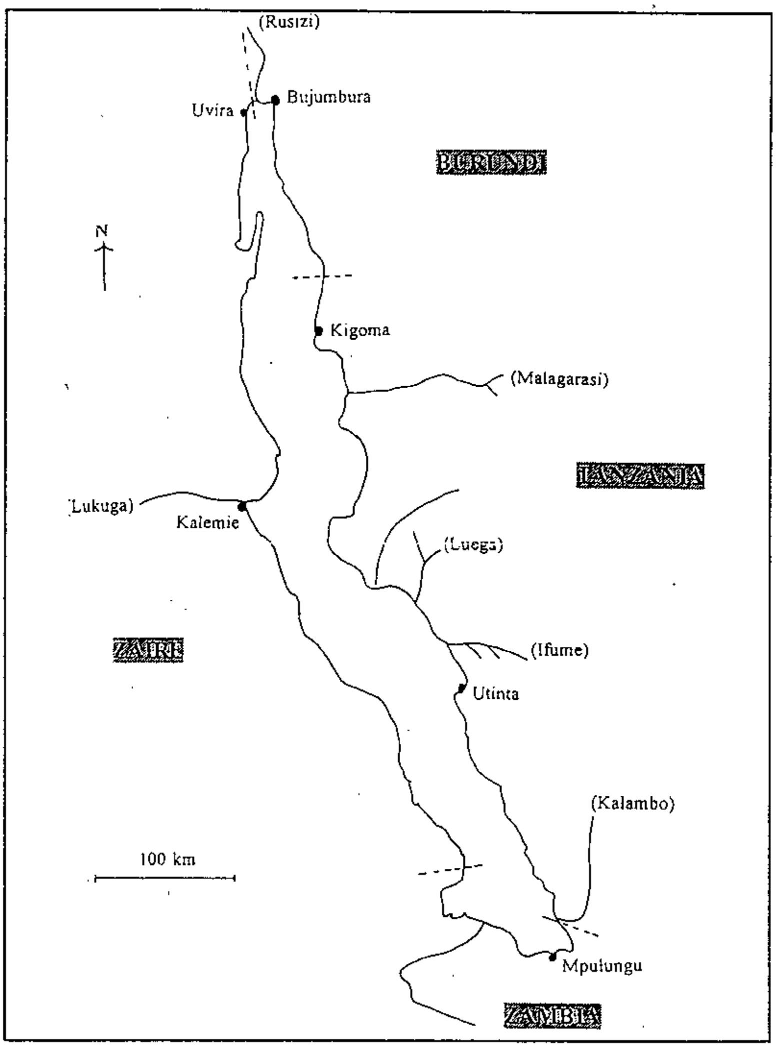
POLLUTION AND ITS EFFECTS ON BIODIVERSITY

BASELINE REVIEW

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



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RAF/92/G32 - POLLUTION CONTROL AND OTHER MEASURES TO PROTECT BIODIVERSITY IN LAKE TANGANYIKA

Baseline review - 4: Pollution of International Waters

by

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Baseline review - 4: 'Pollution of International Waters'

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SUMMARY

Pollution effects on biodiversity (excluding vertbrates) of Lake Tanganyika

1. This study aims to:

- identify the main sources of pollution to Lake Tanganyika and, where possible, quantify the pollutant inputs
- obtain a lakewide assessment of pollution and its effects on lower organism biodiversity
- evolve systematic programmes of pollution and biodiversity description and monitoring that are repeatable - such that change (or lack of change) can be determined with confidence
- develop (in each of the riparian countries) teams capable of maintaining the investigations from planning and executing field and laboratory programmes, to analysing data, and reporting on the findings in the most appropriate ways to fellow scientists, lake managers and policy-makers
- developing pollution control strategies as necessary.

2. 'Pollution' in this study is taken as the anthropogenically accelerated inputs of nutrients (eutrophication), organic (oxygen-demanding) components of sewage and e.g. sugar cane factory wastes, heavy metals, pesticides and compounds likely to stem from oil exploration and shipping. As far as possible, 'biodiversity' will be taken as the total range of organisms present/detected - that is, excluding fish which are more appropriately handled by the sister studies on biodiversity *per se*.

3. The extraordinary number of species in the lake is attributed very much to the large size of the lake, to its great age and 1.8M-y isolation, and to the ecological diversity. In addition, however, a number of physical features such as large size and depth, also render the lake susceptible to pollution as they result in it retaining very high percentages of the water- and wind-borne pollutants entering it. As in many lacustrine systems, there is always the possibility too, of the 'cascade' effect of pollution on one species affecting species at other trophic levels relatively quickly.

4. From databases comprising more than 3,000 titles relating to Lake Tanganyika, approximately 200 are cited. Very few of these refer to either 'pollution' or 'biodiversity, and documentation on the effects of the one on the other is scant indeed. Moreover, with very few exceptions, papers on 'species diversity' are of somewhat limited value. First, they are restricted to relatively few phylogenetic groups and second, they usually amount to little more than lists with no indication of the 'effort' invested in generating the species data; the new project aims to address these shortcomings by (i) attempting - at some sampling sites at least - to describe species diversity *in toto* i.e. from the sub-micron picoplankton to lower organisms and rooted plants decimetres and metres in greatest dimension, and (ii) providing information on sample size, such that future workers can generate comparable datasets.

5. Many of the references cited are of inestimable value however, in providing information that aids decision-making on the arrays of measurands, the numbers and locations of sampling sites, the sampling schedules, and the human and equipment resources needed to carry out the work. As a basis for discussion, the following areas are considered in need of priority attention:

- eutrophication in the Kigoma (Tanzania) and Bujumbura (Burundi) areas
- atmospheric pollution lakewide
- pesticide inputs from cotton plantations in the Rusizi catchment (Burundi)
- heavy metals from diamond mining in the Malagarasi catchment (Tanzania)
- waste from sugar cane processing in Uvira area (Zaire)
- oil pollution lakewide.

6a. Open and in-shore waters will be investigated, and samples of water and biota representative of the water column from the surface to the sediment, the sediment itself surface will be collected and analysed for pollution and biodiversity status. In order to establish the effects of pollution on biodiversity, the species composition/richness/diversity at approximately 10 polluted sites (visited on average 8 times per year) will be compared with that found at 10 unpolluted sites similarly sampled, and corresponding as far as possible in features such as aspect, exposure, water depth, bottom substrate, and proximity to shore or inflow.

6b. The range of physico-chemical determinands presently envisaged is as follows:

- light, temperature, transparency, total suspended particulates
- conductivity/salinity, dissolved oxygen, pH, alkalinity
- calcium, sulphate, fluoride, silica (reactive and total)
- ammonia, nitrate, nitrite, organic nitrogen
- phosphorus (P), including the soluble (dissolved) reactive and unreactive phosphate fractions, and the total P present
- organic matter (dissolved and total)
- chlorophyll$_a$
- oils (fuel, bilge etc.) in water, sediments, and the tissues of selected molluscs, crustaceans and fish
- pesticides and PCBs in fish tissues and molluscs (possibly also PAHs)
- trace elements, Cu, Zn, Mn, Fe, Pb, Cd, Hg (in molluscan, crustacean and fish tissues)

7. The estimated costs of equipment considered necessary for successful completion of the Pollution-Biodiversity work are far from finalised, but they amount to approximately £800,000 (1.2M US$). This is excluding costs of the use of the large vessels. However, it embraces a considerable resource by way of office, field and laboratory gear that can be shared by the other projects. Also, approximately 50% of the sum is earmarked for (good) microscopes. This reflects the considerable importance attached to the very careful and meticulous approaches that will be necessary in order to properly address biodiversity assessment and species identification. It is possible, however, that some microscopes can be 'lent' from UK, and/or in part, be purchased from the training/education budgets.

8. The number of local staff required for the work is presently estimated at approximately 35 per country - including drivers, field operatives, technicians, scientists, and administrative and office support staff. These have not been costed - although it will be a simple matter to do so once the latest rates of pay are available. We propose to place one or two British graduates in Africa for the duration of the project; this contribution is in addition to, not a substitute for the existing British consultant input.

9. Equipment and other resource requirements, and a draft costed work schedule are appended.

RESUMÉ

Effets de la pollution sur la biodiversité (des organismes inférieurs) du Lac Tanganyika

1. Cette étude vise à:

- identifier les sources principales de pollution du Lac Tanganyika et, si possible, quantifier les apports de polluants
- obtenir une évaluation globale du degré de pollution et ses effets sur la biodiversité des organismes inférieurs
- développer des programmes systématiques de description et de contrôle de la pollution et de la biodiversité qui soient répétables - de telle manière qu'un changement (ou une absence de changement) puisse être déterminé(e) avec confiance
- développer (dans les pays limitrophes) des équipes capables de maintenir les investigations allant de la planification et l'exécution de programmes sur le terrain et en laboratoire, à l'analyse de données et l'établissement de compte-rendus sur les résultats, de la manière la plus adéquate pour les collègues scientifiques, les gérants du lac et les législateurs
- développer des stratégies de contrôle de la pollution.

2. Le terme 'pollution' dans cette étude est considéré comme l'apport accéléré par les activités anthropogéniques de nutriments (ou eutrophication), de composants organiques (demandeurs d'oxygène) issus des eaux d'égouts ou des rejets de sucreries, de métaux lourds, pesticides et composés susceptibles de découler de l'exploration et le transport du pétrole. Autant que possible, la 'biodiversité' sera considérée comme la gamme totale d'organismes présents/détectés, ceci excluant le poisson qui sera de façon plus appropriée traité par l' étude sœur sur la biodiversité *per se*.

3. L'extraordinaire nombre d'espèces dans le lac est en grande partie attribuable à la grande taille du lac, son grand âge et son isolation de 1.8 M-a, et à la diversité écologique. De plus, cependant, certaines caractéristiques physiques telles que la large taille et la profondeur rendent le lac sensible à la pollution car elles contribuent à augmenter le taux de rétention des polluants aquatiques et aériens qui le pénètrent. De même que dans de nombreux systèmes lacustres, il existe toujours la possibilité de l'effet 'cascade' de la pollution sur une espèce qui affecte relativement rapidement des espèces à d'autres niveaux trophiques.

4. Des bases de données comprenant plus de 3000 titres sur le Lac Tanganyika, environ 200 sont citées. Très peu d'entre elles font référence à soit la 'pollution' soit la 'biodiversité, et la documentation sur les effets de l'un sur l'autre est insuffisante. De plus, à part quelques exceptions, les articles sur la 'diversité des espèces' sont d'une valeur quelque peu limitée. Premièrement, ils sont restreints à relativement peu de groupes phylogénétiques et deuxièmement, ils se limitent en général à des listes sans indication des efforts mis en œuvre pour générer les données sur les espèces; le nouveau projet a pour objectif de combler ces lacunes en (i) essayant - au moins à certains sites d'échantillonnage - de décrire la diversité spécifique *in toto* i.e. du plancton microscopique jusqu'aux organismes inférieurs d'une dimension inférieure à 1 dm., et même les plantes aquatique d'une dimension de quelques mètres, en (ii) procurant l'information sur la taille d'échantillonnage de telle façon que de futurs chercheurs puissent générer des bases de données comparables.

5. Beaucoup parmi les références citées sont d'une inestimable valeur cependant pour procurer des informations aidant à la décision concernant les rangs des paramètres, les nombres et emplacements des sites d'échantillonnage, les programmes d'échantillonnage et les ressources humaines et en équipement nécessaires pour faire le travail. Comme base de discussion, sont considérés prioritaires les points suivants:

- eutrophication dans le Kigoma (Tanzanie) et le Bujumbura (Burundi)
  pollution atmosphérique sur le lac
- pesticides provenant des plantations de coton dans le bassin du Rusizi (Burundi)
- métaux lourds provenant des mines de diamant dans le bassin du Malagarasi (Tanzanie)
- rejets de l'industrie du sucre de canne dans la région de Uvira (Zaire)
- pollution par les hydrocarbures sur tout le lac

6a. Les eaux du large et du rivage seront étudiées, et des échantillons d'eau et de flore/faune représentatifs de la colonne d'eau de la surface jusqu'aux sédiments seront prélevés et analysés pour déterminer l'état de la pollution et de la biodiversité. Pour établir les effets de la pollution sur la biodiversité, la composition/richesse/diversité des espèces à environ 10 sites pollués (visités en moyenne 8 fois par an) sera comparée à celle de 10 sites non-pollués échantillonnés de manière similaire, et correspondant autant que possible pour des caractéristiques d' aspect, exposition, profondeur d'eau, substrat de fond et proximité du rivage ou du large.

6b. La liste des paramètres physico-chimique envisagés à ce stade est:

- lumière, température, transparence, particules totales en suspension
- conductivité/salinité, oxygène dissous, pH, alcalinité
- calcium, sulphate, fluorure, silice (réactive et totale)
- ammoniac, nitrate, nitrite, azote organique
- phosphore (P), incluant les fractions solubles (dissoutes) et de phosphate non-réactif, et le P total présent
- matière organique (dissoute et totale)
- chlorophylle$_a$
- hydrocarbures (carburants, de la cale, etc.) dans l'eau, les sédiments et les tissus de certains mollusques, crustacés et poissons
- pesticides et PCBs dans les tissus de poissons et mollusques (voire aussi PAHs)
- traces de Cu, Zn, Mn, Fe, Pb, Cd, Hg (dans les tissus de mollusques, crustacés et poissons).

7. L'estimation des coûts d'équipement considéré nécessaire pour mener le projet Pollution-Biodiversité à bon terme est loin d'être finalisée, mais le chiffre de £800,000 ($1.2M) est retenu provisionnellement. Ceci exclut les coûts d'utilisation de grands navires. Cependant il englobe des resources considérables en terme de matériels de bureau, de terrain et de laboratoire qui peuvent être partagés avec d'autres projets. Par ailleurs, environ 50% du total est affecté à l'achat de bons microscopes. Ceci reflète l'importance considérable attachée à l'approche très attentionnée et méticuleuse nécessaire pour traiter le sujet de la biodiversité et l'identification des espèces. Il est cependant possible que certains microscopes soient 'prêtés' par le UK, et/ou en partie, acquis de par les budgets de formation et d'éducation.

8. Le personnel local nécessaire pour le travail est estimé à 35 personnes par pays - incluant chauffeurs, opérateurs de terrain, techniciens, scientifiques et personnel d'administration. Les salaires de ceux-ci n'ont pas encore été chiffrés - bien qu'il sera simple de le faire une fois les taux de salaires disponibles et mis à jour. Nous projetons d'envoyer 1 ou 2 graduées Britanniques en Afrique pour la durée du programme; cette contribution est en plus de, et non au lieu de, celle des consultants Brittaniques existants.

9. Un programme préliminaire de travail lié à ces coûts est fourni en appendice.

RAF/92/G32 - POLLUTION CONTROL AND OTHER MEASURES TO PROTECT BIODIVERSITY IN LAKE TANGANYIKA

Baseline review - 4: Pollution of International Waters

1. Introduction

This document reviews literature on pollution and its effects on biodiversity in Lake Tanganyika. On the basis of the gaps in knowledge identified, it presents a preliminary costed programme of work that is considered the most appropriate for establishing the extent of pollution and its effects on biodiversity. Its main aim is to engender discussion between the lake peoples, and the project personnel, scientists and policy-makers in UK and Africa leading to the design of the final programme - with priority activities and decisions on how, when and where each of the different components will be tackled. Some thoughts on the effects of possible changes in climate and other long-term shifts in pollution and catchment management, are briefly addressed.

This section firstly defines what is meant by the terms 'pollution' and 'biodiversity' in the context of the project on pollution effects on biodiversity. Secondly, it lists the main aims of the work presently envisaged, and thirdly the scope of the baseline review. The programme aimed at assessing pollution and its effects on biodiversity is presented in detail later in this document (after the gaps in knowledge have been identified), but the introductory section concludes with the main features of this programme.

1.1 'Pollution' and 'biodiversity' as applied to the Lake Tanganyika project

In this study, 'pollution' is viewed as the anthropogenically accelerated inputs of the following classes of substances to the lake - *via* the catchment or directly onto the lake surface in wet or dry deposition, including spillage from ships and boats (see also Alabaster 1981):

- nutrients, especially phosphorus and nitrogen species in catchment run-off and in sewage effluent; these are the main agents of eutrophication *per see* (Harper 1992) and, more significantly, the cause of the enhanced production and biomass accumulation of nuisance plants, e.g. floating hydrophytes such as *Pistia stratiotes*, and potentially toxic, planktonic bloom-forming cyanobacteria, and mat-forming algae.
- organic (oxygen-demanding) compounds in sewage, and effluent from e.g. sugar-cane plantations.
- heavy metals from mining and leather tanning industries etc; these are often of concern because a number of them accumulate in sediment (Degens and Kulbicki 1973a), fish food organisms, and thus fish tissue (FAO/SIDA 1983; Maage, Eckhoff and Kjellevold 1994).
- pesticides including chloro-hydrocarbons stemming from agricultural land including coffee and cotton-growing areas: residues of many of these compounds also accumulate progressively more acutely in sediments, in sediment-dwelling biota (especially molluscs) and the organisms including fish and birds at the top of the food chains (Mattheissen 1977; Deelstra, Power and Kenner 1976).
- materials including drilling muds, stemming from oil exploration (Shackleton 1980; Livingston 1981; Cohen 1990; Nzori *et al* 1990; Ndabigengesere 1992; Baker 1992); accidental spills from e.g. electricity-generating plants, garages, for example (author's observations).
- miscellaneous substances from e.g. salt factories.

