOSS (LTBP) survey, 2000
- Kuwamura, 1987b
- Poll, 1971
- Snoeks et al., 1994
- Takamura, 1993

Rusizi National Park

- BIOSS (LTBP) survey, 2000
- Boulenger, 1920
- Ntakimazi 1995 (Ecotone Survey)
- Kawabata and Mihigo, 1982
- Kwetuenda, 1983
- Kwetuenda, 1987
- Mihigo, 1983
- Moore, 1903
- Poll, 1956
- Poll, 1971

Nsumbu National Park

- Allgayer,1986
- BIOSS (LTBP) survey, 2000
- De Vos and Snoeks, 1994
- De Vos and Thys Audenaerde, 1997
- Hori et al., 1995
- Konings, 1988
- Moore, 1903
- Nakaya et al, 1993
- Poll 1956
- Poll, 1971

Gombe National Park

- BIOSS (LTBP) survey, 2000
- Ndaro, 1990
- Snoeks et al. 1994

Currently, only three of the national park boundaries actually extend into the lake (Mahale, Rusizi and Nsumbu), while Gombe's boundary falls short of the shoreline. Part of the BIOSS recommendations to the SAP was to consolidate and, where feasible, extend the boundaries of these parks to provide a network of protected areas for the lake's species (see Chapter 5 for detailed discussion and analysis). This section provides additional data in support of that recommendation and treats each park as if its boundaries include the littoral zone.

The complete list of fish found in the waters of each park is presented in Table 8.8 (Appendix 8.4). The total numbers of species recorded in each park and the contribution the BIOSS surveys made in adding to these lists are noted in Table 3.7.

Table 3.7 Number of fish species recorded in the waters adjacent each national park

National Park	Number of species	Number of species BIOSS contributed to the total (%)
Mahale	160	45 (28%)
Rusizi	102	5 (5%)
Nsumbu	99	66 (66%)
Gombe	67	52 (77%)

The BIOSS survey contributed to these park lists to varying degrees. In Gombe's waters, BIOSS found 52 species not recorded in any other references included in the literature database (i.e. 77% of the total). BIOSS added 66 species (66% of the total) to Nsumbu's total, 45 species (28% of total) to Mahale's list, but only 5 additional species (5%) to Rusizi's list. These results may indicate intensity of sampling in previous surveys for example the Ecotones survey was significant for Rusizi's waters, while Gombe has received less attention from aquatic surveys. It should also be noted that these results are also directly affected by the literature entered into the database – the greater availability of Burundian publications in Bujumbura, where the bulk of the data entry was carried out, will have an influence. This sort of distortion will lessen as more data are submitted.

Takamura (1993) surveyed the waters off Mahale, recording 92 species of fish, 26% of which were non-cichlids. BIOSS recorded more species (128); but with the same percentage being non-cichlid fish. De Vos and Snoeks (1994) note the importance of Rusizi system to the diversity of non-cichlid fish, with some 30 species being recorded in its marshes and tributaries. Comparison of the database lists of species unique to the North basin (see section 3.3.2) and fish species found within the waters off Rusizi reinforces the importance of this park for non-cichlids. Of the 32 species found exclusively to the North basin, nine of the eleven species found within Rusizi's waters are nonciclids (Anabantidae, Characidae and Cyprinidae).

De Vos et al (1994) also note that the majority, i.e. 68%, of the 103 non-cichlids found in Lake Tanganyika's associated water bodies were found in the Malagarasi drainage system. In 1999 the Wildlife Division of the Tanzanian government submitted an information sheet to Ramsar seeking approval to designate 3.25m ha in the Malagarasi-Muyovozi Wetlands as a Ramsar site. This came to LTBP's attention after submission of the BIOSS advice to the SAP, which recommended that the riparian countries look to Ramsar as a way of raising the internationalprofile of Lake Tanganyika's waters. Tanzania's bid was successful and on the 13th of August 2000 the Malagarasi-Muyovozi wetland was designated as a Ramsar site. Fish are explicitly recognised in the paragraph listing the wetland's characteristics:

> "…The site is extremely important for large mammals, migratory and resident waterbirds, fish and plants (with perhaps as many as 50 indigenous fish species), as well as providing significant livelihood support to local communities."
>
> Source: www.ramsar.org/profiles_ur_tanzania.htm

From the park lists generated by the BIOSS literature database, it is possible to identify those species that have been recorded exclusively in one park (Table 3.8). The lists from Mahale and Rusizi support the advice BIOSS submitted to the SAP on the importance of these parks to the conservation of Lake Tanganyika's fish (see chapter 5). The low number of species recorded exclusively in Gombe is probably a reflection of the little attention its waters have received, and its smaller size relative to Mahale and Nsumbu, rather than the paucity of its aquatic biodiversity.

Table 3.8 Fish species recorded exclusively in the waters of each national park (bold indicates a species is endemic to Lake Tanganyika)

Family	Mahale (34)	Rusizi (26)	Nsumbu (15)	Gombe (2)
Anabantidae		*Ctenopoma muriei*		
Bagridae	*Phyllonemus filinemus*	*Bagrus docmak*		
		Chrysichthys grandis		
		Chrysichthys stappersii		
Characidaedss		*Alestes imberi*		
		Brycinus rhodopleura		
		Micralestes stormsi		
Cichlidae	*Bathybates horni*	*Astatoreochromis vanderhorsti*	*Lamprologus labiatus*	*Lamprologus kungweensis*
	Bathybates vittatus	*Gnathochromis permaxillaris*	*Lepidiolamprologus kendalli*	
	Cyprichromis microlepidotus	*Hemibates stenosoma*	*Lepidiolamprologus nkambae*	
	Julidochromis ornatus	*Oreochromis leucostictus*	*Lestradea stappersii*	
	Julidochromis transcriptus	*Tangachromis dhanisi*	*Limnochromis abeelei*	
	Lamprologus signatus	*Trematocara nigrifons*	*Neolamprologus mustax*	
	Neolamprologus buescheri	*Trematocara unimaculatum*	*Neolamprologus petricola*	
	Neolamprologus christyi	*Triglachromis otostigma*	*Neolamprologus pulcher*	
	Neolamprologus gracilis	*Xenotilapia caudafasciata*	*Perissodus eccentricus*	
	Neolamprologus hecqui	*Xenotilapia nigrolabiata*	*Simochromis pleurospilus*	
	Neolamprologus longior	*Xenotilapia ornatipinnis*	*Tropheus kasabae*	
	Neolamprologus multifasciatus			
	Neolamprologus wauthioni			
	Ophthalmotilapia heterodonta			
	Ophthalmotilapia nasutus			
	Paracyprichromis nigripinnis			
	Plecodus multidentatus			
	Pseudosimochromis curvifrons			

Family	Mahale (34)	Rusizi (26)	Nsumbu (15)	Gombe (2)
Cichlidae	*Spathodus erythrodon*			
	Tanganicodus irsacae			
	Telmatochromis brichardi			
	Telmatochromis burgeoni			
	Telmatochromis vittatus			
	Tropheus polli			
Citharinidae			*Citharinus gibbosus*	
Cyprinidae	*Barbus taeniopleura*	*Barbus altianalis altianalis*		
	Labeo dhonti	*Barbus lineomaculatus*		
		Barbus serrifer		
		Barbus somerini		
		Chelaethiops minutus		
		Raiamas salmolucius		
Mastacembelidae	*Afromastacembelus albomaculatus*	*Caecomastacembelus frenatus*	*Caecomastacembelus micropectus*	*Caecomastacembelus flavidus*
Mochokidae	*Synodontis dhonti*		*Synodontis serratus*	
	Synodontis granulosus			
	Synodontis nigromaculatus			
	Synodontis polli			
Mormyridae			*Marcusenius stanleyanus*	
Polypteridae	*Polypterus endlicheri*	*Protopterus aethiopicus*		

3.3.6 Fish not found in park waters

It is also useful to note which fish species have **not** been recorded within the national parks, and are therefore not subject to any direct conservation effort. Spreadsheet analysis was used to identify these species: a total of 163 fish species were found and using the literature database, we have determined where they have been recorded. Figure 3.5 shows the distribution of these 'unprotected' species.

Areas of interest highlighted by the map include: south of Uvira (already identified by BIOSS in its recommendations to the SAP[9] as deserving of some form of protection), the Burundi coast south of Rumonge, Kipili in Tanzania (also noted earlier as an area which has been under surveyed), Mpulungu (interesting considering its proximity to a population centre and therefore potentially more threatened) and the coast north of Nsumbu in Zambia.

This map has to be reviewed in light of the conservation strategy advocated by BIOSS. The strategy is presented in our advice to the SAP and chapter 5 of this report provides the supporting analysis for the recommended approach. In brief, we recommended to the SAP that the development of an integrated coastal zone management (ICZM) would provide the best strategy to address the largely localised threats facing Lake Tanganyika's biodiversity, and would enable some level of protection to be extended to species not represented in the park areas.

We regard this map as a good foundation to inform the development of ICZM for Lake Tanganyika. It draws from current knowledge of the conservation status of fish species in the lake and broadly identifies sites of potential conservation interest that can then be prioritised for future work in this area.

A subset of this broad analysis is the degree to which species found exclusively in one country fall within its protected area network, and perhaps most importantly, which species are not protected. Table 3.9 re-presents the exclusive national lists for fish and highlights those species falling outside of the protected areas in bold. Amongst the countries with aquatic parks, i.e. excluding DR Congo, Zambia records the highest percentage of species exclusive to its waters that are unprotected with 77% falling outside of Nsumbu's borders. Burundi is next with 44% of its species falling outside of Rusizi's waters (note the lack of formal protection afforded to these waters). Tanzania, with its two parks with boundaries extending into the lake has 29% of its exclusive fish species falling outside of Gombe and Mahale.

Similar analysis can be done by comparing species found exclusively in one of the three basins against park lists. Zambian waters host the majority of fish species found exclusively in the south basin (Table 3.2). Of the 22 species recorded in the southern basin, 17 are in Zambian waters and only six[10] of these are found within Nsumbu's waters, i.e. fall inside the current protected area network. This reinforces the need to look beyond protected areas as the only solution to species conservation: there is an obvious need to balance Zambia's reliance on Lake Tanganyika and its shores to support people in the area and the biodiversity in these waters. Rusizi offers more protection to the 34 species found exclusively in the north basin as 11 are found in its waters (see Table 5.8, Chapter 5 for a review of Rusizi's current status).

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[9] See Allison et al (2000), the SAP document for more detail.

[10] Four cichlids and two noncichlids, a species each from Mochokidae and Mormyridea. Three of the six species are endemic to Lake Tanganyika.

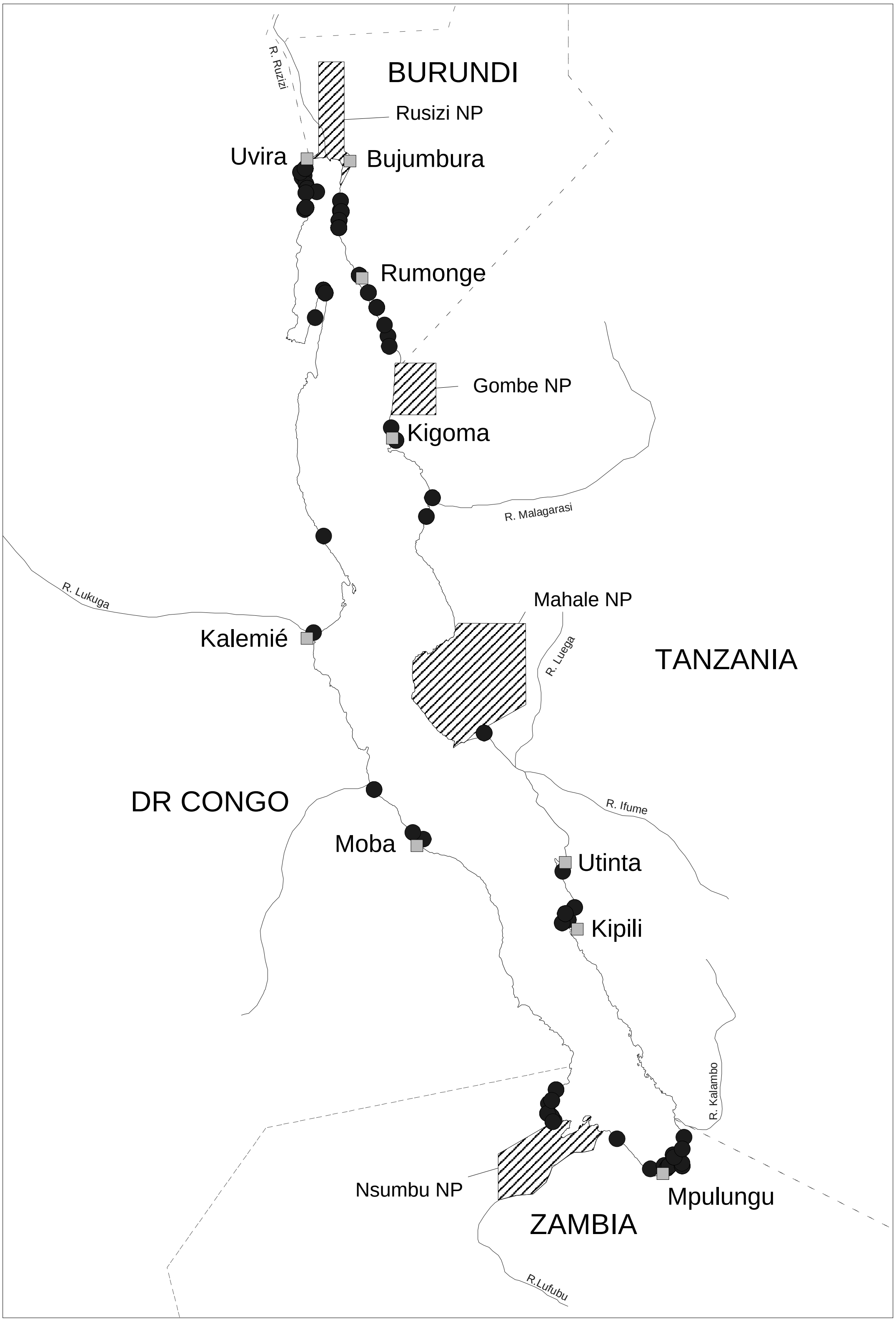

Figure 3.5 Map showing the location of those fish species not recorded in the waters off Lake Tanganyika's four national parks

Table 3.9 Protection afforded those species found exclusively in one country (unprotected highlighted in bold)

Family	**Zambia (78 %)**	**Burundi (44 %)**	**Tanzania (29 %)**	**DR Congo (100 %)**
Anabantidae		*Ctenopoma muriei*		
Bagridae		***Lophiobagrus aquilus***		***Phyllonemus brichardi***
Characidae	***Bryconaethiops boulengeri***	*Brycinus rhodopleura*		
		Micralestes stormsi		
Cichlidae	***Astatotilapia stappersii***	***Astatoreochromis straeleni***	***Neolamprologus leloupi***	***Neolamprologus longicaudatus***
	Baileychromis centropomoides	*Astatoreochromis vanderhorsti*	*Spathodus erythrodon*	***Trematochromis schreyeni***
	Cunningtonia longiventralis	***Neolamprologus boulengeri***		***Tropheus annectens***
	Greenwoodochromis bellcrossi	***Neolamprologus falcicula***		
	Haplochromis paludinosus	*Oreochromis leucostictus*		
	Lepidiolamprologus kendalli	***Xenotilapia nasutus***		
	Lepidiolamprologus nkambae			
	Neolamprologus mustax			
	Telotrematocara macrostoma			
	Xenotilapia lestradii			
Clariidae	***Clarias ngamensis***			
Cyprinidae		*Barbus altianalis altianalis*	*Barbus taeniopleura*	***Barbus urostigma***
		Barbus caudovittatus	*Labeo dhonti*	
		Barbus serrifer	*Varicorhinus leleupanus*	
		Barbus somerini		
		Raiamas salmolucius		
Distichodontidae		***Distochodus sexfasciatus***		
Mastacembelidae		*Afromastacembelus plagiostomus*		***Afromastacembelus tanganicae***
				Caecomastacembelus zebratus
Mochokidae	***Synodontis polystigma***	***Synodontis benthicola***		
	Synodontis serratus			
	Synodontis unicolor			
Mormyridae	*Marcusenius stanleyanus*			
	Mormyrops deliciosus			
Polypteridae	***Polypterus endlicheri congicus***		***Polypterus ornatipinnis***	

The following bullet points provide a preliminary list of additional information that would advance a strategy of ICZM for Lake Tanganyika on the basis of this map.

- Analysis of the species (fish and other taxa) at each site in terms of endemism, rarity, metapopulation dynamics, value to local communities or "globally".
- Analysis of the relative merit of the species (fish and other taxa) found at each site in comparison to the current network of protected areas, i.e. complementarity (see section 5.4.4).
- Assessment of the threats – nature and degree – facing each of these sites and prioritisation of action on a national and regional basis.
- Assessment of the current use of these waters and adjacent land by local communities to help determine the type and level of protection that could be implemented at each and the likely costs to these people of any change in status.

From this dataset it is possible to conduct analyses of interest at taxonomic levels above the species, for example in a 'higher taxon' (family and genus) assessment of the fishes not found in the existing parks network (Table 3.10). The 37 'unprotected' Cichlidae species are shared amongst 21 genera, with Neolamprologus making the greatest contribution of 19%. Of the remainder, no genera contribute more than 10% of the total number of species found outside the park network. While in the Cyprinidae, the Barbus genus contributes half of the 24 'unprotected' species (of which only 4 of the 12 are endemic to Lake Tanganyika).

Table 3.10 Number of fish species per family that are not recorded in a national park

Family	Number of species	Number of endemic species
Amphiliidae	2	-
Anabantidae	1	-
Bagridae	6	5 (84%)
Characidae	5	1 (20%)
Cichlidae	37	32 (86%)
Clariidae	6	-
Cyprinidae	24	5 (21%)
Cyprinodontidae	2	-
Distichodontidae	1	-
Kneriidae	1	1 (100%)
Mastacembelidae	4	4 (100%)
Mochokidae	5	-
Mormyridae	3	-
Polypteridae	3	-
Schilbeidae	2	-
Tetraodontidae	1	-

3.3.7 Protected area lists for molluscs

As noted earlier, the only mollusc data available for analysis at this stage is that collected within the BIOSS field programme. As we know this dataset very well it is possible to provide some background information to its collection to aid interpretation. In Mahale and Gombe divers[11] collected data over a range of habitats, while crocodiles in the waters off Nsumbu and Rusizi limited BIOSS to sampling sandy sites with a dredge. No molluscs were recovered in the Rusizi dredging and therefore this site is not included in further discussions of mollusc diversity in protected areas. Though at least three species are known to exist near the Rusizi (West, unpublished data), their distribution is clearly patchy, perhaps as a function of the heavy sediment loads deposited by the Rusizi. Table 3.11 presents the lists of all species

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[11] At Mahale, divers sampled at greater depths, extending to 20m, however the sampling programme was later revised to a maximum of 15m and this is the greatest depth of samping at Gombe.

recorded in the waters of the three national parks; species found exclusively in one park are indicated in bold.

Table 3.11 Lists of all molluscs found in national parks during the BIOSS survey

Mahale	Gombe	Nsumbu
Anceya giraudi	*Lavigeria grandis*	***Bathanalia howesii****
Lavigeria grandis	***Lavigeria nassa***	***Limnotrochus thomsoni****
Lavigeria paucicostata	*Lavigeria sp A*	*Neothauma tanganyicense**
Lavigeria sp A	*Lavigeria sp B*	*Syrnolopsis minuta**
Lavigeria sp B	*Mutela spekei**	*Tanganyicia neritinoides**
*Mutela spekei**	*Neothauma tanganyicense**	*Tanganyicia rufofilosa**
*Neothauma tanganyicense**	***Paramelania imperialis****	
Nov. gen spinulosa	*Reymondia horei*	
Paramelania crassigranulata*	*Spekia zonata*	
Paramelania iridescens*	*Syrnolopsis lacustris**	
Pseudospatha tanganyicensis*	*Syrnolopsis minuta**	
Reymondia horei	*Tanganyicia neritinoides**	
Reymondia minor		
Spekia zonata		
Stormsia minima		
*Syrnolopsis lacustris**		
*Syrnolopsis minuta**		
*Tanganyicia neritinoides**		
*Tanganyicia rufofilosa**		
Bold text indicates species found exclusively in a park '*' indicates sand-dwelling species		

Protected waters off Mahale Mountains National Park host nineteen species of mollusc whereas waters off Gombe Stream National Park host twelve recorded species. Mahale has a potentially greater range of habitats for molluscs, including extensive shell beds, and is a larger area, (60 vs. 16 km of coastline). Nsumbu has similar habitats to those found at Mahale, and a slightly longer coastline (77 km). Unfortunately we cannot make direct comparisons of mollusc diversity between Nsumbu and the Tanzanian parks because the molluscs in the Nsumbu list were surveyed through dredging (thus these species are found on sandy substrates) whereas divers surveyed the Mahale and Gombe molluscs on a range of sandy and rocky substrates. However, if we consider only the sand-dwelling species from the Tanzanian Parks, noted with asterisks, Mahale dive surveys noted nine sand-dwelling mollusc species, Gombe dive surveys found six sand-dwelling species and Nsumbu dredge surveys noted six sand-dwelling species. Additional species, including *Tanganyicia michelae, Tiphobia horei* and *Paramelania* spp. are known from prior dredge surveys at Nsumbu (West 1995 unpublished data).

It is interesting to note that the extensive dredging at Nsumbu did not recover any bivalve species. This may be an artefact of the sampling gear and bivalve life history strategies. Bivalves in Tanganyika, especially the large *Mutela spekei*, spend considerable time buried in the substrate with only their siphon extended. Their burrows are obvious to divers who can readily excavate bivalves, but they may pass undetected by the dredge.

3.4 Discussion and Conclusions

In common with many biodiverse sites around the world, Lake Tanganyika has a long history of scientific investigation into its flora and fauna. As these historical records predate the relatively recent development of formal biodiversity assessment methods they present a rich but challenging source of data that can be called on to address current conservation issues. In this context, the BIOSS literature database provides a powerful tool for planners and researchers to organise and interrogate the wealth of data on Lake Tanganyika's aquatic species and their distribution.

As the data have been collected by a variety of methods and for different purposes they represent only presence data, failing to provide the statistically comparable data needed to infer absence at a particular site. This is compounded by a tendency for those making taxonomic collections not to record species already encountered and to direct their focus on the novel (Colwell and Coddington, 1994). Thus, as a survey typically proceeds from accessible areas to less frequently visited ones, the presence of common, ubiquitous species are no longer of interest, and tend to be under-recorded (Colwell and Coddington, 1994). In Lake Tanganyika, the emphasis of taxonomists and evolutionary biologists on the disjunct distribution of some species, in support for theories of sympatric and micro-allopatric speciation (see Martens, 1977) have tended to mask the fact that the vast majority of species are actually very widely distributed. This fact is seldom articulated, but can also be discerned by analysis of known distributions of species in the faunal lists in Coulter (1991) and other authors such as de Vos et al (1994) and . We emphasise this discrepancy between common portrayal and reality because it is of vital importance in determining the requirements for conservation. A lake in which each rock contained a unique assemblage of species found nowhere else would require a huge protected area network to ensure the majority of species were represented. In contrast, a lake in which most species are widely distributed and only a few species have limited distributions could be afforded protection through a careful selection of a limited number of suitable sites backed up by maintenance of environmental quality at a lake-wide scale.

Defendants of the ‘every rock unique’ view of Lake Tanganyika’s biodiversity take refuge in sub-species genetic variability to support their thesis (e.g. Verheyen E, Ruber L, 2000). They do so once again on the basis of taxa that are selected because they are known, through the presence of sub-species or local morphotypes, to exhibit such population structuring. The extent to which this feature is ubiquitous is not known.

The literature database developed under BIOSS was ambitious given the size of the study and the field programme required. We are confident that although the full capability of the database is yet to be realised, its potential has been clearly illustrated. For the first time, planners and researchers can generate species lists for any specified area as illustrated by the national, park and basin lists presented in this chapter. Of the range of maps that could be produced from the database, we have presented maps showing locations of various survey types as well as those fish species not found within the current protected area network. These maps highlight areas of potential conservation importance and so prioritise sites for future research. Results have confirmed the contribution the BIOSS survey has made to the basic knowledge and understanding of Lake Tanganyika’s biodiversity.

The key constraints now relate to the availability of further data and the resources needed, beyond the life of LTBP, to continue developing this planning tool. An informal relationship has been established to keep the database ‘live’ between researchers in Burundi and London: in recognition that this is not sustainable more permanent arrangements are being sought.

Future technical advances will include better integration with the GIS system so that mapping and integration with data from other disciplines (e.g. water quality data, fishing intensity etc.) is possible. The standard set of queries available to novice database users needs to be enlarged to include analyses presented here. As more data are entered on different taxa it should be possible to analyse relationships between the diversity of different taxonomic groups at a set of locations. This would provide important data on the relationship between diversity of different taxa in the same locations – a prerequisite for any attempt to generalise about biodiversity from ‘total biodiversity surrogates’.

With a time series of data at particular sites, it should also be possible to look into the disappearance of species over time. The ability to analyse the relationship between species and habitat, so fundamental to biodiversity conservation, should improve as more studies are carried out.