Gray, McIntyre and Stirn (1991) include 'sewage' and 'litter' (especially plastic products) in addition to the above pollutants, in their manual on marine pollution assessment.

It is worth stressing that the review is not considering as 'pollution' the essentially seasonal enrichment of the upper water mass of the lake due to wind-induced upwelling and other hydrological changes (Coulter 1963, 1967a, 1988). Nevertheless, the considerable importance of these processes will be taken very much into account in designing sampling programmes. Similarly, no original work by this project is envisaged on the emission of sulphurous compounds, hydrocarbons and metals from hydrothermal 'vents' (Degens and Kulbicki 1973b; Tiercelin

1988; Vaslet *et al* 1987; Tiercelin, Boulegue and Simoneit 1989; Tiercelin *et al* 1989; Tiercelin and Pflumio 1993); but again, these phenomena will be taken into account where they impinge on sampling and the interpretation of findings relevant to an understanding of pollution effects on biodiversity. This particular Special Study is also not dealing with sediment pollution, as this forms the basis of another Study. However, it is proposed that a considerable harmonising of the sampling strategies of the pollution and sediment studies be established in order that the impacts on biodiversity of each can be distinguished. This is particularly important since - in quantitative terms at least - some of the reductions in diatom, ostracod and fish species attributed to sediment pollution on soft and hard substrates (Cohen *et al* 1993) may be closely parallelled by changes induced by chemical pollution.

It may prove difficult in some areas to distinguish between the 'natural' and the 'polluted' states as far as eutrophication is concerned. A good example, relates to the Rusizi River; the geology of the upper regions of the catchment of this major feeder water to Lake Tanganyika, ensures that nutrients including phosphate are in plenty long before the river reaches the more heavily populated areas near the lake (Coulter 1991).

'Biodiversity' will encompass - at a few sampling sites at least - all phylogenetic groups i.e. from sub-micron pico-cyanobacteria to biota such as rooted vegetation; otherwise, the biodiversity will concentrate on what are presently perceived as 'key' groups such as micro-Algae, Ostracoda, Mollusca some of which may reflect pollution status. Fish and higher vertebrates will be dealt with under the main biodiversity programmes.

Knowledge about an aquatic ecosystem and the effects of physical and chemical factors on the biota, and the interactions between organisms at different trophic levels, can be furthered significantly by taking account of the sizes, size ranges and size distributions of the organisms (e.g. Gaedke 1993). This is because size controls a variety of ecological processes (e.g. sinking, vertical migration, light harvesting, nutrient uptake) and interactions (e.g. feeding). Pelagic forms alone are likely to span a range of 4 or 5 orders of magnitude in Lake Tanganyika. Such an approach would help to distinguish between groups, assemblages and communities of species that could appear very similar on the basis of the more traditional measures of diversity such as species richness and numbers. Different 'weighting' will need to be applied according to whether the species in a particular array belong to the same Genus or Family, or to a range of Phyla, for example.

Before considering the aims of the study, it is worth pointing out that localised pollution incidents/situations for example, may well result in more species being recorded. Certainly, organisms have a considerable propensity for exploring unusual situations - as exemplified by fish venturing into zones of very low oxygen content (Coulter 1967b). In providing 'new' spectra of physical and chemical conditions, hitherto-unrecorded species and assemblages can be expected. As an example, the build-up of sediment in, and the entry of chemical constituents to the Rusizi delta (Cohen *et al* 1994) may well provide new refuges for invertebrates which could explain the rich avian fauna there (Coulter and Mubamba 1993). In this connection, the present project may be faced with the task of judging whether a species assemblage of pollution-associated organisms is more desirable than one of the same numerical richness associated with the more pristine environments! In this connection, there is likely to be a tendency to attach more 'value' to a 'high profile' fish species forming the basis of a substantial fishery, than say, a key set of microscopic organisms comprising the food chain on which the fish ultimately relies. Different views are also likely to be raised regarding the value of a species where there are conflicts over wildlife or habitat conservation on the one hand, and food production on the other.

1.2 The main aims of the Special Study on the effects of pollution on Lake Tanganyika biodiversity

The main objectives are as follows:

- to obtain information that represents the lakewide situation as regards pollution and its effects on biodiversity.
- to identify the main types of pollution, and their sources, and gauge where feasible, pollutant concentrations and 'loadings'.
- to examine the biodiversity within the polluted/eutrophicated areas, and at appropriate distances from the sources of pollution/nutrient enrichment - including, where they exist, 'pristine' areas of similar physiography (e.g. water depth, substrate).

- to assess the effects of pollution on biodiversity - and thus, the levels of pollution that can be sustained by the lake without loss of biodiversity; zones known, discovered or suspected to be 'special' in terms of e.g. biodiversity, fragility, pollution pressures, or the harbouring of rare or important fish food species, will receive specific attention.
- to establish a sustainable, systematic programme of pollution and biodiversity monitoring that will allow future changes - or lack of change - in the situation to be established; the majority of the data that exist already on biodiversity (in the form of species lists), are of limited use in this connection, due to the relative lack of information on e.g. sample size and 'searching effort' involved in deriving them; exceptions include the work of Hori, Yamaoka and Takamura (1983) who recorded 38 fish species in a haul of some 7,000 individuals off the Luhanga shore (Zaire).
- to establish - through mainly 'on the job' training' - a cadre of Burundian, Tanzanian, Zaïrian and Zambian scientists well-versed in the following:
  - project/mission/cruise planning, with a clear view of the aims of the work
  - the organisation and acquisition of equipment and human resources
  - field sampling, including the recording of field conditions, sample location and type, and the immediate examination, treatment, preservation and storage of the materials collected
  - laboratory analyses
  - data logging and analysis
  - data interpretation.
  - data presentation in written and spoken form.
- where necessary, to design (in association with policy-makers) pollution control and mitigation programmes.
- to develop new, and strengthen existing links between this project and other pollution assessment and control studies on Lake Malawi and Lake Victoria, as well as Lake Tanganyika itself.

1.3 Scope of the review

The review assesses current knowledge on the pollution of Lake Tanganyika (Section 3); as indicated above, it covers eutrophication as well as more 'traditional' aspects of pollution (involving e.g. metals, herbicides, ship fuel residues). Section 4 then assesses the extent of quantitative knowledge on the effects of pollution on the biota and biodiversity of the lake. The gaps in understanding so highlighted by these reviews, are outlined in Section 5, while Section 6 describes the main approaches presently envisaged for assessing the current state of the lake as far as pollution is concerned, and to what extent it affects biodiversity.

The scientific information will eventually be placed in context with the multidisciplinary activities within the sectoral fields to ensure (i) that socio-economic consequences of scientific findings (such as a decline in a fishery, or a key food species due to pollution) are adequately highlighted, and (if) that personnel at government ministry and departmental levels are availed of the issues. Some preliminary information is included on current institutional capability and manpower availability, and how all bodies associated with the project can collaborate to mutual advantage. Three Annexes are appended: a draft work plan containing as much detail as is possible to present at this juncture; a list of specialised equipment needs; and a discussion on the implications of the review for social-economic inputs to the project.

The review results from an examination of some 3000 works. These were generated - using a combination of the key-words 'Lake Tanganyika', 'pollution' and biodiversity' - by computer-based searches of the ASFA and GEOREF bibliographies, and the holdings of the libraries of the Freshwater Biological Association (Windermere, England), and the Institute of Freshwater Ecology (Edinburgh, Scotland). Two works are worthy of mention at the outset: the magnificent monograph on ('Lake Tanganyika and its Life' (Coulter 1991), and the review by Crul (1993).

Just over 200 research papers and published and unpublished reports are cited here i.e. less than 10% of the total number consulted; this reflects the relative paucity of literature on pollution *per see*, and even less on its effects on biodiversity. The majority of the works were consulted at (i) the Documentation Centre of FAO/FINNIDA Lake Tanganyika Research, Bujumbura, Burundi, and (if) the Belgian Centre Regionale de Recherches en Hydrobiologie

Appliquée (CRRHA).

1.4 The basic approach proposed for assessing pollution effects on Lake Tanganyika biodiversity in the light of the review

This section confines itself to the very basic approach suggested for the pollution-biodiversity work. Details of the approaches to, and methods of such aspects as sampling, data handling, interpretation and presentation, are given in section 6 and the Appendices.

To achieve the aims outlined above, a principally simple, stratified sampling strategy combined with attention to known 'hot-spots' of pollution and diversity, and taking account of the following, is proposed:

- variation over a wide range of timescales in major physical and chemical events; these include (i) 'natural' processes and phenomena e.g. reasonably seasonal stratification cycles and fish migrations, and diurnal plankton movements, and irregular run-off events, and (if) less predictable anthropogenically induced oil-spills and sewage discharges, for example.
- on-going limnological studies such as those by the FINNIDA and the CRRHA teams; the temptation to initiate limnological work that is crucial to the success of the pollution and biodiversity study, but which is - in part at least - already covered by these other investigators, must be resisted.
- the need to integrate all aspects of the pollution and related biodiversity work (hereafter termed 'pollution-biodiversity') with the sediment and sediment-related biodiversity studies; maximum use of limited resources (especially of large vessel usage) can only be achieved by a very close inter-meshing of these aspects - especially in terms of the dispersion of sampling stations, the sampling schedules, and the collection of water, plankton, benthos and sediment/substrate material for pollutant and biodiversity analysis.

2. Features of Lake Tanganyika and its biodiversity that give rise to concern over possible pollution

This section concerns the basic *raison d'etre* of the present project, by attempting to explain why there is concern over the pollution of such a massive waterbody as Lake Tanganyika. The main reasons for the concern are three-fold, and they relate to the following:

- species diversity.
- factors that appear to have favoured what is viewed as the extraordinary variety of organisms.
- features that are likely to render the lake prone and sensitive to pollution.

2.1 Biodiversity

During an expedition some 90 years ago Cunnington (1920) recorded a total of approximately 320 animals in Lake Tanganyika; this included 146 fish, 84 Mollusca, 31 'Eucopepoda', 22 Ostracoda, 12 macruran Crustacea, 6 Hydrachnida, 5 Brachiura, 5 Polyzoa and 3 Oligochaeta. Rotifera and Cladoceran Crustacea were not recorded, and the situation regarding these two groups apparently prevails to the present day - although Cladocera have been recorded within the drainage area. [Bearing in mind the apparent ease whereby rotifers can be dispersed, the present authors consider that the likelihood of representatives of this group being completely absent from the lake is slim indeed.]The total number of species in the lake is still not known, but recent inventories suggest that there are more than 1300 animals (Coulter 1991). Subsequent expeditions, show that the number of gastropod molluscs alone, for example, has now exceeded 130 species (Michel 1994), while Martens (1994) lists 64 ostracod species, 60 of which are considered to be endemic. Table 1 lists animal groups and the papers referring to other expeditions, some of which also extend back to the last century (see also Moore 1897).

Table 1. Some other sources of information on species numbers of the better-studied faunal groups (excluding fish) of Lake Tanganyika.

group	author/s
Thecamoebae protozoans	Chardez 1980
Rotifera	Rousselet 1910
Mollusca	Ancey 1894; Brown and Mandahl-Barth 1987; Leloup 1953
Nematoda	Decremer and Coomans 1994
Oligochaete annelids	Beddard 1906
Harpacticoid crustacea	Chappuis 1955
Branchiuran crustacea	Cunnington 1913
Ostracod crustacea	Martens 1984
Copepod crustacea	Leloup 1952
Aves	Benson and Irwin 1967; Gaugris 1979

Fish have attracted most attention in relation to species diversity and speciation (Brooks 1950; Coulter 1994b; Martens, Goddeeris and Coulter 1994); some 250 species have been recorded from the lake itself, while a further 100 or so have been found in the basin as a whole. De Vos *et al* (1994) estimates that nearly 80% of the lacustrine species are endemic. The basin and lake totals, and the number of endemic species are comprised largely of the Cichlidae: 187 basin total, 170 lake total and 160 lake endemics. The number of non-cichlid species is still impressive, however, with 72 species in the lake and an additional 70 or so in the basin; 40 of the lacustrine species are thought to be endemic (De Vos and Snoeks 1994).

Important in exhibiting considerable biodiversity on the plant side, are Algae. For example, some 750 species have been recorded from the plankton (Meel 1954; Hecky and Kling 1981, 1987; Caljon 1987). This reflects the spatial variation as well as temporal changes in the assemblages (Cocquyt, Caljon and Vyverman 1991). However, a feature of the lists of types recorded from the water column is the prominence of species - especially diatoms - that the present authors associate more with the benthos i.e. the surfaces of shallow sands, muds and rocks, and fringing macrophytes. This could indicate considerable re-suspension or erosion of material from sediments and other surfaces due to wind-induced turbulence.

As an indication of further ecological diversity, the lake also contains epilithic algae, that is, forms associated more specifically with pebbly, stony and rocky surfaces (Cocquyt 1991, 1992, 1993). Furthermore, diatoms including subspecies and forms (such as the benthic *Surirella* investigated by Cocquyt and Vyverman, 1992) are likely to be associated with macrophytic vegetation and muds (see e.g. Caljon 1991). The algal flora of some of the feeder waters e.g. the Rusizi (Mpawenayo 1985, 1986) adds more species to the total list.

In general, biodiversity can be expected to be greater in the littoral areas than the pelagic and the profundal zones (Brooks 1950). Some investigators (e.g. Dumont 1994) view the pelagic food webs of the lake as relatively simple; there is only one major, grazing micro-Crustacean, for example, and the 'absence' of Rotifera and Cladocera has been noted elsewhere. However, one of the aims of the GEF project is to establish whether benthic algal assemblages, for example, are intrinsically richer than the corresponding communities in the plankton. Even if this proved to be the case, plankton assemblages might exhibit the greater variation over time. On the other hand, high grazing pressure on the algal benthos from a range of fish species alone (see e.g. Hori, Yamaoka and Takamura 1983; Kawanabe 1981, 1983, 1985, 1989; Kawanabe and Kwetuenda 1988; Kawanabe and Nagoshi 1991; Kawanabe, Kwetuenda and Gashagaza 1992), may result in considerable temporal diversity. In this connection, the microphytobenthos may reflect heavy grazing pressure - and thus, low biomass in spite of high productivity (see Takamura 1987) - in the same way as the plankton as interpreted by Hecky and Kling (1981, 1987) and Hecky *et al* (1981). The last-cited paper is also of interest in surmising on the probability that heterotrophic bacterial production exceeds photosynthetic primary production. In the surface waters off Kigoma, the present author noted the prominence of potentially bacteriophagous Protozoa including colonial vorticellids indicative of organic pollution.

Valuable as they are, many of these records are of somewhat limited use as a baseline for biodiversity, with which to compare future findings. This is because the works rarely provide information on the size of the samples from which the lists of species were derived. As already indicated, the present project aims to record species numbers, richness and biodiversity in such a way that future workers can repeat the sampling programmes and thus generate comparable data. Only in this way can the project secure information that will show whether species diversity has changed, or whether pollution reduces species richness, for example.

2.2 Factors favouring biodiversity and speciation

The extraordinary species richness of Lake Tanganyika, can be attributed to a combination of the following factors:

- very large size (Table 2)
- great age (>20 M y), and more importantly, isolation for some 1.8 M y
- a very considerable range in ecological diversity i.e extensive physical and chemical spectra providing numerous situations/niches for colonisation by organisms; Coulter (1994b), Molsa (1991, 1995) and Nagoshi, Vanagisawa and Kawanabe (1993) are general treatments, while examples concerned with more specific areas are:

- the variety of rocky, sandy, silty and muddy shorelines (Coenen 1993a; Coenen, Hanek and Kotilainen 1993; Hori, Yamaoka and Takamura 1983), and land-water 'ecotones' (Ntakimazi 1995).

- temporal and spatial changes in light penetration (Plisnier 1992, 1993), and nutrient concentrations (Edmond 1975, 1980; and Edmond *et al* 1993).

- the interfaces between contrasting conditions of e.g. oxygen content (Coulter 1967b), and suspended sediment

(Cohen *et al* 1993).

- extremely dynamic and complex water movements (Coulter 1967a, 1988), and other features of the lake hydrodynamics (Huttula, Peltonen and Nieminen 1993; Huttula and Podsetchine 1994; Kotilainen 1993, 1994).

- territorial behaviour of e.g. cichlids may well have also contributed to the speciation process.

Table 2. Some statistics demonstrating the very large size of Lake Tanganyika (from Coulter 1991, and Hecky and Bugenyi 1992).

parameter	value
catchment area	249 000 km^2
lake surface area	32 600 km^2
maximum depth	1 470 m
mean depth	580 m
length	*ca* 650 km
mean width	50 km
volume at modal water level (773 m a.s.l.)	18 800 km^3

However, some groups of organisms are represented by comparatively restricted species arrays in Lake Tanganyika. Prime examples are the already-noted apparent lack of Rotifera (in open water at least) - and Cladoceran Crustacea; Vuorinen (1995) attributes the absence of Cladocera to the unavailability of oxic sediment for the development of resting stages. The upwelling that brings anoxic water to within 80 m of the lake surface, is also suggested by Eccles (1986) to have restricted speciation in demersal fishes.

2.3 Features that are likely to render the lake prone and sensitive to pollution

A number of considerations justify the concern over the threat of pollution to even such an enormous waterbody as Lake Tanganyika. Over and above the facts that (i) the lake is very special, (ii) there are known hot-spots of various forms of pollution (see below), and (iii) there is no reason to expect pollution pressures to decrease, there is a need to take into account the following:

- *via* the 'cascade' effect, pollution could bring about changes in the performance and thus biodiversity of organisms at all trophic levels - although as mentioned above, biodiversity need not necessarily decrease.
- 'structural' and hydrodynamic features of the lake and its basin lend themselves to the accumulation of pollutants and the production of potentially troublesome organisms.

Via the 'trophic cascade', links exist between organisms at different trophic levels in every ecosystem. Realisation of this has founded models of trophic interrelationships (see e.g. Moreau *et al* 1993). The response by one set of organisms e.g. primary producers, to changes in another, such as the top-predators, appears to be particularly well-documented for aquatic systems (e.g. McQueen *et al* 1989; McQueen, Post and Mills 1986). Debate often continues over whether a particular system has changed in response to a 'bottom-up' effect, such as a shift in nutrient supplies (eutrophication, for example), or to the 'top-down' effects of some perturbation of fish stocks. There are British examples suggesting strongly that both 'top' fish predation on herbivorous zooplankton and 'bottom' nutrient enrichment are involved (Bailey-Watts and Kirika 1995). A number of African lakes have been studied in this connection. Lake Kivu (Dumont 1986) is case in point, but the most topical example is Lake Victoria. The introduction of the Nile Perch (*Lates niloticus*) is considered by most - though not universally (see e.g. Reynolds and Greboval 1988) to have played a big part in the degradation of that lake, by way of reducing fish diversity, and decimating the artisinal fisheries (Barel *et al* 1985; Miller 1989; Achieng 1990; Ogutu-Ohwayo 1990, 1993; Kaufman 1992; Kaufman and Cohen 1993; Kudhongania, Twombo and Ogutu-Ohwayo 1992). In this respect, Goldschmidt, Witte and Wanink (1993) are justified in concentrating on the cascade effect of the perch. However, the burgeoning of *Eichhornia crassipes* over the last decade at least, suggests that eutrophication has also contributed to the situation in Lake Victoria. Figure 1 (from Bailey-Watts 1995) attempts to highlight the latter feature while also acknowledging the impact of *Lates* through its predation on, or competition with smaller fish species. It is also noteworthy in this connection that another floating hydrophyte - *Pistia stratiotes* - is present in Lake Tanganyka.

Such cases illustrate very forcibly Man's considerable ability to alter some major features of even very large lakes, and in this respect the concern over Lake Tanganyika is well-justified. A feature of Lake Tanganyika is the extraordinary dynamism; such a large system might be more usually considered 'physically well buffered' and insensitive to external influences. On the contrary, assemblages of phytoplankton and fish can change remarkably quickly. This can be attributed to fluctuations in factors that impinge on the 'whole' system; examples are incident radiation, wind-induced mixing, massive nutrient upwellings, and food chain interactions. These contrast with impacts such as the external inputs of nutrients and pollutants, which are important in the long-term, but probably have little startling effect until a threshold level of a particular substance has been attained.

As with Loch Leven, the Lake Victoria situation is very much a reflection of its unique features. At just 40 m mean depth, for example, this African lake is considerably shallower than Lake Tanganyika, and thus likely to produce more phytoplankton biomass per unit of (limiting) nutrient loading (Bailey-Watts 1994, 1995; Bailey-Watts *et al* 1994). Still, however, the lessons of Lake Victoria must be noted and, in contrast to the situation surrounding Lake Victoria, the early warnings (Fryer 1972) must be heeded.

Features maximising the effects of pollution include the virtually completely closed nature of the basin (1991, 1992). As a consequence of this and the situation that prevails as regards the water balance of the lake (Hecky *et al* 1993 - see Table 3), water stays in the lake for an extraordinarily long time.

Table 3. Some hydrological features of Lake Tanganyika that result in very high retention coefficients for many of the substances that enter the lake.

feature	value
annual inflow volume	14 km^3
annual outflow volume	2.7 km^3
annual precipitation volume	29 km^3
flushing time (lake volume/outflow volume)	7 000 y
residence time (lake volume/(precip. + inflow volume)	440 y

The system will retain an exceedingly high proportion of the nutrients and pollutants that enter it; only with elements in gaseous phase do major fluxes from the waterbody take place. For example, models developed in North America and Europe (e.g. Kirchner and Dillon 1975) predict well, in the absence of significant net fluxes of dissolved phosphorus from lake sediments, the retention coefficient of total phosphorus (i.e. that existing in particulate and dissolved form). If morphometric and hydrological data such as those shown in Table 3 are incorporated into these formulations, retention coefficients of approximately 0.99 are obtained. Such results are well in keeping with those discussed by Hecky *et al* (1993).

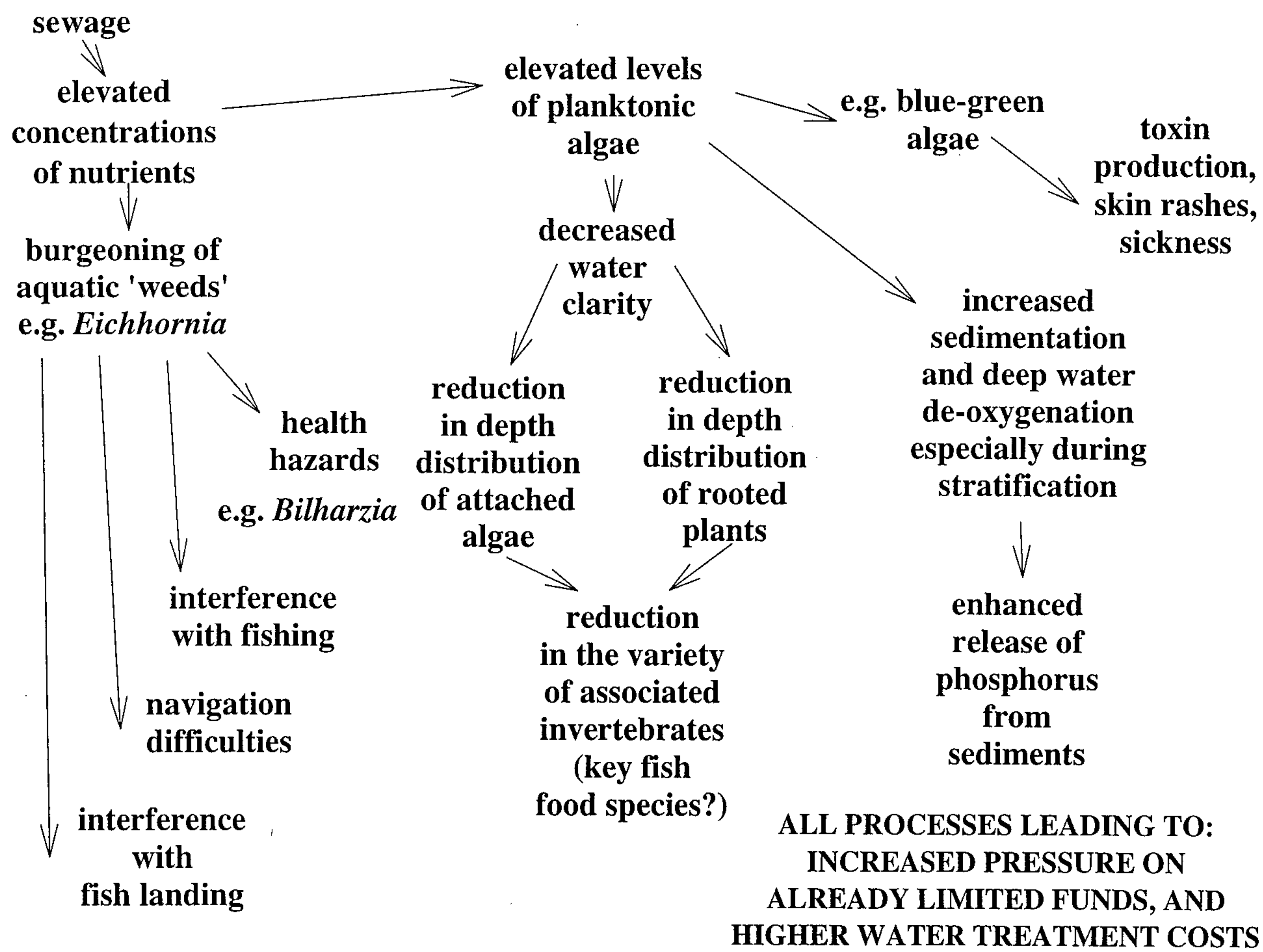

Figure.1. Some consequences of eutrophication in Lake Victoria. (From Bailey-Watts 1995).

3. Pollution in Lake Tanganyika

This section is the first of two which review literature and thus begin to identify gaps in knowledge regarding pollution and its effects on biodiversity; as such they lay the foundation for the design of the new work.

That Coulter (1991) has just two references to 'pollution' in the subject index of his monograph, reflects the overwhelming focus on issues other than pollution, although as mentioned above, the vulnerability of Lake Tanganyika to pollution is well-recognised. Indeed, it now appears that - in contrast to a quarter of a century ago when Thorslund (1971) concluded that water pollution in African countries was not a serious problem - the situation has somewhat changed. The term 'somewhat' is used, as there is still dispute over whether Lake Tanganyika is polluted or even whether there are any real threats of pollution. The polarisation of views may be more apparent than real however, and the following points might be usefully borne in mind when trying to clarify the situation.

Apart from the reasons given above for concern over the pollution of Lake Tanganyika, there is very justifiable concern over all forms of pollution. Firstly, like any freshwater body, Lake Tanganyika acts as a depository of all manner of wind- and water-borne substances from its catchment. In the case of wind-borne pollutants the long distance transport of contaminants from outside of the lake basin and catchment area may also be significant. Secondly, the literally vital resource - the water itself is directly affected. Thirdly, the underlying sediment which plays such a key role in the lake ecosystem, especially in the shallower waters, acts both as a repository for and a reservoir of pollutants such as heavy metals and pesticides. Fourthly, fish which, in Africa in general and Lake Tanganyika in particular, constitute a major source of animal protein and vital trace elements (Benemariya, Robberecht and Deelstra 1993), are also likely to become contaminated.

Table 4 lists the various types of pollution that could threaten the biodiversity of Lake Tanganyika. It includes relatively easily identified point-sources of pollution, as well as the much less readily quantifiable diffuse inputs of pollutants and nutrients - from the catchment and in a number of ways directly over the lake surface. Extreme run-off from steep terrain bordering the east side of the lake, just south of Bujumbura, may also merit attention unless this can be viewed as a natural phenomenon rather than pollution *per se*.

Table 4: Sources of pollution in the basin catchment area of Lake Tanganyika

type of pollution	sources within the Lake Tanganyika catchment
urban domestic wastewater; industrial wastewater	R. Ntahangwa, Bujumbura, Burundi[a]
chlorinated hydrocarbons - pesticides	cotton plantations in the Rusizi river
Heavy metals	Northern (Burundi) lake waters [c]
river-borne sediments and associated nutrients from fertilisers	R. Rusizi, R. Malagarasi
mercury (inorganic and organic) from gold mining operations	R. Malagarasi catchment
Ash residues	Cement works, Kalemie
Organic wastes, sulphur dioxide	Sugar cane and refining plant, near Uvira
Shipping operations	Lake-wide; oil depots e.g. Bujumbura

[a] Vandelannoote *et al* (in press, and 1994a); Bigawa *et al* (1994).
[b] Deelstra (1977a, b)
[c] Sindayigaya et al (1994)

For some pollutants such as urban domestic and industrial wastes, pesticides and heavy metals, a limited amount of information on contamination already exists. However, the data were generated from relatively few sampling sites. They thus provide very little information on species, or on seasonal, temporal or spatial variations of the contaminants. To our knowledge, no significant data have been reported for the remaining sources of pollution listed.

With the ever increasing pace of agricultural activities in the catchment, and the tendency to cultivate on steep slopes bordering the lake shores and the inflowing rivers, the amounts of soil being washed into the lake, already quite significant, are likely to continue to rise. Apart from the physical impact of such materials, the pesticides, nitrates and heavy metals associated with such particulate matter may well constitute a substantial component of the inputs of such contaminants.

The lake is also vulnerable to 'informal' industrial activities e.g. gold mining, which are taking place in the various catchment areas. The scale of such mining operations in developing countries world-wide has expanded rapidly in the last decade, and the use of mercury in gold mining in tropical regions constitutes an increasing and particularly serious source of mercury contamination and exposure (Jernelöv and Ramel 1995).

Pollution can be as high as 1 kg of mercury for every kg of gold recovered. 70% of such losses are to the atmosphere with a further 20% escaping as mine tailings discharge to the rivers. Once evaporated the mercury may remain in the atmosphere for as long as 24 months in dry climates. Reactions in clouds result in shorter overall residence times causing mercury to return to earth in rainfall. In the Amazon region, for example, such mercury-rich rainwater has been shown to result in pollution of fish collected at sites distant from the mining activities (Velga and Meech 1995). On the basis of the available literature relating to the use of mercury in gold mining elsewhere in the tropics, the mining of gold in the Malagasi catchment area is likely to have significant environmental implications. These will be assessed during this project.

Small-scale diamond mining is also being carried out at various locations in the Lake Tanganyika catchment area. The extent of these operations is unclear at present, but the flotation oils and chemicals used to separate the diamonds from the mineral matrix represent a potential source of pollution, which will be evaluated.

Other industrial facilities such as the cement works near Kalemie and the sugar cane production and refining operations located north-west of Uvira may also be sources of pollution. Particulate emissions and high BOD wastes are likely to represent the most serious environmental threats from the cement works and the sugar production works respectively.

Shipping activities represent a further potential source of pollution of the lake. Oils may enter the lake directly from ships due to leakage of fuel oil or from discharged bilge oil. Further pollutants may arise from fuel oil combustion products and from leakage from fuel depots. The levels of such oil contamination will be determined during the project and attempts will be made to distinguish between such anthropogenic sources and those of natural origin.

4. The effects of pollution on the biodiversity of Lake Tanganyika

In an attempt to simplify what was thought initially to be a large task of reviewing the effects of pollution on the biodiversity of this large lake, the subject matter was categorised into three sections based on water depth zones, and dealing respectively with the following:

- littoral areas and associated biological communities occupying that part of the water column extending from the lake edge to the depth to which rooted or other attached organisms are present
- the 'neritic' zone extending from the deepest limit of the littoral zone to 200m water depth
- the 'abyssal' zone i.e. where the water depth exceeds 200m.

However, the review has highlighted such a dearth of works on pollution effects on biodiversity *per se* that such a breakdown is unwarranted at this stage. It is retained above as an indication of our thinking as regards sampling strategies.

As discussed above in relation to cascade events, there is increasing awareness of the peculiarly inextricable links between e.g. physical factors and conditions, nutrient and pollutant status, and the organisms at different trophic levels in aquatic ecosystems. Other examples are reflected in the relationships between hydrological processes and primary production (Coulter 1963 and 1968), lake morphometry and fish yields (Henderson and Wellcome 1974), primary productivity and fish yields (Melack 1976), and the effects of physical factors on food chains and fish stocks in the oceans (Mann 1993). In spite of this, the original intention of this review was to present issues (within each of sections based on water depth above) on the effects of pollution on the primary producers (e.g. higher plants, phytoplankton and phytobenthos), separately from those on secondary producers (such as the herbivorous zooplankton, invertebrate zoobenthos and fish), and likewise with the effects on other biota (such as carnivorous invertebrates and fish). Plainly, this layout too, is quite inappropriate at this stage - although it also indicates our thinking on the manner in which sampling aimed at ascertaining the effects of pollution on biodiversity will be approached. In these circumstances, the most appropriate way forward appears to be to simply comment, where data exist, on any issues that the papers referred to in the previous section raise in relation to biodiversity.

Vandelannoote *et al* (in press, and 1994a) demonstrate the very marked contrast between the chemistry of the polluted Ntahangwa and the virtually 'pristine' Mugere in terms of nutrient levels and organic content (for example, 300 and 2 μg soluble reactive phosphorus (as P) l^{-1} respectively, and 923 and 238 mg suspended solids l^{-1}). That paper comments little on biota, but the phytoplankton chlorophyll$_a$ levels which are elevated in the lake bay as a result of the pollution, are almost certainly accompanied by shifts in biodiversity; the data of Caljon (1992) support this view, even though no actual biodiversity indices are presented. A similar relationship between increasing pollution levels and decreasing zooplankton and phytoplankton species diversity was observed in the Kenyan waters of Lake Victoria (Foxall *et al* 1985). However, in utilising the potential of macro-invertebrates as indicators of pollution, Vandelannoote, Vyumvuhore and Bitetera (1994) suggest that neither the Ntahangwa nor the lake in the vicinity of that inflow is seriously polluted with regard to heavy metals or pesticides. This is in contrast to the situation regarding organic pollution; Bigawa et al (1994) have detected a number of bacteria that indicate faecal contamination of the Bujumbura Bay. Although the extent of any effects on biodiversity has not been examined, the paper stresses the need for more work on the effects of the bacterial contamination on other links in the trophic chain. The use of other organisms (e. g. diatoms - see Richardson 1968) as indicators of pollution, is to be explored by the present project.

Deelstra (1977a) considered that the pesticide residue levels that he measured in fish some 25 years ago, were well below the limits set in most African countries at that time. Indeed, he felt that those data would provide a useful benchmark with which future information could be compared and trends thus established. However, he (Deelstra 1977b) suggests that the organochlorine levels in the fish tissues were higher in Lake Tanganyika than in other African waters. A new census of pesticide purchase and usage could give some indication of the trends, since Deelstra (1977a,b) provides data for the period 1969-1972.