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 BIOSS 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 BIOSS Survey activities, 1997-2000

A summary of survey activities undertaken by BIOSS teams is given in Table 4.1. The methods used are outlined in Chapter 2 and detailed in the BIOSS 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 BIOSS 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

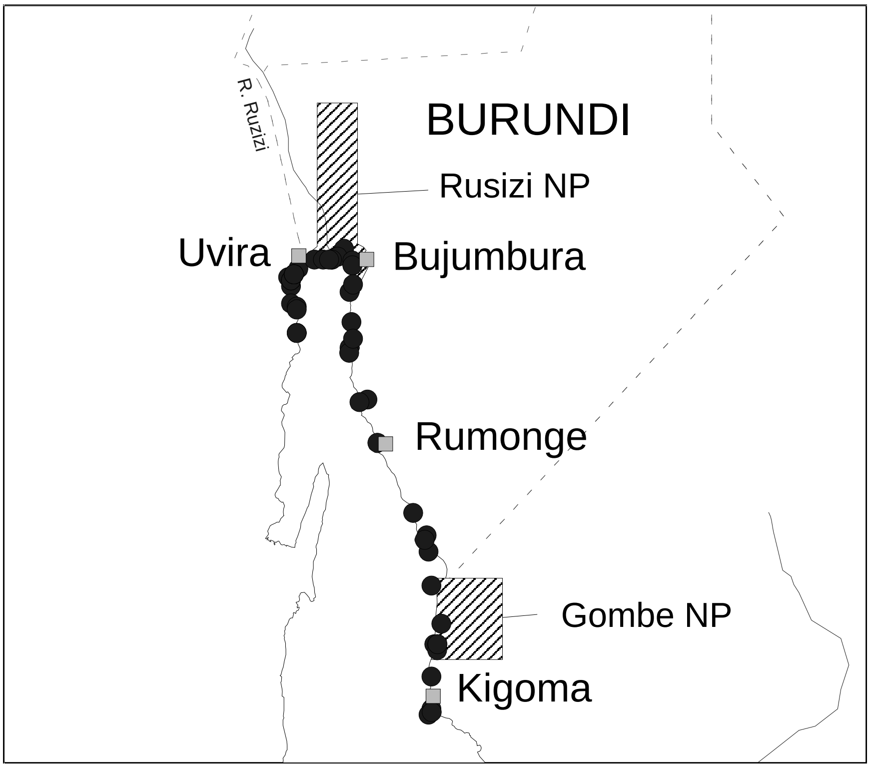


Figure 4.1 Map of BIOSS sampling sites in the north of the lake

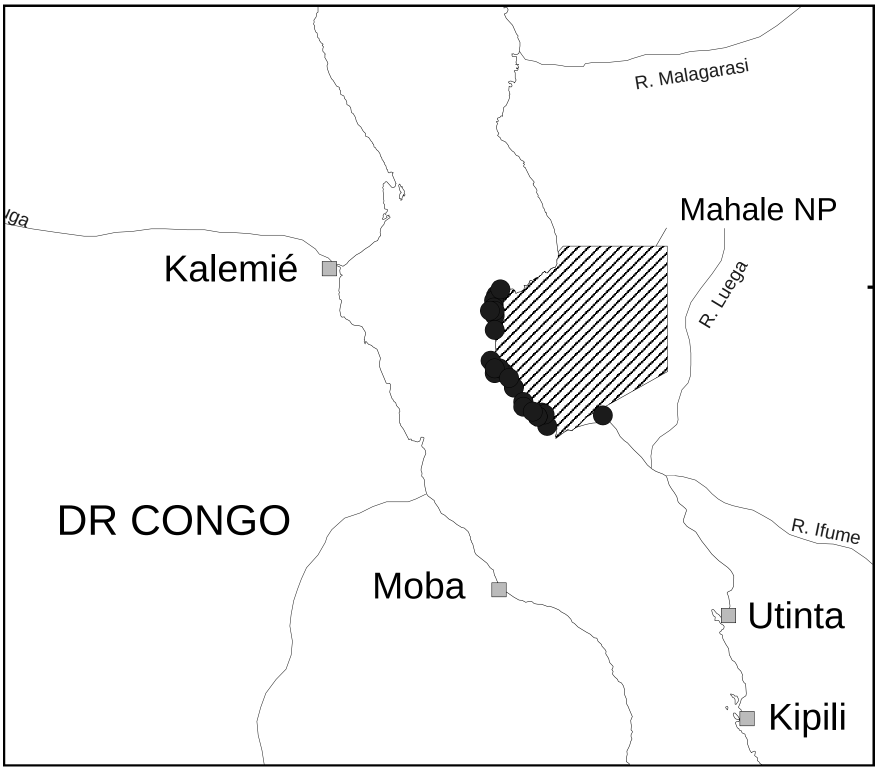


Figure 4.2 Map of BIOSS sampling sites in the Mahale area

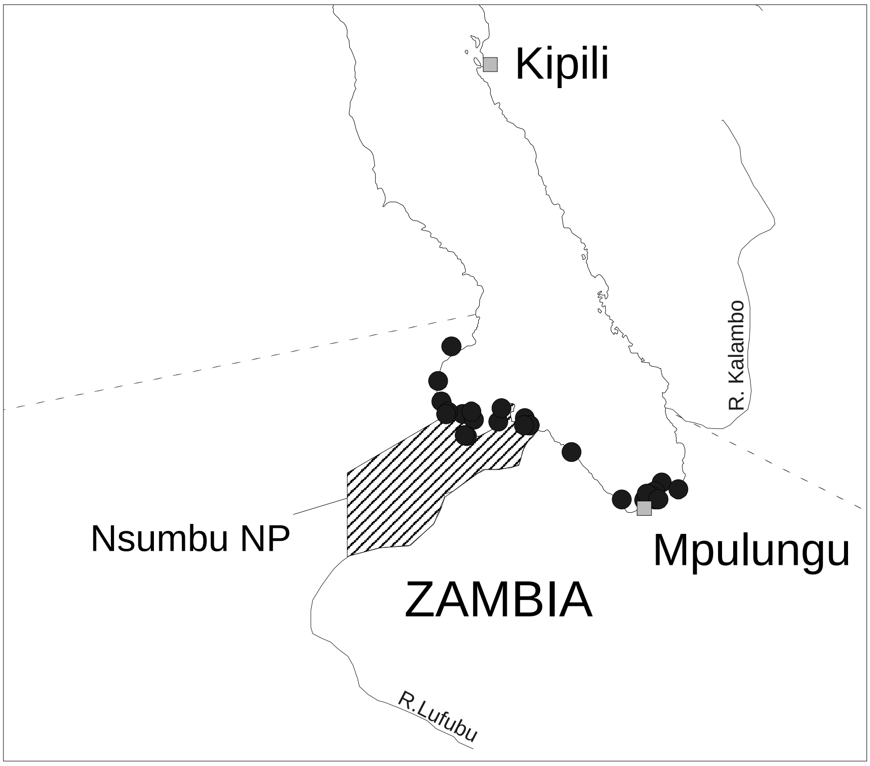
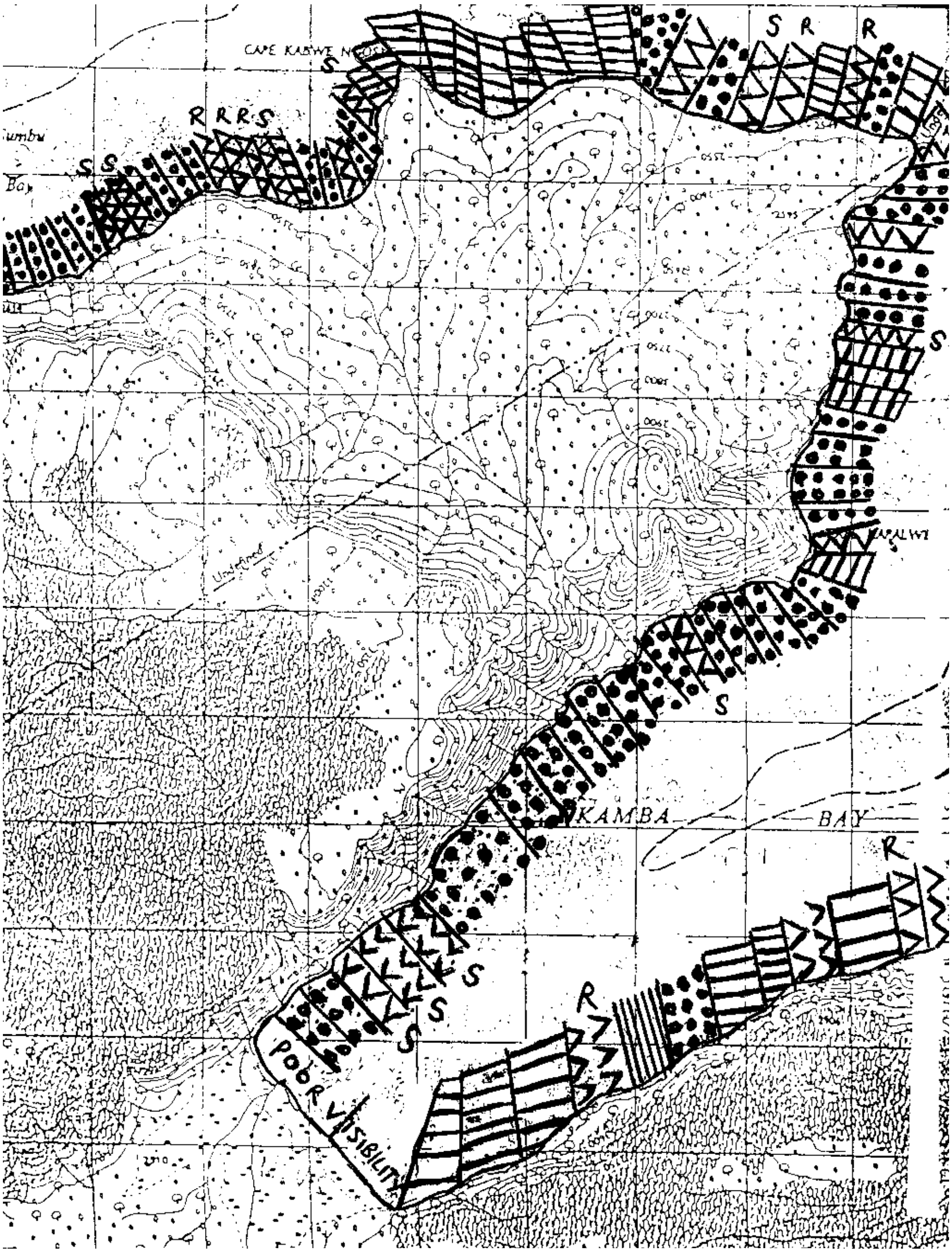


Figure 4.3 Map of BIOSS sampling sites in the South of the lake



Key to symbols	
Symbol	Substrate type
• • • • • • • •	Sand
‖‖‖	Rock
☰	Gravel
VVV	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.

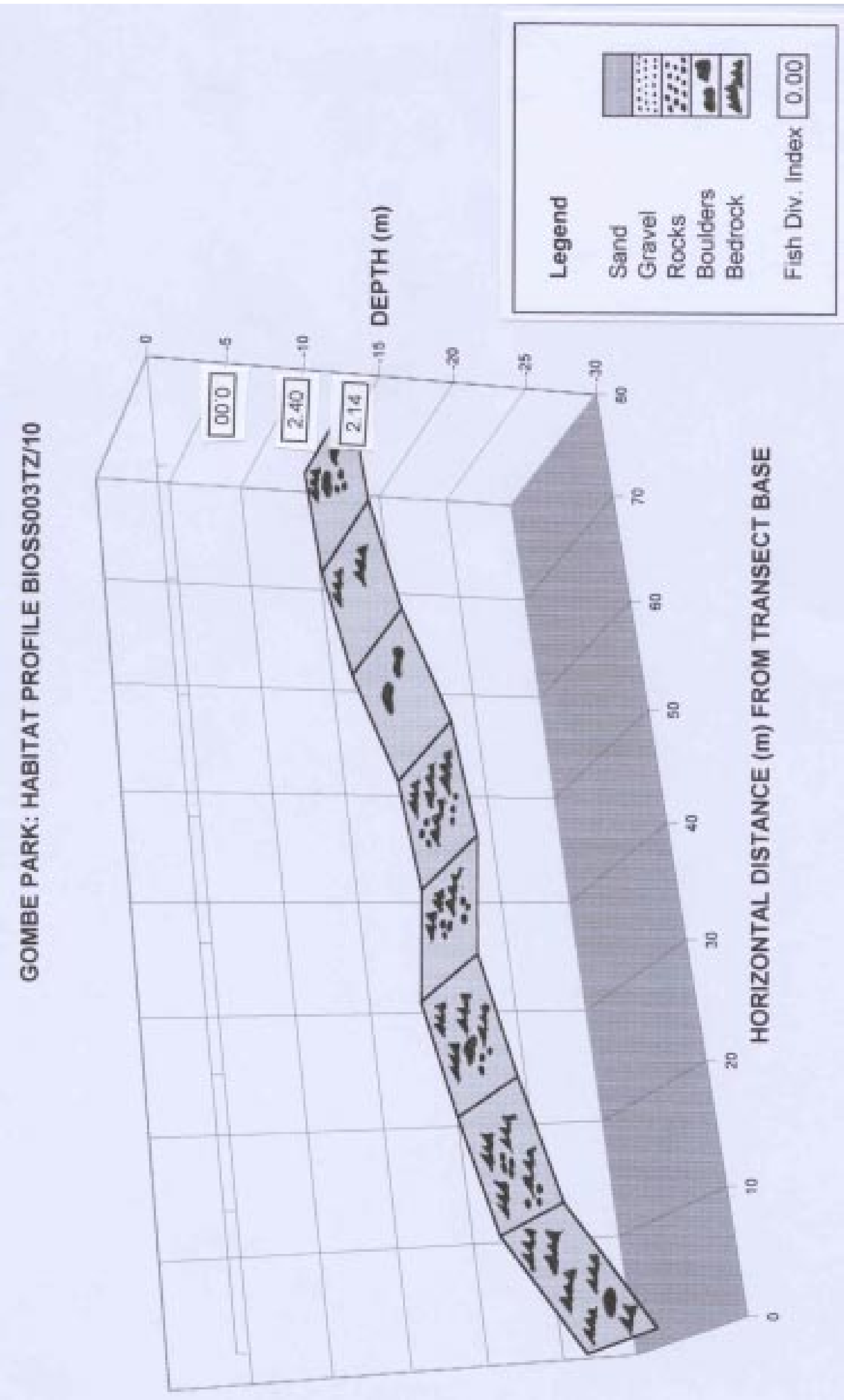


Figure 4.5 Results of a dive profile, taken from Gombe survey.

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-Weiner[12] 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).

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[12] Note that all diversity indices were calculated using Log_{10}. 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. Smax 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).

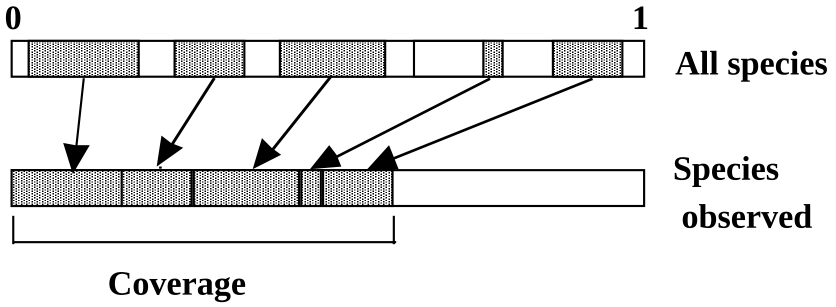

Figure 4.6 The theoretical principles behind coverage-based estimators of species richness. Shaded segments represent the species sampled, which will represent only part of the total species present. The sum of those segments is the coverage. (from Colwell, 1997).

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 jacknife also includes the number of species that occur in two samples (Q_2):

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

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).

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

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 BIOSS. More detailed reports on habitat issues are given in each of the protected area reports (see Appendix 8.1 for list of BIOSS documents).

Fundamental to any attempt to conserve species in situ are efforts to conserve the habitats in which they are found. In a strategy cantered 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 BIOSS surveys. Habitat quality issues were investigated as part of other special studies (Sediments and Pollution), and would ideally have been integrated with BIOSS 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 4.8[13]), the pattern of this largest scale patchiness can be described.

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

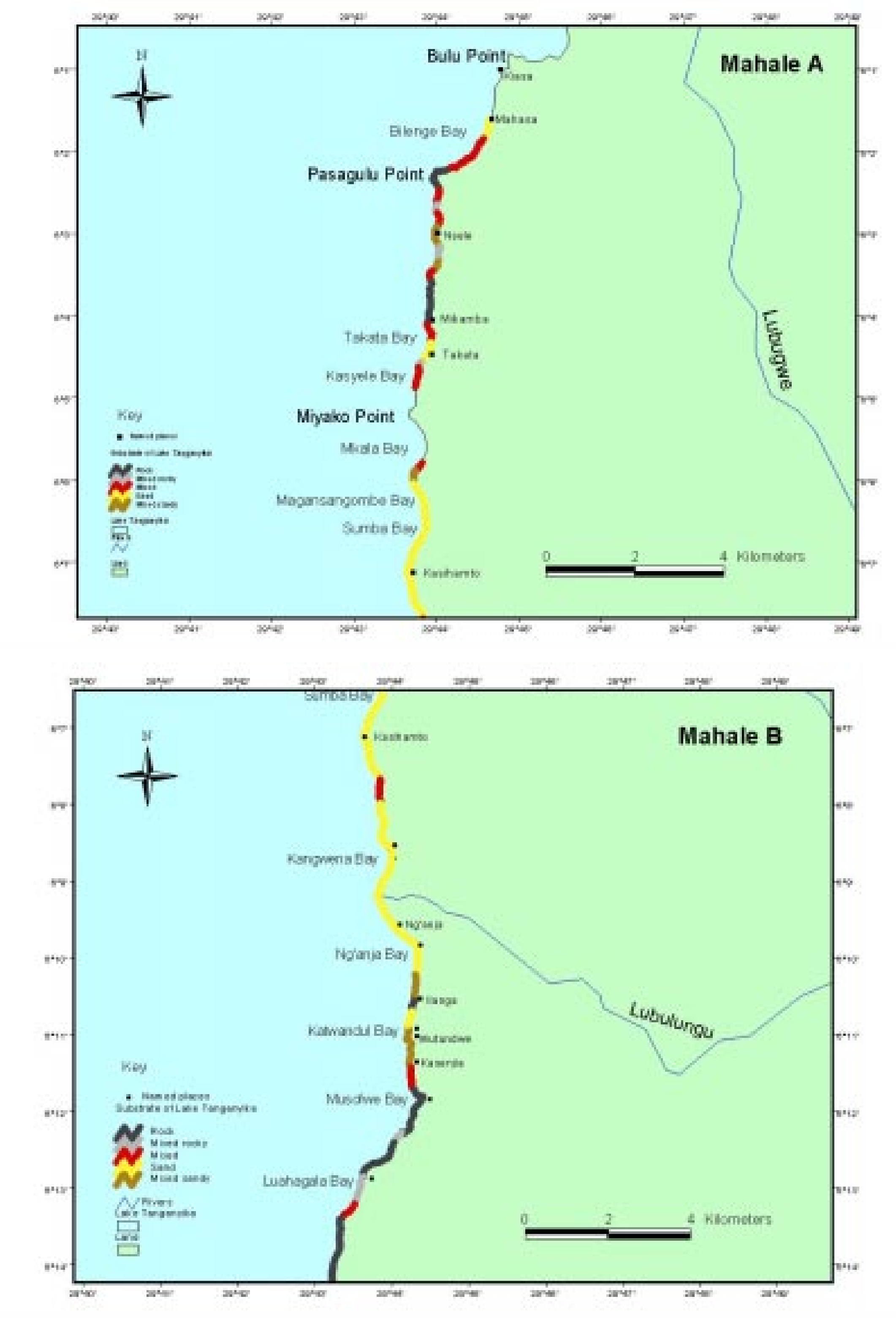


Figure 4.7 **Littoral zone substrate categories from Manta-board surveys, Mahale NP (maps A and B)**

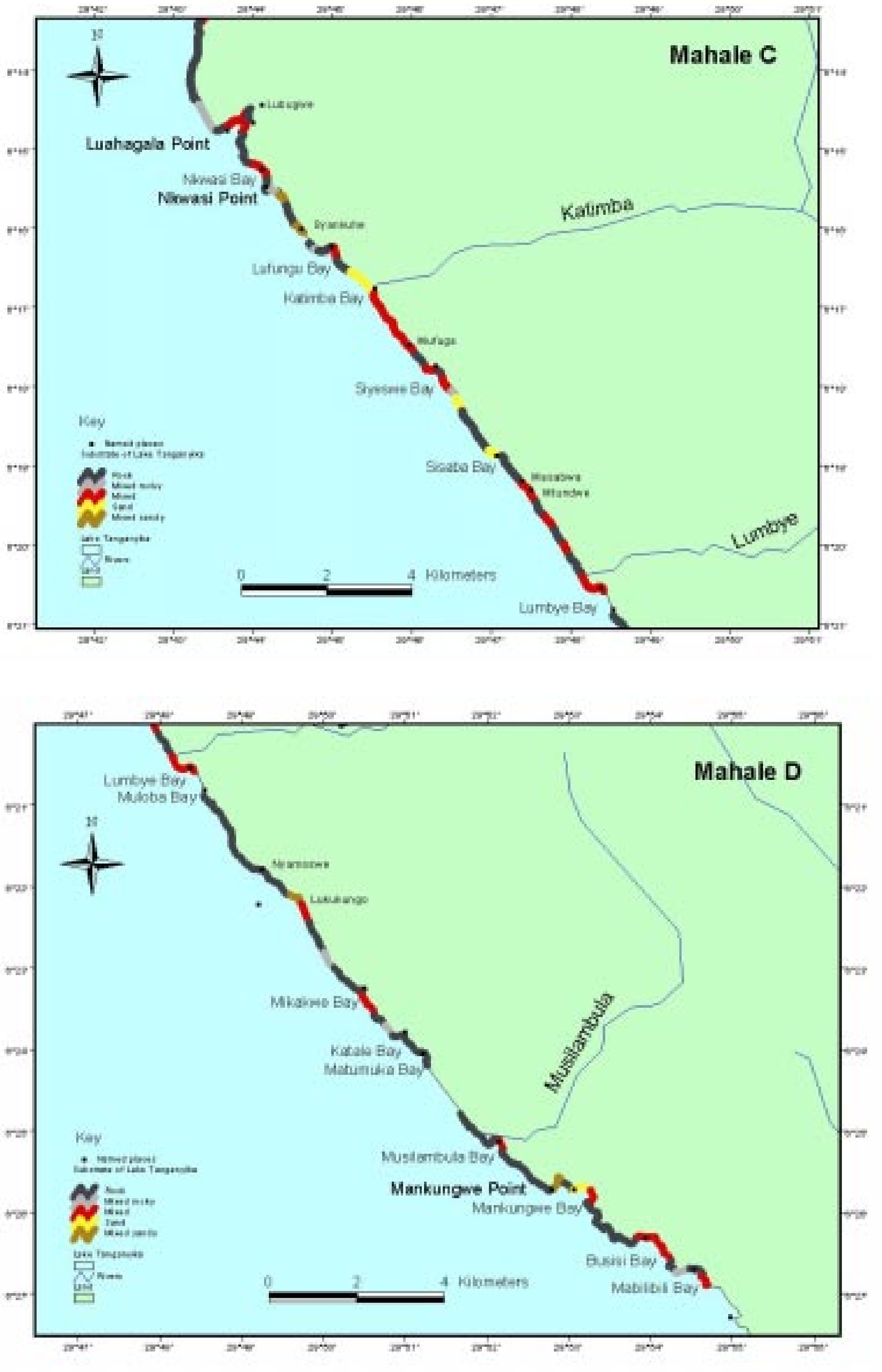


Figure 4.8 Littoral zone substrate categories from Manta-board surveys, Mahale NP (maps C and D)

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 (*N*)	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 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 (*N*)**	***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.

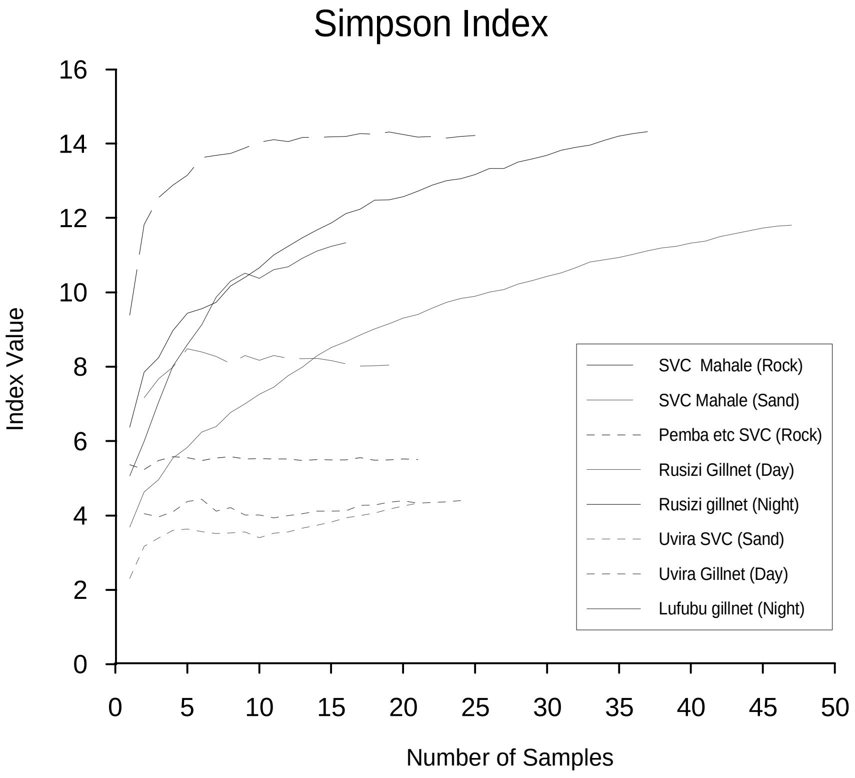
All the above diversity indices and their comparisons will be affected by differences in sampling size and 'completeness' (see Chapter 2). By examining the calculated diversity index from 100 randomisations at each step in the species-accumulation process, we can determine the number of sampling events 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.



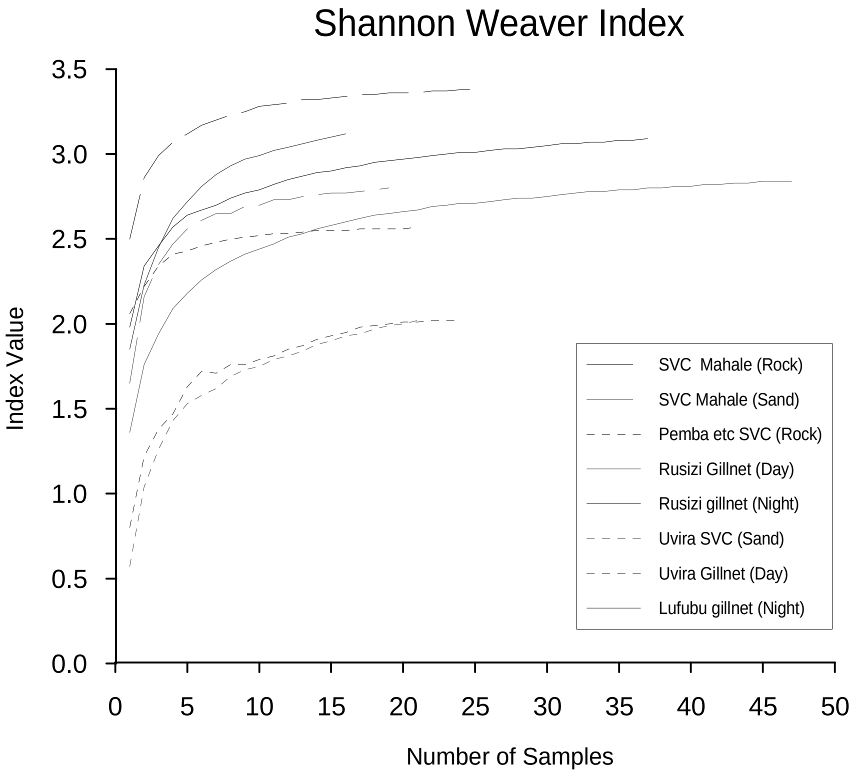


Figure 4.9 Sensitivity of diversity indices to sample size, based on 100 randomisations of sample order.

4.3.3 Fish species richness

Fish species richness estimates (Smax) 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 Smax 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

ICE = Incidence-based Coverage Estimator
Jack1 = Incidence-based 1st order jackknife estimate
Jack2 = Incidence-based 2nd order jackknife estimate
Boot = Incidence-based bootstrap estimate

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.

	Gillnets (nights)		Gillnets (days)		SVC (Rocky)		SVC (Sandy)		RVC (0 - 3 m)		RVC (5 - 15 m)		Total recorded species	
Area	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.

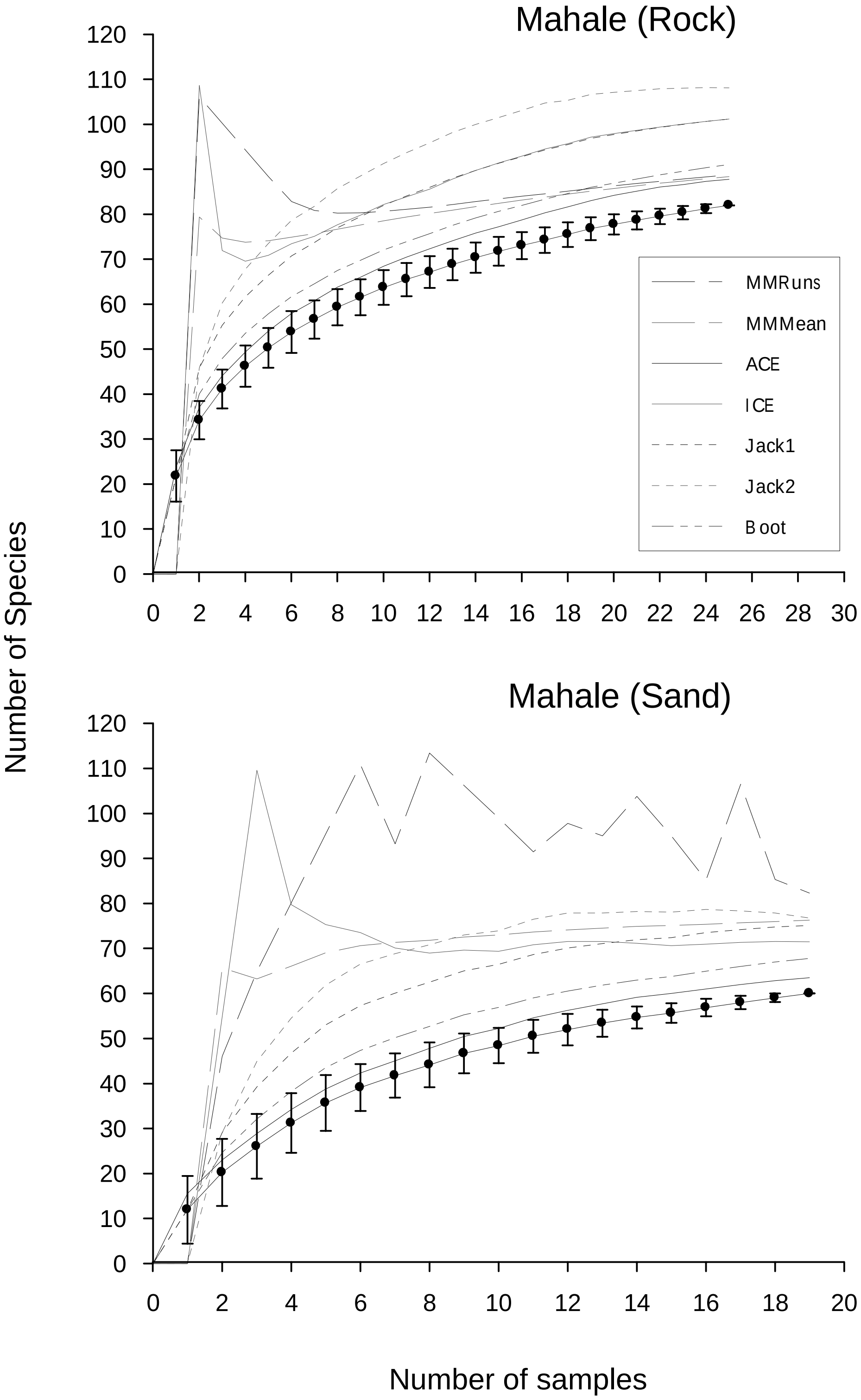
The Jackknife, Bootstrap and ACE estimators tend to shadow the species-accumulation curve, and are therefore sensitive to sample size. Where the species-accumulation curve has not reached an asymptote, then neither will the estimators have stabilised. This makes them less useful than ICE and MMMeans 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

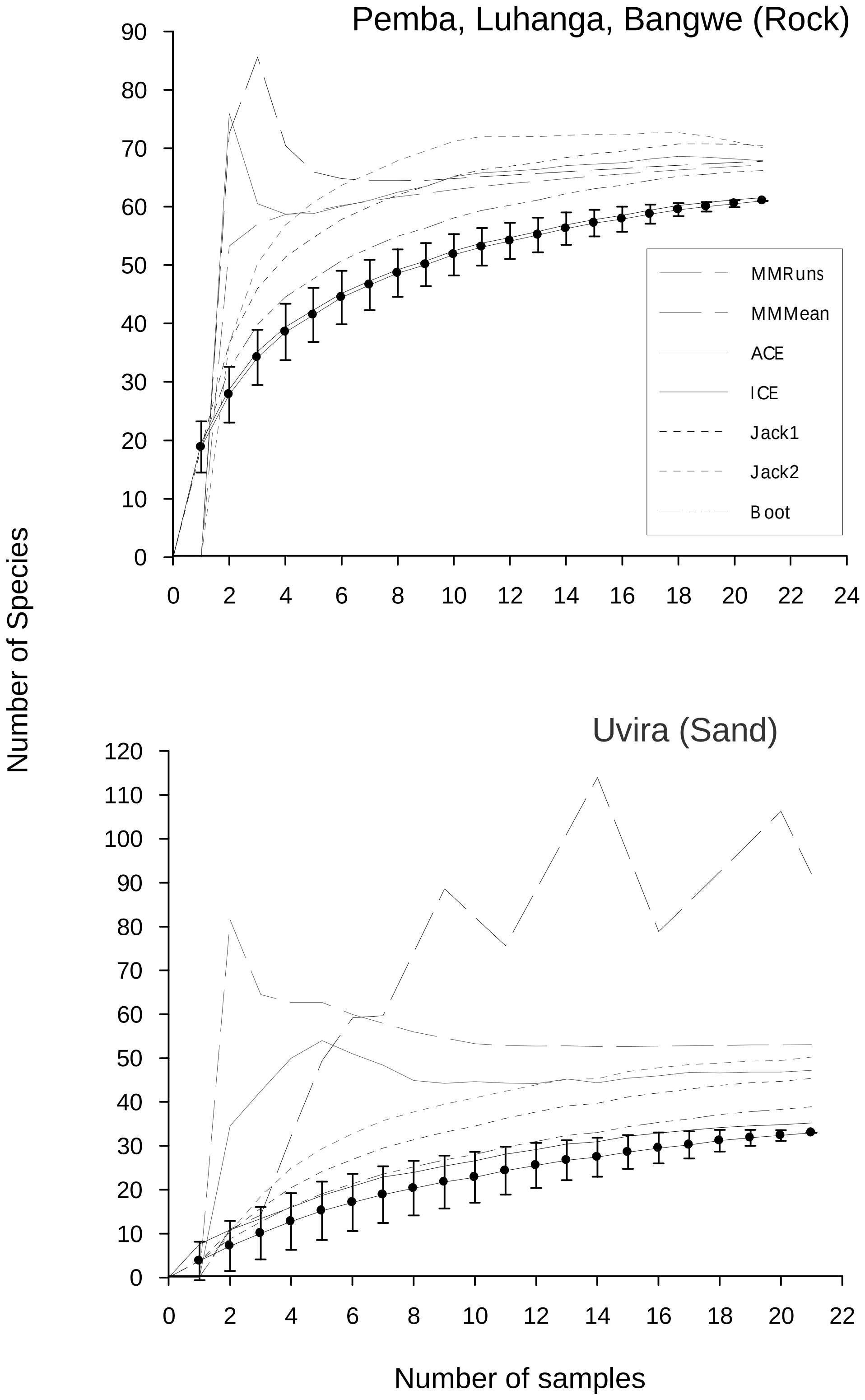
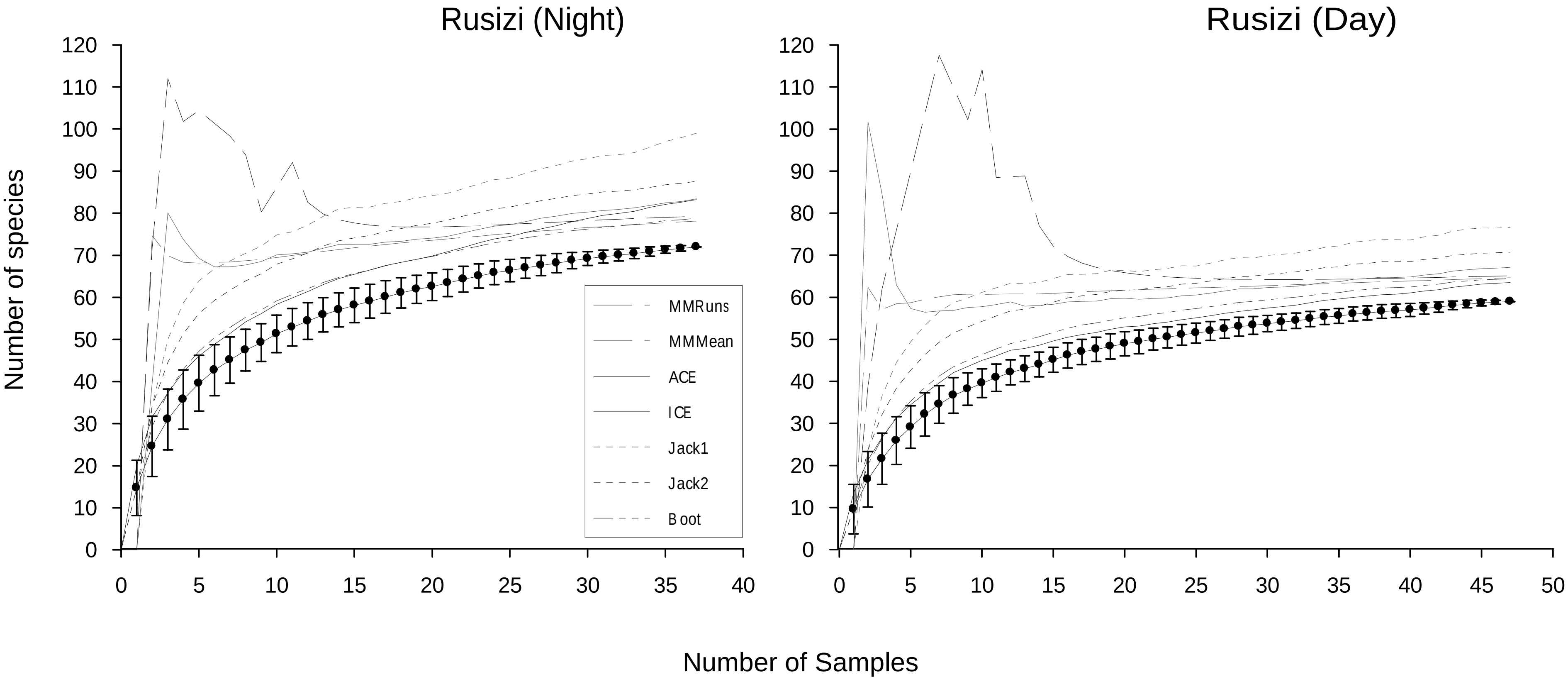


Figure 4.11 Relationship between number of replicate gillnet sampling events and S_{max} estimates: (a) Rusizi and (b) Uvira and Lufubur/Chisala

a) Rusizi, Burundi



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

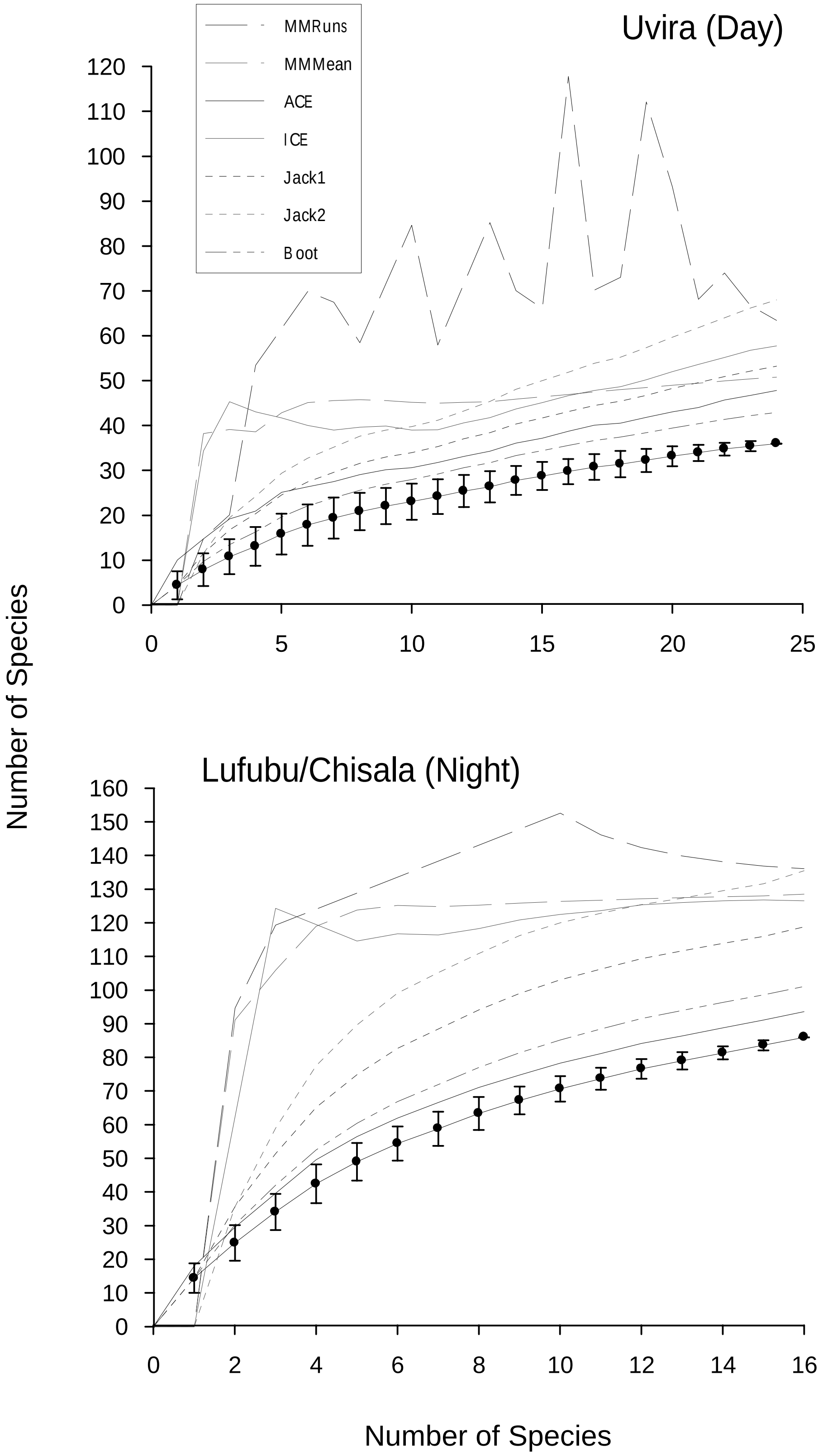
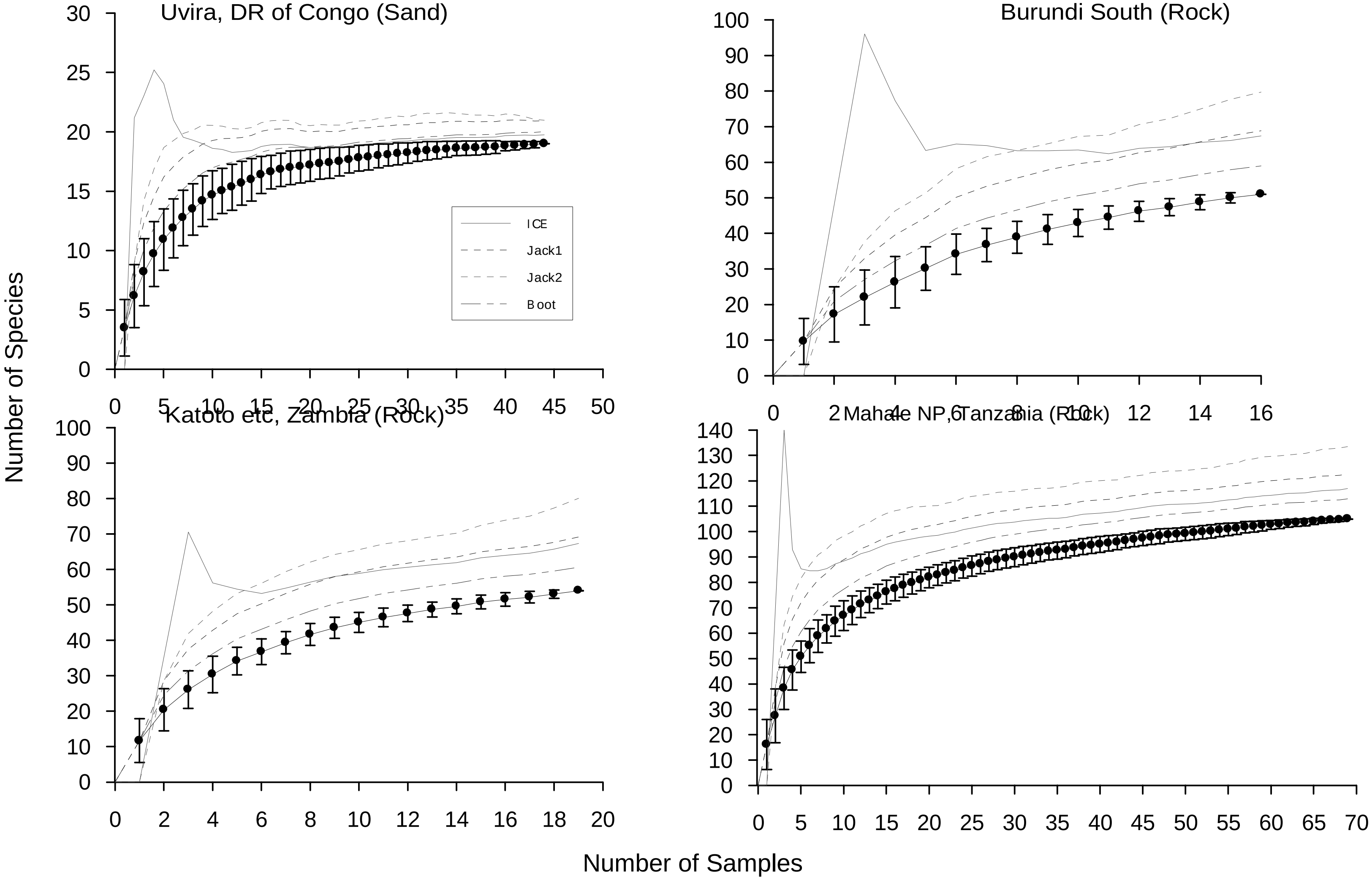


Figure 4.12 Relationship between number of replicate RVC sampling events and S_{max} estimates



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

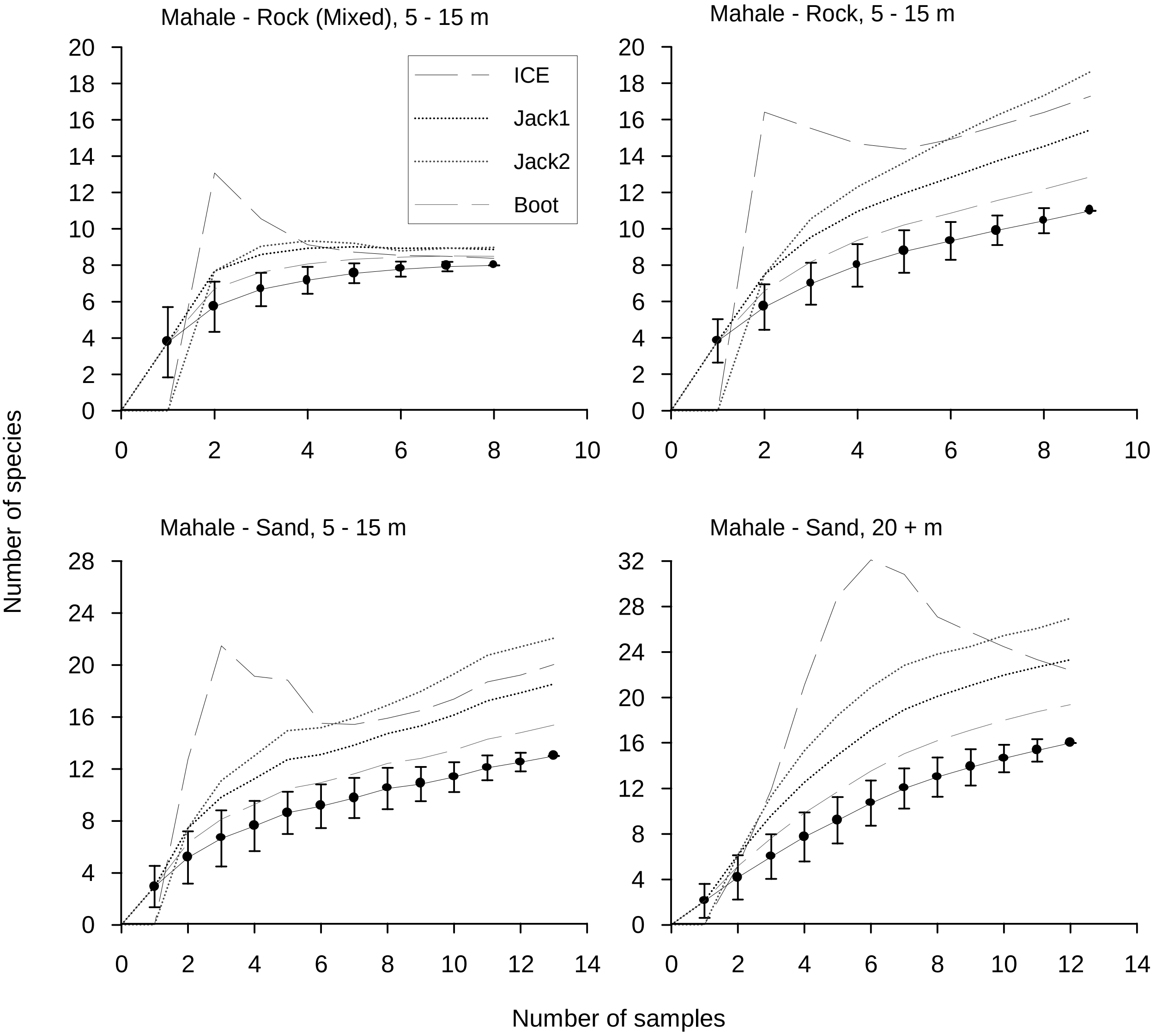
					S_{max} estimates			
Area	**Depth (m)**	**Substrate**	**N**	**S_{obs}**	**ICE**	**Jack1**	**Jack2**	**Boot**
BURUNDI								
Gitaza	5 to 15	Sand	4	6	7.3	7.5	7.5	6.8
DR CONGO								
Pemba etc	5 to 15	Sand	3	4	6.0	5.3	5.7	4.7
Pemba etc	5 to 15	Rock	4	9	11.3	11.3	11.1	10.3
Pemba etc	5 to 15	Mixed (Rock)	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 1st order jackknife estimate
Jack2 = Incidence-based 2nd 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 **Sensititivity 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 MMMeans, 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 BIOSS 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).

BIOSS 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, BIOSS 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, endemicity 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 it 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 Jaaresveld *et al.* 1998; Howard *et al.* 1998). Van Jaaresveld *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 BIOSS 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 BIOSS surveys, and more general and descriptive information from secondary sources, and from BIOSS 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 endemicity

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)	*(%)*
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

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 endemicity 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 BIOSS. 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 BIOSS 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 to 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 km^2 – 4,000 km^2) 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 (PolSS) 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 are remain oligotrophic and PolSS 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 it 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 is 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	
Aquatic species	Flagship species: fish – Tropheini and Lamprologini tribes, *Petrochromis spp.* Species richness: high
Aquatic habitats	Sandy, rocky and mixed (sand and rock) habitats well represented throughout park. *Neothauma* shell beds at Sitolo, Mabilibili and Busisi bays. Stromatolites at Nsele.
Other	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	
Legal status	Well established; the park extends 1.6 km into lake.
Costs/benefits to local community	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.
Enforcement	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	
Infrastructure	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
Attractions	Lakeside scenery and beaches. Abundance of species favoured as sport fish. Water visibility ideal for underwater viewing of aquatic fauna.
Market	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.
Security	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	
Aquatic species	Flagship species: Fish - *Polypterus spp* and *Protopterus aethiopicus* Species richness: High. Particularly rich in non-cichlid species. Includes river to lake to river migrants such as *Alestes macrophthalmus* and *Raiamas spp.*
Aquatic habitats	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.
Other	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 – *Lates sp, Boulengerochromis microlepis, Limnothrissa miodon*.
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	
Legal status	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.
Costs/benefits to local community	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
Enforcement	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	
Infrastructure	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
Attractions	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.
Market	Predominantly expatriates working in Bujumbura. Some overseas ornithologists visit as part of East African tour.
Security	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	
Aquatic species	Flagship species: fish – *Lates spp*, *Boulengerochromis microlepis*, *Citharinus gibbosus*. Species richness: high
Aquatic habitats	Predominantly sandy, but rock and mixed (sand and rock) habitats also well represented. *Neothauma* shell beds between Nsumbu village and Nundo Point.
Other	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	
Legal status	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.
Costs/benefits to local community	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.
Enforcement	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	
Infrastructure	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.
Attractions	Game viewing. Species prized as sport fish. Fishing competitions organised by tourist lodges.
Market	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.
Security	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	
Aquatic species	Flagship species; fish – *Cyphotilapia frontosa* Species richness: high
Aquatic habitats	Rocks, cobbles and sand in shallow littoral zone. Rock at about 40 m depth.
Other	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	
Legal status	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.
Costs/benefits to local community	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.
Enforcement	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	
Infrastructure	Transport; boats from hotels in Kigoma. Facilities; accommodation is simple but adequate.
Attractions	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.
Market	Primate enthusiasts. As research is the primary focus for the park, there has been a deliberate policy of limiting visitor numbers.
Security	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	
Aquatic species	Flagship species: fish - Pemba; *Tropheus duboisi* (Red colour-morph). Luhanga; *Neolamprologus leleupi* Species richness: high
Aquatic habitats	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	
Legal status	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.
Costs/benefits to local community	Costs; these would be minimal. Benefits; the SSIs would act as focus for reforestation.
Enforcement	No formal enforcement is required. The aim would be to conserve through increased awareness of conservation importance.
Tourism Potential	
Infrastructure	Transport; the road link from Uvira is good. Facilities; accommodation is available for 9 people at CRH, Uvira.
Attractions	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.
Market	Research scientists, expeditions conducted by organisations such as Earthwatch or Frontier, expatriates from Bujumbura dive club.
Security	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 leant 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.

6. SUMMARY AND RECOMMENDATIONS FOR FUTURE MONITORING, RESEARCH AND MANAGEMENT ACTION

6.1 Introduction

The Lake Tanganyika Biodiversity Project was conceived largely as an environmental protection project, but has, in its design and operation, responded to the move towards adoption of integrated conservation and development (ICAD) programmes. The East African Great Lakes provide a critical test for the realities of implementing the new ICAD programmes currently being adopted by national governments, international agencies, NGOs and resource user communities in response to the UN Conference on Environment and Development (Rio de Janeiro 1992). The post-Rio conservation agenda is guided by international environmental agreements, principally the Convention on Biological Diversity (CBD). The CBD promotes a utilitarian approach to conservation – through sustainable use and equitable sharing of benefits derived from exploitation of that biodiversity. Thus, our summary and recommendations are framed within this paradigm. We recognise that there is a moral imperative to ensure that biodiversity conservation does not take place at the expense of rights to social and economic development in the region.

At the same time as the adoption of ICAD approaches to environmental management, the international development agenda has shifted from support for national economic growth, towards poverty-targeting or 'pro-poor' growth (Allen and Thomas, 2000). In natural-resource management projects, this development strategy is being pursued through adoption of the 'sustainable livelihoods approach' (Scoones 1998, Carney 1998). This approach, while seeking to understand the extent and causes of poverty, dependence and vulnerability, focuses primarily on strategies used by the poor and vulnerable to survive and prosper in difficult circumstances. In other words, the approach uses an analysis of people's assets, abilities and strengths to identify possible routes out of poverty (Ellis 2000). One of the key components of the 'asset pentagon' available to the poor is 'natural capital' or 'natural endowment' - the renewable natural resources available to and managed by individuals, households, communities and nations. These may include soil fertility, water, agrobiodiversity, fuelwood, fisheries and other 'goods and services' provided by the natural environment. Sustainable use of natural capital, including biodiversity, is therefore a key component of current approaches to poverty eradication (e.g. Tisdell 1999). This is particularly relevant for the inhabitants of the riparian countries of Lake Tanganyika.

The theoretical basis for integrated environment and development programmes is that there need not be a conflict between conservation and development (in the form of poverty eradication). Indeed, for development to be sustainable, the two must be reconciled: maintaining 'natural capital' is integral to sustainable development, and only through development will the poor have the resources and ability to exercise choice in not having to degrade the environment in order to survive. While the notion that it is the poor who are the enemies of the environment is disputed (Broad 1994; Chambers, 1994), these ideas underpin utilitarian perspectives on biodiversity conservation and current approaches to poverty eradication through support for sustainable livelihoods. Perhaps nowhere else on earth is the challenge to integrated conservation and development approaches so great as around the shores of the African Great Lakes, where some of the world's poorest people survive by exploiting some of the World's most biodiverse environments. The assumptions that underpin ICAD approaches are that people in Lake Tanganyika can benefit from biodiversity conservation. This key assumption has not been subjected to any critical scrutiny by the project, and later in this chapter we attempt to redress this important oversight.