Levels of heavy metals measured in two species of fish *(Lates stapersii and Stolothrissa tanganyikae)* collected from the Burundi waters of the lake have been reported (Sindayigaya *et al* 1994) to be low and were considered by the authors to reflect natural background levels rather than pollution. Such concentrations may, however, not be representative of the levels in samples from other areas of the lake, or in other fish species. A more extensive survey of metal concentrations in a range of fish whose feeding habits are representative of the possible uptake routes will be carried out during the present project.

5. Gaps in knowledge regarding pollution and its effects on biodiversity in Lake Tanganyika

That there are gaps in knowledge regarding pollution and its effects on biodiversity is already plain from the foregoing sections. The situation is also reflected in the fact that papers and reports on these issues are outnumbered by a factor of *ca* 100:1 by works on other aspects e.g. lake dynamics, organism ecology and fisheries indicated in Table 5.

Table 5. An indication of the extent of the database on aspects of the structure and functioning of Lake Tanganyika.

area of investigation	references
lake morphometry	Coenen 1993; Coenen, Hanek and Kotilainen 1993;
hydrodynamics	Huttula, Peltonen and Nieminen 1993; Kotilainen 1994;
hydrology	Podsetchine and Huttula 1995;
fisheries	Coenen (ed.) 1993; Hanek, Coenen and Kotilainen 1993; Annual statistics - Tanzania e.g. 1994);
sampling	research vessels: Hanek (ed.) 1995; fisheries: Hanek and Coenen 1994; fish movements and other migrations: Coulter 1976b; limnology: Plisnier 1993, 1994; zooplankton: Burgis 1984, 1986; Kurki 1993; Vuorinen 1993; Vuorinen and Kurki 1994;
biological indicators	Gray, McIntyre and Stirn 1991

There is thus, a wealth of background data - albeit largely in need of analysis and publication. It can place the GEF project in the very fortunate position of being able to concentrate more or less solely on the biodiversity and biodiversity-related issues, rather than basic fisheries, limnology and ecology. Above all, this knowledge bank - along with the publications of Coulter for example - will shorten considerably the decision-making processes on the dispersion of sampling sites, sample replication, and the schedules of sampling. It will also facilitate somewhat more rapid judgements than would have been otherwise possible, on issues over sampling gear and laboratory analyses. For example, there is a wealth of information on features that determine extremely important matters, such as how much rope is needed for anchoring, for the deployment of closing water bottles and other collecting apparatus! There are also data that indicate the types of analysis and analytical instrumentation most appropriate for detecting and estimating nutrient and major ion levels, for example. Trends or significant fluctuations in fish catch statistics may indicate a pollution-driven effect in a particular zone of the lake that is worthy of further investigation.

There are numerous lists of species (see above) but these are commonly restricted to individual Phyla or lower taxonomic grouping. More importantly, considering the main aim of the present study, data on 'species composition' have been invariably reported without details of the manner in which they were derived.

While a number of pollution 'hot-spots' are known (see above), there are virtually no data on the quantities (loadings) of material emanating from them, or how much of the pollutant reaches the lake.

In summary, there appears to be little, or no quantitative information on a number of aspects with a strong bearing on pollution and its effects on biodiversity. These are:

- sources of pollution in the catchment, and loadings/fluxes to the lake
- as above, but concerning the atmospheric deposition directly on to the lake surface
- the microflora - especially in the littoral benthos
- the zoobenthos in both the littoral shallows and the deeper water sediments/deposits

Moreover, even where data exist, they have rarely been derived in a manner that allows future investigators to repeat the work; as a result, there are precious few bodies of information which constitute baselines on which to gauge changes in the biodiversity of the lake.

6. Recommended approaches for assessing the effects of pollution on biodiversity in Lake Tanganyika

The first part of this section outlines the approaches characterising the project as a whole. Later parts go in to a little more detail on these points.

6.1 Priority research areas

In the light of the aims of the study (see section 1.2) and the gaps in knowledge identified above (section 5), the priorities of the new project are seen as follows:

- to identify the types and sources of pollution (including those coming from the atmosphere) and, where possible, estimate the rates at which the pollutants are reaching the lake.
- to establish datasets that describe biodiversity (as far as possible *in toto*), at a number of polluted and unpolluted sites within each of the major biotopes (e.g. rocky, sandy and silty in- and off-shore areas; muddy sediments and open waters) and international sectors of the lake.
- to provide information that illustrates where, and to what extent (in temporal, spatial and taxonomic terms) biodiversity is affected by pollution.
- to generate the data in a manner that can be repeated, to ensure that pollution-induced changes in biodiversity can be monitored and identified in the future, i.e. beyond the 'life' of the present project.
- to establish the equipment and intellectual resources in order that the study can be continued beyond the life of the GEF project.

In order to attain these goals, and achieve the related objectives listed in section 1.2, a number of approaches are proposed. The following sections focus on these approaches, and the basic tasks of establishing what observations and recordings will be made, where and when samples will be taken, and how these will be secured. On the basis of these considerations, a preliminary work plan has been designed (Appendix 1).

The main aims of the work will be achieved by the following means and consequent outputs.

A major feature is the inclusion of the catchment in considerations about the pollution of Lake Tanganyika. Considerable importance is attached to the influence of the catchment on the lake into which it drains, and on ultimately, the lacustrine biodiversity. Pollutant content of the main feeder waters as well as the lake itself, and in selected biota will be determined. This will facilitate some estimation of the fluxes of chemical pollutants (including nutrients) on three scales: (i) from the catchment to the lake; (ii) between the lake water and the biota; and (iii) between the water column and the sediments. Attention to inflow chemistry could also establish whether biota that move into the rivers are threatened by exposure to pollutants there rather than the considerably more dilute lake environment. Prime examples are spawning fish such as commercially important *Hydrocynus vittatus, Alestes macrophthalmus, Citharinus gibbosus* and *Barbus tropidolepis* in the Lufubu (Badenhuizen 1965).

A first step to identifying the major catchment-derived sources of pollutants, will be made by analysing map data and satellite imagery of the locations, distribution/cover in the watershed, of (i) different types of land use (forestry operations, agricultural practices, human occupancy, waste disposal areas, and heavy industrial zones), and (ii) the major feeder rivers. A Geographical Information Systems (GIS)-configured database of this information will be combined with models using published nutrient loss coefficients to gain some first estimates of the inputs of nutrients, and the relative contributions from different sub-catchments.

As to actually measuring the loadings/burdens/input rates of materials to the lake (and so refining the models), a network of river flow and e.g. pipe discharge gauges, and weather stations for the recording of rainfall and evaporation, will be installed near the lake (at river mouths etc). Water and sediment samples would be collected primarily from the mouths of the major feeder rivers at least monthly throughout the year, with the option of increasing the sampling intensity during the main rainy seasons. This 'core' sampling programme will be supplemented by occasional synoptic collections of samples from known outfalls and emissions of nutrients and conventional pollutants associated with e.g. on-shore fish handling/processing stations, villages and townships. The magnitude of the loading of fuel/fuel products from ships and boats into the lake may have to be estimated from boat numbers, duration of use and estimates of discharge rates. If time permits, extra attention will be given to the nature of land (*vis a vis* pollution) lying within 1 km of the lake edge - and particularly so for the areas abutting zones presently earmarked for the 'reserves'.

A simple framework on which these studies about the influence of eutrophication pressures on Lake Tanganyika biodiversity can be designed, is as follows:

pressures + sensitivity = responses

The *pressures* are determined by the catchment characteristics (land use, topography, climate), and developments that are likely to 'adversely' affect species numbers and composition; examples are urbanisation, and land degradation due to agricultural practices and deforestation; this aspect of the work will be synchronised with that of the sediment study - with that programme providing the river samples for the pollution group to analyse. The factors determining the *sensitivity* of the system to the pressures include a wide variety of physical and chemical features as well as the nature of the 'resident' biota of differing susceptibilities/resilience. The *responses* are the physical, chemical and (especially) biotic features which comprise the main focus of the project.

In order that the influence of pollution processes/activities on biodiversity of the lake as a whole can be assessed, we will examine the taxonomic composition of all biota i.e. in both the water column (at least down to the upper boundary of the monimolimnion) and in, or more or less associated with, rocky, sandy/silty, and muddy substrates. Only in this way, can a comprehensive assessment be attained of the likely (broad) spectra of physical and chemical niches and situations that determine bidiversity and speciation potential. The collection of organisms (from the smallest picoplankton $\leq 1\mu m$ through to the nekton of $\geq 1m$) will be done through a combination of stratified random sampling strategies (to achieve lake-wide assessment) and additional targeting of known or suspected pollution and/or biodiversity 'hot-spots', and areas of major conservation interest. In this connection, macrophyte-dominated shores - although of apparently limited extent - will be assessed since they are likely to harbour considerable biodiversity.

The needs and views of local communities regarding the Lake Tanganyika project will be addressed, by publicising the results of the pure and applied research work, and by involving people living/working on the lake or in its catchment, in decisions regarding the establishment of sampling sites and the maintenance of recording equipment.

Bearing in mind the overall focus of pollution-biodiversity study on lake management, the majority of the activities envisaged need to be of reasonably immediate relevance to decision-makers. The potential value of the results will not be realised, however, unless they are presented in a form appropriate to the particular needs of the 'customer'. Pages of chemical concentrations or lists of animal and plant species abundances will rarely suffice. While the provision of such information may meet basic statutory requirements, it is unlikely to be of much use to decision-makers such as municipal engineers, environmental health officers and town planners; it follows that the data will be of even more limited value to ministerial chiefs. There will be other requirements: summaries and written interpretations of the results tailored to the particular decision-maker. This may be initially viewed by the scientist or technician simply as extra work. However, experience elsewhere suggests that such exercises heighten considerably the scientist's awareness of the relevance, 'meaning' and value of his/her endeavours; as a result, interest and self-esteem increase, work is carried out more efficiently, and scientific and investigative skills improve and broaden. In this connection, a mechanism for producing regular e.g. quarterly bulletins ('Lake Tanganyika newsletter') should be seriously considered, in addition to any other more traditional reports and publications.

Considering the enormous database that will be generated by the project, there will be a need for a mechanism for exchanging data at national and regional levels. Currently available desk- and lap-top computers render data exchange a relatively simple and efficient matter - even within and between the lake countries where traditional lines of communication can be prone to failure, and require power-stabilising facilities. Selecting the systems from the enormous range of word-processing, charting, data handling, statistical analysis and graphics software, can be a major task. However, a package consisting of WordPerfect, HYDATA, HYQUAL (Institute of Hydrology 1993), Lotus, Excel and SigmaPlot has proved very adequate elsewhere. While some organisations may have to resort to mailing of disks etc., fax and electronic mail facilities, and the supporting communication networks are improving and increasing in popularity all the time. Custom-designed programmes for the sorting of biological data - species population densities, and size distributions for example - are also available (Robson and Bailey-Watts 1987).

The importance and value of such facilities which enhance dissemination of data, and speed up the initiation of databases cannot be over-estimated. If teams of investigators maintain frequent and regular contact through the swapping of data and other information, comparability of results (and thus, the ability to detect changes or lack of changes in e.g. the concentration and distribution of an organism or chemical factor) is assured. Secondly, the very discussing of results generates new ideas and interpretations of the information. Ultimately, this will enhance the scientific credibility of the organisations involved, and their ability to manage the lake and its basin.

A central database is not essential, save for the fact that it could constitute an additional back-up facility for the findings which will be otherwise available on each of the four lake country systems. As with those systems, the data must be made freely available to all participants - and especially the overall coordinating committee.

6.2 What to measure

We suggest that the 'core' list of physical and chemical analyses includes the following:

- light, temperature, transparency, total suspended particles
- conductivity/salinity, dissolved oxygen, pH, alkalinity
- calcium, sulphate, fluoride, silica (reactive and total)
- ammonia, nitrate, nitrite, organic nitrogen
- phosphorus (P), including the soluble (dissolved) reactive unreactive phosphate fractions, and the total P present
- organic matter (dissolved and total)
- chlorophyll$_a$
- oils (fuel, bilge etc.) in water, sediments, and the tissues of selected molluscs, crustaceans and fish
- pesticides and PCBs in fish tissues and molluscs (possibly also PAHs)
- trace elements, Cu, Zn, Mn, Fe, Pb, Cd, Hg (in mollusc and fish tissues)

Note that samples of the lake biota, especially molluscs and fish, from the water column and e.g. muds, rocks and sands/silts, will be collected and analysed for nutrient and pollutant (e.g. pesticide, metal) content. This will be done with the view to 'tracing' the fate of certain pollutants by means of chemical 'finger prints' or 'signatures' in the tissues of these organisms.

Our aspirations regarding the general approaches to assessing biodiversity in the range of biotopes outlined above have been summarised in section 1.1. In addition, as long as organisms can be sampled at random (including under the microscope), repeatable and quantitative assessments of species diversity can be obtained very rapidly. Such information is obtained almost as an 'optional extra' while generating size data using the procedures described by Bailey-Watts and Kirika (1981) and Bailey-Watts (1986). These authors use the non-parametric graphical method based on rankits (Sokal and Rohlf 1969), to display the size distributions of the organisms. If the species identities are incorporated in such displays, much more instructive diagrams than simple lists of organisms result.

The above list may seem (and possibly prove) rather ambitious, but the project is special in providing the opportunity to do what amounts to the first really comprehensive baseline/pollution survey of this very special waterbody; we should capitalise as much as possible on this chance.

A key area in which we will invest is quality control assurance. This is, of course, particularly relevant to the determinations of pesticides, PCBs, oils and trace metals. The costs of suitable NBS or similar reference materials should therefore be included in our budget. The same applies to the other more 'basic' analyses. The programme set in motion at the earliest possible juncture a series of such tests, including the 'simplest' measurements e.g. of water clarity, and the most sophisticated determinations e.g. of pesticide residues. A similar set of protocols will need to be developed as far as possible for areas of work concerned with the identification of biota. It is essential that adequate supervision of, and training in all procedures is carried out from the outset, but there is a need to be especially vigilant over exercises relating to quality assurance . By their very nature, comparability tests are very routine and repetitive, and the work can be viewed as boring; such a situation can result in many mistakes. However, if the analyst, microscopist or field operative responsible for the tests is allowed some involvement in aspects of the work leading up to, and developing from his/her main work, such mistakes can be minimised. For example, in the area of phytoplankton assessment, the microscopist/taxonomist should be well-versed in the *rationale* of the work, and how it fits in with related investigations on other organisms, and the pollution issues; he/she needs to be involved in the planning of the work programmes, and above all, willing to help regularly with field sampling and associated laboratory work, and especially data handling and presentation. It is important to acknowledge the fact too, that few people fail to be enthused by the sight of their own names in print - in scientific journals or departmental reports; it is therefore recommended that 'prime movers' include their assistants' names on such articles wherever appropriate.

6.3 Dispersion of sampling sites

It appears that most of the 'pollution' of Lake Tanganyika stems from the towns at the northern part of the lake, and a number of pollution studies reflect this (Ndabigengesere, 1992; Vandelannoote, in press). As a result, and bearing in mind that a range of types of pollution are also known to exist in the northern sector, a significant number of sampling sites for pollution and associated biodiversity investigations, will be set up there. Nevertheless, a corresponding set of comparatively pristine sites elsewhere on the lake will be selected, in order to active the main aim of the project - the impact of pollution on biodiversity in Lake Tanganyika. The maps produced by Coenen (1993a), Coenen, Hanek and Kotilainen (1993) will be invaluable in this connection, since ideally there is a need for sites differing in pollution status but resembling each other in as many other respects e.g. aspect, slope and type of sediment.

In addition to the requirement for 'pairing' polluted sites with unpolluted areas, the project is committed to an assessment of the lakewide situation as regards pollution and biodiversity - and to involving scientists and other personnel in all four riparian countries. The project thus envisages a stratified sampling strategy combined with attention to known 'hot-spots' of pollution in particular (but to some extent, those of diversity as well). Note: a purely random positioning of sampling sites would not necessarily achieve a representative lakewide assessment.

It is not safe to assume that the chemical, including pollutant, composition of water sampled from the main column, describes adequately the environment of anything other than the pelagic or free-living biota. Separate samples at, and near the sediment water interface will thus be collected to ensure meaningful assessment of the associations between, pollution and the benthic biota, or the impacts of pollution on the species composition of the bottom-dwelling flora and fauna.

As a first basis for discussion with the other contributors to the project, we suggest that the following numbers of sampling sites be attempted:

- 10 polluted sites; these are regardless of the type of pollution, but as a basis for discussion, the following are suggested as priority study areas: *eutrophication* from Kigoma and Bujumbura, *atmospheric pollution* lakewide, *pesticide* inputs from the cotton plantations in the Rusizi catchment, *heavy metal* burdens from the Malagarasi and *organic (sugar) waste* from the Uvira area.

- 10 sites similar the polluted areas in terms of aspect, sediment type (e.g. muddy, sandy, pebbly or rocky) etc; if the foregoing polluted, sites are selected, they more or less ignore the Zambian sector but the latter would receive more attention in providing comparatively 'pristine' study sites.

- 2 transects per site, perpendicular to the shore and extending from 'in-shore' to open water (to account for littoral and pelagic communities and chemistry); 4 sampling stations along each transect; replicate samples (of water, near-sediment water, and the sediment itself - all for biological and pollutant analysis) at each station.