At present, discussions on integrating conservation and development in Lake Tanganyika take place against a background of key uncertainties in the information base for management. Projects by FAO/FINNIDA and the current GEF project have made enormous progress in addressing key, broad issues for management: institutional development, legal frameworks, management objectives and priorities for fisheries and biodiversity conservation. They have also, through original research and synthesis of existing information, greatly contributed to this knowledge base. The Strategic Action Programmes resulting from this project has proposed priorities for further action, including intervention and funding by external agencies. Despite this progress, several key information gaps remain, most of them at the interface between technical special studies and socio-economic analysis. While we recognise that management action should not have to wait for perfect information, our contention is that several key areas of existing knowledge (such as the link between conservation and development) have not been addressed by the LTBP project, and that these key areas could determine the whole approach to future management in the lake basin.

In this look to the future, we draw partly on our own and others' inputs into the SAP, to highlight information and management needs. As this is a technical document, rather than a management document, we focus particularly on areas of interest to those whose work has a technical remit. Thus, we concentrate on the research and monitoring needed to support the management recommendations we make. We hope this will assist with the technical basis for proposals seeking funding to implement the SAP. We divide our overview into three areas broadly representing monitoring needs, future research priorities and management approaches, but recognise that these three contain many cross-linkages, with choice of management direction determining research priorities and so on.

6.2 Monitoring

Two types of monitoring of the environment have been recognised: performance and ecological (see Abbot and Gujit, 1998). *Performance monitoring* is used to assess the effectiveness of management interventions, such as community initiatives, district plans, government laws and policies, and donor projects etc. In contrast, *ecological monitoring* assesses changes in the biophysical environment such as quality and extent of reed beds, fish species richness or community structure. Emphasis is often on the latter, however, both are essential to monitor success of conservation and management programmes.

By providing information on changes and trends, on what works or how activities might be improved, monitoring underpins the activities of decision makers and planners. To be effective, monitoring programmes must deliver relevant information at the right time in a format that is appropriate to the end user. Note that this "end user" is rarely involved in data collection and may not have even had a role in analysing the information or been part of the programme design. Awareness of these constraints and given the limited technical remit of BIOSS, recommendations for biodiversity monitoring were necessarily very technical in nature. We developed appropriate criteria for site selection, agreed locations in consulation with other special studies and provided a standardised methodology for collection of biological data collection (see SOP for details).

Monitoring programmes should aim to assess both the symptoms and the causes of change. Thus, a monitoring programme that detects degradation in, say, habitat quality is not useful unless the cause of that change can be elucidated. Scientific monitoring programmes tend to be focused on the proximate causes of change (e.g. turbidity, impact of fishing, water quality). In order for the monitoring programmes outlined in the SOP to be successful even at this function, the riparian institutions will have to achieve a level of integration of pollution, sediments and biodiversity work that the special studies failed to accomplish during the LTBP project. Trained teams are in place and technical methodologies have been established and, in some cases, recorded in sampling protocols that aim to standardise monitoring techniques across the lake (e.g. the BIOSS SOP). Thus, the prognosis for sustained monitoring are good, but the momentum generated by the project needs to be acted upon quickly if it not to be lost.

Technical monitoring programmes of the type designed by BIOSS can serve an important 'alarm' function. An alarm is only useful, however, if someone is able to respond to it. Monitoring programmes need to also address the root causes of change – including human population change and migration, the pattern of land tenure and land use, and the location and impact of coastal and lake-basin development – and think in terms of addressing or mitigating these pressures on biodiversity.

A monitoring programme is also only useful if it continues beyond its conception! Many monitoring studies are designed to be comprehensive and rigorous, but their rigour is never tested because the programmes are not sustained, or too many resources are spent on data collection and insufficient remain for proper long-term data storage and analysis and, most importantly, to maintain capacity to act on the information produced (Darwall and Allison, in press). A quote from Roberts (1991) summarises the folly of many monitoring programmes:

> *…much field recording "tells us only that lots of people are keeping lots of records: often for no good reason, using dubious methods, and producing vast quanitities of un-analysed and often unanalysable data"*

Such programmes are a drain on institutional resources and are of no practical use. Modest ambition, coupled with realistic assessment of institutional capacity are a prerequisite for the design of sustainable environmental monitoring programmes. Many development projects still fail to allocate sufficient resources to post-project analysis, sustainability and process issues, in their concern to meet shorter-term project success indicators specified in logical frameworks.

Assessing whether management interventions to conserve biodiversity are successful can be problematic. Most measures rely on biological indicators of success, such as increases in diversity indices or species richness, the abundance of selected 'indicator' taxa (Noss, 1990; Spellerberg, 1991). These may not be evident for some years, even if the project has successfully addressed threats to diversity. They also require considerable technical and financial resources to implement them. Of potential interest to project evaluation teams are monitoring and evaluation tools recently developed specifically for integrated conservation and development projects, based on analysis of the degree to which a project has successfully reduced identified threats to biodiversity (Margoluis and Salafsky, 1998; Salafsky and Margoluis, 1999). This supports our assertion that monitoring the root causes of biodiversity loss is as important as trying to assess the magnitude of the loss.

6.3 Research

6.3.1. Expanding survey activities

Considerable work remains in documenting the biodiversity of Lake Tanganyika. Much of the Tanganyika coastline has not been adequately surveyed. Some of the biggest gaps in knowledge include: the Congolese coastline south of Baraka to the Zambian border, the Tanzanian coastline between Ujiji and Mahale Mountains National Park and south of Mahale to the Zambian border. These areas combined constitute well over 50% of the Lake's perimeter. Studies show that as new areas in Tanganyika are investigated new species are found, even among the relatively well-known groups (West *et al.* 1999; L. DeVos, pers. comm.; J. Snoeks; pers. Comm., K. Martens, pers. comm.).

At the same time these explorations are undertaken, it is critical that the base of taxonomic expertise is increased, especially within the region. Some groups, like sponges, decapods, insects and the many worms and worm-like groups, have not been recently, and in some cases have never been, properly described and monographed using modern techniques and classification ideologies. Even for relatively well-known groups (fish, molluscs and ostracodes), taxonomic expertise is concentrated in the Northern Hemisphere. Producing basic identification materials for all groups and ensuring taxonomic training for regional scientists is a critical step in documenting Tanganyika's biodiversity and engaging regional scientists to take a proactive role in understanding and managing it. Some institutions and funding agencies have already recognized this urgent need to increase taxonomic training, especially in developing countries (e.g. the US National Science Foundation's Partnerships for Enhancing Expertise in Taxonomy program).

6.3.2 Developing methods of assessing aquatic ecosystem health

Biotic indices have been used as a relatively quick and easy way of assessing the health of aquatic ecosystems. Essentially the invertebrate fauna is surveyed and the proportions of certain taxa, for which the oxygen requirements and environmental tolerances are well understood, are manipulated into an index, which reflects the relative health of the ecosystem. The technique requires considerable research input prior to application (e.g. see Kerans and Karr, 1994). This technique has been used widely in European and North American streams, where the taxonomy of aquatic invertebrates is well understood (reviews by Fore et al. 1996 and Wright et al. 1998)). Much taxonomic and ecological work remains before this technique would be viable for assessing the state of East African waters, though there are clearly enormous benefits of having such a method of assessing ecosystem health for natural resource managers. Such techniques are only recently being developed elsewhere in Africa (Roux et al 1993; Crosa et al, 1998).

6.3.3 Assessing biodiversity values

The definition of biodiversity as variation (genetic, taxonomic, ecological) implies that the more variation (e.g. species richness) the more valuable a system is in conservation terms. This would be the case only if all species (or other units of biodiversity) had the same value. In practice, this is not the case. Humans place differential values on biodiversity, depending on whether it has ‘use values’ as well as ‘intrinsic value’.

There are three types of economic value that can be associated with biodiversity: **direct use**, **indirect use**, and **non-use** values (e.g. Barbier et al, 1994). Within these categories are several sub-divisions.

Direct use values refer to economic benefits that accrue directly as a result of the continued existence of a genotype, species, community, or ecosystem. Direct uses may be *consumptive* (the organism is harvested or removed from its environment, as in fisheries or the aquarium trade) or *non-consumptive* (economic benefits generated without harvesting, such as revenue from eco-tourism).

Indirect use values are the economic benefits that arise indirectly from the continued existence of biodiversity. In Lake Tanganyika, the diversity of organisms may be involved in maintaining crucial ecosystem functions, such as a relatively stable and productive environment for fisheries production (but see later for a critique of this assumption). The interactions between primary production and consumption by higher trophic levels may also play a role in maintaining water quality. The disruption of the role of diverse fish communities in nutrient cycling in Lake Victoria has been proposed as one side-effect of the introduction of Nile Perch, that caused the rapid decline of the hapolochromine fish fauna (see Kaufman, 1992 for review). Another example of indirect use values, and their loss, is the increase in Bilharzia in Lake Malawi purported to be linked to reduction in populations of mollusc-eating fishes that were thought to control the intermediate snail hosts of the disease (Turner et al, 1995). This has costs to human health and even to the tourist industry. The indirect value of the snail-eating fish can be estimated through the cost to human communities of poor health, and to the provision of increased health services in the riparian countries, and any decline in lakeshore tourism.

Biodiversity has value beyond mere utility, and environmental economists have tried to estimate these **non-use** values too. **Existence values** are calculated by economists on the basis of what people are willing to pay to ensure that, for example, a particular cichlid species continues to survive. **Intrinsic values** recognise the rights of all living things to share the planet. **Bequest values** recognises that our environment has value to future generations, and that species or ecosystems that are of little or no use to us may find uses to future generations. In calculating such values, it must be borne in mind that they are highly subjective and culturally determined.

Traditionally, resource values have been calculated on the basis of direct use values only. Environmental economists argue that this is why modern societies under-value the environment, and degrade it to convert ‘natural capital’ into ‘financial capital’ (Costanza et al., 1997). They argue that if environmental/biodiversity values can be ‘captured’ or estimated, then the true costs of alternative land, water or resource uses can be calculated. This provides the basis for an analysis of trade-offs between preservation and consumptive use, or to assess the real value of extinctions, in terms of loss, not only of direct use values (the old approach) but also of non-use and indirect use values. With these environmental valuation techniques has come the realisation that when we lose a species, we may lose a lot more than we anticipated. Putting a value on bequest, existence and other such concepts is rather difficult in practice, but does serve to bring such values to the attention of policy makers.

This utilitarian approach to environment is becoming much utilised in global environmental management – the use of tradable carbon permits to manage carbon dioxide emissions in combating global warming, and the principle of 'polluter pays' are two examples.

In the case of Lake Tanganyika, use values are of most concern regionally, while non-use values are more important internationally (Table 6.1). An understanding of the differential values of different biodiversity will help to determine priority approaches. This is already recognised implicitly in the SAP process, but needs to be made explicit to justify decisions. For example, the species flock of endemic leeches of Lake Tanganyika have some intrinsic value, possible bequest value, but little or no use and existence value, while *Lates stappersii* has a high direct use value, but as a single, common species it has modest existence and intrinsic value.

Recognition of these differences would help to choose between funding a taxonomic and ecological study on the leeches, or a fishery management initiative. The fact that the values of *Lates* accrue locally, while the value of the leeches accrues internationally, will also provide the SAP with guidance of where funding support can be expected.

The key points to reinforce are:

- Species richness alone is not a reliable guide to biodiversity value. Areas of low richness (e.g. the pelagic zone of Lake Tanganyika) can have very high use values.
- Costs and benefits of biodiversity conservation accrue differently to different groups of people (e.g. local resource users, international scientists). An understanding of the distribution of costs and values will help define and direct conservation action, and identify stakeholders' potential roles in conservation activity to safeguard their own interests.

Table 6.1 provides an overview of the economic values of biodiversity, and illustrates these concepts with reference to Lake Tanganyika's biodiversity. Consideration of economic values of biodiversity, hypothesised relationships between biodiversity and ecosystem function, and the objectives of the CBD, leads to BIOSS suggesting the following guiding rationale for biodiversity conservation in Lake Tanganyika:

1. The purpose of biodiversity conservation in Lake Tanganyika is to maintain the lake's unique, diverse, ecosystems, and their constituent taxonomic and genetic diversity. This will be achieved through efforts to maintain habitat quality and ecosystem integrity, and through regulation of the exploitation of the fish species.
2. Biodiversity conservation in Lake Tanganyika should aim to emphasise the conservation of ecosystem function. The most important ecosystem function, regionally, is the production of fish. Internationally, the function of major interest is the set of conditions that have allowed rapid evolutionary radiation in several taxonomic lineages, making the lake an important scientific resource, and of exceptional species richness.
3. Biodiversity conservation in Lake Tanganyika should also aim to promote the sustainable use of biodiversity, principally through fisheries management, but also through tourism and other non-consumptive uses.
4. Any economic benefits derived from biodiversity conservation in Lake Tanganyika need to be shared equitably within the lake region.

We deliberately avoid the aim of conserving 'each and every species'. This is both very difficult to achieve, and would be almost impossible to monitor or assess. In the long term, it is also a less meaningful goal than conserving the conditions under which the remarkable evolutionary radiations, that make the lake a biodiversity 'hotspot' of international importance, took place.

Table 6.1 Biodiversity values and stakeholders: some examples from Lake Tanganyika

Values	Biodiversity Resource	Uses and Users
Direct Use		
Consumptive	Food fish	fishers, processors, market traders, transport companies, rural and urban consumers throughout region.
	Sport fish	Recreational fishers, tourism development
	Ornamental fish	Aquarium fish exporters, local employees, riparian governments (export revenue), aquarium dealers, aquarists in Europe, North America.
	Fish genetic diversity	Aquaculture development – global
Non-consumptive	Eco-tourism: coastal habitats, 'Charismatic species': cichlids, other fish and vertebrates, molluscs, crabs.	Ecotourists, diving tourism and associated development including employment and foreign exchange revenue.
Indirect Uses		
Ecosystem services	All species – particularly phytoplankton, 'keystone' species (e.g. shrimps, clupeids, top predators)	Environmental modulation - role in maintaining lake function, e.g. position of thermocline: trophic cascade effects Ecosystem productivity and stability, to benefit all those dependent on direct uses (above).
Knowledge	All species - especially diverse endemic lineages (cichlids, molluscs and Ostracods).	Scientific research on evolutionary processes that ultimately benefits all human society.
Aesthetic	Habitats, charismatic or flagship species	Anyone who derives satisfaction from looking at the lake's biodiversity or habitats
Non Use Values		
Existence	Charismatic species usually	Conservation-minded individuals
Intrinsic	All biodiversity	All humanity
Bequest	All biodiversity	Future generations

There are currently no studies of biodiversity values on Lake Tanganyika, or any other African Great Lake. Such work should be a priority to inform further development of coastal aquatic parks and other conservation measures and is crucial to inform on-going debates on the relevance and value of parks for conservation and development in low-income countries (Wells, 1992; McClanaham, 1999; Salafsky and Wollenberg, 2000).

Such valuation studies should include:

- Assessment of direct and indirect benefits from fishing and aquatic parks to the local economy.
- A contingent valuation (CV) survey to evaluate willingness to pay for preserving current levels of resource use.

- Stakeholder focus groups to examine the opinions of different social groups on fishing and the aquatic parks.

Both direct and indirect use values need to be analysed. The biodiversity of Lake Tanganyika provides direct use value from goods such as fish, which are consumed or removed from the lake by the aquarium trade. Through tourism and scientific research activities, biodiversity also supports non-extractive industries. These direct uses have an economic value, which is to some extent revealed through household consumption, market expenditures and sales. Lake Tanganyika's aquatic resources and biodiversity support a range of ecological services. Although these services have no market price, their economic benefits can be quantified through looking at the costs of losing them.

6.3.4 Identifying conservation-development linkages

If biodiversity conservation and development are to be reconciled, and if, as it is proposed in previous conservation-related proposals for Lake Tanganyika (Cohen, 1991; Coulter, 1999), people will benefit from biodiversity conservation, then it is imperative to explore carefully the links between biodiversity and the benefits derived from biodiversity. There has been a tendency to assume such linkages rather than to critically analyse them.

The techniques of livelihoods analysis, which build on experience gained in the application of participatory rural appraisal techniques and formal questionnaire surveys, are only recently being implemented (Scoones 1998; Ellis 2000). The first studies of the formal application of rural livelihoods analysis to the management of small-scale fisheries are only now beginning to emerge (Sarch and Allison 2000; Allison and Ellis, *in press*). We know of no applications of such analysis to the utilisation and conservation of aquatic biodiversity. Livelihoods analysis can identify the role of local stakeholders much more precisely than has hitherto been possible (Meadows and Zwick, 2000). Livelihoods analysis and stakeholder identification can be linked to valuation of biodiversity in order to make rational decisions on the promotion of integrated conservation and development strategies. A recent analysis of linkages between biodiversity conservation and livelihoods (Salafsky and Wollenberg, 2000) provides a possible methodological framework for assessing the feasibility of an integrated conservation and development approach on Lake Tanganyika.

Linkages between livelihoods and biodiversity can be direct and indirect, as illustrated in Table 6.1. The key assumption in the case of the proposed indirect linkage between biodiversity conservation and the maintenance of ecosystem services is that biodiversity is integral to the optimal maintenance of such services. This assumption is founded in the literature relating enhanced ecosystem functions (e.g. productivity, resilience, stability, nutrient cycling efficiency etc) to maintenance of high diversity (reviewed by McCann, 2000). The hypothesised links between diversity and ecosystem function are illustrated in Figure 6.1.

Much of this evidence comes from model ecosystems and controlled experiments, most of which have been criticised for problems with experimental design. The most recent review on the subject opines that the hypotheses presented in Figure 6.1 which are held to apply in any discussion of the link between biodiversity conservation and the maintenance of critical ecosystem services, persist despite "enthusiasm outweigh[ing] supporting scientific evidence" (Schwartz et al 2000). One critical weakness in any discussion of the link between livelihoods and biodiversity is therefore that the link between biodiversity and the maintenance of ecosystem services is unsubstantiated. This point does not seem to have been addressed in the literature advocating integrated conservation and development.

Although indirect values such as ecosystem services are often invoked as a reason why people should conserve biodiversity, it is even more common to propose that people can derive more direct benefits from conserving biodiversity than from allowing its over-use. The notion that human welfare is maintained and enhanced by biodiversity conservation is the fundamental premise for the recent interest in extractive reserves and promotion allowing people access to biological resources as a means of protecting them. It is a premise that rests on the extent to which people depend on the biodiversity for their livelihoods. The general models for conservation and development outlined by Salafsky and Wollenberg

(2000) provide a useful starting point for analysis of potential for integrated conservation and development.

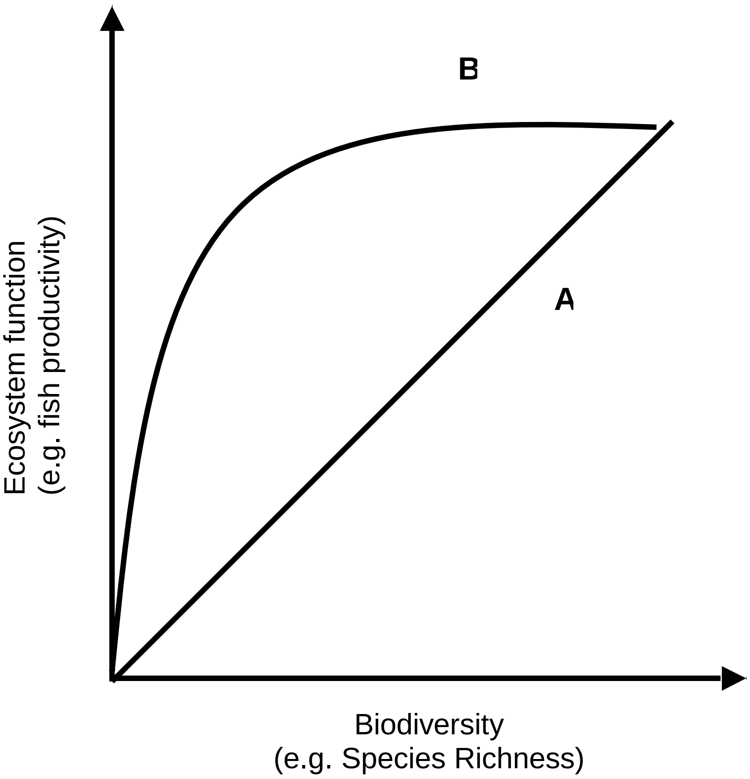


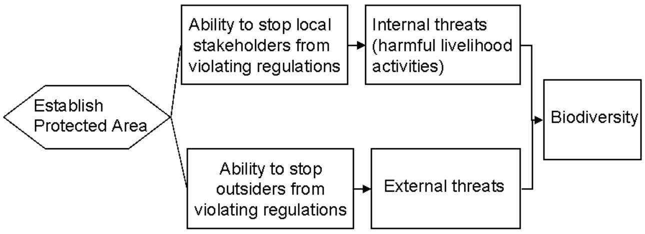
Figure 6.1 Conceptual models of biodiversity-ecosystem function linkages proposed in the literature (after Schwartz et al, 2000)

From the figure, Model A represents thinking where every species has a role in supporting ecosystem function and the loss of a single species affects ecosystem function. Model B accepts that some species play little or no part in regulating ecosystem function (the redundancy model) and some species can be lost without loss of ecosystem function.

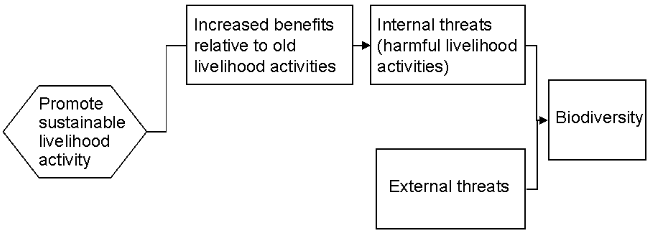
In the following analysis, we take what is known about biodiversity-livelihoods linkages in the Lake Tanganyika basin, and analyse the potential for direct linkage, indirect linkage and non-linked conservation and development approaches. We recognise that this analysis is limited by the type of data available at present. We have already highlighted the lack of data on the economic value of biodiversity, and have alluded to the limited amount of information on what elements of biodiversity people actually use (no livelihoods analysis surveys). Nevertheless, the information from Socio-economics, Sedimentation, Biodiversity and Fishing Practices special studies allow the main linkages to be identified conceptually, which should allow us to offer some advice on the most realistic way forward for biodiversity conservation in Lake Tanganyika.

Figure 6.2 illustrates three models representing general approaches to conservation projects and programmes. All three models aim to use some form of project interventions (the hexagon on the left of the model to maintain the state of biodiversity (the box on the right).

1. No Linkage: State-run protected area strategy



2. Indirect linkage: Economic substitution strategy



3. Direct Linkage: Linked Incentives Strategy

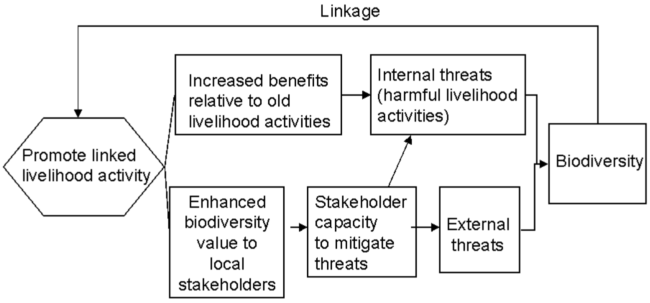


Figure 6.2 Models of three conservation strategies. Hexagons indicate possible intervention strategies, while rectangles indicate conditions at the site of the intervention (from Salafsky and Wollenberg, 2000)

Biodiversity can be thought of as having three main attributes: the species (or other taxonomic unit) present, the area of habitat present and the degree to which the habitat is able to maintain its ecological functions. This target condition is affected by one or more human-caused direct threats, subdivided into internal threats that are caused by the stakeholders living at the project site, and external threats caused by outsiders. Examples of direct threats in Lake Tanganyika include over harvesting of fish or water pollution by factories in Bujumbura. Behind these direct threats are causal factors that are less often visible, but may be significant drivers of the threats. These many include local livelihood needs, government development policies or local road and transportation development (Salafsky and Wollenberg, 2000). In the case of Lake Tanganyika, the security situation around the Northern and Western lake probably means that people are unwilling to make long-term investments in land and the maintenance of soil fertility, as tenure is uncertain. This is likely to result in few measures being taken to conserve soils, and therefore in increased sedimentation and land degradation.

Conservation projects[16] can use a mixture of different strategies or interventions to combat threats at a given site. The three conservation paradigms illustrated in Figure 6.2 correspond to three such strategies: direct protection, economic substitution and linked incentives.

Model 1: Direct protection is the current model for conservation in Lake Tanganyika. People are excluded from areas set aside for biodiversity conservation, and they benefit little from conservation activities (Meadows and Zwick, 2000). The 'fines and fences' approach used by national parks, and indeed the notion that people must be kept apart from nature in order to conserve it has been much attacked in recent decades (see Chapter 5 for discussion). While such approaches may be effective in meeting conservation objectives, given adequate resources for enforcement (Margules and Pressey, 2000), they do not address the needs of people living around, or displaced by such conservation enclaves. In the protected area model, livelihood activities appear as an internal threat to conservation, and the response to that threat is to implement a protected area. Much of the thinking behind the LTBP project's early conceptualisation was driven by this model, and it remains the best established approach to conservation in the region, despite its current failure in Rusizi and the pressures on parks elsewhere. Given the levels of poverty and livelihood insecurity experienced by many in the lake catchment, there is also a moral imperative to prioritise development and seek compatibility between development and conservation. The protected area strategy remains an anachronism given this imperative and serious analysis of alternatives is urgently required.

Model 2: In the economic substitution model, the project's strategy is to attempt to implement livelihood activities such as the development of rural industries that provide an alternative to livelihood options seen to threaten biodiversity, such as farming on steep lakeshore hillsides, or fishing with beach seines. This approach is being attempted by a DANIDA funded Coastal Zone Environmental Management programme in Malawi. Identifying and promoting such alternative livelihood activities is incorporated as a main objective of the socio-economics component of LTBP (Meadows and Zwick, 2000) but alternatives have proven difficult to identify. These authors were, however, able to suggest a range of development interventions to assist in modifying existing livelihood activities to add value to harvested natural resources and reduce environmentally damaging activities (Box 2 in Meadows and Zwick, 2000). Economic substitution models have suffered from unclear linkages between conservation and economic incentives, and from the 'honey pot' effect, where development activities near parks attract people into the area, thereby placing greater strain on the natural resource base (Salafsky and Wollenberg, 2000). Providing income-generating alternatives to local people that are not linked to incentives for biodiversity conservation also fails to mitigate against external threats. Anyone not benefiting from alternative livelihood activities provides a potential threat to the environment. In the Lake Tanganyika basin, this could include the many people displaced by civil conflict.

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[16] A project is here broadly defined as "any actions undertaken by any group of people interested in achieving certain defined goals and objectives" (Aalafsky and Wollenberg, 2000).

Model 3: The linked incentives model attempts to ‘close the loop’ by linking biodiversity and the livelihood intervention. The linkage is the driving force behind a sequence of activities leading to conservation. Livelihood activities that counter internal threats should enhance the value of the biodiversity to the local people, thus prompting them to take actions to mitigate both the internal and external threats to the biodiversity. In other words they both benefit financially or in terms of livelihood security and are empowered by the conservation project. In Lake Tanganyika, the development of eco-tourism, sport fishing and the aquarium trade are often cited as examples of ways in which biodiversity conservation can be linked to enhanced livelihood opportunities. We believe such thinking to be unrealistic (see Chapter 5 for discussion and analysis) but also point out that no analysis of costs and benefits of conservation has ever been undertaken (see previous section).

We have already pointed out that linkages between biodiversity and indirect benefits to local livelihoods in the form of ecosystem services are unsupported by evidence (see Figure 6.1 and associated text). We would also contend that there are limited linkages between the most biodiverse areas and livelihood activities in Lake Tanganyika. Lindley (2000) has pointed out that the links between threats to inshore fish diversity and fishing are indirect. Most fishing activity targets the species-poor pelagic ecosystem, and a theoretical threat exists whereby collapse of the offshore pelagic fishery through over fishing could lead to increased exploitation of inshore areas by people desperate to obtain nutrition and income. At present, much of the inshore fish fauna is relatively lightly fished by a wide variety of small-scale gears. Thus, the degree of dependence of livelihoods on diversity is low, and the biodiversity-livelihood linkage is weak. Weak biodiversity-livelihood linkages are not a good prerequisite for integrated conservation and development programmes that seek to sustain both livelihoods and diversity by enhancing the value of such linkages (Salafsky and Wollenberg, 2000). Neither is there a link between livelihood sustainability of people involved in farming and the lake’s biodiversity. Loss of littoral zone diversity through increased sedimentation will have little impact on livelihoods of farmers in the catchment. Thus, there are no ways to link incentives to biodiversity conservation with improved livelihoods. This suggests that integrated conservation and development programmes (Model 3) are not feasible

Our main conclusions are thus:

- Linkages between biodiversity and livelihoods in Lake Tanganyika are weak and indirect at best.
- Linkages between biodiversity and ecosystem function (and therefore provision of ecosystem services) are unproven but also likely to be weak
- Financial benefits from alternative livelihoods associated with conservation activities are likely to be very limited

And therefore:

- Integrated conservation and development programmes that are self-sustaining are not currently feasible in the Lake Tanganyika basin. Funding for conservation activities will have to come from external sources if conservation is not to impose costs on those living around the lake.

External funding could come from either governments or international agencies. Analysis of lessons learnt from biodiversity conservation projects in Africa (Hart et al, 1998) suggests that the commitment of many African national governments to biodiversity conservation programmes is weak. Such programmes are seen as the external imposition of an international environmental agenda and governments can even be hostile to programmes promoted and managed by external agents that are perceived to favour “animals and trees over people”. Hart et al (1998) conclude that biodiversity conservation programmes are unlikely to be sustainable unless they are integrated into country development strategies, or financed indefinitely by the international community.

We leave it to others to assess whether ownership of the SAP, legal convention and Lake Basin Management Authority is sufficient (and carries sufficient political weight) to compete for resources within country development strategies, or whether continued international finance will be required to support the international interest in Lake Tanganyika's biodiversity. The main conclusion of the Socio-economic special study is that:

> "the biodiversity of the lake will only be managed sustainably and conserved through programmes of poverty alleviation, livelihood diversification, and social and economic development in lakeshore communities, within a context of security and institutional reform"
>
> (Zwick and Meadows, 2000, p40).

These authors admit, however, the difficulties of achieving this. We agree with their interpretation and would reiterate our suggestion that funding for such activities should not come from the local people who need the resources but not the diversity. It should come from those who value the biodiversity but don't need the resources i.e. - the 'global community'. This implies continued international funding of conservation programmes, and detailed attention to ways of transferring financial resources for conservation in support of the type of poverty alleviation programmes identified by Zwick and Meadows (2000). Such a conclusion is not unique, and there have recently been other voices raised to question the prevailing orthodoxy of development through conservation. Godoy et al (2000) argue that local forest dwellers in Central America should be paid for non-local values of rainforests as an incentive to resist deforestation. We argue that the lake dwellers of Central Africa require the same consideration in order to preserve the non-local values of Lake Tanganyika.

6.3.5 Inshore-offshore trophic and fishery linkages

The importance of inshore-offshore trophic links has long been considered, in the particular context of interdependency of Lake Tanganyika's fisheries (Coulter, 1991; Lindley, 2000). The interdependency has, however, never been formally studied, even qualitatively. Identifying the main inshore-offshore linkages could provide a more rigorous basis on which to base both current management decision-making, and future research in this neglected field of study in African Great Lakes.

Of particular relevance is identification of the role of inshore ecosytems as spawning and nursery grounds for commercial fish. It is well documented (see Coulter, 1991 for review) that three of the commercial perch species (namely *Lates mariae*, *L. microlepis* and *L. augustifrons*) have a juvenile inshore phase lasting up to one year[17]. The key habitats for these species are the reed beds composed of *Ceratophyllum*, *Vallisneria* and *Patamogeton* and, to a lesser degree, the roots of emergent vegetation (*Phragmites*) and even among rocks (Thompson et al, 1977). *L. microlepis* appear to use macrophyte beds as nursery areas, and may spend up to a year (25-180 mm TL) in these habitats, young *L. microleps* live inshore after leaving weed cover, recruiting to the pelagic zone on reaching maturity at around 500 mm TL (age 3-4 yrs).

Field and laboratory studies into the habitat preferences of juveniles of two *Lates* species are reported in Kondo and Abe (1985). Both species are found to settle on grass beds, with *L. angustifrons* preferring the short grasses composed of Vallisneria sp.; while *L. mariae* prefers the taller grass beds composed of *Potamogeton schweinfurthii*. Nocturnally active, both species fed mainly on shrimp, moving onto fish as they grow. Shrimps are abundant in the shallows (<6m), with 12 of the 13-recorded endemic species being found in weedy habitats (Kimbadi, 1989). These 12 species belong to the *Atyidae, while* the 13th species is from the Palaemodindae family (Kimbadi, 1993).

These biological results are important foundation for understanding the linkages between inshore and offshore habitats. While more detailed research is required, we highlight the need to locate these sites of littoral vegetation, assess the pressures on them and identify suitable management actions.

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[17] In contrast *L. stappersi* juveniles remain in the pelagic zone

The biological interactions within multi-species fisheries are formally recognised in Article II of the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR), signed in 1980. This convention has been viewed as pioneering the way towards what is now widely known an 'ecosystems approach' to natural resource management. CCAMLR's interpretation of 'ecosystem' is firmly rooted in a biological understanding of the fishery, i.e. the trophic implications of targeting different species in the Southern Ocean surrounding the Antarctic. More recent adoption of the ecosystems approach by the CBD (as its primary framework for action) and others such as The World Bank and IUCN, explicitly acknowledge the environmental, socio-economic and cultural components of 'ecosystem' and thus recognise the broader context of managing natural resources, particulary those with significant biodiversity. A significant initative in ocean research and management is the idea of a 'large marine ecosystem' - of which 50 have been identified in the world (see www.edc.uri.edu/lme/default.htm). The GEF (under its international waters and biodiversity programmes) are supporting The Gulf of Guinea Large Marine Ecosystem Project[18].

Independantly, but in line with this trend in managing biodiverse resources, approaches to fisheries management are moving from traditional top-down sectoral control of catch and effort towards a more livelihood-based form of management that is integrated, adaptive, environmentally and locally appropriate. Many of the principles of the ecosystems approach, as defined in CBD documentation (see www.biodiv.org, particularly the working papers of SBSTTA[19]) replicate or are complementary to concepts governing coastal zone management (Clarke, 1992). Indeed CZM could be seen to provide a more rigorous implementation framework to some of the more theoretical concepts defined under the ecosystem approach. See the BIOSS recommended management response (Section 6.4.2) to management of the biodiverse littoral zone and the importance of sustaining the pelagic fishery.

6.4 Management

In our consideration of management of biodiversity, the results from BIOSS now need to be integrated with the outcomes of the other threat-based special studies of the project. For this purpose we provide a short précis of key results from sediments, fishing practices and pollution, but refer readers to the relevant technical documents of these studies.

6.4.1 Threats

Coastal development, particularly the loss of terrestrial vegetation leading to increased siltation, presents a great threat to littoral biodiversity. At present, over much of the lakeshore, this effect is relatively localised around fishing villages and major towns. It is more widespread in the more densely populated areas around the north basin and along the Tanzanian coast. Only major catchment deforestation in erosion prone catchments could provide a wider threat to diversity. The sediments special study addressed the extent to which catchment-wide deforestation presents an immediate threat to biodiversity. Increased sedimentation and other human impacts along the coast of the lake may have altered community structure and reduced biodiversity in adjacent sub-littoral areas. It is not known if any species extinctions have taken place as a result of these activities. It is more likely that local variants may have been lost, and that the distribution of some species has been reduced or fragmented (Patterson, 2000).

Fishing activities provide a potential threat to biodiversity conservation. There are questions regarding the sustainability of exploitation of pelagic fish, particularly the larger Centropomids (*Lates* sp.). Sustainable exploitation issues are within the scope of the Lake Tanganyika Research project (LTR) and are presented as a Fisheries Management Plan for Lake Tanganyika. It is unlikely that these species are threatened by extinction, or significant loss of intra-specific genetic diversity. In recognition of the diversity of littoral zone and to complement the intense research attention on pelagic fisheries, FPSS focused on the incredible range of fishing practices deployed in the littoral zone. Over 50 different practices were described reflecting the diversity of fish and habitat type (Lindley, 2000).

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[18] See: www.africaonline.co.ci/AfricaOnline/societes/goglme/goglme.html

[19] Subsidiary body on Scientific, Technical and Technological Advice (SBSTTA)

There is little use of habitat-destructive fishing gear in the lake (e.g. bottom trawls, explosives). Thus, fishing activities only impact directly on fish communities. It is possible, of course, that impacts on fish assemblages have knock-on effects on the rest of the ecosystem, but not enough is known about ecosystem dynamics to assess this at present.

Beach seines have already been banned from Tanzania, due to their perceived negative impacts on biodiversity and sustainability of exploitation. There is little evidence of impact, but such evidence is difficult to obtain, so the ban has been implemented under an environmentalist interpretation of the precautionary principle. Experience from the ban of beach seines from the Kenyan shores of Lake Victoria illustrates the role these gears play in a riparian community (Wilson et al, 1999). While beach seines are expensive gears and tend to be owned by prominent people, they require the co-operation of others to pull the net. This provides an important opportunity for men in families who do not have fishing gears to take part in the fishery and access high quality protein. In addition, operation of beach seines is one of the few ways that women actively fish: the value of bringing fresh fish home to their children should not be underestimated.

In Lake Tanganyika, it appears that the ban is not enforced completely, reflecting the very real logistic and practical constraints to monitoring and enforcement of such fisheries legislation in the lake. Sandy shore fish communities are also impacted by other gears, such as gillnets, which target the larger species. There are also a variety of small-scale gears in use on a subsistence basis, whose collective impact on sub-littoral fish community diversity may be significant.

Rocky-shore fish species will be relatively unexpected by fishing activity. Net fishing, except with relatively small gillnets, is not possible where the underwater topography is rocky and complex. Line-fishing and trap fishing are practiced, targeted at a few of the larger species (catfish, murmured, *Lates* sp. Boulengerochromis). All these species are widely distributed, and these activities are unlikely to impact significantly on biodiversity (although once again, ecosystem effects of reducing the abundance of larger, predatory fish is not known). Optimal sustainable use issues are another matter, best considered by fishery management agencies, such as those involved in the LTR project.

A key recommendation from FPSS was that the important role that the pelagic fishery played in the livelihoods of lakeside communities. Many small-scale fishermen target pelagic fish, but have been largely invisible to research focusing on more intensive fishing methods. However this livelihood link is of critical importance to Lake Tanganyika's biodiversity – if the pelagic fishery is not managed appropriately and fails to support these fleets of small-scale fishermen, they will retreat towards the coast putting pressure on the biodiverse littoral zone.

Organic pollution and other contamination from industrial, mining and domestic sources all have potentially serious consequences for biodiversity, again, particularly in the coastal areas. Sheltered bays with limited circulation are most immediately threatened by eutrophication and even quite small, localised sources of pollution. Kigoma harbour and adjacent Bay provide examples of impacted coastal waters. Of the areas adjacent to terrestrial protected areas, only the waters off Rusizi are potentially threatened by river-borne pollution sources. The waters off Gombe, Mahale and Nsumbu are a long way from current major pollutant sources, and are likely to be fairly pristine (Bailey Watts et al, 2000).

6.4.2 Recommended management response

Taking these insights from other special studies regarding the nature of the threats to biodiversity alongside results from BIOSS presented in the previous chapters, lead us to the conclusion that the SAP must have a regionally integrated strategy to deal with localised threats in the littoral zone. Focusing solely on transboundary issues (i.e. the initial impetus for this project) would miss critically important threats, and does not provide guidance for lakeshore development – only for threat mitigation. We feel that by adopting the principles of coastal zone management (CZM[20]), riparian countries can achieve threat mitigation within the context of sustainable development.

A CZM plan for Lake Tanganyika would zone areas according to their conservation importance, degree of threat, and requirements for human development. This system of zoning would set out the type of coastal development permitted in different areas, thus concentrating effort and resources on ensuring such development does not threaten littoral biodiversity. The planning process would aim to minimise conflicts between identified coastal zone uses, and to locate developments according to an agreed plan, rather than the present unplanned approach to lakeshore development (e.g. construction of roads, harbours, settlements etc.). This would also provide a mechanism to mitigate effects of past unplanned development which have an adverse impact on water quality, biodiversity and fisheries resources.

Note that this BIOSS recommendation does not ignore the existence of transboundary threats - appropriate management of the pelagic fishery, as prioritised by FPSS, is a good example of a threat requiring international cooperation. Nor does it ignore the potential for transboundary threats to develop in the future. Rather, BIOSS sees CZM as complimentary, not contradictory, to effective management of transboundary issues. We are not alone in arguing for a CZM approach to the management of large lakes. Such an approach is explicitly recommended in the FAO Code of Conduct For Responsible Fisheries (Article 10: FAO, 1995), and a coastal zone management approach guides an on-going DANIDA project on environmental management in the Lakeshore Districts in Malawi. Legal frameworks for CZM are already in place, with recent importance of CZM in the region highlighted in the 1993 Arusha Resolution on Integrated Coastal Zone Management in Eastern Africa (Shah et al., 1997).

CZM provides a framework which should achieve a co-ordinated approach to addressing threats across the region, ultimately prevent localised threats becoming transboundary in nature, facilitate sharing lessons/experience amongst the four riparian countries and so enhance the regional cooperation necessary for transboundary issues. TANGIS, the geographical information system developed within LTBP, would be a critical information management tool to development and implementation of this strategy.

The core principle of sustainable development requires that the wider strategy of littoral-zone conservation takes into account human-development needs. By adopting a coastal zone management strategy, the regional body set up under the SAP and the Convention, can target resources where they are most needed. Thus avoiding the potentially ineffective strategy of spreading resources widely to maintain a whole-basin, whole-lake approach.

A coastal zone management approach will provide appropriate levels of protection to specific habitats. The original project document specified only two options – national parks, or unprotected areas. In practice, an integrated strategy that specified permissible coastal development on a zoned basis could be a more relevant and cost-effective strategy for biodiversity conservation and threat mitigation and prevention in Lake Tanganyika.

A key implication for the adoption of CZM is the need for appropriate institutional support. As is common in most countries in the world, riparian government responsibility is currently allocated on sectoral grounds. CZM requires that some form of co-ordinating body that draws together fisheries, agriculture, planning, community development, infrastructure, local government etc. so that future development is well planned and managed. Mitigating the effects of past poor development is another key role for such a body.

In an ideal situation, CZM would be government policy and appropriate mechanisms established to facilitate localized planning and management actions. However, co-operation can occur at many levels: for example parks, fisheries, agriculture, tourism, community development could come together and address issues over the aquatic boundary of a national park; or the various departments in a lakeside administration (village, sub-county or district)

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[20] Note that the BIOSS contribution to the SAP provides a briefing on CZM, to which readers are referred. See also Scialabba (1998)

could plan future developments jointly. Current trends in the management of common-pool resources[21], such as Lake Tanganyika are for bottom-up approaches. Any implementation of CZM in Lake Tanganyika should draw from these experiences. In fact, FPSS noted in its advice to the SAP that community initiatives along the Zambian coast offered a good basis on which to develop appropriate management plans for fisheries (Cowan and Lindley, 2000): CZM could provide stakeholders with an appropriate framework to begin this work. Experience of implementing CZM in Ireland has been found to be more sustainable if introduced at a small-scale, building on local initiatives (Power et al, 2000). This approach in Ireland also helped address some of the uncertainty about coastal processes and a lack of baseline data: circumstances familiar to stakeholders on Lake Tanganyika.

As with most resource management issues the role of central government is important but complex. National level ministries can provide the necessary framework and support for co-ordinated management at the lake. However, the great distances between the capitals and the lake are a real constraint to the degree to which central government can take a hands-on approach to managing the lake. We believe the flexibility of CZM presents riparian governments and communities with a mechanism to begin making wise management choices for their shores of Lake Tanganyika, in advance of a regionally based management plan.

6.5 Concluding summary

The highest biodiversity, in terms of number of species, is situated in the sub-littoral zone (down to 40 m). We find that a high percentage of this biodiversity is ubiquitous in its distribution, but that there are a limited number of taxa with spatially restricted distributions. 73% of described lacustrine fish (90% of species recorded in BIOSS surveys) were found in waters adjacent to existing national parks. A conservation strategy based primarily on maintaining and extending the functions of the existing terrestrial parks is therefore recommended

This report provides the first detailed analysis of biodiversity assessment surveys for large areas of the lake, based on replicated survey designs. The analysis is limited largely to fish, due to difficulties in surveying other groups. Survey protocols for molluscs have been developed and could now be used to supplement comparative surveys based on fish. Surveys of biota have been guided and stratified by surveys of habitat that have highlighted the need to consider habitats as a fundamental unit of conservation. This extensive dataset has been rigorously analysed to assist the design of future surveys.

The current threats to diversity in the littoral zone are most immediate from localized environmental degradation (deforestation in small and medium-sized catchments, effluent from coastal towns and villages), situated almost exclusively in the coastal zone. Therefore Lake Tanganyika needs a management approach that co-ordinates planning and management of all activities based on the land and the water. By explicitly recognizing the ecological, physical and social links between the two resources, and the need to balance development and conservation, CZM provides managers with a formal structure and a set of well-established management principles to follow.

LTBP had a strong technical focus, providing essential baseline information for the first management plan for the lake. The basis for scientific monitoring and underpinning of management has been established under LTBP, but the wider skills in communication, joint planning, co-operation between different ministries/disciplines and management are still required. Throughout our report, we have stressed the need to consider process issues as well as deliver technical outputs. If the international community still values this unique lake, we would recommend ongoing support that concentrates more on building the institutional capacity needed to ensure sustainable development of this biodiverse resource. We would also recommend a critical analysis of the costs and benefits of such conservation and explicit and development of management approaches that will assist in ensuring that benefits of conservation flow to those who live around the lake, while the costs are borne by all who value it.

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[21] Common-pool resources denotes resources that are neither public, nor private

7. BIBLIOGRAPHY

Agrawal, A., 1995. Dismantling the divide between indigenous and scientific knowledge. *Development and Change* 26: 413-439.

Allen, T. and A. Thomas, 2000. *Poverty and Development into the 21st Century*. Oxford University Press.

Alin, S.R., Cohen, A.S., Bills, R., Gashgaza, M.M., Michel, E., Tiercelin, J., Martens, K., Coveliers, P., Mboko, S.K., West, W., Soreghan, M., Kimbadi, S. and G. Ntakimazi. 1999. Effects of Landscape Disturbance on Animal Communities in Lake Tanganyika, East Africa. *Conservation Biology* 13 (5): 1017 – 1034.

Allison, E.H., 1998. The Convention on Biological Diversity and the Global Environment Facility – An Aide Memoire. Pollution Control And Other Measures to Conserve Biodiversity in Lake Tanganyika. UNDP/GEF (RAF/92/G32).

Allison, E.H., K. Goudswaard and A.I. Payne, 1996. Baseline review: Biodiversity. Pollution Control And Other Measures to Conserve Biodiversity in Lake Tanganyika. UNDP/GEF (RAF/92/G32).

Allison, E.H., V. Cowan and R. Paley (Eds), 2000. Standard Operating Procedures, Biodiversity Special Study. Pollution Control And Other Measures to Conserve Biodiversity in Lake Tanganyika. UNDP/GEF (RAF/92/G32).

Allison, E.H. and F. Ellis (submitted). The sustainable livelihoods approach and the management of small-scale fisheries. *Marine Policy*

Anderson, A.N. 1995. Measuring more of biodiversity: genus richness as a surrogate for species richness in Australian ant faunas. *Biological Conservation* 73: 39-43.

Armstrong, M. 1986. *A Handbook of Management Techniques*. Kogan Page Ltd, London

Attwood, C.A. and Bennett, B.A. 1994. Variation in the dispersal of galjjoen from a marine reserve. *Canadian Journal of Fisheries and Aquatic Sciences* 51: 1247-1257

Bailey-Watts, A., Foxall, C. and K. West. 2000. *Pollution Special Study (PSS): overall findings of study*. Pollution Control And Other Measures to Conserve Biodiversity in Lake Tanganyika. UNDP/GEF (RAF/92/G32).

Balmford, A., A.H.M. Jayasuriya and M.J.B. Green, 1996. Using higher-taxon richness as a surrogate for species richness: II. Local applications. *Proceedings of the Royal Society of London, Series B*: 1571-1575.

Barbier, E.B., J.C. Burgess and C. Folke, 1994. Paradise Lost? The Ecological Economics of Biodiversity. Earthscan, London.

Bengtsson, J. 1998. Which species? What kind of diversity? Which ecosystem function? Some problems in studies of relations between biodiversity and ecosystem function. *Applied Soil Ecology* 10: 191-199.

Brichard, P., 1989. *Pierre Brichard's Book of Cichlids and All The Other Fishes of Lake Tanganyika*. TFH Pul. Inc. Nepture City, USA, 544 pp.

Broad, R., 1994. The poor and the environment: friends or foes? *World Development* 22: 811-822.

Brokenshaw, D., D. Warren and O. Werner (eds) 1980. *Indigenous Knowledge Systems and Development*. University Press of America, Lanham, MD.

Boulenger, G.A. (1920). Poissons de la mission Stappers, 1911-1913, pour l'exploration hydrographique et biologique des lacs Tanganyika e Moéro. Revue Zool. afr. 8 (1): 1-57.

Chambers, R., 1994. The poor and the environment: Whose reality counts? Institute of Development Studies, Sussex. *Working Paper 3*, 17 pp.

Chao, A. and S-M. Lee (1992). Estimating the number of classes via sample coverage. *Journal of the American Statistical Association* **87:** 210-217.

Chessman, B.C., 1995. Rapid assessment of rivers using macroinvertebrates: A procedure based on habitat-specific sampling, family level identification and a biotic index. *Australian Journal of Ecology* 20: 122-129.

Clark, J.R., 1998. *Coastal Seas – The Conservation Challenge*. Blackwell Science, Oxford. 134 pp

Cohen, A. (ed), 1991. *Report on the First International Conference on the Conservation and Biodiversity of Lake Tanganyika*. Biodiversity Support Programme, USAID/WWF,NC and WRI.

Cohen, A. 1994. Extinction in ancient lakes: Biodiversity crises and conservation 40 years after J.L. Brooks. *Archiv fur Hydrobiologie. Beiheft. Ergebnisse der Limnologie* 44: 407-423.

Cohen, A.S. 2000. Linking spatial and temporal change in the diversity structure of ancient lakes: examples from the ecology and palaeoecology of the Tanganyikan ostracodes. *Advances in Ecological Research* 31: 521-537.

Cohen, A. and M. Johnston. 1987. Speciation in brooding and poorly dispersing lacustrine organisms. *Palaios* 2: 426-435.

Cohen, A.S., R. Bills, C.Z. Cocquyt and A.G. Caljon, 1993. The impact of sediment pollution on biodiversity in Lake Tanganyika. *Conservation Biology* 7: 667-677.

Cohen, A.S., L.S. Kaufman and R. Ogutu-Ohwayo, 1996. Anthropogenic impacts and conservation efforts on the African Great Lakes: a review. In: Johnson, T.C. and E.O. Odada (eds*), The Limnology, Climatology and Paleoclimatology of the East African Lakes*. Gordon and Breach, Newark, New Jersey, USA.

Cohen, A.S., M.J. Soreghan, and C.A. Scholz. 1993. Estimating the age of formation of lakes: an example from Lake Tanganyika, East Africa Rift system. *Geology* 21:511-514.

Colwell, R.K., 1997. EstimateS: Statistical Estimation of Species Richness and Shared Species from Samples. User Guide and Application, Version 5. http://viceroy.eeb.uconn.edu/estimates

Colwell, R.K. and J.A. Coddington. 1994. Estimating terrestrial biodiversity through extrapolation. *Philosophical Transactions of The Royal Society Of London Series B* 345: 101-118

Cornwall, A., I. Guijt and A. Welbourn, 1993. Acknowledging process: challenges for agricultural research and extension methodology. *IDS Discussion Paper 33*, Institute of Development Studies, Brighton, U.K.

Costanza, R. *et al.* 1997. The value of the world's ecosystem services and natural capital. *Nature* 387: 253-260.

Coulter, G.W. (ed). 1991. *Lake Tanganyika and its Life*. Natural History Museum/Oxford University Press, London.

Coulter, G.W. 1994. Lake Tanganyika. in *Speciation in Ancient Lakes*, edited by K. Martens, B. Goddeeris and G. Coulter. *Advances in Limnology* series 44: 13-18.

Coulter, G.W. 1999. Sustaining both biodiversity and fisheries in Ancient Lakes – the cases of Lakes Tanganyika, Malawi/Nyasa, and Victoria: 177-187. In Kanawabe, H., Coulter, G.W. and A.C. Roosevelt (eds.), *Ancient Lakes: Their Cultural and Biological Diversity*. Kenobi Productions, Belgium.

Coulter, G.W. and R. Mubamba, 1993. Conservation in Lake Tanganyika, with special reference to underwater parks. *Conservation Biology* 7: 678-685.

Cowan, V.J. and R.H. Lindley. 2000*. Fishing Practices Special Study advice to the Strategic Action Programme*. Pollution Control And Other Measures to Conserve Biodiversity in Lake Tanganyika. UNDP/GEF (RAF/92/G32).

Cranston, P.S. and T. Hillman, 1992. Rapid assessment of biodiversity using “biological diversity technicians”. *Australian Biologist* 5: 144-154.

Crosa, G., L. Yameogo, D. Calamari and J.M. Hougard 1998. Long term quantitative ecological assessment of insecticides treatments in four African rivers: A methodological approach. *Chemosphere* 37: 2847-2858

Darwall, W. and E.H. Allison (in press) Monitoring, assessing and managing fish stocks in Lake Malawi: Current approaches and future possibilities. *Journal of Aquatic Ecosystem Health and Management.*

DeMartini, E.E. 1993. Modelling the potential of fishery reserves for managing Pacific coral reef fishes. *Fishery Bulletin 91*(3): 414-423

DeVos, L., L. Segers, L. Taverne and T. van den Audenaerde, 1994. Composition et distributions de l’ichthyofaune dans les affluents du Nord du Lac Tanganyika. Rapport sur les 2é Journeés Scientifiques du Centre Régionnal de Recherche en Hyrobiologie Appliquée, 30-31 mars 1994, Bujumbura, Burundi.

Ellis, F., 2000. Livelihoods and Diversity in Developing Countries. *Oxford University Press*.

FAO, 1995. The Code of Conduct for Responsible Fisheries, FAO, Rome (available from http://www.fao.org)

Fausch, K.D., J. Lyons, J.R. Karr and P.L. Angermeier, 1990. Fish communities as indicators of environmental degradation. *American Fisheries Society Symposium* 8: 123-144.

Few, R. 2000. Participation or containment? Community Involvement in Protected Area Planning. (Paper from the conference on Environmental Resources: Conflict, Co-operation and Governance).

Folke, C., Holling, C.S. and C. Perrings. 1996. Biological diversity, ecosystems, and the human scale. *Ecological Applications 6* (4): 1018-1024.

Fore, L.S., J.R. Karr and R.W. Wisseman, 1996. Assessing invertebrate responses to human activities: Evaluating alternative approaches. *Journal of the North American Benthological Society* 15: 212-231.