During the early stages of the project, at least, we suggest that attention to the abyssal zone (≥ 200m water depth) be kept to a minimum. This is with the exception where it links with those components of the sediment study concerned with deposition rates on the lake floor. Samples will be taken from the upper zone of the monimolimnion since certain organisms and fish are recorded from this part of the lake. The marshes - albeit associated with the lake - will also receive rather less attention than the main basin. In both cases, however, the situation will be reviewed in the light of progress with the main investigations.

The data obtained from each of the (lakewide) spatial surveys of pollutant levels and biodiversity (presumably including pollution indicator species), will also be incorporated into the GIS for spatial analysis, including contouring, and presentation. Ultimately, in order to assess the likely impacts of the pollutants and biodiversity, these maps will be compared with corresponding distributional arrays of ground information and (where possible) remotely sensed data on the following: suspended sediment, bottom deposits, water depth, colour and clarity. The causal relationships between biodiversity and the types and levels of pollution, will also be explored by means of multivariate analysis.

Existing information on the associations between a particular species or species assemblage and pollutants or other chemical constituents is meagre for Africa. However, the present study has an opportunity to redress this situation, by examining the potential for developing a system akin to the British 'RIVPACS' scheme (River InVertebrate Prediction And Classification Scheme - Wright *et al* 1992; Wright, Furse and Armitage 1993). A prominent feature of this tool is the manner in which the lack of a species due to a 'shortcoming' in running waters - such as non-availability of suitable substrate - can be distinguished from a pollution-induced impact on the fauna. A considerable amount of calibration is necessary in developing such a scheme, but the use of organisms in assessing pollution status is likely to attract considerable attention, as it requires generally less expensive and custom-specific instrumentation compared to that required for chemical analyses.

Equivalent information on physical features including water depth, movement and clarity, and on chemical features including nutrient and major ion status, will be collected routinely for the lake environment. Here, for example, even under conditions of nutrient sufficiency, gas-vacuolate cyanobacteria cannot attain 'bloom' densities unless the water column is stratified. Figure 2 (from Bailey-Watts 1995) uses another example from Lake Victoria to illustrate this.

6.4 Sampling schedules

The final sampling schedules cannot be settled until a number of field reconnaissances and sampling and analytical protocols have been tried and tested. These will be developed in conjunction with local personnel under what is envisaged as a more or less continuous series of training elements from the outset of the practical phases of the project. In general terms, however, the following schedules and sampling 'efforts' can be used as a starting point; these will almost certainly not turn out to be the final arrangements, but at the very least they provide a basis on which costs can begin to be established.

Sampling frequency (and spatial coverage) will differ between water column and sediment/substrate, and between the planktonic and the benthic communities (Table 6 - p. 21). Logistics dictate that sites close to the laboratory bases will be monitored more frequently than remote pelagic zone and deep sediment stations.

Even in what may be viewed as potentially very well 'physically-buffered' systems such as Lake Tanganyika, the populations of many of the biota may be highly dynamic. Data on the population dynamics of some of these will be used to design the schedules. In general, however, planktonic algae and protozoa (with short population spans), for example, can be sampled adequately at weekly or 10-day intervals - at a few sites at least. Contrastingly, biodiversity and organism composition in a number of benthic assemblages could be reasonably assessed by means of monthly, even seasonal, collections. Seasonal/annual synopses may suffice for certain aspects of fish diversity. While assessments of population densities and density fluctuations *per se* should not detract from the main focus

	physical factors	*chemical factors*	*biological factors*
PRODUCTION	**high temperatures year-round**	**adequate nutrient supplies** **[MAJOR FOCUS FOR INTERVENTION]**	
	shallowness	**low nitrate-N:bio-available P ratio; favours N_2-fixing species**	**rapid nutrient cycling (involving fish)?**
	tendency to stratify	**many of which are large**	
BIOMASS ACCUM'N		**adequate nutrient supplies** **[MAJOR FOCUS FOR INTERVENTION]**	**selective grazing on nano-algae (<15-µm) by zooplankton**
	long hydraulic residence time		**reduced populations of small fish species that feed on large cyanobacteria**

Figure 2. Factors, including physical features enhancing the production and biomass accumulation of large cyanobacteria in Lake Victoria; there are many parallels with the situation in Lake Tanganyika. (From Bailey-Watts 1995).

which is on biodiversity, it is worth pointing out that there two are linked; in general terms biodiversity of a given type of assemblage (e.g. fish or phytoplankton) is likely to decrease with increasing abundance - although extraneous perturbations (such as pollution) may result in a sparse and species-poor assemblage.

Table 6. Draft sampling strategies; note: 10% sample replication accounts for the difference between 'number of samples' and 'total number of samples'.

Matrix	locations	transects/location	sites/transect	sampling /yr	no. of samples	total no. samples/yr
water main column	20	2	4	8	1 280	1 408
water, near-sediment	20	2	4	8	1 280	1 408
sediment	20	2	2	2	160	176
depth profile	4	10 per site	-	8	320	352
Mollusc tissue	10	2 comparative	-	8	160	176
Fish tissue	6	4 composite	-	8	192	212
Crustacean tissue	6	2 composite	-	8	96	106

6.5 Training

UK-African collaboration and training in all aspects of the work are planned in order to assure sustainable programmes of pollution and biodiversity assessment, and the development and implementation of strategies for reversing pollution trends that are deemed to have reduced biodiversity. Thus, while the main scientific work is aimed at protecting biodiversity, attention must also be focused on (i) building first-class teams of field operatives, laboratory technicians and investigative scientists in each of the four countries, and (ii) collaborating and cooperating with lake shore communities and other personnel.

It is also recommended that frequent, short training and re-training courses, seminars, workshops - *each involving small groups of people* - be held from the outset; experience world-wide supports the view that one or two 'informal' days with a group of say, 8 people (two from each lake country in this case), is likely to be far more effective than a rigidly structured gathering of dozens of people for a fortnight. Very experienced trainers from the lake countries and from abroad could be assigned to such tasks. The importance of thorough training and instruction in any aspect of the project cannot be over-stated. This includes the writing up and reporting of the results; in this connection, the scientists must be capable producing the data *and* interpreting them appropriately for not just their fellow investigators and research directors, but also for the policy-makers - government personnel and local communities. Special attention needs to be paid also, to those areas concerned with organisms. In sharp contrast to many chemical and physical determinations which are executed using reasonably standardised 'recipes', biodiversity assessments and determinations of the species composition, abundances and size distributions of the populations are rather less routine.

Scientists (at graduate, Master's or Doctoral level) will be encouraged to visit the UK. Experience highlights the value of assigning these to appropriate on-going projects; this appears to generate the most suitable supervision and collaboration. However, it is recommended that such visits are restricted to periods of a few months. Continuous sojourns of 2 or 3 years away from the African environment and its particular situations and challenges are considered to be of little lasting benefit.

The project will produce training manuals, and scientific reports and papers, targeted at e.g. fishery scientists, lake and water resource managers, policy-makers, as appropriate. In the areas of pollution assessment, and of pollution-related biodiversity developments in particular, this latter tranche of outputs will aid the development of new, and the strengthening of existing links between this project and those on Lake Victoria and Lake Malawi. In this connection it should be noted that Dr. Menz (Project Coordinator) and a number of the NRI consultants were heavily involved in the Lake Malawi fisheries project, and both Dr. Bailey-Watts and Dr. Foxall have contributed to project identifications and evaluations, and training on Lake Victoria.

7. Resource requirements

7.1 Equipment

This section is concerned primarily with our general thinking on what equipment can, and should be made available to the project and why certain types of apparatus are favoured over others. The equipment items ideally required are listed in Appendix B. These (first) lists include - in addition to more or less 'standard' field and laboratory gear - the instrumentation and other resources needed for the activities listed below in order of the phasing of the work as presently envisaged, i.e.

- planning of field surveys etc.
- reaching the sampling sites
- sampling
- the immediate handling/treatment of samples and their transport back to the laboratory
- the main analyses of the materials and samples
- data logging, analysis, interpretation, and presentation in written and spoken form
- electronic communication, and equipment protection.

The comments below take into account the conditions that prevail in the two centres that have been visited by Dr. Bailey-Watts i.e. Bujumbura (Burundi) and Kigoma (Tanzania); the Uvira (Zaire) and Mpulungu (Zambia) areas have still to be reconnoitred. The costs - which at this stage can only be considered 'ball-park' type estimates - reflect the requirements we envisage for 'furnishing' four locations. In the absence of information on the specific needs of the shore-based laboratory/laboratories in each of the 4 the riparian countries become clearer, we have costed items assuming there will be one site per country and that each site has the same requirements. Some large and expensive items are listed but not costed, since it may prove that the hire of these is both cheaper and more convenient. Examples are the instruments and machinery for the determination of trace metals, pesticides, PCBs and PAHs which would require an injection of capital of many £10^5k, while subcontracting of the determinations might not exceed £50,000.

Issues over field equipment

The project will be able to borrow/hire the following sophisticated instrumentation developed by the institute:

- probes for depth profiling and the capture and instantaneous recording and storage of data on, the following: temperature, light intensity and spectral characteristics, turbidity, conductivity, dissolved oxygen content, pH and depth of sampling.

- deployable stations (buoys) for the continuous recording of weather and limnological parameters; each of the recording components are arranged in vertical series (chains), facilitating the 'real-time' description of changes in water column stability which are likely to influence major features of the temporal succession, and associated changes in biodiversity, of the phytoplankton - and of organisms which feed on this micro-flora.

Especially in the early stages of the work, there will be a major need for extensive and rapid surveys. For this we intend to use 'state-of-the-art' field sampling gear such as Global Positioning Systems, and pumped intake arrangements for the collection of samples of e.g. plankton integrated over measured sectors of the lake, and for the continuous monitoring of physico-chemical and biological parameters as a research vessel cruises from one position to another. Positions of sampling stations in open water at least, will be established with Global Positioning Systems, although near-shore and shallow sites may also be marked with buoys, for example; paid guards are likely to be needed in some situations!

Wherever possible and appropriate, however, the performance/efficiency of simpler techniques (such as the use of Lund tubes for sampling of the smaller elements in the plankton) will be compared with these sophisticated instruments with the view to using the simpler, cheaper and more easily replaceable items in the long-term.

Issues over laboratory equipment

Many of the methods used for the analyses envisaged for the pollution-biodiversity studies have been developed by IFE and published in the form of practical manuals as well as scientific research papers. These will be made available to the project's African centres.

Regarding the more routine type of analyses, our present thinking favours avoidance of the 'Hach syndrome'. The present costings will thus be done on the basis of the 'traditional' titration/calorimetric laboratory approach. A Dionex-type instrument can be used to determine many of the inorganic ions, but this would be an expensive option - especially bearing in mind that it would probably be unsustainable once the project has finished.

A number of the major ions can also be measured by titration. Considerably more sophisticated methods are, however, envisaged for the metals and organic compounds of interest in this study. Pesticides will be identified and quantified by gas chromatography (GO) and gas chromatographic-mass spectrometric (GCMS) techniques. Heavy metals will be determined using atomic adsorption spectroscopy (AAS) and inductively coupled plasma (ICP) methods.

The general distribution of aliphatic and aromatic hydrocarbons that characterise ship fuels and waste products, will be determined using gas chromatography. However, where the opportunity arises to 'trace' the fate of these fuels through 'finger-printing' (see above), techniques which combine G-C with atomic or mass spectroscopy will be employed, since these permit identification of the inorganic components (e.g. Ni, V or S) in these fuels.

On the biodiversity front, there can be no alternative to the provision of exceedingly good microscopes with photomicrographic facilities. Ideally, fluorescence capability should also be included, and the access to expertise and instrumentation for genetic techniques should also be considered.

7.2 Personnel

Local and expatriate personnel are crucial to the success of all aspects of the study. However, experience of working in other tropical situations including the lakes cited above, highlights the particular value of placing a UK national (in this case) in the Lake Tanganyika area for the duration of the project - with responsibility delegated by Dr. Bailey-Watts and his specialist team (see below) for all activities, especially liaison with the African scientific coordinator at each station.

The Technical Proposal identifies - in addition to Dr. Bailey-Watts (Institute Freshwater Ecology) who has overall responsibility for the pollution and pollution-related biodiversity studies - the following as possessing the appropriate specialist experience and skills for initiating and supervising the work programme: Drs. Hilton (also IFE) and Foxall (Centre for Environmental and Risk Management, University of East Anglia), and Professor Hammerton (lately Director, Clyde River Purification Board). Within the budget as it stands at present, the intention is that, through Drs. Bailey-Watts and Foxall in particular, this supervisory group will spend a total of approximately 10 person-weeks in the lake area each year for the duration of this aspect of the GEF project. However, we propose that *in addition*, a UK Environmental Sciences graduate be based in one of the countries throughout the project with the facility for visiting - for whatever lengths of time seem appropriate - the other 3 project bases. Discussions have also been initiated over the possibility of appointing a second person to share this role - again, providing a resource additional to that already committed to the project.

In spite of the proven strengths of the corpus of UK and other non-African consultants and collaborators on this project, the successful management of the lake, and continued strengthening of African limnology in the longer term i.e. 'post-GEF', rests very much on the abilities of the existing and developing scientists in the 4 riparian countries. A good deal of work is still needed by way of establishing the African teams for the Pollution-biodiversity work - and this is one of the first items on the Work Plan (Appendix A). Dr. Bailey-Watts has already established contacts with the following authorities in Tanzania with expertise which should be extensively capitalised on for the pollution-biodiversity programme. These are the Ministry of Water, Energy and Minerals (MWEM) through its Planning Division and the Hydrological Unit in particular (hydrology, chemical water analysis; the Ministry of Tourism, Natural Resources and the Environment (MTNRE), through the Directorate of the Environment (water resources and quality data); the Ministry of Agriculture and Livestock Development's (MALD) Tanzanian Fisheries Research Institute (TAFIRI); The Tropical Pesticides Research Institute (TPRI, Arusha) - pesticide and other sophisticated chemical analyses - and the National Institute for Medical Research (NIMR, Mwanza) - waterborne disease issues. From recent (albeit short) visits to Burundi and Tanzania, it is plain that impressive and above all, enthusiastic field operatives and graduate laboratory assistants, and post-graduate researchers in a number of relevant disciplines are available in these countries. Meetings with Zairian and Zambian representatives on the FAO FINNIDA project also demonstrate no shortage of valuable intellectual resources in these countries. Moreover, the people met are well aware of the need for major interests in the applied aspects of the work - not just the 'pure' science.

Numbers of local personnel needed for the project are difficult to finalise at his stage, but Table 7 provides a basis for discussion.

Table 7. A preliminary estimate of the number of local personnel required for the pollution-biodiversity study*.

post	number required per country
driver/mechanic	2
handler for small e.g. inflatable craft	4
field operative (recorder/sampler)	4
laboratory cleaner	4
laboratory steward	4
technicians/laboratory assistant	6 (3 physical/chemical; 3 biological)
research scientist	3 (1 physical/chemical; 1 botanical; 1 zoological)
station administrator	1
station scientific coordinator**	1
secretary	2
office assistant/typist	4

* N.B. the biologists required for this work are those with interests and/or experience in the 'lower' organisms i.e. 'below' fish.

** Ideally, an equivalent UK graduate would be appointed to liaise with this local scientific coordinator.

8. Future issues

While not meriting immediate attention, there are issues that would be worthy of consideration bearing in mind the desire to protect Lake Tanganyika over centuries, even decades. These are simply listed as subjects for discussion:

- population increase
- increased pollution of the lake
- 'degradation' of catchment e.g. deforestation
- change in land use e.g. drainage of wetlands
- climate change (effects on vertical mixing).

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10. References

Achieng, A.P. 1990. The impact of the introduction of Nile perch (*Lates niloticus L.*) on the fisheries of Lake Victoria. *J. Fish Biol. 37: Suppl.* 1: 17-23.

Alabaster, J. S. 1981. Review of the state of aquatic pollution of East African inland waters. *United Nations Food and Agriculture Organisation Report,* CIFA/OP9.

Ancey, C. F. 1894. Sur quelques especes de mollusques et sur un genre nouveau du LacTanganika. *Bulletin de la Societe zoologique de France, 19:* 28-29.

Ancey, C. F. 1906. Reflexions sur la faune ichthyologique du Lac Tanganika. *Bulletin scientifique de la France et de la Belgique,* 5: 229.

Annual Statistics Reports for 1967 to 1994. *Statistics for Lake Tanganyika.* Dar es Salaam, Tanzania: Ministry of Tourism, Natural Resources and Environment.

Badenhuizen, G. R. 1965. Lufubu River reserch notes. Fisheries Research Bulletin 1963-1964. (Compiled by Game and Fisheries Department, Ministry of Lands and Natural Resources,Lusaka.)

Bailey-Watts, A.E. 1986. Seasonal variation in phytoplankton assemblage size spectra in Loch Leven. *Hydrobiologia,.* 33: 25-42.

Bailey-Watts, A.E. 1994. Eutrophication. In: P.S. Maitland, P.J. Boon and D.S. McLusky (eds.), *The Fresh Waters of Scotland: a national resource of international significance.* Wiley, London, pp. 385-411.

Bailey-Watts, A. E. 1995. *'Lake water quality - proposals for strengthening water quality monitoring and for research priorities'; ca* 65pp including 6 Figures and 3 Tables. In: Bullock, A., Keya, S.O., Muthuri, F.M., Bailey-Watts, A. E., Williams, R. and Waughrey, D. *Lake Victoria Environmental Management Programme: Tasks 11, 16 and 17.* Draft final report to the Food and Agricultural Organisation of the United Nations in support of the National Working Groups of Kenya, Tanzania and Uganda for Regional Task Force II (Water quality and land use, including wetlands). Nairobi, Kenya. 350pp.

Bailey-Watts, A.E., Gunn, I.D.M. and Lyle, A.A. 1994. Factors affecting the sustainability of Scottish freshwater lochs subject to eutrophication. In: Proceedings of a Conference on *'Sustainability and Resource Management'* (Ed. G.J. Dickinson). The Biogeography Research Group, The Centre for Research in Environmental Science and Technology, and Scottish Natural Heritage. In press.

Bailey-Watts, A.E. and Kirika, A. 1981. Assessment of size variation in Loch Leven phytoplankton: Methodology and some of its uses in the study of factors influencing size. *Journal of Plankton Research,* 3: 261-282.

Bailey-Watts, A. E. and Kirika, A. 1995. *Phytoplankton dynamics and the major ecological determinants in Loch Leven NNR during 1994.* Report to Scottish Natural Heritage and the Forth River Purification Board. 17 pp, 1 Appendix and 7 Figures.

Baker, J. M. 1993. Oil and Africal Lakes. *Mitteilungen internationale der theoretische und angewandte Limnologie,* 23: 71-77.

Barel, C. D. N., Dorit, R., Greenwood, P. H., Fryer, G., Hughes, N., Jackson, P. B. N., Kawanabe, H., Lowe-McConnell, R. H., Nagoshi, M., Ribbink, A. l., Trewavas, E., Witte, F. and Yamaoka, K. 1985. Destruction of fisheries in Africa's lakes. *Nature, London,* 315: 19-20.

Bazigos, G. P. 1976. The design of fisheries statistical surveys. Inland waters. Populations in non-random order, sampling methods for echo surveys, double sampling. *United Nations Food and Agriculture Organisation Fisheries Technical Paper,* 133: 1-46.

Beddard, F. E. 1906. Report on the Oligochaeta, Zoological results of the Third Tanganyika expedition, 1904 1905. *Proceedings of the Zoological Society of London,* 15: 206-218.

Benemariya, H., Robberecht, H. and Deelstra, H. 1993. Daily dietary intake of copper, zinc and selenium by different population groups in Burundi, Africa. *The Science of the Total Environment,* 136: 49-76.

Benson, C.W. and Irwin, M. P. S. 1967. A contribution to the ornithology of Zambia. Zambia Museum Papers 1, Oxford University Press.

Bigawa, S., Vandelannoote, A., Ollevier, F. and Grisez, L. 1994. L'etat de la pollution bacterienne du lac Tanganyika dans la baie de Bujumbura. *Journees scientifiques du Centre Regional Recherches en Hydrobiologie Applique (CRRHA).* Conference held 30-31 mars 1994. pp. 7-8.

Bootsma, H. A. and Hecky, R.E. 1993. Conservation of the African Great Lakes: A limnological perspective. *Conserv. Biol.*, 73 : 644-656.

Brooks, J. L. 1950. Speciation in ancient lakes. *Quarterly Review of Biology, Baltimore*, 25: 30 36, 131-176.

Brown, D. S. and Mandahl-Barth G. 1987. Living molluscs of Lake Tanganyika, a revised and annotated list. *Journal of Conchology*, 32: 305-327.

Burgis, M. J. 1984. An estimate of zooplankton biomass for Lake Tanganyika. *Verhandlungen der Internationalen Vereinigung für theoretische und angewandte Limnologie, Stuttgart*, 22: 1199-1203.

Burgis, M. J. 1986. Food chain effidency in the open water of Lake Tanganyika. *Bulletin des seances. Academie r. des sciences d'outre mer*, 30: 283 284.

Caljon, A. G. 1987. Phytoplankton of a recently landlocked brackish-water lagoon of Lake Tanganyika: a systematic account. *Hydrobiologia*, 153: 31-54.

Caljon, A. 1991. Sedimentary diatom assemblages in the northern part of Lake Tanganyika. *Hydrobiologia*, 226: 179-191.

Caljon, A. G. 1992. Water quality in the Bay of Bujumbura (Lake Tanganyika) and its influence on phytoplankton composition. *Mitteilungen internationale der theoretische und angewandte Limnologie*, 23: 71-77.

Chappuis, P. A. 1955. Harpacticoides psammiques du Lac Tanganyika. *Revue de zoologie et de botanique africaines*, 51: 68-80.

Chardez, D. 1980. Sur quelques Thecamoebiens du Lac Tanganyika. *Revue Vervietoise d'Histoire Naturelle*, 44: 26-29.

CIFA. 1988. CIFA Sub-Committee for Lake Tanganyika. Fourth session, Rome, 25-27 Apr. 1988. Report on environmental activities of the United Nations system in Lake Tanganyika; 1987; CIFA: DM/LT/87/Inf.4: 1-3.

Cocquyt, C. and Vyvernan, W. 1994. Composition and diversity of the algal flora in the East African Great Lakes: A comparative survey of Lakes Tanganyika, Malawi Nyassa and Victoria. *Arch. Hydrobiol. Beih. Ergebn. Limnol.* 44: 161-172.

Cocquyt, C. 1991. Epilithic diatoms from thrombolitic reefs of Lake Tanganyika. *Belg. J. Bot.*, 124: 102-108.

Cocquyt, C. 1992. Epilithic diatoms from surface sediments of the northern part of Lake Tanganyika. *Hydrobiologia*, 230: 135-156.

Cocquyt, C. 1993. Rapport de la mission au CRRHA: Etude du plancton et du benthos du Lac Tanganyika 8/7-7/8/1993. 3 pp. + Figures. and Tables.

Cocquyt, C., Caljon, A .and Vyverman, W. 1991. Seasonal and spatial aspects of Phytoplankton along the north-eastern coast of Lake Tanganyika. *Ann. Limnol.*, 273: 215-225.

Cocquyt, C. and Vyverman, W. 1992. *Surirella sparsipunctata* Hustedt and *S. sparsipunctata* var. *laevis* Hustedt Bacillariophyceae: a light and electron microscopical study. *Hydrobiologia*, 269-270: 97-101.

Coenen, E. J. 1993. Field guide containing maps of the Lake Tanganyika shoreline. FAO/FINNIDA Research for the Management of the Fisheries on Lake Tanganyika. GCP/RAF/271/FIN-FM/01, 88 pp.

Coenen, E.J. (ed). 1993. Historical data report on the fisheries, fisheries statistics, fishing gears and water quality of Lake Tanganyika Tanzania . Bujumbura: FAO; FAO/FINNIDA Research for the Management of the Fisheries of Lake Tanganyika GCP/RAF/271/FIN-TD/ 15, 1-115.

Coenen, E.J. 1994. Frame survey results for Lake Tanganyika, Burundi 28-31.10.1992 and comparison with past surveys. FAO FINNIDA Research for the Management of the Fisheries on Lake Tanganyika. Bujumbura, Burundi: Project FAO/ FINNIDA Research for the Management of Fisheries on Lake Tanganyika; GCP/RAF/271/FIN-TD/18:1-26.

Coenen, E. J. (ed.) 1995. Historical Data Report on the Fisheries statistics, limnology, Bromatology, Zooplankton, Fish Biology and Scientific Publications review of Lake Tanganyika, Zaire. FAO/FINNIDA, Research for the Management of the Fisheries on Lake Tanganyika. GCP/RAF/271/FIN-TD/32, 153 pp.

Coenen, E., Hanek G. and Kotilainen, P. 1993. Shoreline classification of Lake Tanganyika based on the results of an aerial Frame survey 29.09.92 - 03.10.92. FAO/FINNIDA Research for the Management of the Fisheries on Lake Tanganyika. GCP/RAF/271/FIN-TD/10, 11pp.

Coenen, E.J., Hanek, G. and Kotilainen, P. 1993. Shoreline classification of Lake Tanganyika based on the results of an aerial frame survey 29.09.92-03.10.92. Bujumbura, Burundi: FAO/FINNIDA Research for the Management of the Fisheries on Lake Tanganyika. GCP/RAF/271/FIN-TN/10:1- 9.

Cohen, A.S. 1994. Extinction in ancient lakes: Biodiversity crises and conservation 40 years after J.L. Brooks. *Arch.Hydrobiol.Beih.Ergehn.Limnol.*, 44: 451-479.

Cohen, A. S., Bills, R., Cocquyt, C. and Caljon, A. 1993. The impact of sediment pollution on biodiversity in Lake Tanganyika. *Biol. Conserv.*, 73: 667- 677.

Commerford, J., Edmond. J. M., Spivack, A. J. and Stallard, R. F. 1982. The ion balance of Lake Tanganyika and the geochemistry of the Malagarasi River. *Transactions American Geophysical Union*. 63: 50.

Coulter, G. W. 1963. Hydrological changes in relation to biological production in southern Lake Tanganyika. *Limnology and Oceanography,* 8: 463-477.

Coulter, G.W. 1966. Hydrological processes in Lake Tanganyika. *Fish. Res. Bull. Zambia*, 53-56.

Coulter, G. W. 1967a. Hydrological processes in Lake Tanganyika. *Fisheries Research Bulletin,* Zambia, *4:* 53-56.

Coulter, G. W. 1967b. Low apparent oxygen requirements of deepwater fishes in Lake Tanganyika. *Nature, London,* 215: 317-318.

Coulter, G. W. 1968. Hydrological processes and primary production in Lake Tanganyika. *Proceedings 11th Conference Great Lakes Research, International Association of Great Lakes Research:* 609-626.

Coulter, G.W. 1988. Seasonal hydrodynamic cycles in Lake Tanganyika. *Verhandlungen internationale Vereinigung der theoretsche und angewandte Limnologie.*, 23: 86-89.

Coulter, G. W. (Ed.) 1991. *Lake Tanganyika and its Life.*The British Museum (Natural History), and OUP.

Coulter, G. W. 1992. Vulnerability of Lake Tanganyika to pollution, with comments on the social aspects. **I have 'lost' the rest of this reference!**

Coulter, G.W. 1994a. Lake Tanganyika. *Arch.Hydrobiol.Beih.Ergebn.Limnol.*, 44: 13-18.

Coulter, G.W. 1994b. Speciation and fluctuating environments, with reference to ancient East African lakes. *Arch. Hydrobiol. Beih. Ergebn. Limnol.*, 44: 127-137.

Coulter, G.W. and Mubamba, R. 1993. Conservation in Lake Tanganyika, with special reference to underwater parks. *Conserv. Biol.*, 73: 678-685.

Coulter, G. W. and Mubamba. 1994. R. Underwater parks may not be the best conservation tool for Lake Tanganyika - Response. *Conserv. Biol.*, 82: 330-331.

Crul, R.C.M. 1993. Limnology and hydrology of Lake Tanganyika. UNESCO/IHP-IV Project M-5-1. Comprehensive and comparative study of great lakes First draft; 1993; Monographs of the African Great Lakes. 43 pp. and Figures.

Cunnington, W. A. 1913 . Report on the Branchiura. Zoological results of the Third Tanganyika Expedition (1904-1905). *Proceedings of the Zoological Society of London,* 2: 262-283.

Decremer , W. and Coomans, A. 1994. A compendium of our knowledge of the free-living nematofauna of ancient lakes. *Arch.Hydrobiol.Beih.Ergebn.Limnol.*, 44: 173-181.

Deelstra, H. 1977a. Danger de pollution dans le Lac Tanganyika. *Bulletin de la Societe de Bege Etudes Geographie,* 46: 23-35.

Deelstra, H. 1977b. Organochlorine insecticide levels in various fish species in Lake Tanganyika. *Med. Fac. Landbouww. Rijksuniv. Gent.,* 42: 869-882.

Deelstra, H., Power, J. L. and Kenner, C. T. 1976. Chlorinated hydrocarbon residues in the fish of Lake Tanganyika. *Bulletin of Environmental Contamination and Toxicology,* 15: 689 698.

Deelstra, H. and Van Cauwenberghe, K. 1982. Seasonal changes in fat and fatty acid composition of *Limnothrissa miodon* Boulenger from Lake Tanganyika, with reference to their nutritive value. *Hydrobiologia,* 89: 123 127.

Degens, E. T. and Kulbicki, G. 1973a. Data file on metal distribution in East African rift sediments. *Woods Hole Oceanographic*

Institution Technical Report, 73-15: 1-280.

Degens, E. T. and Kulbicki, G. 1973b. Hydrothermal origin of metals in some East African Rift lakes., *Mineralium Deposita,* 8: 388-404.

Degens, E. T., von Herzen, R. and Wong, H.-K. 1971. Lake Tanganyika: water chemistry, sediments, geological structure. *Naturwissensch.,* 585: 229-241.

De Vos, L. and Snoeks, K. 1994. The non-Cichlid fishes of the Lake Tanganyika basin. *Arch. Hydrobiol. Beih. Ergebn. Limnol.,* 44: 391-405.

De Vos, L., Segers, L., Taverne, L. and Van den Audenaerde, T. 1994. Composition and distribution de l'ichtyofaune dans les affluentes du Nord du Lac Tanganyika. Rapport sur les deuxieme Journees Scientifiques du Centre Regionnal de Recherche en Hydriobiologie Appliquee, 30-31 Mars, 1994, Bujunbura, Burundi.

Dubois, J. Th. 1958. Evolution de la temperature, de l'oxygene dissous et de la transparence dans la baie nord du Lac Tanganika. *Hydrobiologia,* 10: 215 240.

Dubois, J. Th. 1958. Composition chimique des affluents du nord du Lac Tanganika. *Bulletin des Seances Academie r. des sciences coloniales(d'outre mer), Bruxelles,* 4: 1226 1237.

Dumont, H.J. 1986. The Tanganyika sardine in Lake Kivu: another ecodisaster for Africa? *Environm. Conserv.,* 132: 143- 148.

Dumont, H.J. 1994. Ancient lakes have simplified pelagic food webs. *Arch. Hydrobiol. Beih. Ergebn. Limnol.,* 44: 223-234.

Eccles, D. H. 1986. Is speciation of demersal fishes in Lake Tanganyika restrained diversity physical limnological conditions? *Biological Journal of the Linnean Society,* 29: 115 122.

Edmond, J. 1975a. Report on a study of nutrient chemistry, Lake Tanganyika, March-April 1975. *United Nations Food and Agriculture Organisation Report,* FI:DP/BDI/70/508.

Edmond, J. 1975b. Lake chemistry. In: *LakeTanganyika geochemical and hydrographic study, 1973 expedition,:* 65-75. Craig, H. (ed.). *Publication of Scripps Institute of Oceanography,* Series 75, 5.

Edmond, J. 1980. Chemistry of Lake Tanganyika, a 1400 m, thermally stratified, rift valley lake. *Transactions American Geophysical Union.* 61: 1004.

Edmond, J., Stallard, R. F., Craig, H., Craig, V., Weiss, R. F. and Coulter, G. W. 1993. Nutrient chemistry of the water column of Lake Tanganyika. *Limnology and Oceanography,* 38: 725-738.

FAO/SIDA. 1983. Manual of methods in aquatic environmental research . Part 9. Analyses of metals and organochlorines in fish. Rome: *FAO Fish. Tech. Pap.,* 212: 1-33.

Ferro, W. 1975. Data files limnology - Lake Tanganyika Northern Bay. Data collected 1972-1975. *United Nations Food and Agriculture Organisation Report,* FI:DP/BDI/73/020: 1-5.

Ferro, W. and Coulter, G. W. 1974. Limnological data from the north of Lake Tanganyika. *United Nations Food and Agriculture Organisation Report,* FI:DP/BDI/73/020/10: 1-19.

Foxall, C.D., Litterick, M. and Njuguna, S. (1985). *Report on the baseline study of the water quality of Lake Victoria, Kenya.* Vol I, Lake Basin Development Authority, Kisumu, Kenya.

Fryer, G. 1972. Conservation of the Great Lakes of Africa: a lesson and a warning. *Biological Conservation,* 4: 256 262.

Gaedke, U. 1993. Ecosystem analysis based on biomass size distributions: a case study of a plankton community in a large lake. *Limnol. Oceanogr.* 381: 112-127.

Gaugris, Y. 1976. Additions a l'inventaire des oiseaux du Burundi. *L'Oiseau et La Revue Fran,caise d'Ornithologie,* 46: 273-289.

Gaugris, Y. 1979. Les oiseaux aquatiques de la plaine de la basse Rusizi (Burundi). *L'Oiseau et La Revue Francaise d'Ornithologie,* 49: 133-153.

Global Environment Facility (GEF). 1994. Biodiversity: Definition by the convention on biological Diversity: *GEF.*

Goldschmidt, T., Witte, F. and Wanink, J. 1993. Cascading effects of the introduced Nile perch on detrivorous/planctivorous species in the sublittoral areas of Lake Victoria. *Conserv. Biol.*, 73: 686-700.

Gray, J.S., McIntyre, A.D. and Stirn, J. 1991. Manual of methods in aquatic environment research. Part 11. Biological assessment of marine pollution with particular reference to benthos. Rome: FAO; , 324: 1-49.

Greene, C. and Jones, E. N. 1970. Physical and chemical properties of Lake Tanganyika. *Technical Memorandum* No. 2213-331-70, New London Laboratory Naval Underwater Systems Center, U. S. A.: 1-17.