Fryer, G., 1999. Local knowledge of the fishes of the Ancient Lakes of Africa, and an example of comprehensive understanding. In: H. Kawanabe, G.W. Coulter and A.C. Roosevelt (eds*) Ancient Lakes: Their Biological and Cultural Diversity*. Kenobi Productions, Japan, pp 263-270.

Gaston, K.J. and P.H. Williams, 1993. Mapping the world's species – the higher taxon approach. *Biodiversity Letters* 1: 2-8.

Glowka, L. *et al,* 1994. *A Guide to the Convention on Biological Diversity*. IUCN, Gland, Switzerland.

Godoy, R., Wilkie, D., H. Overman, A. Cubas, G. Cubas, J. Demner, K. McSweeny and N. Brokaw, 2000. Valuation of consumption and sale of forest goods from a Central American rain forest. *Nature* 406: 62-63.

Greig-Smith, P., 1961. Data on pattern within plant communities. I. The analysis of pattern. *Journal of Ecology* 49: 695-702.

Groombridge, B. and M.D. Jenkins, 1996. *Assessing Biodiversity Status and Sustainability*. WCMC Biodiversity Series No. 5, World Conservation Press, Cambridge, U.K.

Hanek, G., E. J. Coenen and P. Kotilainen. 1993. Aerial Frame Survey of Lake Tanganyika Fisheries. FAO)/FINNIDA Research for the Management of the Fisheries on Lake Tanganyika. GCP/RAF/271/FIN-TD/09 (En): 34 p.

Harper, J.L. and D.L. Hawksworth (Eds), 1994. Biodiversity: Measurement and Estimation. *Philosophical Transactions of the Royal Society B* 345 (1311).

Hart, T., C. Imboden, D. Ritchie and F. Swartzendruber, 1998. Biodiversity conservation projects in Africa: Lessons learnt from the first generation. *Environment Department Dissemination Notes No. 62*, World Bank, Washington D.C.

Hellier, A., A.C. Newton, S. Ochoa Gaona, 1999. Use of indigenous knowledge for rapidly assessing trends in biodiversity: a case study from Chiapas, Mexico. *Biodiversity and Conservation* 8: 868-889.

Hilsenhoff, W.L., 1988. Rapid field assessment of organic pollution with a family-level biotic index. *Journal of the North American Benthological Society* 7: 65-68.

Hodgeson, N., 1997. The Lake Tanganyika Programme and Evolving GEF Operational Strategies. UNDP/GEF (RAF/92/G32).

Horrill, J.C., Darwall, W.R.T. and M. Ngoile. 1996. Development of a Marine Protected Area: Mafia Island, Tanzania. *Ambio* 25: 50-57.

Howard, P.C., Viskanic, P., Davenport, T.R.B., Kigenyi, F.W., Baltzer, M., Dickinson, C.J., Lwanga, J.S., Matthews, R.A. and A. Balmford. 1998. Complementarity and the use of indicator groups reserve selection in Uganda. *Nature 394*: 472-475.

Hughes, R.M. and T. Oberfdorff, 1998. Applications of IBI concepts and methods to waters outside the United States. In: Simon, T.P (Ed*). Assessing the sustainability and biological integrity of water resources using fish communities.* CRC Press, Boca Raton, FLA.

Idechong, N.T. and T. Graham. 1998. The Ngerukewid Islands of Palau: 40 years of managing a marine protected area. *Parks (IUCN journal for protected area managers) 8(2)*: 17-22.

Irvine, K. and I. Donohue. 1999. Review of taxonomic knowledge of the benthic invertebrates of Lake Tanganyika. Report to LTBP, Sedimentation Special Study. Pollution Control And Other Measures to Conserve Biodiversity in Lake Tanganyika. UNDP/GEF (RAF/92/G32), 38p.

Irvine, K., I. Donahue, E. Verheyen, R. Sinyinza, and M. Taylor, 2000. Impact of sedimentation on biota. Report to LTBP, Sedimentation Special Study. Pollution Control And

Other Measures to Conserve Biodiversity in Lake Tanganyika. UNDP/GEF (RAF/92/G32),80p.

Jentoft, S. and B. McCay, 1995. User participation in fisheries management: Lessons drawn from international experience. *Marine Policy* 19: 227-246.

Jermy, Long, Sands, Stork and Winser (eds) 1995. *Biodiversity Assessment: A Guide to Good Practice.* Department of the Environment/HMSO, London.

JICA, 1980. Mahale: Study for the proposed Mahale Mountains National Park. Japanese International Co-operation Agency/Tanzania National Parks Authority.

Kaiser, J., 1997. Unique, All-taxa survey in Costa Rica “Self-Destructs”. *Science* 276: 893.

Karr, J.R., 1981. Assessment of biotic integrity using fish communities. *Fisheries* 6: 21-27.

Kaufman, L., 1992. Catastrophic change in species-rich freshwater ecosystems: The lessons of Lake Victoria. *BioScience* 42: 856-858.

Kerans, B.L. and J.R. Karr 1994. A benthic index of Biotic Integrity (B-IBI) for rivers of the Tennessee Valley. *Ecological Applications* 4: 768-785.

Kershaw, K.A., 1957. The use of cover and frequency in the detection of pattern in plant communities. *Ecology* 38: 291-299.

Kimbadi, S 1989. Preliminary report on relation among body size, clutch size and egg size of shrimps in the northwestern part of Lake Tanganyika. In, Ecological and Limnilogical Study on Lake Tanganyika and its adjacent regions: VI. Kawanabe, H. (ed).

Kimbadi, S. 1993. A preliminary study of shrimps at Cape Ganza, Ubwari Peninsula in the northwestern part of Lake Tanganyika, In, Ecological and Limnological Study on Lake Tanganyika and its adjacent regions: VIII. Nagoshi, M., Y. Yanagisawa and H. Kawanabe (eds). pp 35-36.

King, M and U. Faasili, 1998. A network of small, community owned village fish reserves in Samoa. *Parks (IUCN journal for protected area managers) 8(2)*: 11-16.

Kondo, T. and N. Abe (1995). Habitat Preference, Food-Habits and Growth of Juveniles of Lates-Angustifrons and Lates-Mariae (Pisces, Centropomidae) in Lake Tanganyika. *Ecological Research* 10(3): 275-280.

Lauck, T., Clark, C.W., Mangel, M. and G.R. Munro.1998. Implementing the precautionary principle in fisheries management through marine reserves. *Ecological Applications* 8 (1) Supplement: S72-S78.

Lindley, R.H. 2000. *Fishing Gears of Lake Tanganyika*. Pollution Control And Other Measures to Conserve Biodiversity in Lake Tanganyika. UNDP/GEF (RAF/92/G32).

LTBP, 1995. Project Memorandum. Pollution Control and Other Measures to Protect Biodiversity in Lake Tanganyika: UNDP/GEF (RAF/92/G32).

LTBP, 1996. Project Inception Report. Pollution Control and Other Measures to Protect Biodiversity in Lake Tanganyika: UNDP/GEF (RAF/92/G32).

LTBP, 1997. Annual Project Performance Evaluation Report. Pollution Control and Other Measures to Protect Biodiversity in Lake Tanganyika: Annual Project Performance Evaluation Report. UNDP/GEF (RAF/92/G32)

LTBP, 1998. Transboundary Diagnostic Analysis: Documentation and Report. Pollution Control and Other Measures to Protect Biodiversity in Lake Tanganyika. UNDP/GEF (RAF/92/G32).

LTBP, 2000. Transboundary Diagnostic Analysis: Documentation and Report. Pollution Control and Other Measures to Protect Biodiversity in Lake Tanganyika UNDP/GEF (RAF/92/G32).

MacArthur, R.H., 1972. *Geographical Ecology*. Harper and Row, New York.

Magurran, A.E., 1988. *Ecological Diversity and its Measurement*. Princeton University Press, Princeton, USA.

Mangel, M. 2000. On the fraction of habitat allocated to marine reserves. *Ecological Letters?? 3* (1): 15-22.

Margoluis, R. and N. Salafsky, 1998. *Measures of success: designing, managing and monitoring conservation and development projects.* Island Press, Washington, D.C.

Margules, C.R. and R.L. Pressey. 2000. Systematic conservation planning. *Nature* 405: 243-253.

Martens, K. 1997. Speciation in ancient lakes. TREE 12:178-182.

Martin, G., 1995. *Ethnobotany: A Methods Manual*. WWF International, UNESCO and Royal Botanic Gardens, Kew/ Chapman and Hall, London.

McCann, K.S., 2000. The diversity-stability debate. *Nature* 405: 228-233.

McNeely J.A. (ed) 1995. *Expanding partnerships in Conservation* Island Press, Washington DC., pp270-279.

McClanaham, T.R., 1999. Is there a future for coral reef parks in poor tropical countries? *Coral Reefs*, 18:321-325.

Meadows, K. and K. Zwick, 2000. Socio-economic Special Study – Final Report. Pollution Control and Other Measures to Conserve Biodiversity in Lake Tanganyika (RAF/92/G32). GEF/NRI, 55 p.

Minns, C.K. and D.A. Hurley, 1988. Effects of net length and set time on fish catches in gill nets*. North American Journal of Fisheries Management* 8: 216-223.

Mishler, B.D. and M.J. Donaghue, 1982. Species concepts: A case for pluralism. *Systematic Zoology* 31: 491-503.

Molsa, H., E. Reynolds, E. Coenen and O.V. Lindqvist, 1999. Fisheries research towards resource management on Lake Tanganyika. *Hydrobiologia* 407: 1-24.

Moran, P.J., D.B. Johnson, B.A. Miller-Smith, C.N. Mundy, D.K. Bass, J. Davidson, I.R. Miller and A.A. Thompson, 1989. A guide to the AIMS manta tow technique. The Crown-of-thorns Study. Australian Institute of Marine Science, Townsville. 20 pp.

Moreno, C.E. and G. Halffter. 2000. Assessing the completeness of bat biodiversity inventories using species accumulation curves. Journal of Applied Ecology 37: 149-158.

Mosse, D., J. Farrington and A. Rew, (editors) 1998*. Development as Process: Concepts and methods for working with complexity*. ODI Development Policy Studies 2/Routledge, London.

Mouillot, D. and A. Lepretre, 1999. A comparison of species diversity estimators*. Research in Population Ecology* 41: 203-215.

Mununga, K.M., 1997. Park Biography – Nsumbu National Park. Unpublished letter to LTBP, Wildlife Ranger In Charge, National Parks and Wildlife Service, Nsumbu National Park, Box 410005, Nsumbu/Kasama, Zambia.

Murray, J., 1992. A Survey Report Detailing Conservation and Development Issues around Gombe National Park, Tanzania. Unpublished MS.

Myers, N. 1989. Threatened biotas: 'Hotspots' in tropical forests. *Environmentalist* 8: 1-20

Nkotagu, H. and K. Mwambo. 2000. *The Hydrology of selected watersheds along the Lake Tanganyika shoreline*. Pollution Control And Other Measures to Conserve Biodiversity in Lake Tanganyika. UNDP/GEF (RAF/92/G32).

Noss, R.F., 1990. Indicators for monitoring biodiversity: a hierarchical approach. *Conservation Biology* 4: 355-364.

Ntakimazi, G., 1995. Le rôle des Ecotones terre/eau dans la diversité biologique et les ressources du lac Tanganyika. Projet UNESCO/MAB/DANNIDA 510/BDI/40, 1991-1994. Rapport final, 84 p.

Ntakimazi, G., B. Nzigidahera, F. Nicayenzi, et K. West. 2000. L'Etat de la diversité biologique dans les millieux aquatiques et terrestres du delta de la Rusizi. BIOSS report, LTBP. 68p.

Oliver, I. and A.J. Beattie, 1993. A possible method for the rapid assessment of biodiversity. *Conservation Biology* 7: 562-568.

Oliver, I. and A.J. Beattie, 1996a. Invertebrate morphospecies as surrogates for species: a case study. *Conservation Biology* 10: 99-109.

Oliver, I. and A.J. Beattie, 1996b. Designing a cost-effective invertebrate survey: a test of methods for rapid assessment of biodiversity. *Ecological Applications* 6: 594-607.

Ostrom, E., 1990. *Governing the commons – the evolution of institutions for collective action*. Cambridge University Press.

Patterson, G. 2000. *Special study on sediment discharge and its consequences (SedSS): summary of findings.* Pollution Control And Other Measures to Conserve Biodiversity in Lake Tanganyika. UNDP/GEF (RAF/92/G32).

Patterson, G. and J. Makin, (Eds) 1998. *The State of the Biodiversity in Lake Tanganyika: A Literature Review*. Pollution Control And Other Measures to Conserve Biodiversity in Lake Tanganyika. UNDP/GEF (RAF/92/G32).

Pearson, M.P. and A.I. Shehata. 1998. Protectorates management for conservation and development in the Arab Republic of Egypt. *Parks (IUCN journal for protected area managers) 8* (2): 29-35.

Perrow, M.R., I.M. Cote and M.Evans, 1996. Fish. In: Sutherland, W.J. (ed), *Ecological Census Techniques – A Handbook*. Cambridge University Press.

Pickett, S.T.A., R.S. Ostfeld, M. Shachak and G.E. Likens, 1997. *The Ecological Basis of Conservation: Heterogeneity, Ecosystems, and Biodiversity.* Chapman and Hall, New York.

Pinkerton, E. and M. Weinstein, 1995. *Fisheries that work: sustainability through community-based management.* The David Suzuki Foundation, Vancouver, Canada.

Poll, M. (1956). *Resultats, Scientifique Explorations Hyrobiologique de Lac Tanganyika* (1946-1947), Poissons Cichlidae. **3** (5b), 1-619 pp. ‘Buxelles: Institut Royal des Sciences Naturelles de Belgique.

Power, J., J. McKenna, M. J. MacLeod, A. J. G. Cooper and G. Convie. 2000. Developing integrated participatory management strategies for Atlantic dune systems in county Donegal, Northwest Ireland. *Ambio 29*(3): 143-149.

Prance, G.T. 1994. A comparison of the efficacy of higher taxa and species numbers in the assessment of biodiversity in the tropics. *Philosophical Transactions of the Royal Society, London B* 345: 89-99.

Prendergast, J.R., Quinn, R.M., Lawton, J.H., Eversham, B.C. and D.W. Gibbons. 1993. Rare species, the coincidence of diversity hotspots and conservation strategies, *Nature* 365: 335-337.

Purvis, A. and A. Hector, 2000. Getting the measure of biodiversity. *Nature* 405: 212-219.

Reid, W.V., McNeely, J.A., Tunstall, D.B., Bryant, D.A. and M. Winograd. 1993. *Biodiversity indicators for policy-makers*. World Resources Institute, Washington, D.C.

Reid, W. V., 1998, Biodiversity Hotspots, *Trends in Ecology and Evolution* 13(7*)*: 275-280.

Resh, V.H., 1994. Variability, accuracy and taxonomic costs of rapid assessment approaches in benthic macroinvertebrate biomonitoring. *Bolletino di Zoologia* 61: 375-383.

Reynolds, J. E. 1999. Lake Tanganyika Framework Fisheries Management Plan. FAO/Norway Programme of Assistance to Developing Countries for the Implementation of the Code of Conduct for Responsible Fisheries (GCP/int/648/NOR). FAO, Rome.

Roberts, C.M. 1995. Rapid build-up of fish biomass in a Caribbean marine reserve. *Conservation Biology 91(4)*: 815-826.

Roberts, C.M. and N.V.C. Polunin. 1991. Are marine reserves effective in management of reef fisheries? *Reviews in Fish Biology and Fisheries 1*: 65-91.

Rogers, C.S. *et al.,* 1994. *Coral Reef Monitoring Manual for the Caribbean and Western Atlantic*. National Parks Service, Virgin Islands National Park.

Roland, R. and M. Trudel, 1998. A Training Strategy for the Lake Tanganyika Biodiversity Project. Pollution Control and Other Measures to Conserve Biodiversity in Lake Tanganyika. UNDP/GEF RAF/92/G32.

Roux, D.J., H.R. Van Vleit and M. Van Veelen, 1993. Towards integrated water-quality monitoring – Assessment of ecosystem health. *Water SA* 19: 275-280.

Salafsky, N. and R. Margoluis, 1999. Threat Reduction Assessment: A practical and cost-effective approach to evaluating conservation and development projects. *Conservation Biology* 13: 830-841.

Salafsky, N. and E. Wollenberg, 2000. Linking livelihoods and conservation: A conceptual framework and scale for assessing the integration of human needs and biodiversity. *World Development* 28: 1421-1438.

Sanyanga, R.A., Machena, C. and N. Kautsky. 1995. Abundance and distribution of inshore fish in fished and protected areas in Lake Kariba, Zimbabwe. *Hydrobiologia* 306: 67-78.

Sarch, M-T. and E.H. Allison (2000) Fluctuating fisheries in Africa's inland waters: Well-adapted livelihoods, maladapted management. *Proceedings of the 10th Conference of the*

International Institute of Fisheries Economics and Trade, Oregon, USA, July 2000 (also submitted to 'World *Development*').

Scoones, I., 1998. Sustainable rural livelihoods: a framework for analysis. IDS *Working Papers No. 72*. Institute of Development Studies, Sussex.

Schwartz, M.W., C.A. Brigham, J.D. Hoeksema, K.G. Lyons, M.H. Mills and P.J. van Mantgem, 2000. Linking biodiversity to ecosystem function: implications for conservation ecology. *Oecologia* 122: 297-305.

Shah, N.J., O. Linden, C.G. Lundin and R. Johnstone, 1997. Coastal Management in Eastern Africa: Status and Future. *Ambio* 26: 227-234.

Sholtz, U., Njaya, F.J., Chimatiro, S, Hummel, M., Donda, S. and Mkoko, B.J. 1998. Status and Prospects of Participatory Fisheries Management Programs in Malawi. Pp 407 – 425 in T. Petr (editor), *Inland Fishery Enhancements.* Fisheries Technical Paper 374, FAO, Rome.

Shumway, C.A., 1999. *Forgotten Waters: Freshwater and Marine Ecosytems in Africa. Strategies for Biodiversity Conservation and Sustainable Development.* Boston University/Biodiversity Support Program, USAID, USA.

Sillitoe, P., 1998. The development of indigenous knowledge – A new applied anthropology*.* *Current Anthropology* 39: 223-252.

Smith, E.P. and G. van Belle (1984). Nonparametric estimation of species richness. *Biometrics* 40: 119-129.

Soberón, J. and J. Llortente, 1993. The use of species accumulation functions for the prediction of species richness. *Conservation Biology* 7: 480-488.

Solbrig, O., 1991. Biodiversity: Scientific Issues and Collaborative Research Proposals. *Man and the Biosphere, Digest 9*, UNESCO, Paris.

Southwood, T.R.E and P.A. Henderson, 2000. Species Richness, Diversity and Packing. Chapter 13 in '*Ecological Methods*' Third Edition. Blackwell Scientific, Oxford.

Spellerberg, I.F., 1991. *Monitoring Ecological Change*. Cambridge University Press, U.K.

Sutherland, W.J., (Ed), 1996. *Ecological Census Techniques: A Handbook*. Cambridge University Press.

Sullivan, K.M. and M. Chiappone, 1993. Hierarchical methods and sampling design for conservation monitoring of tropical marine hard bottom communities*. Aquatic Conservation: Marine and Freshwater Ecosystems* 3: 169-187.

Takamura, K. 1983. Fish fauna on Mahale Mountains Coast and a discussion of its characteristics. In, Ecological and Limnilogical Study on Lake Tanganyika and its adjacent regions: II. Kawanabe, H. (ed).

Takahashi, T. M.M. Gashagaza and K Nakaya 1995. Fishes of Lake Tanganyika in Burundi. In, Ecological and Limnological Study on Lake Tanganyika and its adjacent regions: VIII. Nagoshi, M. Y. Yanagisawa and H. Kawanabe (eds).

Tangley, L. 1990. Cataloging Costa Rica's diversity. *BioScience* 40: 633-636.

Thompson, K.W., C. Hubbs and B.W. Lyons 1977. Analysis of potential environmental factors, especially thermal, which would influence the survivorship of exotic Nile Perch if introduced into artificially heated reservoirs in Texas. Texas Parks and Wildlife Department, Technical Series,22: 1-37.

Tisdell, C.A., 1999. *Biodiversity, Conservation and Sustainable Development: Principles and Practices with Asian examples.* Edward Elgar, Cheltenham, U.K.

Toham, A.K. and G.G. Teugels, 1999. First data on an index of biotic integrity (IBI) based on fish assemblages for the assessment of the impact of deforestation in a tropical West African river system. *Hydrobiologia* 397: 29-38.

Turner, G.F., Tweddle, D. and R.D. MaKwinja, 1995. Changes in demersal cichlid communities as a result of trawling in southern Lake Malawi. In *The impact of Species Changes in African Lakes* (Eds T.J. Pitcher and P.J.B. Hart) pp 397-412. Chapman and Hall, London.

Turner, G.F, 1999. What is a fish species? *Reviews in Fish Biology and Fisheries* 9: 281-297.

UNEP, 1994. The Convention on Biological Diversity. UNEP, Nairobi.

UNEP/AIMS, 1993. Monitoring Coral Reefs for Global Change. Reference Methods for Marine Pollution Studies No 61, UNEP 1993, 72 pp.

Van Jaaresveld, A.S., Freitag, S., Chown, S.L., Muller, C., Koch, S., Hull, H., Bellamy, C., Kruger, M., Endrody-Younga, S., Mansell, M.W. and C.H. Scholtz. 1998. Biodiversity Assessment and Conservation Strategies. *Science* 279: 2106-2108.

Verheyen E and L. Ruber. 2000. Conservation of the endemic cichlid fishes of Lake Tanganyika: Implications from population-level studies based on mitochondrial DNA. Advances In Ecological Research, VOL 31: 539-551.

Walls, K., 1998. Leigh Marine Reserve, New Zealand. *Parks (IUCN journal for protected area managers) 8* (2): 5-10.

Wetzel, R.G. 1983. Limnology. 2nd edition. CBS College Publishing, New York.

Wells, M. 1992. Biodiversity conservation, affluence and poverty: Mismatched costs and benefits and efforts to remedy them. Ambio 21: 237-243.

West, K. 1997. Perspectives on the diversification of species flocks: systematics and evolutionary mechanisms of the gastropods (prosobranchia:thiaridae) of Lake Tanganyika, East Africa. Unpublished PhD dissertation. University of California, Los Angeles. 150p.

West, K., E. Michel, J.P. Kiza and J. Clabaugh. 1999. The Thiarid Gastropods of Lake Tanganyika: Diagnostic Key and Taxonomic Classification with Notes on the Fauna. Pollution Control and Other Measures to Protect Biodiversity in Lake Tanganyika (UNDP/GEF/RAF/92/G32). 74p

Western, D. and R.M.Wright (eds), 1994. *Natural Connections: Perspectives in Community Based Conservation* Island Press, Washington DC.

Wheeler, Q.D. and R. Meier (eds), 2000. *Species concepts and phylogenetic theory: A debate*. Columbia University Press, New York.

Williams, M.J. 1998. Fisheries in the Great Barrier Reef Marine Park – seeking the balance. *Parks (IUCN journal for protected area managers) 8* (2): 47 - 53.

Williams, P.H. and K.J. Gaston, 1994. Measuring more of biodiversity: can higher-taxon richness predict wholesale species richness? *Biological Conservation* 67: 211-217.

Wilson, D. C., M. Medard, et al. (1999). The implications for participatory fisheries management of intensified commercialization on Lake Victoria. *Rural Sociology 64*(4): 554-572.

Worthington, E.B. (1996) Early Research on East African Lakes: An Historical Sketch. In: Johnson, T.C. and E.O. Odada (eds*), The Limnology, Climatology and Paleoclimatology of the East African Lakes*. Gordon and Breach, Newark, New Jersey, USA.

Wright, J.F., M.T. Furse and D Moss, 1998. River classification using invertebrates: RIVPACS applications. *Aquatic Conservation-Marine and Freshwater Ecosystems* 8: 617-631.

Zar, J.H., 1996. *Biostatistical Analysis*. 4th Edition. Prentice-Hall.

Zeide, B., 1997. Assessing biodiversity. *Environmental Monitoring and Assessment* 48: 249-260.

8. APPENDICES

8.1 List of BIOSS-related reports and documentation

Allison, E., 1998. An Aide-Memoire: The Convention on Biological Diversity and the Global Environmental Facility.25p.

Allison, E., R. G. T. Paley, and V. Cowan (eds.) 2000. Standard operating procedures for BIOSS field sampling, data handling and analysis. 80p.
English and French

Allison, E., V.J. Cowan and R.G.T. Paley 2000. BIOSS advice to the Strategic Action Programme. 30p.
English and French

Bills, R. 1997. Lake Tanganyika cichlid genera key. (internal BIOSS report)
English

Cowan, V. and R. G. T. Paley. 2000. An overview of achievements and outputs of the Biodiversity Special Study. 17p. –
English and French

Darwall, W. and P. Tierney. 1998. Survey of aquatic habitats and associated biodiversity adjacent to the Gombe Stream National Park, Tanzania. 51p.
English

Darwall, W. and P. Tierney. 1998. Aquatic habitats and associated biodiversity of the Kigoma area, Tanzania. 33p.
English

Martens, K. 1997. Key to Recent Invertebrata of Lake Tanganyika. 34p. (internal BIOSS report)

Ntakimazi, G., B. Nzigidahera, F. Nicayenzi, et K. West. 2000. L'Etat de la diversité biologique dans les millieux aquatiques et terrestres du delta de la Rusizi. 68p.
French

Ntakimazi, G. 1999. Practical key to families of Lake Tanganyika fishes (modified from Levegue et. al., 1990) French

Paley, R. G. T., G. Ntakimazi, N. Muderhwa, R. Kayanda, B. Mnaya, M. Risasi, R. Sinyinza. 2000. Mahale Mountains National Park: March/April 1999 Aquatic Survey. 41p.
English

Paley, R. G. T. and R. Sinyinza. 2000. Nsumbu National Park, Tanzania: July/August 1999 Aquatic Survey.
English

West, K., D. Brown, E. Michel, J. Todd, J.-M. Kiza, and J. Clabaugh. 2000. Guide to the Gastropods of Lake Tanganyika. 120p. - [to be published externally Fall 2000]

8.2 Data supporting Chapter 2: species at each depth/substrate category combination, Mahale National Park Survey 1999

Sample numbers are given in brackets. For SVC (Table 8.1) the number of individuals of each species is given. While for RVC (Table 8.2) a measure of relative abundance is given (see Chapter 2).

Table 8.1 Species observed uniquely by Stationary Visual Census (SVC)

SVC					
5m R+MR (4)		**10 m** R+MR (6)		**15 m** R+MR (5)	
Lamprichthys tanganicanus	33	*Cyprichromis leptosoma*	11	*Lestradea perspicax*	30
Ophtalmotilapia ventralis	26	*Xenotilapia ochrogenys*	2	*Grammatothria lemairei*	20
Petrochromis fasciolatus	25	*Aethiomastacembelus ellipsifer*	1	*Neolamprologus sp walteri*	7
Neolamprologus gracilis	6	*Malapterurus electricus*	1	*Boulengerochromis microlepis*	3
Simochromis babaulti	5	*Neolamprologus furcifer*	1	*Synodontis granulosus*	1
Eretmodus cyanosticus	3				
Ctenochromis horei	2				
Aulonocranus dewindti	1				
Batybates fasciatus	1				
Petrochromis macrognatus	1				
5m S (3)		**10m** S (8)		**15m** S (12)	
Lamprichthys tanganicanus	75	*Callochromis melanostigma*	3	*Tropheus brichardii*	36
Ectodus descampsii	20	*Neolamprologus sexfasciatus*	2	*Xenotilapia spilopterus*	20
Ctenochromis horei	6	*Malapterurus electricus*	1	*Lamprologus signatus*	15
Caecomastacembelus moori	1			*Petrochromis orthognatus*	7
				Neolamprologus gracilis	3
				Neolam. pleuromaculatus	2
				Ophtalmotilapia ventralis	2
				Altolamprologus calvus	1
				Batybates fasciatus	1

Table 8.2 Species observed uniquely by Rapid Visual Census (RVC)

RVC					
5m R+MR (4)		**10 m** R+MR (6)		**15 m** R+MR (5)	
Tropheus polli	2.25	*Cyprichromis microlepidotus*	1.00	*Cyprichromis leptosoma*	1.20
Xenotilapia sima	2.00	*Malapterurus electricus*	0.83	*Neolamproogus fasciatus*	1.00
Lamprichthys tanganicanus	1.75	*Simochromis babaulti*	0.83	*Julidochromis tanscriptus*	0.80
Eretmodus cyanostictus	1.25	*Aethiomastacembelus ellipsifer*	0.50	*Ctenochromis horei*	0.40
Gammatotria lemairei	1.25	*Neolamprologus furcifer*	0.33	*Gnathochromis pfefferi*	0.40
Lamprologus moorii	1.25				
Xenotilapia ochrogenys	1.25				
Petrochromis macrognathus	1.00				
Spathodus erythrodon	1.00				
Aethiomastacembelus cunningtoni	0.75				
Julidochromis ornatus	0.75				
Ophtalmotilapia nasutus	0.75				
Acapoeta tanganicae	0.50				
Petrochromis fasciatus	0.50				
Tropheus duboisi	0.25				
5m S (3)		**10m** S (8)		**15m** S (12)	
Gnathochromis pfefferi	1.67	*Asprotilapia leptura*	0.63	Cyphotilapia frontosa	1.33
Xenotilapia sima	1.33	*Neolamprologus chrystyi*	0.63	Cyprichromis microlepidotus	0.75
Tropheus polli	1.00	*Julidochromis marlieri*	0.50	*Neolamprologus brevis*	0.67
Eretmodus cyanostictus	0.67	*Lamprologus moorii*	0.50	*Neolamprologus sexfasciatus*	0.58
Ophtalmotilapia nasutus	0.67	*Neolamprologus leleupi*	0.50	*Neolamprologus hecqui*	0.42
Petrochromis fasciatus	0.67	*Petrochromis orthognathus*	0.50	*Plecodus multidentatus*	0.42
Aulonocranus dewindti	0.33	*Ectodus descampsi*	0.38	*Synodontis multipunctatus*	0.42
Lamprichthys tanganicanus	0.33			*Lamprologus ornatipinnis*	0.33
Telmatochromis vittatus	0.33			*Petrochomis trewavasae*	0.33
				Neolamprol. caudopunctatus	0.25
				Neolamprologus moorii	0.25
				Ophtalmotilapia ventralis	0.25
				Simochromis diagramma	0.25
				Julidochromis regani	0.17
				Neolamprologus furcifer	0.17
				Xenotilapia ochrogenys	0.17
				Barbus tropidolepis	0.08

8.3 Data supporting Chapter 2: Parameters from fitted asymptotic models (Linear Dependence and Clench models) used to calculate minimum required sampling size

Table 8.3 Parameters from fitted models to calculate required sampling size - stationary visual census (SVC) for fish

				Linear Dependence Model							Clench Model						
Country	**Area**	**Substrate**	**N**	**a**	**s.e. (a)**	**b**	**s.e. (b)**	**r^2**	**S_{max}**	**n (90%)**	**a**	**s.e. (a)**	**b**	**s.e. (b)**	**r^2**	**S_{max}**	**n (90%)**
Burundi	Burundi South	Rock	3	15.642	0.799	0.596	0.0558	0.997	26	4	17.359	0.511	0.458	0.2630	0.999	38	20
	Burundi South	Sand	4	2.216	0.259	0.223	0.0815	0.984	10	10	2.303	0.293	0.143	0.0580	0.986	16	63
	Gitaza	Rock	3	26.767	2.454	0.990	0.1270	0.985	27	2	34.180	2.099	0.989	0.0900	0.997	35	9
DR Congo	Pemba etc	Rock	21	15.213	0.782	0.261	0.0159	0.958	58	9	21.812	0.615	0.316	0.0114	0.994	69	28
	Pemba etc	Sand	2	3.164		0.500		1.000	6	5	3.298		0.325		1.000	10	28
	Uvira	Rock	4	8.673	0.184	0.278	0.0154	0.999	31	8	9.028	0.223	0.180	0.0123	0.999	50	50
	Uvira	Sand	21	3.716	0.053	0.100	0.0026	0.998	37	23	4.133	0.033	0.078	0.0012	0.999	53	116
Tanzania	Gombe	Rock	13	14.374	0.538	0.267	0.0137	0.989	54	9	17.929	0.298	0.259	0.0064	0.999	69	35
	Gombe	Sand	18	7.331	0.236	0.123	0.0069	0.991	60	19	8.323	0.227	0.100	0.0050	0.996	83	90
	Kigoma	Rock	9	6.335	0.237	0.213	0.0148	0.994	30	11	7.019	0.212	0.163	0.0098	0.998	43	55
	Kigoma	Sand	3	4.393	0.311	0.278	0.0634	0.997	16	8	4.521	0.325	0.172	0.0414	0.997	26	52
	Mahale	Rock	25	15.812	0.865	0.204	0.0135	0.944	78	11	22.432	0.905	0.242	0.0127	0.987	93	37
	Mahale	Sand	19	10.587	0.286	0.176	0.0067	0.992	60	13	13.027	0.145	0.167	0.0028	0.999	78	54
	Mahale	Shell	2	5.032		1.125		1.000	4	2	6.163		1.041		1.000	6	9
Zambia	Cameron Bay	Rock	4	17.839	0.867	0.419	0.0397	0.996	43	5	19.484	0.686	0.310	0.0226	0.999	63	29
	Cameron Bay	Sand	2	5.083		0.818		1.000	6	3	5.670		0.634		1.000	9	14
	Katoto etc	Rock	10	16.064	0.610	0.331	0.0175	0.991	49	7	19.835	0.293	0.315	0.0070	0.999	63	29
	Katoto etc	Sand	5	7.651	0.187	0.130	0.0131	0.999	59	18	7.759	0.218	0.075	0.0091	0.999	103	120

Table 8.4 Parameters from fitted models to calculate required sampling size - rapid visual census (RVC) for fish

			Linear Dependence Model								Clench Model						
Country	**Area**	**Depth**	**N**	**a**	**s.e. (a)**	**b**	**s.e. (b)**	**r^2**	**S_{max}**	**n (90%)**	**a**	**s.e. (a)**	**b**	**s.e. (b)**	**r^2**	**S_{max}**	**n (90%)**
Burundi	Burundi South	0 to 3	4	10.415	0.7409	0.253	0.0508	0.994	41	9	10.703	0.9863	0.157	0.0435	0.993	68	57
	Burundi South	5 to 15	16	9.058	0.2053	0.170	0.0059	0.996	53	14	10.597	0.1310	0.146	0.0030	0.999	73	62
	Gitaza	0 to 3	2	15.697		0.553		1.000	28	4	16.509		0.369			45	24
	Gitaza	5 to 15	11	14.111	0.2323	0.340	0.0074	0.998	42	7	17.671	0.5526	0.334	0.0151	0.997	53	27
DR Congo	Pemba etc	0 to 3	7	11.605	0.5899	0.284	0.0260	0.991	41	8	12.993	0.5709	0.223	0.0187	0.996	58	40
	Pemba etc	5 to 15	18	18.913	1.2057	0.305	0.0231	0.941	62	8	27.435	1.1808	0.375	0.1206	0.988	73	24
	Uvira	0 to 3	4	7.228	0.1326	0.377	0.0145	0.999	19	6	7.739	0.1641	0.266	0.1260	0.999	29	34
	Uvira	5 to 15	44	3.066	0.0721	0.167	0.0044	0.983	18	14	4.640	0.0434	0.221	0.0025	0.999	21	41
Tanzania	Kigoma	0 to 3	3	12.874	0.8629	0.718	0.0788	0.994	18	3	14.867	0.6240	0.600	0.0440	0.999	25	15
	Kigoma	5 to 15	9	8.022	0.1805	0.219	0.0090	0.998	37	11	8.871	0.0917	0.167	0.0034	0.999	53	54
	Mahale	0 to 3	20	14.846	0.6212	0.197	0.0108	0.977	75	12	19.346	0.5460	0.205	0.0082	0.995	94	44
	Mahale	5 to 15	69	10.632	0.3749	0.108	0.0043	0.940	98	21	16.450	0.3137	0.146	0.0034	0.992	113	62
Zambia	Katoto etc	0 to 3	8	25.459	1.5720	0.655	0.0481	0.971	39	4	36.312	0.5458	0.786	0.0152	0.999	46	11
	Katoto etc	5 to 15	19	10.903	0.3338	0.206	0.0083	0.989	53	11	13.981	0.1454	0.209	0.0031	0.999	67	43

Table 8.5 Parameters from fitted models to calculate required sampling size - gillnet surveys for fish

				Linear Dependence Model							Clench Model						
Country	**Area**	**Set-time**	**N**	**a**	**s.e. (a)**	**b**	**s.e. (b)**	**r^2**	**S_{max}**	**n (90%)**	**a**	**s.e. (a)**	**b**	**s.e. (b)**	**r^2**	**S_{max}**	**n (90%)**
Burundi	Bujumbura Bay	Day	18	12.662	0.5580	0.292	0.0154	0.974	43	8	17.746	0.2535	0.342	0.0063	0.999	52	26
	Bujumbura Bay	Night	2	25.417		0.543		1.000	47	4	26.686		0.361		1	74	25
	Rusizi	Day	47	6.931	0.2260	0.124	0.0047	0.966	56	19	9.996	0.1528	0.151	0.0029	0.997	66	60
	Rusizi	Night	37	10.293	0.4185	0.150	0.0070	0.957	69	15	14.832	0.3613	0.183	0.0057	0.993	81	49
DR Congo	Pemba etc	Day	14	8.530	0.3110	0.190	0.0108	0.990	45	12	10.026	0.2672	0.165	0.0073	0.997	61	55
	Uvira	Day	24	3.666	0.0968	0.094	0.0043	0.992	39	24	4.164	0.0921	0.076	0.0031	0.997	55	118
Tanzania	Mahale	Day	4	8.500	0.2040	0.212	0.0166	0.999	40	11	8.726	0.1810	0.130	0.0092	0.999	67	69
	Mahale	Night	23	16.590	0.7076	0.169	0.0095	0.973	98	14	21.605	0.6760	0.175	0.0078	0.993	123	51
Zambia	Cameron Bay	Day	6	11.666	0.1172	0.206	0.0051	0.999	57	11	12.197	0.2303	0.136	0.0067	0.999	90	66
	Chikonde	Night	7	21.054	0.6652	0.414	0.0192	0.996	51	6	25.113	0.3682	0.371	0.0086	0.999	68	24
	Kalambo	Night	12	10.883	0.3783	0.194	0.0112	0.993	56	12	12.454	0.3119	0.160	0.0071	0.998	78	56
	Katoto etc	Day	2	14.831		1.099		1.000	13	2	18.000		1.000		1.000	18	9
	Katoto etc	Night	9	14.903	0.4522	0.251	0.0128	0.996	59	9	16.911	0.3308	0.203	0.0071	0.999	83	44
	Lufubu	Night	16	13.675	0.2295	0.147	0.0041	0.998	93	16	15.508	0.1017	0.119	0.0014	0.999	130	76
	Mpulungu	Day	3	6.426	0.0856	0.128	0.0108	0.999	50	18	6.46	0.1056	0.07	0.0075	0.999	92	129
	Mpulungu	Night	27	7.756	0.3465	0.141	0.0084	0.965	55	16	10.103	0.3733	0.146	0.0077	0.989	69	62
	Nsumbu NP	Night	44	6.326	0.1366	0.092	0.0026	0.989	69	25	8.185	0.0698	0.095	0.0011	0.999	86	95

Table 8.6 Parameters from fitted models to calculate required sampling size - - diver transect surveys for molluscs

					Linear Dependence Model							Clench Model						
Country	**Area**	**Depth**	**Substrate**	**N**	**a**	**s.e. (a)**	**b**	**s.e. (b)**	**r^2**	**S_{max}**	**n (90%)**	**a**	**s.e. (a)**	**b**	**s.e. (b)**	**r^2**	**S_{max}**	**n (90%)**
Burundi	Gitaza	5 to 15	Sand	4	3.524	0.1665	0.508	0.0415	0.996	7	5	3.908	0.3704	0.393	0.0696	0.991	10	23
DR Congo	Pemba etc	5 to 15	Sand	3	2.608	0.0881	0.508	0.0349	0.999	5	5	2.802	0.2030	0.362	0.0570	0.997	8	25
	Pemba etc	5 to 15	Rock	4	5.224	0.2550	0.498	0.0425	0.996	10	5	5.823	0.4340	0.388	0.0543	0.994	15	23
	Pemba etc	5 to 15	Mixed (Rock)	5	3.418	0.0770	0.350	0.0152	0.999	10	7	3.703	0.1747	0.255	0.0249	0.997	15	35
	Uvira	5 to 15	Mixed (Sand)	4	4.909	0.1457	0.545	0.0268	0.998	9	4	5.579	0.2083	0.442	0.0294	0.999	13	20
Tanzania	Mahale	5 to 15	Sand	13	2.823	0.1421	0.214	0.0163	0.981	13	11	3.366	0.1470	0.191	0.0135	0.993	18	47
	Mahale	5 to 15	Mixed (Rock)	8	4.961	0.1032	0.622	0.0156	0.997	8	4	6.846	0.3622	0.714	0.0493	0.992	10	13
	Mahale	5 to 15	Rock	9	3.787	0.2296	0.343	0.0298	0.979	11	7	4.651	0.2126	0.323	0.0227	0.994	14	28
	Mahale	> 20 m	Sand (Mixed)	4	1.554	0.0279	0.111	0.0114	0.999	14	21	1.565	0.0329	0.062	0.0076	0.999	25	145
	Mahale	> 20 m	Sand	12	2.401	0.0328	0.108	0.0036	0.999	22	21	2.505	0.0587	0.071	0.0043	0.998	35	127
	Mahale	> 20 m	Shell	5	2.783	0.2472	0.152	0.0489	0.988	18	15	2.865	0.2737	0.094	0.0330	0.989	30	96

8.4 Data supporting Chapter 3: full lists of fish species generated by the literature database

Table 8.7 Fish species list by country, as generated by the literature database (bold indicating when a species is exclusive to that country).

Family	Zambia (205)	Burundi (192)	Tanzania (192)	DR Congo (175)
Anabantidae		***Ctenopoma muriei***		
Bagridae	*Auchenoglanis occidentalis*	*Auchenoglanis occidentalis*	*Auchenoglanis occidentalis*	*Auchenoglanis occidentalis*
	Bagrus docmak	*Bagrus docmak*	*Chrysichthys brachynema*	*Bagrus docmak*
	Bathybagrus tetranema	*Bathybagrus tetranema*	*Chrysichthys grandis*	*Chrysichthys brachynema*
	Chrysichthys brachynema	*Chrysichthys brachynema*	*Chrysichthys graueri*	*Chrysichthys grandis*
	Chrysichthys grandis	*Chrysichthys grandis*	*Chrysichthys platycephalus*	*Chrysichthys graueri*
	Chrysichthys graueri	*Chrysichthys graueri*	*Chrysichthys sianenna*	*Chrysichthys platycephalus*
	Chrysichthys platycephalus	*Chrysichthys platycephalus*	*Chrysichthys stappersii*	*Chrysichthys sianenna*
	Chrysichthys sianenna	*Chrysichthys sianenna*	*Lophiobagrus cyclurus*	*Chrysichthys stappersii*
	Chrysichthys stappersii	*Chrysichthys stappersii*	*Phyllonemus filinemus*	*Lophiobagrus cyclurus*
	Lophiobagrus cyclurus	***Lophiobagrus aquilus***	*Phyllonemus typus*	***Phyllonemus brichardi***
	Phyllonemus filinemus	*Lophiobagrus cyclurus*		*Phyllonemus filinemus*
	Phyllonemus typus	*Phyllonemus filinemus*		
		Phyllonemus typus		
Centropomidae	*Lates angustifrons*	*Lates angustifrons*	*Lates angustifrons*	*Lates angustifrons*
	Lates mariae	*Lates mariae*	*Lates mariae*	*Lates mariae*
	Lates microlepis	*Lates microlepis*	*Lates microlepis*	*Lates microlepis*
	Lates stappersi	*Lates stappersi*	*Lates stappersi*	*Lates stappersi*
Characidae	*Alestes imberi*	*Alestes imberi*	*Alestes imberi*	*Alestes rhodopleura*
	Alestes macrophthalmus	*Alestes macrophthalmus*	*Alestes macrophthalmus*	
	Alestes rhodopleura	*Alestes rhodopleura*	*Alestes rhodopleura*	
	Bryconaethiops boulengeri	***Brycinus rhodopleura***	*Hydrocynus vittatus*	
	Hydrocynus vittatus	*Hydrocynus vittatus*		
		Micralestes stormsi		

Family	Zambia (205)	Burundi (192)	Tanzania (192)	DR Congo (175)
Cichlidae	*Altolamprologus calvus*	*Altolamprologus compressiceps*	*Altolamprologus calvus*	*Altolamprologus compressiceps*
	Altolamprologus compressiceps	***Astatoreochromis straeleni***	*Altolamprologus compressiceps*	*Asprotilapia leptura*
	Asprotilapia leptura	***Astatoreochromis vanderhorsti***	*Asprotilapia leptura*	*Astatotilapia burtoni*
	Astatotilapia burtoni	*Astatotilapia burtoni*	*Astatotilapia burtoni*	*Aulonocranus dewindti*
	Astatotilapia stappersii	*Aulonocranus dewindti*	*Aulonocranus dewindti*	*Bathybates fasciatus*
	Aulonocranus dewindti	*Bathybates fasciatus*	*Bathybates fasciatus*	*Bathybates graueri*
	Baileychromis centropomoides	*Bathybates ferox*	*Bathybates ferox*	*Bathybates horni*
	Bathybates fasciatus	*Bathybates graueri*	*Bathybates graueri*	*Bathybates leo*
	Bathybates ferox	*Bathybates horni*	*Bathybates horni*	*Bathybates minor*
	Bathybates graueri	*Bathybates leo*	*Bathybates leo*	*Bathybates vittatus*
	Bathybates horni	*Bathybates minor*	*Bathybates minor*	*Benthochromis melanoides*
	Bathybates leo	*Bathybates vittatus*	*Bathybates vittatus*	*Benthochromis tricoti*
	Bathybates minor	*Benthochromis tricoti*	*Benthochromis tricoti*	*Boulengerochromis microlepis*
	Bathybates vittatus	*Boulengerochromis microlepis*	*Boulengerochromis microlepis*	*Callochromis macrops*
	Benthochromis melanoides	*Callochromis macrops*	*Callochromis macrops*	*Callochromis melanostigma*
	Benthochromis tricoti	*Callochromis melanostigma*	*Callochromis melanostigma*	*Callochromis pleurospilus*
	Boulengerochromis microlepis	*Callochromis pleurospilus*	*Callochromis pleurospilus*	*Cardiopharynx schoutedeni*
	Callochromis macrops	*Cardiopharynx schoutedeni*	*Cardiopharynx schoutedeni*	*Chalinochromis brichardi*
	Callochromis melanostigma	*Chalinochromis brichardi*	*Chalinochromis brichardi*	*Ctenochromis benticola*
	Cardiopharynx schoutedeni	*Ctenochromis benticola*	*Ctenochromis horei*	*Ctenochromis horei*
	Chalinochromis brichardi	*Ctenochromis horei*	*Cyathopharynx furcifer*	*Cyathopharynx furcifer*
	Ctenochromis horei	*Cyathopharynx furcifer*	*Cyphotilapia frontosa*	*Cyphotilapia frontosa*
	Cunningtonia longiventralis	*Cyphotilapia frontosa*	*Cyprichromis leptosoma*	*Cyprichromis microlepidotus*
	Cyathopharynx furcifer	*Cyprichromis leptosoma*	*Cyprichromis microlepidotus*	*Ectodus descampsi*
	Cyphotilapia frontosa	*Cyprichromis microlepidotus*	*Ectodus descampsi*	*Enantiopus melanogenys*
	Cyprichromis leptosoma	*Ectodus descampsi*	*Enantiopus melanogenys*	*Eretmodus cyanostictus*
	Ectodus descampsi	*Enantiopus melanogenys*	*Eretmodus cyanostictus*	*Gnathochromis pfefferi*
	Enantiopus melanogenys	*Eretmodus cyanostictus*	*Gnathochromis permaxillaris*	*Grammatotria lemairii*

Family	Zambia (205)	Burundi (192)	Tanzania (192)	DR Congo (175)
Cichlidae	*Eretmodus cyanostictus*	*Gnathochromis permaxillaris*	*Gnathochromis pfefferi*	*Greenwoodochromis christyi*
	Gnathochromis permaxillaris	*Gnathochromis pfefferi*	*Grammatotria lemairii*	*Haplotaxodon microlepis*
	Gnathochromis pfefferi	*Grammatotria lemairii*	*Haplotaxodon microlepis*	*Hemibates stenosoma*
	Grammatotria lemairii	*Greenwoodochromis christyi*	*Hemibates stenosoma*	*Julidochromis dickfeldi*
	Greenwoodochromis bellcrossi	*Haplotaxodon microlepis*	*Julidochromis dickfeldi*	*Julidochromis marlieri*
	Greenwoodochromis christyi	*Hemibates stenosoma*	*Julidochromis marlieri*	*Julidochromis ornatus*
	Haplochromis paludinosus	*Julidochromis dickfeldi*	*Julidochromis ornatus*	*Julidochromis regani*
	Haplotaxodon microlepis	*Julidochromis marlieri*	*Julidochromis regani*	*Julidochromis transcriptus*
	Hemibates stenosoma	*Julidochromis regani*	*Julidochromis transcriptus*	*Lamprologus bifrenatus*
	Julidochromis dickfeldi	*Lamprologus callipterus*	*Lamprologus bifrenatus*	*Lamprologus callipterus*
	Julidochromis marlieri	*Lamprologus kungweensis*	*Lamprologus callipterus*	*Lamprologus kungweensis*
	Julidochromis ornatus	*Lamprologus lemairii*	*Lamprologus kungweensis*	*Lamprologus labiatus*
	Julidochromis regani	*Lamprologus ocellatus*	*Lamprologus lemairii*	*Lamprologus lemairii*
	Lamprologus bifrenatus	*Lamprologus ornatipinnis*	*Lamprologus ocellatus*	*Lamprologus ocellatus*
	Lamprologus callipterus	*Lamprologus signatus*	*Lamprologus ornatipinnis*	*Lepidiolamprologus attenuatus*
	Lamprologus kungweensis	*Lepidiolamprologus attenuatus*	*Lamprologus signatus*	*Lepidiolamprologus cunningtoni*
	Lamprologus labiatus	*Lepidiolamprologus cunningtoni*	*Lepidiolamprologus attenuatus*	*Lepidiolamprologus elongatus*
	Lamprologus lemairii	*Lepidiolamprologus elongatus*	*Lepidiolamprologus cunningtoni*	*Lepidiolamprologus profundicola*
	Lamprologus ocellatus	*Lepidiolamprologus profundicola*	*Lepidiolamprologus elongatus*	*Lestradea perspicax*
	Lamprologus ornatipinnis	*Lestradea perspicax*	*Lepidiolamprologus profundicola*	*Lestradea stappersii*
	Lamprologus signatus	*Limnochromis auritus*	*Lestradea perspicax*	*Limnochromis abeelei*
	Lepidiolamprologus attenuatus	*Limnotilapia dardennii*	*Limnochromis auritus*	*Limnochromis auritus*
	Lepidiolamprologus cunningtoni	*Lobochilotes labiatus*	*Limnochromis staneri*	*Limnochromis staneri*
	Lepidiolamprologus elongatus	*Microdontochromis tenuidentatus*	*Limnotilapia dardennii*	*Limnotilapia dardennii*
	Lepidiolamprologus kendalli	***Neolamprologus boulengeri***	*Lobochilotes labiatus*	*Lobochilotes labiatus*
	Lepidiolamprologus nkambae	*Neolamprologus brevis*	*Microdontochromis tenuidentatus*	*Neolamprologus brevis*
	Lepidiolamprologus profundicola	*Neolamprologus brichardi*	*Neolamprologus brevis*	*Neolamprologus brichardi*
	Lestradea perspicax	*Neolamprologus buescheri*	*Neolamprologus brichardi*	*Neolamprologus fasciatus*

Family	Zambia (205)	Burundi (192)	Tanzania (192)	DR Congo (175)
Cichlidae	*Lestradea stappersii*	***Neolamprologus falcicula***	*Neolamprologus buescheri*	*Neolamprologus finalimus*
	Limnochromis abeelei	*Neolamprologus fasciatus*	*Neolamprologus caudopunctatus*	*Neolamprologus furcifer*
	Limnochromis auritus	*Neolamprologus finalimus*	*Neolamprologus christyi*	*Neolamprologus gracilis*
	Limnochromis staneri	*Neolamprologus furcifer*	*Neolamprologus cylindricus*	*Neolamprologus leleupi*
	Limnotilapia dardennii	*Neolamprologus leleupi*	*Neolamprologus fasciatus*	***Neolamprologus longicaudatus***
	Lobochilotes labiatus	*Neolamprologus meeli*	*Neolamprologus furcifer*	*Neolamprologus longior*
	Microdontochromis tenuidentatus	*Neolamprologus modestus*	*Neolamprologus gracilis*	*Neolamprologus modestus*
	Neolamprologus brevis	*Neolamprologus mondabu*	*Neolamprologus hecqui*	*Neolamprologus mondabu*
	Neolamprologus brichardi	*Neolamprologus niger*	*Neolamprologus leleupi*	*Neolamprologus niger*
	Neolamprologus buescheri	*Neolamprologus pleuromaculatus*	***Neolamprologus leloupi***	*Neolamprologus petricola*
	Neolamprologus caudopunctatus	*Neolamprologus pulcher*	*Neolamprologus longior*	*Neolamprologus pleuromaculatus*
	Neolamprologus christyi	*Neolamprologus savoryi*	*Neolamprologus meeli*	*Neolamprologus prochilus*
	Neolamprologus cylindricus	*Neolamprologus schreyeni*	*Neolamprologus modestus*	*Neolamprologus savoryi*
	Neolamprologus fasciatus	*Neolamprologus sexfasciatus*	*Neolamprologus mondabu*	*Neolamprologus sexfasciatus*
	Neolamprologus furcifer	*Neolamprologus tetracanthus*	*Neolamprologus moorii*	*Neolamprologus tetracanthus*
	Neolamprologus hecqui	*Neolamprologus toae*	*Neolamprologus multifasciatus*	*Neolamprologus toae*
	Neolamprologus leleupi	*Neolamprologus tretocephalus*	*Neolamprologus niger*	*Neolamprologus tretocephalus*
	Neolamprologus meeli	*Neolamprologus wauthioni*	*Neolamprologus obscurus*	*Neolamprologus wauthioni*
	Neolamprologus modestus	*Ophthalmotilapia nasutus*	*Neolamprologus pleuromaculatus*	*Ophthalmotilapia heterodonta*
	Neolamprologus mondabu	*Ophthalmotilapia ventralis*	*Neolamprologus savoryi*	*Ophthalmotilapia nasutus*
	Neolamprologus moorii	***Oreochromis leucostictus***	*Neolamprologus schreyeni*	*Ophthalmotilapia ventralis*
	Neolamprologus multifasciatus	*Oreochromis niloticus*	*Neolamprologus sexfasciatus*	*Oreochromis niloticus*
	Neolamprologus mustax	*Oreochromis niloticus niloticus*	*Neolamprologus tetracanthus*	*Oreochromis niloticus eduardianus*
	Neolamprologus niger	*Oreochromis tanganicae*	*Neolamprologus toae*	*Oreochromis niloticus niloticus*
	Neolamprologus obscurus	*Paracyprichromis brieni*	*Neolamprologus tretocephalus*	*Oreochromis tanganicae*
	Neolamprologus petricola	*Paracyprichromis nigripinnis*	*Neolamprologus wauthioni*	*Paracyprichromis nigripinnis*
	Neolamprologus prochilus	*Perissodus microlepis*	*Ophthalmotilapia heterodonta*	*Perissodus eccentricus*
	Neolamprologus pulcher	*Petrochromis famula*	*Ophthalmotilapia nasutus*	*Perissodus microlepis*