Hanek, G. (ed.). 1993. 1992 Lake Tanganyika Fisteries Directory. Bujumbura, Burundi: FAO; FAO/FINNIDA Research for the management of the Fisheries on Lake Tanganyika. GCP/RAF/ 271/FIN-TD/08, 1-63.

Hanek, G. 1994. Management of Lake Tanganyika fisheries resources. Bujumbura, Burundi: Project FAO-FINNIDA Research for the Management of the Fisheries on Lake Tanganyika; GCP/ RAF/271/FIN-TD/25, 1-21.

Hanek, G. (ed.). 1995. R/V Tanganyika Explorer: Guidelines and Bujumbura, Burundi: Project FAO-FINNIDA Research for the management of the fisheries on Lake Tanganyika; GCP/RAF/271/FIN-FM/15, 1-72.

Hanek, G. and Coenen, E.J. 1994. Report on LTR's second Scientific Sampling Programme assessment meeting, Kigoma, 11-12. 04.1994 FAO-FINNIDA Research for the Management of the Fisheries on Lake Tanganyika. Bujumbura, Burundi: GCP/RAF/27L/FIN-TD/17, 1-20.

Hanek, G., Coenen, E.J. and Kotilainen, P. 1993. Aerial frame survey of lake Tanganyika fisheries. Bujumbura, Burundi: FAO/FINNIDA Research for the management for the fisheries on Lake Tanganyika. GCP/RAF/271/FIN-TD/ 09, 1-29.

Hanek, G., Coenen E. J. and Kotilainen, P. 1994. Aerial Frame Survey of 1993 Lake Tanganyika Fisheries. FAO/FINNIDA Research for the Management of the Fisheries on Lake Tanganyika. GCP/RAF/271/FIN-TD/O9, 1-29 pp.

Harper, D. M. (1992). *Eutrophication of Freshwaters: principles, problems and restoration.* Chapman and Hall, London.

Hecky, R. E. (1993). The eutrophication of Lake Victoria. *Verhandlungen internationale Vereinigung fur theoretische und angewandte Limnologie,* **25**: 39-48.

Hecky, R. E. 1984. African lakes and their trophic efficiencies: a temporal perspective. In *Trophic Interactions Within Aquatic Ecosystems,*: 405-448. Meyers, D. G. and Strickler, J. R. (eds). A. A. A. S. Symposium 85, Washington D. C.: Westview Press.

Hecky, R. E., Bootsma, H. A., Mugidde, R. and Bugenyi, F. W. B. (1994). Phosphorus pumps, nitrogen sinls and silicon drains: plumbing nutrients in the African Great Lakes. In: *The Limnology, Climatology and Palaeoclimatology of the East African Lakes.* International Symposium sponsored by the International Decade for the East African Lakes (IDEAL), Jinja, Uganda, February 1993.

Hecky, R. E. and Bugenyi, F. W. B. (1992). Hydrology and chemistry of the African Great Lakes and water quality issues: problems and solutions. *Mitteilungen Internationale Vereinigung fur theoretische und angewandte Limnologie,* **25**: 39-48.

Hecky, R. E., Fee, E. J., Kling, H. J. and Rudd, J. W. 1978. Studies on the planktonic ecology of Lake Tanganyika. *Canadian Department of Fish and Environment. Fisheries and Marine Service Technical Report,* 816: 1-51.

Hecky, R. E., Fee, E. J., Kling, H. J. and Rudd J. W. 1981. Relationship between primary production and fish production in Lake Tanganyika. *Transactions of the American Fisheries Society,* 110: 336-345.

Hecky, R. E. and Kling, H. J. 1981. The phytoplankton and protozooplankton of the euphotic zone of Lake Tanganyika: Species composition, biomass, chlorophyll content, and spatio-temporal distribution. *Limnology and Oceanography,* 26: 548 564.

Hecky, R. E. and Kling, H. J. 1987. Phytoplankton ecology of the Great Lakes in the rift valleys of Central Africa. *Archiv für Hydrobiologie Ergebnisse der Limnologie (Stuttgart),* 25: 197-228.

Henderson, H. F. and Welcomme, R. L. 1974. The relationship of yield to morpho-edaphic index and numbers of fishermen in African inland fisheries. *United Nations Food and Agriculture CIFA Report, Occasional Papers,* 1: 1-19.

Hori, M., Yamaoka, K. and Takamura, K. 1983. Abundance and micro-distribution of cichlid fishes on a rocky shore of Lake Tanganyika. *African Study Monographs, Kyoto University,* 3: 25-38.

Huc, A. Y., LeFournier, J., Vandenbroucke, M., Bessereau, G. 1990. Northern Lake Tanganyika; an example of organic sedimentation in an anoxic rift lake. In: Katz, Barry J. *Lacustrine basin exploration; case studies and modern analogs.* AAPG-Memoir. 50: 169-185.

Hutchinson, G. E. 1930. On the chemical ecology of Lake Tanganyika. *Science,* 71: 616.

Huttula,T., Peltonen, A. and Nieminen, J. 1993. Hydrodynamic measurements on Lake Tanganyika. FAO/FINNIDA Research for the Management of the Fisheries on Lake Tanganyika. GCP/RAF/271/FIN-FM/02, 48 pp.

Huttula, T. et Podsetchine, V. 1994. Modele Hydrologique au lac Tanganyika - FAO/FINNIDA Recherche pour l 'Amenagement des peches au lac Tanganyika. GCP/RAF/271/FIN-TD/20, 19pp.

Institute of Hydrology. 1993. *HYQUAL Water Quality Database Operation Manual.* Wallingford, IoH.

Jernelöv, A. And Ramel, C. (1995). Evaluation of the role and distribution of mercury in ecosystems with special emphasis on tropical regions. *Ambio,* 24 (5): 319-320.

Kaufman, L. 1992. Catastrophic change in species-rich freshwater ecosystems. The lessons of Lake Victoria. *BioScience,* 42: 846-858.

Kaufman, L. and Cohen, A. 1993. The Great Lakes of Africa. *Conserv. Biol.,* 73: 632-633.

Kawanabe, H. (ed). 1981. Ecological and limnological study on Lake Tanganyika and its adjacent regions I. 45 pp.

Kawanabe, H. (ed). 1983. Ecological and limnological study on Lake Tanganyika and its adjacent regions II. 68 pp.

Kawanabe, H. (ed). 1985. Ecological and limnological study on Lake Tanganyika and its adjacent regions III. 83 pp.

Kawanabe, H. (ed). 1989. Ecological and limnological study on Lake Tanganyika and its adjacent regions VI. 110 pp.

Kawanabe, H. and Kwetuenda, M. K. (eds). 1988.Ecological and limnological study on Lake Tanganyika and its adjacent regions V. 109 pp.

Kawanabe, H., Kwetuenda, M.K. and M.M. Gashagaza. 1992. Ecological and limnological studies of Lake Tanganyika and its adjacent regions between African and Japanese scientists: An introduction. *Mitteilungen internationale Vereinigung der theoretische und angewandte Limnologie,* 232: 79-84.

Kawanabe, H. and Nagoshi, M (eds). 1991. *Ecological and limnological study on Lake Tanganyika and its adjacent regions* IV. 142 pp.

Kilham, P. and Hecky, R. E. 1973. Fluoride. Geochemical and ecological significance in East African waters and sediments. *Limnology and Oceanography,* 18: 932-945.

Kirchner, W. B. and Dillon, P. J. 1975. An empirical method of estimating the retention of phosphorus in lakes, Water Resources Research, 11: 182-183.

Kondo, T. and Hori, M. 1986. Abundance of zooplankters on a rocky shore of Lake Tanganyika: a preliminary report. *Afr. Stud. Monogr.,* 6: 17-23.

Kotilainen, P., 1993, Field notes for hydrodynamic studies. FAO/FINNIDA Research for the Management of the Fisheries on Lake Tanganyika. GCP/RAF/271/FIN-FM/10 En: 32pp.

Kotilainen, P. 1994. Field notes for hydrodynamics. Bujumbura, Burundi: FAO; 1994; FAO/FINNIDA Research for the Management of the Fisheries on Lake Tanganyika. GCP/RAF/271/FIN-FM/10, 1-58 + 5 maps + 8 ann.

Kudhongania, A.W., Twongo, T. and Oguto-Ohwayo, R. 1992. Impact of the Nile Perch on the Fisheries of Lake Victoria and Kyoga. *Hydrobiologia,* 232: 1-10.

Kurki, H. 1993, Field Notes on Zooplankton. FAO/FINNIDA Research for the Management of the Fisheries on Lake Tanganyika. GCP/RAF/271/FIN-FM/09, 26 pp.

Kuwamura, T. 1986a. Substratum spawning and biparental guarding of the Tanganyikan cichlid *Boulengerochromis micro-lepis* with notes on its life history. *Physiology and Ecology, Japan,* 23: 31-43.

Leloup, E. 1952b. Les invertebres. Resultats scientifiques de l'exploration hydrobiologique du Lac Tanganika (1946 1947). *Institut Royal des Sciences Naturelles de Belgique, 1:* 71-100.

Leloup, E. 1953. Gasteropodes. Resultats scientifiques de l'exploration hydrobiologique du Lac Tanganika (1946-1947). *Institut Royal des Sciences Naturelles de Belgique,* 3: 1-272.

Lindqvist, O. V. and Mikkola H. 1989. Lake Tanganyika: review of limnology, stock assessment, biology of fishes and fisheries .

United Nations Food and Agriculture Organisation Report, GCP/RAF/229/FIN: 1-51.

Livingstone, D. A. 1981. Deep drilling in African lakes. *Palaeoecology of Africa and of the Surrounding Islands and Antarctica,* 13: 121

Lowe-McConnell, R. H. 1956. The breeding behaviour of *Tilapia* species (Pisces: Cichlidae) in natural waters: observations on *T. karomo* Poll and T. *variabilis* Boulenger. *Behaviour,* 9: 140 163.

Maage, A., Eckhoff, K. and Kjellevold, M. 1994. Fluorine, iodine, iron, zinc and selected fatty acid profiles in fish and staple food from East Africa. Bergen, Norway: Institute of Nutrition, Directorate of Fisheries; *FAO project GCP/INT/467/NOR, Fish in Nutrition,* 1-10, 4 Tables.

Madden, C.J. and J.W. Day. 1992. An instrument system for high-speed mapping of chlorophyll a and physico-chemical variables in surface waters. *Estuaries,* 15: 421-427.

Mann, K.H. 1993. Physical oceanography, food chains, and fish stocks: a review. *ICES Journal of marine Science,* 50: 105-119.

Martens, K. 1984. Annotated checklist of non-marine ostracods (Crustacea: Ostracoda) from African inland waters. *Documentatlon Zoologique, Musee r. de l'Afrique Centrale, Terruren, Belgique, No.* 20: 1-51.

Martens, K. 1994. Ostracods in ancient lakes. *Archiv fur Hydrobiologie, Beiheft Ergebnisse der Limnologie,* 44: 203-222.

Martens, K., Goddeeris, B. and Coulter,G. (eds.). 1994. Speciation in ancient lakes: Advances in Limnology. *Archiv fur Hydrobiologie, Beiheft Ergebnisse der Limnologie,* 44, 508 pp., 1 Plate, 78 Figures, 62 Tables and 2 Appendices.

Matthiessen, P. 1977. A visit to Tanzania with reference to the problem of pesticide run off into Lake Tanganyika. *London, Centre for Overseas Pest Research,* 9p. (mimeo). *Limnologie,* 22: 2662.

McQueen, D. J., Johannes, M. R. S., Post, J. R., Stewart, T. J. and Lean, D. R. S. (1989). Bottom-up and top-down impacts on freshwater pelagic community structure. *Ecological Monographs,* **59**: 289-309.

McQueen, D. J., Post, J. R. and Mills, E. L. (1986). Trophic relationships of freshwater pelagic ecosystems. *Canadian Journal of Fisheries and Aquatic Sciences,* **43**: 1571-1581.

Meel, L. van. 1954. Le phytoplancton- Resultats Scientifiques de l'Exploration hydrobiologique du lac Tanganika 1946-1947. Bruxelles: *Inst. R. Sci. Nat. Belg.,* 41: 1-651, 78 pls.

Melack, J. M. 1976. Primary productivity and fish yields in tropical lakes. *Transactions of the American Fisheries Society,* 105: 575-580.

Meybeck, M. 1985. Evaluation preliminaire de la pollution du Lac Tanganyika. *United Nations Educational, Scientific* and *Cultural Organisation Report,* Nairobi: 1-46.

Michel, E. 1994. Why snails radiate: a review of gastropod evolution in long-lived lakes, both recent and fossil. *Archiv fur Hydrobiologie, Beiheft Ergebnisse der Limnologie,* 44: 285-317.

Miller, D.J. 1989. Introductions and extinctions of fish in the African Great Lakes. *Trends in Ecology and Evolution,* 42: 56-59.

Molsa, H. 1991. International symposium on limnology and fisheries of Lake Tanganyika. Kuopio, Finland: University of Kuopio; 1991; *Center for Training and Development* 12/91, 1-91.

Moore, J. E. S. 1897. On the general zoological results of the Tanganyika Expedition. *Proceedings of the Zoological Society of London,:* 436-439.

Moreau, J., Nyakacyeni, B., Pearce, M., and Petit, P. 1993. Trophic relationships in the pelagic zone of Lake Tanganyika Burundi Sector. Toulouse, France; Bujumbura, Burundi: Laboratoire d'Icthyologie Appliquee, Min.A.T.E., 138-143.

Mpawenayo, B. 1985. La flore diatomique des rivieres dc la plaine de la Rusizi au Burundi. *Bulletin Societe r. de botanique de Belgique,* 118: 141-156.

Mpawenayo, B. 1986. De waters van de Ruzizi-vlakte (Burundi): Milieu, Algenflora en-vegetatie. These Doctorate, Vrije Universiteit, Brussel.

Nagoshi, M., Yanagisawa, Y., Kawanabe, H. (eds.). 1993. *Ecological and limnological studies on Lake Tanganyika and its adjacent regions.* VIII, 136 pp.

Narita, T. 1983. Species composition, vertical distribution and density of zooplankters, and some limnological features off the coast of Mahale Mountains in Lake Tanganyika. In: *Ecological and Limnological Study of Lake Tanganyika*, 2: 12-14. Kawanabe, H. (Ed.). Japan: Kyoto University.

Narita, T., Mulimbwa, N. and Mizuno, T. *1985.* Vertical distnbution and seasonal abundance of zooplankters in Lake Tanganyika. *African Study Monographs, Kyoto,* 6: 1-16.

Ndabigengesere, A. 1992. *La charge polluante du lac Tanganyika par les arrivees dans la baie de Bujumbura.* Bujumbura, Burundi: Univ. Burundi, 200 pp.

Ndahigeze, S. 1995 Updated catalogue of Regional Documentation Centre for Lake Tanganyika Fisheries Research.' FAO/FINNIDA Report No. GCP/RAF/271/FIN-FM/16.194pp.

Ndayizeye, P. 1985. Influence des dechets industriels sur la qualite de l'eau du Lac Tanganyika. *Memoire de Maitrise en Biologie, Universite du Burundi, Bujumbura.*

Ntakimazi, G. 1995. *Le role des ecotones terre/eau dans là diversite biologique et les ressources du Lac Tanganyika.* Projet UNESCO/MAB/DANIDA 510/BDI/40, 1991-1994.

Nzori, S., Taranyenko, Y. I., Mpanda, S. and Mbede, E. 1990. Petroleum prospects of the East African Rift lake-basins of Tanganyika, Nyasa and Rukwa. 15th colloquium of African geology, Nancy, Sept. 10-13, 1990.). *Occasional Publication International Center for Training and Exchanges in the Geosciences*, 20: 157 *et seq.*.

Ogutu-Ohwayo, R. 1993. The effects of predation by Nile perch, *Lates niloticus* L., on the fish of Lake Nabugabo, with suggestions for conservation of endangered endemic cichlids. *Conserv. Biol.*, 73: 701-711

Ogutu-Ohwayo, R. 1990. The reduction in fish species diversity in lakes Victoria and Kyoga East Africa following human exploitation and introduction of non-native fishes. *J. Fish Biol., 37 Suppl. A*: 207-208.

Plisnier, P.D. 1993. Field Manual for limnological sampling on Lake Tanganyika. FAO/FINNIDA Research for the Management of the Fisheries on Lake Tanganyika. GCP/RAF/271/FIN-FM/07, 38 pp.

Plisnier, P. D. 1994. Field Manual for the Second Year of Limnological sampling on Lake Tanganyika. FAO/FINNIDA Research for the Management of the Fisheries on Lake Tanganyika. GCP/RAF/271/FIN-FM/13, 53pp.

Podsetchine, V. and Huttula, T. 1995. Hydrological modelling. FAO-FINNIDA Research for the Management of the Fisheries on Lake Tanganyika. GCP/RAF/271/PIN-TD/29, 27pp.

Podsetchine, V. and Huttula, T. 1995. Hydrological Modelling. Bujumbura , Burundi: FAO/FINNIDA Research for the Management of the Fisheries on Lake Tanganyika; 1995; GCP/RAF/271/FIN- TD/29, 1-27.

Proceedings and working papers. 1991. First International conference on the Conservation and Biodiversity of Lake Tanganyika. 11-13.3.1991 Bujumbura, Burundi.