Family	Zambia (205)	Burundi (192)	Tanzania (192)	DR Congo (175)
Cichlidae	*Neolamprologus savoryi*	*Petrochromis fasciolatus*	*Ophthalmotilapia ventralis*	*Perissodus straeleni*
	Neolamprologus sexfasciatus	*Petrochromis macrognathus*	*Oreochromis niloticus*	*Petrochromis famula*
	Neolamprologus tetracanthus	*Petrochromis orthognathus*	*Oreochromis niloticus eduardianus*	*Petrochromis fasciolatus*
	Neolamprologus toae	*Petrochromis polyodon*	*Oreochromis niloticus niloticus*	*Petrochromis macrognathus*
	Neolamprologus tretocephalus	*Petrochromis trewavasae*	*Oreochromis tanganicae*	*Petrochromis orthognathus*
	Neolamprologus wauthioni	*Plecodus elaviae*	*Paracyprichromis nigripinnis*	*Petrochromis polyodon*
	Ophthalmotilapia nasutus	*Plecodus multidentatus*	*Perissodus microlepis*	*Petrochromis trewavasae*
	Ophthalmotilapia ventralis	*Plecodus paradoxus*	*Perissodus straeleni*	*Plecodus elaviae*
	Oreochromis niloticus	*Plecodus straeleni*	*Petrochromis famula*	*Plecodus multidentatus*
	Oreochromis tanganicae	*Pseudosimochromis curvifrons*	*Petrochromis fasciolatus*	*Plecodus paradoxus*
	Paracyprichromis brieni	*Reganochromis calliurus*	*Petrochromis macrognathus*	*Plecodus straeleni*
	Paracyprichromis nigripinnis	*Simochromis babaulti*	*Petrochromis orthognathus*	*Pseudosimochromis curvifrons*
	Perissodus eccentricus	*Simochromis diagramma*	*Petrochromis polyodon*	*Simochromis babaulti*
	Perissodus microlepis	*Simochromis margaretae*	*Petrochromis trewavasae*	*Simochromis diagramma*
	Perissodus straeleni	*Simochromis marginatus*	*Plecodus elaviae*	*Simochromis marginatus*
	Petrochromis famula	*Spathodus marlieri*	*Plecodus multidentatus*	*Simochromis pleurospilus*
	Petrochromis fasciolatus	*Tangachromis dhanisi*	*Plecodus paradoxus*	*Spathodus marlieri*
	Petrochromis macrognathus	*Tanganicodus irsacae*	*Plecodus straeleni*	*Tanganicodus irsacae*
	Petrochromis orthognathus	*Telmatochromis bifrenatus*	*Pseudosimochromis curvifrons*	*Telmatochromis bifrenatus*
	Petrochromis polyodon	*Telmatochromis brichardi*	*Reganochromis calliurus*	*Telmatochromis dhonti*
	Petrochromis trewavasae	*Telmatochromis burgeoni*	*Simochromis babaulti*	*Telmatochromis temporalis*
	Plecodus elaviae	*Telmatochromis dhonti*	*Simochromis diagramma*	*Telmatochromis vittatus*
	Plecodus multidentatus	*Telmatochromis temporalis*	*Simochromis loocki*	*Tilapia rendalli*
	Plecodus paradoxus	*Telmatochromis vittatus*	*Simochromis margaretae*	*Trematocara nigrifons*
	Plecodus straeleni	*Trematocara kufferathi*	*Simochromis marginatus*	*Trematocara unimaculatum*
	Pseudosimochromis curvifrons	*Trematocara marginatum*	***Spathodus erythrodon***	*Trematocara variabile*
	Reganochromis calliurus	*Trematocara nigrifons*	*Tanganicodus irsacae*	***Trematochromis schreyeni***
	Simochromis babaulti	*Trematocara stigmaticum*	*Telmatochromis bifrenatus*	*Triglachromis otostigma*

Family	Zambia (205)	Burundi (192)	Tanzania (192)	DR Congo (175)
Cichlidae	*Simochromis diagramma*	*Trematocara unimaculatum*	*Telmatochromis brichardi*	***Tropheus annectens***
	Simochromis loocki	*Trematocara variabile*	*Telmatochromis burgeoni*	*Tropheus brichardi*
	Simochromis marginatus	*Triglachromis otostigma*	*Telmatochromis dhonti*	*Tropheus duboisi*
	Simochromis pleurospilus	*Tropheus brichardi*	*Telmatochromis temporalis*	*Tropheus kasabae*
	Tangachromis dhanisi	*Tropheus duboisi*	*Telmatochromis vittatus*	*Tropheus moorii*
	Tanganicodus irsacae	*Tropheus moorii*	*Trematocara caparti*	*Tropheus polli*
	Telmatochromis bifrenatus	*Tylochromis polylepis*	*Trematocara kufferathi*	*Tylochromis polylepis*
	Telmatochromis burgeoni	*Xenochromis hecqui*	*Trematocara marginatum*	*Xenochromis hecqui*
	Telmatochromis dhonti	*Xenotilapia bathyphila*	*Trematocara nigrifons*	*Xenotilapia bathyphila*
	Telmatochromis temporalis	*Xenotilapia boulengeri*	*Trematocara unimaculatum*	*Xenotilapia boulengeri*
	Telmatochromis vittatus	*Xenotilapia burtoni*	*Trematocara variabile*	*Xenotilapia flavipinnis*
	Telotrematocara macrostoma	*Xenotilapia caudafasciata*	*Tropheus brichardi*	*Xenotilapia longispinis*
	Tilapia rendalli	*Xenotilapia flavipinnis*	*Tropheus duboisi*	*Xenotilapia ochrogenys*
	Trematocara caparti	*Xenotilapia longispinis*	*Tropheus moorii*	*Xenotilapia ornatipinnis*
	Trematocara kufferathi	***Xenotilapia nasutus***	*Tropheus polli*	*Xenotilapia sima*
	Trematocara marginatum	*Xenotilapia nigrolabiata*	*Tylochromis polylepis*	
	Trematocara nigrifons	*Xenotilapia ochrogenys*	*Xenochromis hecqui*	
	Trematocara stigmaticum	*Xenotilapia ornatipinnis*	*Xenotilapia bathyphila*	
	Trematocara unimaculatum	*Xenotilapia sima*	*Xenotilapia boulengeri*	
	Trematocara variabile		*Xenotilapia caudafasciata*	
	Triglachromis otostigma		*Xenotilapia flavipinnis*	
	Tropheus kasabae		*Xenotilapia longispinis*	
	Tropheus moorii		*Xenotilapia ochrogenys*	
	Tylochromis polylepis		*Xenotilapia ornatipinnis*	
	Xenochromis hecqui		*Xenotilapia sima*	
	Xenotilapia bathyphila		*Xenotilapia spilopterus*	
	Xenotilapia boulengeri			
	Xenotilapia burtoni			

Family	Zambia (205)	Burundi (192)	Tanzania (192)	DR Congo (175)
Cichlidae	*Xenotilapia caudafasciata*			
	Xenotilapia flavipinnis			
	Xenotilapia lestradii			
	Xenotilapia longispinis			
	Xenotilapia nigrolabiata			
	Xenotilapia ochrogenys			
	Xenotilapia ornatipinnis			
	Xenotilapia sima			
	Xenotilapia spilopterus			
Citharinidae	*Citharinus gibbosus*		*Citharinus gibbosus*	
Clariidae	*Clarias liocephalus*	*Clarias gariepinus*	*Clarias gariepinus*	*Clarias liocephalus*
	Clarias ngamensis	*Dinotopterus cunningtoni*	*Dinotopterus cunningtoni*	*Dinotopterus cunningtoni*
	Dinotopterus cunningtoni	*Tanganikallabes mortiauxi*	*Heterobranchus longifilis*	*Heterobranchus longifilis*
	Tanganikallabes mortiauxi		*Tanganikallabes mortiauxi*	*Tanganikallabes mortiauxi*
Clupeidae	*Limnothrissa miodon*	*Limnothrissa miodon*	*Limnothrissa miodon*	*Limnothrissa miodon*
	Stolothrissa tanganicae	*Stolothrissa tanganicae*	*Stolothrissa tanganicae*	*Stolothrissa tanganicae*
Cyprinidae	*Acapoeta tanganicae*	*Acapoeta tanganicae*	*Acapoeta tanganicae*	*Acapoeta tanganicae*
	Labeo cylindricus	***Barbus altianalis altianalis***	*Barbus lineomaculatus*	*Barbus tropidolepis*
	Raiamas moorii	***Barbus caudovittatus***	***Barbus taeniopleura***	***Barbus urostigma***
		Barbus lineomaculatus	*Barbus tropidolepis*	*Chelaethiops minutus*
		Barbus serrifer	***Labeo dhonti***	*Raiamas moorii*
		Barbus somerini	*Raiamas moorii*	
		Barbus tropidolepis	***Varicorhinus leleupanus***	
		Chelaethiops minutus		
		Labeo cylindricus		
		Raiamas moorii		
		Raiamas salmolucius		

Family	Zambia (205)	Burundi (192)	Tanzania (192)	DR Congo (175)
Cyprinodontidae	*Aplocheilichthys pumilus*	*Aplocheilichthys pumilus*	*Aplocheilichthys pumilus*	*Aplocheilichthys pumilus*
	Lamprichthys tanganicanus	*Lamprichthys tanganicanus*	*Lamprichthys tanganicanus*	*Lamprichthys tanganicanus*
Distichodontidae		***Distochodus sexfasciatus***		
Malapteruridae	*Malapterurus electricus*	*Malapterurus electricus*	*Malapterurus electricus*	*Malapterurus electricus*
Mastacembelidae	*Aethiomastacembelus cunningtoni*	*Aethiomastacembelus cunningtoni*	*Aethiomastacembelus cunningtoni*	*Aethiomastacembelus cunningtoni*
	Aethiomastacembelus ellipsifer	*Aethiomastacembelus ellipsifer*	*Aethiomastacembelus ellipsifer*	*Aethiomastacembelus ellipsifer*
	Afromastacembelus albomaculatus	*Afromastacembelus albomaculatus*	*Aethiomastacembelus platysoma*	*Aethiomastacembelus platysoma*
	Caecomastacembelus micropectus	***Afromastacembelus plagiostomus***	*Afromastacembelus albomaculatus*	*Afromastacembelus albomaculatus*
	Caecomastacembelus moorii	*Caecomastacembelus flavidus*	*Caecomastacembelus flavidus*	***Afromastacembelus tanganicae***
		Caecomastacembelus frenatus	*Caecomastacembelus frenatus*	*Caecomastacembelus flavidus*
		Caecomastacembelus micropectus	*Caecomastacembelus moorii*	*Caecomastacembelus frenatus*
		Caecomastacembelus moorii	*Caecomastacembelus ophidium*	*Caecomastacembelus moorii*
		Caecomastacembelus ophidium		*Caecomastacembelus ophidium*
				Caecomastacembelus zebratus
Mochokidae	*Synodontis dhonti*	***Synodontis benthicola***	*Synodontis dhonti*	*Synodontis dhonti*
	Synodontis granulosus	*Synodontis dhonti*	*Synodontis granulosus*	*Synodontis granulosus*
	Synodontis lacustricolus	*Synodontis granulosus*	*Synodontis lacustricolus*	*Synodontis lacustricolus*
	Synodontis multipunctatus	*Synodontis multipunctatus*	*Synodontis multipunctatus*	*Synodontis multipunctatus*
	Synodontis nigromaculatus	*Synodontis petricola*	*Synodontis nigromaculatus*	*Synodontis petricola*
	Synodontis petricola	*Synodontis polli*	*Synodontis petricola*	*Synodontis polli*
	Synodontis polli		*Synodontis polli*	
	Synodontis polystigma			
	Synodontis serratus			
	Synodontis unicolor			
Mormyridae	*Hippopotamyrus discorhynchus*	*Hippopotamyrus discorhynchus*	*Hippopotamyrus discorhynchus*	*Hippopotamyrus discorhynchus*
	Marcusenius stanleyanus			
	Mormyrops deliciosus			

Family	Zambia (205)	Burundi (192)	Tanzania (192)	DR Congo (175)
Polypteridae	*Polypterus endlicheri*		*Polypterus endlicheri*	
	Polypterus endlicheri congicus		***Polypterus ornatipinnis***	
Protopteridae	*Protopterus aethiopicus*	*Protopterus aethiopicus*		*Protopterus aethiopicus*
Tetraodontidae	*Tetraodon mbu*		*Tetraodon mbu*	

Table 8.8 Full list of fish species by national park, generated by the literature database (bold indicates when a species is exclusively found in one park).

Family	Mahale (160)	Rusizi (102)	Nsumbu (99)	Gombe (67)
Anabantidae		***Ctenopoma muriei***		
Bagridae	*Auchenoglanis occidentalis*	*Auchenoglanis occidentalis*	*Auchenoglanis occidentalis*	*Chrysichthys graueri*
	Chrysichthys brachynema	***Bagrus docmak***	*Chrysichthys brachynema*	*Chrysichthys platycephalus*
	Chrysichthys graueri	*Chrysichthys brachynema*	*Chrysichthys sianenna*	
	Chrysichthys platycephalus	***Chrysichthys grandis***	*Lophiobagrus cyclurus*	
	Chrysichthys sianenna	*Chrysichthys graueri*	*Phyllonemus typus*	
	Lophiobagrus cyclurus	*Chrysichthys platycephalus*		
	Phyllonemus filinemus	*Chrysichthys sianenna*		
	Phyllonemus typus	***Chrysichthys stappersii***		
Centropomidae	*Lates angustifrons*	*Lates angustifrons*	*Lates angustifrons*	*Lates mariae*
	Lates mariae	*Lates mariae*	*Lates mariae*	
	Lates microlepis	*Lates microlepis*		
	Lates stappersi	*Lates stappersi*		
Characidae	*Alestes macrophthalmus*	***Alestes imberi***	*Hydrocynus vittatus*	
	Alestes rhodopleura	*Alestes macrophthalmus*		
		Alestes rhodopleura		
		Brycinus rhodopleura		
		Hydrocynus vittatus		
		Micralestes stormsi		
Cichlidae	*Altolamprologus calvus*	*Altolamprologus compressiceps*	*Altolamprologus calvus*	*Altolamprologus compressiceps*
	Altolamprologus compressiceps	***Astatoreochromis vanderhorsti***	*Altolamprologus compressiceps*	*Asprotilapia leptura*
	Asprotilapia leptura	*Astatotilapia burtoni*	*Asprotilapia leptura*	*Aulonocranus dewindti*
	Astatotilapia burtoni	*Aulonocranus dewindti*	*Aulonocranus dewindti*	*Benthochromis tricoti*
	Aulonocranus dewindti	*Bathybates fasciatus*	*Bathybates fasciatus*	*Boulengerochromis microlepis*
	Bathybates fasciatus	*Bathybates ferox*	*Bathybates ferox*	*Cardiopharynx schoutedeni*
	Bathybates ferox	*Bathybates graueri*	*Bathybates leo*	*Chalinochromis brichardi*

Family	Mahale (160)	Rusizi (102)	Nsumbu (99)	Gombe (67)
Cichlidae	*Bathybates graueri*	*Bathybates leo*	*Boulengerochromis microlepis*	*Ctenochromis horei*
	Bathybates horni	*Bathybates minor*	*Callochromis macrops*	*Cyathopharynx furcifer*
	Bathybates leo	*Boulengerochromis microlepis*	*Chalinochromis brichardi*	*Cyphotilapia frontosa*
	Bathybates minor	*Callochromis macrops*	*Ctenochromis horei*	*Cyprichromis leptosoma*
	Bathybates vittatus	*Callochromis melanostigma*	*Cyathopharynx furcifer*	*Ectodus descampsi*
	Benthochromis tricoti	*Callochromis pleurospilus*	*Cyphotilapia frontosa*	*Enantiopus melanogenys*
	Boulengerochromis microlepis	*Cardiopharynx schoutedeni*	*Cyprichromis leptosoma*	*Eretmodus cyanostictus*
	Callochromis macrops	*Ctenochromis horei*	*Ectodus descampsi*	*Grammatotria lemairii*
	Callochromis melanostigma	*Cyathopharynx furcifer*	*Enantiopus melanogenys*	*Haplotaxodon microlepis*
	Callochromis pleurospilus	*Ectodus descampsi*	*Gnathochromis pfefferi*	*Julidochromis marlieri*
	Cardiopharynx schoutedeni	*Enantiopus melanogenys*	*Grammatotria lemairii*	*Julidochromis regani*
	Chalinochromis brichardi	***Gnathochromis permaxillaris***	*Haplotaxodon microlepis*	*Lamprologus callipterus*
	Ctenochromis horei	*Gnathochromis pfefferi*	*Julidochromis dickfeldi*	***Lamprologus kungweensis***
	Cyathopharynx furcifer	*Grammatotria lemairii*	*Julidochromis marlieri*	*Lamprologus lemairii*
	Cyphotilapia frontosa	***Hemibates stenosoma***	*Lamprologus callipterus*	*Lamprologus ornatipinnis*
	Cyprichromis leptosoma	*Lamprologus callipterus*	***Lamprologus labiatus***	*Lepidiolamprologus attenuatus*
	Cyprichromis microlepidotus	*Lamprologus lemairii*	*Lamprologus lemairii*	*Lepidiolamprologus cunningtoni*
	Ectodus descampsi	*Lamprologus ornatipinnis*	*Lamprologus ocellatus*	*Lepidiolamprologus elongatus*
	Enantiopus melanogenys	*Lepidiolamprologus attenuatus*	*Lepidiolamprologus attenuatus*	*Lepidiolamprologus profundicola*
	Eretmodus cyanostictus	*Lepidiolamprologus cunningtoni*	*Lepidiolamprologus cunningtoni*	*Limnotilapia dardennii*
	Gnathochromis pfefferi	*Lestradea perspicax*	*Lepidiolamprologus elongatus*	*Lobochilotes labiatus*
	Grammatotria lemairii	*Limnochromis auritus*	***Lepidiolamprologus kendalli***	*Microdontochromis tenuidentatus*
	Haplotaxodon microlepis	*Limnotilapia dardennii*	***Lepidiolamprologus nkambae***	*Neolamprologus brevis*
	Julidochromis dickfeldi	*Lobochilotes labiatus*	*Lepidiolamprologus profundicola*	*Neolamprologus brichardi*
	Julidochromis marlieri	*Neolamprologus pleuromaculatus*	*Lestradea perspicax*	*Neolamprologus furcifer*
	Julidochromis ornatus	*Ophthalmotilapia ventralis*	***Lestradea stappersii***	*Neolamprologus modestus*
	Julidochromis regani	***Oreochromis leucostictus***	***Limnochromis abeelei***	*Neolamprologus mondabu*
	Julidochromis transcriptus	*Oreochromis niloticus*	*Limnotilapia dardennii*	*Neolamprologus niger*

Family	Mahale (160)	Rusizi (102)	Nsumbu (99)	Gombe (67)
Cichlidae	*Lamprologus callipterus*	*Oreochromis niloticus niloticus*	*Lobochilotes labiatus*	*Neolamprologus savoryi*
	Lamprologus lemairii	*Oreochromis tanganicae*	*Neolamprologus brevis*	*Neolamprologus toae*
	Lamprologus ocellatus	*Plecodus elaviae*	*Neolamprologus brichardi*	*Neolamprologus tretocephalus*
	Lamprologus ornatipinnis	*Plecodus paradoxus*	*Neolamprologus caudopunctatus*	*Ophthalmotilapia ventralis*
	Lamprologus signatus	*Reganochromis calliurus*	*Neolamprologus fasciatus*	*Oreochromis tanganicae*
	Lepidiolamprologus attenuatus	*Simochromis babaulti*	*Neolamprologus furcifer*	*Perissodus microlepis*
	Lepidiolamprologus cunningtoni	*Simochromis diagramma*	*Neolamprologus leleupi*	*Petrochromis orthognathus*
	Lepidiolamprologus elongatus	***Tangachromis dhanisi***	*Neolamprologus meeli*	*Petrochromis polyodon*
	Lepidiolamprologus profundicola	*Telmatochromis dhonti*	*Neolamprologus modestus*	*Plecodus paradoxus*
	Lestradea perspicax	*Trematocara kufferathi*	*Neolamprologus moorii*	*Plecodus straeleni*
	Limnochromis auritus	*Trematocara marginatum*	***Neolamprologus mustax***	*Simochromis diagramma*
	Limnotilapia dardennii	***Trematocara nigrifons***	***Neolamprologus petricola***	*Simochromis marginatus*
	Lobochilotes labiatus	*Trematocara stigmaticum*	***Neolamprologus pulcher***	*Telmatochromis bifrenatus*
	Microdontochromis tenuidentatus	***Trematocara unimaculatum***	*Neolamprologus savoryi*	*Telmatochromis temporalis*
	Neolamprologus brevis	*Trematocara variabile*	*Neolamprologus sexfasciatus*	*Tropheus brichardi*
	Neolamprologus brichardi	***Triglachromis otostigma***	*Neolamprologus tetracanthus*	*Tropheus duboisi*
	Neolamprologus buescheri	*Tropheus moorii*	*Ophthalmotilapia ventralis*	*Tropheus moorii*
	Neolamprologus caudopunctatus	*Tylochromis polylepis*	*Oreochromis tanganicae*	*Tylochromis polylepis*
	Neolamprologus christyi	*Xenochromis hecqui*	***Perissodus eccentricus***	*Xenotilapia flavipinnis*
	Neolamprologus fasciatus	***Xenotilapia caudafasciata***	*Perissodus microlepis*	*Xenotilapia sima*
	Neolamprologus furcifer	*Xenotilapia longispinis*	*Perissodus straeleni*	
	Neolamprologus gracilis	***Xenotilapia nigrolabiata***	*Petrochromis famula*	
	Neolamprologus hecqui	*Xenotilapia ochrogenys*	*Petrochromis fasciolatus*	
	Neolamprologus leleupi	***Xenotilapia ornatipinnis***	*Petrochromis macrognathus*	
	Neolamprologus longior	*Xenotilapia sima*	*Petrochromis orthognathus*	
	Neolamprologus meeli		*Petrochromis polyodon*	
	Neolamprologus modestus		*Petrochromis trewavasae*	
	Neolamprologus mondabu		*Plecodus paradoxus*	

Family	Mahale (160)	Rusizi (102)	Nsumbu (99)	Gombe (67)
Cichlidae	*Neolamprologus moorii*		*Simochromis diagramma*	
	Neolamprologus multifasciatus		***Simochromis pleurospilus***	
	Neolamprologus niger		*Telmatochromis dhonti*	
	Neolamprologus pleuromaculatus		*Telmatochromis temporalis*	
	Neolamprologus savoryi		*Trematocara kufferathi*	
	Neolamprologus sexfasciatus		*Trematocara marginatum*	
	Neolamprologus tetracanthus		*Trematocara stigmaticum*	
	Neolamprologus toae		***Tropheus kasabae***	
	Neolamprologus tretocephalus		*Tropheus moorii*	
	Neolamprologus wauthioni		*Tylochromis polylepis*	
	Ophthalmotilapia heterodonta		*Xenochromis hecqui*	
	Ophthalmotilapia nasutus		*Xenotilapia boulengeri*	
	Ophthalmotilapia ventralis		*Xenotilapia flavipinnis*	
	Oreochromis niloticus		*Xenotilapia ochrogenys*	
	Oreochromis niloticus niloticus		*Xenotilapia sima*	
	Oreochromis tanganicae			
	Paracyprichromis nigripinnis			
	Perissodus microlepis			
	Perissodus straeleni			
	Petrochromis famula			
	Petrochromis fasciolatus			
	Petrochromis macrognathus			
	Petrochromis orthognathus			
	Petrochromis polyodon			
	Petrochromis trewavasae			
	Plecodus elaviae			
	Plecodus multidentatus			
	Plecodus paradoxus			

Family	Mahale (160)	Rusizi (102)	Nsumbu (99)	Gombe (67)
	Plecodus straeleni			
	Pseudosimochromis curvifrons			
	Reganochromis calliurus			
	Simochromis babaulti			
	Simochromis diagramma			
	Simochromis marginatus			
Cichlidae	***Spathodus erythrodon***			
	Tanganicodus irsacae			
	Telmatochromis bifrenatus			
	Telmatochromis brichardi			
	Telmatochromis burgeoni			
	Telmatochromis dhonti			
	Telmatochromis temporalis			
	Telmatochromis vittatus			
	Trematocara marginatum			
	Trematocara variabile			
	Tropheus brichardi			
	Tropheus duboisi			
	Tropheus moorii			
	Tropheus polli			
	Tylochromis polylepis			
	Xenochromis hecqui			
	Xenotilapia boulengeri			
	Xenotilapia flavipinnis			
	Xenotilapia longispinis			
	Xenotilapia ochrogenys			
	Xenotilapia sima			

Family	Mahale (160)	Rusizi (102)	Nsumbu (99)	Gombe (67)
Citharinidae			***Citharinus gibbosus***	
Clariidae	*Clarias gariepinus*	*Clarias gariepinus*		*Tanganikallabes mortiauxi*
	Tanganikallabes mortiauxi			
Clupeidae	*Dinotopterus cunningtoni*	*Dinotopterus cunningtoni*		
	Limnothrissa miodon	*Limnothrissa miodon*	*Limnothrissa miodon*	*Limnothrissa miodon*
	Stolothrissa tanganicae	*Stolothrissa tanganicae*		
Cyprinidae	*Acapoeta tanganicae*	*Acapoeta tanganicae*	*Labeo cylindricus*	*Varicorhinus leleupanus*
	Barbus taeniopleura	***Barbus altianalis altianalis***		
	Barbus tropidolepis	***Barbus lineomaculatus***		
	Labeo dhonti	***Barbus serrifer***		
	Raiamas moorii	***Barbus somerini***		
	Varicorhinus leleupanus	*Barbus tropidolepis*		
		Chelaethiops minutus		
		Labeo cylindricus		
		Raiamas moorii		
		Raiamas salmolucius		
Cyprinodontidae	*Aplocheilichthys pumilus*	*Aplocheilichthys pumilus*	*Lamprichthys tanganicanus*	*Lamprichthys tanganicanus*
	Lamprichthys tanganicanus	*Lamprichthys tanganicanus*		
Malapteruridae	*Malapterurus electricus*	*Malapterurus electricus*	*Malapterurus electricus*	
Mastacembelidae	*Aethiomastacembelus ellipsifer*	*Aethiomastacembelus cunningtoni*	*Aethiomastacembelus ellipsifer*	*Aethiomastacembelus cunningtoni*
	Aethiomastacembelus platysoma	***Caecomastacembelus frenatus***	***Caecomastacembelus micropectus***	***Caecomastacembelus flavidus***
	Afromastacembelus albomaculatus	*Caecomastacembelus ophidium*	*Caecomastacembelus moorii*	*Caecomastacembelus moorii*
	Caecomastacembelus moorii			
	Caecomastacembelus ophidium			

Family	**Mahale (160)**	**Rusizi (102)**	**Nsumbu (99)**	**Gombe (67)**
Mochokidae	***Synodontis dhonti***	*Synodontis multipunctatus*	*Synodontis lacustricolus*	*Synodontis multipunctatus*
	Synodontis granulosus		*Synodontis multipunctatus*	*Synodontis petricola*
	Synodontis lacustricolus		*Synodontis petricola*	
	Synodontis multipunctatus		***Synodontis serratus***	
	Synodontis nigromaculatus			
	Synodontis petricola			
	Synodontis polli			
Mormyridae	*Hippopotamyrus discorhynchus*	*Hippopotamyrus discorhynchus*	***Marcusenius stanleyanus***	
Polypteridae	***Polypterus endlicheri***	***Protopterus aethiopicus***		