Reynolds, J.E. and Greboval, D.F. 1988. Socio-economic effects of the evolution of Nile perch fisheries in Lake Victoria: a review. Rome: FAO; CIFA Tech. Pap., 1-148.

Richardson, J. L. 1968. Diatoms and lake typology in East and Central Africa. *Internationale Revue der gesamten Hydrobiologie und Hydrographie,* 53: 299-338.

Robson, P. J. and Bailey-Watts, A. E. 1987. A computer-based system for recording and sorting phytoplankton count data. *British phycological Journal*, 22: 261-267.

Rousselet, C. F. 1910 . Report on the Rotifera. Zoological results of the Third Tanganyika Expedition (1904-1905). *Proceedings of the Zoological Society of London,*: 792-796.

Rudd, J. W. M. 1980. Methane oxidation in Lake Tanganyika (East Africa). *Limnology and Oceanography,* 25: 958-963.

Rufli, H. 1976. Preliminary analysis on zooplankton sampling in Lake Tanganyika in May 1976. *United Nations Food and Agriculture Organisation Report,* FI: DP/URT/71/012/44: 1-10.

Rufli, H. 1978. Bibliography of fisheries and limnology for Lake Tanganyika. *United Nations Food and Agriculture Organisation,* CIFA *Occasional Paper,* 5: 1-12.

Rufli, H. and Chapman, D. W. 1976. Preliminary analysis of zooplankton sampling and estimates of fish abundance in Lake

Tanganyika in October 1975. *United Nations Food and Agriculture Organisation Report,* FI:DP/URT/71/012/31: 1-14.

Rufli, H. and Chapman, D. W. 1978. Seasonal changes in zooplankton abundance and composition off Kigoma, Lake Tanganyika. *United Nations Food and Agriculture Organisation Report,* FI:DP/URT/71/ 012/37.

Shackleton, N. J. 1980. Deep drilling in African Lakes. *Nature,* 288: 211-212.

Shimizu, A 1987. Algal benthos in the north-western parts of Lake Tanganyika. In: Kawanabe, H. and Nagoshi, M (eds). Ecological and limnological study on Lake Tanganyika and its adjacent regions IV. pp. 111-113.

Sindayigaya, E., Van Cauwenbergh, R., Robberecht, H. and Deelstra, H. 1994. Copper, zinc, manganese, iron, lead, cadmium, mercury and arsenic in fish from Lake Tanganyika, Burundi. *Sci.Total Environ.,* 144: 103-115.

Sokal, R. R. and Rohlf, F. J. 1969. *Biometry: the principles and practice of statistics in biological research.* San Francisco, Freeman. 776 pp.

Spivack, A. and Edmond, J. M. 1980. The ion balance of Lake Tanganyika. *Transactions American Geophysical Union,* 61: 46.

Stoffers, P. and Botz, R. 1994 Formation of hydrothermal carbonate in Lake Tanganyika, east-central Africa. *Chemical Geology,* 115: 117-122.

Symoens, J. J. 1955a. Observation d'une fleur d'eau a Cyanophycees au Lac Tanganika. *Folia scientifica Africae centralis,* 1: 17.

Symoens, J. J. 1955b . Sur le maximum planctonique observe en fin de saison seche dans le bassin nord du Lac Tanganika. *Folia scientifica Africae centralis,* 1: 12.

Symoens, J. J. 1956b. Sur la formation de "fleurs d'eau" de la Cyanophycees (*Anabaena flos-aquae*) dans le bassin nord du Lac Tanganika. *Bulletin* des *seances, Academie r. des Sciences Coloniales, Bruxelles,* 2: 414-429.

Symoens, J. J. 1959). Le developpement massif de Cyanophycees planctoniques dans le Lac Tanganika .9th *International Botanical Congress, Montreal,* 2A: 37.

Takamura, K. 1987. Primary production of algae attached on rocks at Mbembe and Uvira coasts of Lake Tanganyika. In: Kawanabe, H. and Nagoshi, M (eds). Ecological and limnological study on Lake Tanganyika and its adjacent regions IV. pp. 110.

Talling, J. F. 1965. The photosynthetic activity of phyto-plankton in EastAfrican lakes. *InternationaleRevuedergesamten Hydrobiologie u. Hydrographie,* 50: 1-32.

Talling, J. F. 1986. The seasonality of phytoplankton in African lakes. *Hydrobiologia,* 138: 139-160.

Thorslund, A. E. 1971. Report on survey of inland water pollution in Uganda, Kenya, Zambia and Tanzania. FAO Regular Programme Report, 11. FAO, Rome.

Tiercelin, J. J. 1988. Hydrothermal activity, metalliferous sediments and hydrocarbons. Examples of North Tanganyika and Kivu Troughs, East African Rift. *International Workshop-field seminar.* Lacustrine facies models in rift systems and related natural resources, Barcelona, October *1988,* abstr.

Tiercelin, J.J., Pflumio, C., Castrec, M., Boulegue, J., Gente, P., Rolet, J., Coussement, C., Stetter,-Karl, O., Hubert, R., Buku, S. and Mifundu, W. 1993. Hydrothermal vents in Lake Tanganyika, East Africa Rift system. *Geology,* 21: 499-502.

Tiercelin, J. J., Boulegue and Simoneit, B. R. T. 1993. Hydrocarbons, sulphides, and carbonate deposits related to sublacustrine hydrothermal seeps in the North Tanganyika Trough, East African Rift. *Special Publication of the Society for Geology Applied to Mineral Deposits.* 9: 96-113.

Tiercelin, J-J., Thouin, C., Kalala, T. and Mondeguer, A. 1989. Discovery of sublacustrine hydrothermal activity and associated massive sulfides and hydrocarbons in the north Tanganyika trough, East African Rift., *Geology,* 17: 1053-1056.

Tiercelin, J-J., Vaslet, N., Thouin, C., Kalala, T., Charlou, J. L., Fouquet, Y. and Mondeguer, A. 1988. Decouverte d'une activite hydrothermale a sulfures massifs en contexte d'ouverture intracontinentale. Les sites de Pemba et du Cap Banza, fosse nord-Tanganyika, rift est-africain. *Colloque National sur l'Hydrothermalisme Oceanique, Brest, novembre 1988,* 138-140.

UNEP. 1994. *The pollution of lakes and reservoirs.* Nairobi: UNEP.

Vandelannoote, A., Robberecht, H., Deelstra, H., Vyumvuhore, F., Bitetera, L. and Ollevier, F. In press. The impact of the River Ntahangwa, the most polluted Burundian affluent of Lake Tanganyika, on the water quality of the lake. *Hydrobiologia,* 000-000.

Vandelannoote, A., Vyumvuhore, F. and Bitetera, L. 1994. L'influence des rivieres Ntahangwa et Mugere sur le lac Tanganyika: les aspects physico-chemiques de la pollution macro-organique et de la pollution physique. *Journees scientifiques du Centre Regional Recherches en Hydrobiologie Applique (CRRHA).* Conference held 30-31 mars 1994. p. 4.

Vaslet, N., Tiercelin, J. J., Mondeguer, A. and Thouin, C. 1987. Activite hydrothermale, sediments metalliferes et hydro-carbures. Le cas des fosses nord-Tanganyika et Kivu rift est-africain). *Ler Congres Francais de Sedimentologie, Paris, novembre* 1987, res.: 323-324.

Velga, M.M. and Meech, J.A. (1995). Gold mining activities in the Amazon: clean-up techniques and remedial procedures for mercury pollution. *Ambio,* 24 (6): 371-375.

Vuorinen, I. 1993. Sampling and counting zooplankton on Lake Tanganyika. FAO/FINNIDA. Research for the Management of Lake Tanganyika. GCP/RAF/271/FIN-FM/06, 19 pp.

Vuorinen, I. and Kurki, H. 1994. Zooplankton sampling on Lake Tanganyika. FAO/FINNIDA Research for the Management of the Fisheries on Lake Tanganyika. GCP/RAF/271/FIN-TD/22, 42pp

Wells, T. M., and Cohen, A. S. 1994. Human impacts and background controls of faunal diversity and community structure in L. Tanganyika, Africa. *Geological Society of America,* 26: 488.

Wright, J. F., Blackburn, J. H., Westlake, D. F., Furse, M. T. and Armitage, P. D. (1992). Anticipating the consequences of river management for the conservation of macroinvertebrates. In: *River conservation and management* (eds. P. J. Boon, P. Calow and G. E. Petts), pp. 137-149, John Wiley, Chichester.

Wright, J. F., Furse, M. T. and Armitage, P. D. (1993). RIVPACS - a technique for evaluating the biological quality of rivers in the U.K.. *European Water Pollution Control,* **3**: 15- 25.

Appendix A: Draft, costed work plan for the pollution-biodiversity studies.

Aspects of the Work Plan with a bearing on costs

The main activities of this Pollution-Biodiversity Study are to firstly assess pollution levels and measure biodiversity and secondly, by identifying and where possible quantifying the sources of pollution to the lake, assess the extent to which these pressures threaten what is widely viewed as an extraordinarily rich assemblage of species. To achieve these aims, and the associated targets of resource building and training in limnology, lake management and aquatic conservation, it is important that the main sampling and data acquisition components of the Sediment Pollution Study and those concerned with particularly the fish components of the Biodiversity programme, are run in parallel with the pollution-biodiversity investigations. This is especially important where the large ship has to be used e.g. for open, deep water generally, and where there is a need for lake-wide assessments, and for travelling between the different national sectors of the lake even if few samplings are made between these sectors. Relatively few, but long, cruises (?4 weeks duration) will facilitate the collection of sediment material, and samples of water and biota, which would be subsampled and distributed as appropriate to the analytical requirements of the project as a whole. This 'sharing' of boat time, sampling gear and associated position-fixing and probe recording facilities - yielding data needed by all the teams - would also maximise efficiency of use of human resources; all of the UK consultants appointed as experts in limnology, plankton and pollution can already handle the practical aspects of procuring samples for each other. There is a need to ensure that each could also be called upon to execute the routine aspects of the sediment programme. Most importantly, collaboration with local consultants, and training of local scientific and technical appointees, will ensure that cadres of Burundi, Tanzanian, Zaïrian and Zambian personnel will be equally capable of carrying out these tasks. (Some other related, aspects of training are presented in Section 6.5).

The above approach will also maximise the 'release' of personnel and expertise which will be much needed for the in-shore activities, e.g. sampling the mouths of a selection of those feeder waters which cannot be accessed with the large vessel. Demands for boats for work in shallower stations and the littoral zones may not be quite so heavy as envisaged for major vessel and the open water programme. However, compared with the pelagial, there is a far wider spectrum of physical, chemical and biological situations (and presumably, biodiversity) to be explored, and thus a (considerably) larger number of stations to be sampled - even if a 'core' number of only 3 or 4 are studied in each country sector in detail (e.g. monthly).

The other main considerations influencing the schedule relate to (i) seasonal variation in the weather, and rainfall-derived run-off of sediment and associated agricultural fertilisers and pesticides, and (ii) general patterns to be expected as regards spatial and temporal variation in the abundance and species composition of the biotic communities of pelagic zones as opposed to in-shore areas, and the free-living plankton and nekton compared with the assemblages of flora and fauna more or less intimately associated with bottom sediments or other surfaces. The (draft) schedule of activities is as follows (with numbers referring to month/year), and assuming that the pollution-biodiversity studies now start in 4/96 and end in 10/99.

- armed with information gained from preparing the Baseline Review (**by end 1/96**) and the Inception Report (**by end 3/96**), we will prepare the PLTSP **by end 4/96**

- main 'exploratory, thrust for the Pollution-biodiversity work is **3/96 to 6/99 inclusive,** by about which time (?) the FLTSP has to be completed; the following targets are set within this period:

- **3/96 to 8/96 inc.** - 'settling in' and establishment of laboratory bases; procurement of equipment; furnishing of laboratories; appointment of local personnel.
- **5/96 to 12/96 inc.** - African-UK collaboration and training in field, laboratory and office methods practices, using material collected from the lake and catchment waters; preliminary selection and establishment of sampling sites; first installations of recording equipment e.g. staff gauges.
- **1/97 to 3/97 inc.** - 'trial' analyses, reporting and presentation of data generated from 'practice' samples;

revision (where appropriate) of sample sites, and first decisions regarding the schedules/frequencies of sampling.

- **4/97 to 5/99 approx.** - routine sampling schedules - with options for adjustment/modification as appropriate; on-going sample analysis, data logging and analysis and writing-up.
- **5/99 approx. to 11/99 inc.** - production of final report.

- **12/99 to x/00?** contribution to (i) the plans and recommendations on sustainability and future monitoring of pollution etc., (ii) the selection and management of 'reserves', (iii) establishment of a 'research-to-management-to-policy' machinery - and coordination of activities at the *regional* level.

Estimated costs

The estimates are far from finalised. However, the equipment considered necessary for successful completion of the pollution-biodiversity work amounts to approximately £800,000 (Appendix B) or 1.2M US$. This is excluding costs of the use of the large vessels. While not an inconsiderable sum, it embraces a considerable resource by way of office, field and laboratory gear that can be shared by the other projects. It should also be noted that the present listings assign approximately 50% of the equipment budget to (good) microscopes. This reflects the considerable importance attached to the very careful and meticulous approaches that will be necessary in order to properly address biodiversity assessment and species identification. It is possible, however, that some microscopes can be 'lent' from UK.

Table 7 in Section 7.2 indicates the local staff required; these have not been costed - although it will be a simple matter to do so once the latest rates of pay are available. We propose to place one or two UK graduates in Africa for the duration of the project. They would maintain contact with the Dr Menz (Project Coordinator) and Dr Banister (Scientific Liaison Officer), and the African project leaders in each country; their scientific work (including the training of young scientists in each of the riparian countries) would also be closely supervised by Drs. Bailey-Watts and Foxall and the other UK consultants. It is stressed that these inputs are in addition to, not a substitute for the existing consultants.

Appendix B: Equipment required for the Pollution Special Study - including the resources for carrying out biodiversity work associated with pollution assessments.

Equipment/resources needed during the planning of field surveys etc.

Computer hardware - including printers and scanning pens; computer software: at the very least, the WordPerfect for Windows version 6.0 is needed for general writing; Excel and SigmaPlot for data analysis, other spreadsheet work and good quality graphs and graphics.

Literature, including maps, for desk studies and the planning of initial field reconnaissances, pilot sampling programmes, and laboratory and data analytical trials - all aimed at identifying the sampling sites to be operated for the duration of the project. As indicated above, much of this literature is housed in Bujumbura.

Sub-total £15,000∴ £60,000 for whole project

Equipment/resources needed to reach the sampling sites

Vehicles and boats plus fuel; use of major vessel/s; safety equipment (no sign of life-jackets in the small craft used by Dr. Bailey-Watts at Kigoma); maps; GPS; phone/radio communication facilities.

Sub-total £100,000 for whole project

Equipment/resources (in addition to the instrumentation outlined in Section 7.1) for the logging of environmental conditions and for the immediate handling/treatment of samples and their transport back to the laboratory

For recording field conditions: waterproof pens and notepads and field record proformas; cameras; probes (for air and water temperature, pH, sampling depth, water depth, dissolved oxygen and electrical conductivity, turbidity/water clarity).

For sampling and collecting water, sediment and biota: sampling tubes, closing water bottles; nets; grabs; corers; 'scrapers'; assorted ropes.

For the immediate treatment of samples: 'cool boxes', black cloth, fixatives and preservatives; portable filtration kits; portable (manual) centrifuges; dishes; lenses; assorted specimen and water containers.

Sub-total (excluding entries in following Table) £30,000∴ 120,000 for whole project

Item/Size	cost (£)	number	total cost (£)
Buckets - 10litre (with plastic/metal grip)	4	15	60
Plastic boxes (Stewart)			1000
Divers' knives	10	4	40
Buckets (metal) - 10 litre	45	4	180
thermo-insulated boxes (large)	35	4	140
aluminium foil	6	5	30
measuring tapes	5	2	10
high-density polythene knives	0.5	50	25
plastic tweezers	2	20	40

pyrex dishes (for mussel and fish preparation)	15	5	75
hexane (cleaning aluminium foil)	26 /2½litre	3	78
Stainless steel knives	10/set	2	20
Stainless steel tweezers	20/set 4	2	40
Teflon wash bottle	45	2	90
95% Ethanol	25 litres	1	200
phosphate-free detergent			
weighing bottles (glass)	10	5	50
Dissecting board	25	2	50
Peristaltic pump			
			sub-total £2,128 ∴ £8,512 for whole project

Equipment/resources needed for the longer term storage and preservation of samples, and for main analyses of the materials and samples

Instruments

Item/Size	**cost (£)**	**number**	**total cost (£)**
Freezer (chest - large)	300	1	300
Oven (100-150 litre)	1000	1	1000
hot plate / stirrer	200	5	1000
Distilled water (still)	500	1	500
top pan balance (0.01g)	1000	2	2000
portable top pan	500	2	1000
Shaker	600	1	600
Spectrophotometers			
(visible and accessories)	1500	1	1500
uv/visible	3000	1	3000
Electric vacuum pump (filtration)	200	2	400
Hand vacuum pump	50	4	200
Water bath	300	2	600
Pressure cooker	50	2	100
Muffle furnace ?	900	1	900
Flame photometer			
			sub-total £13,100 ∴ £52,400 for whole project

Microscopes			**sub-total £100 000 ∴ £400,000 for whole project**

Small items

Item/Size	**cost (£)**	**number**	**total cost (£)**
Aluminium Foil - 90 metres	6	5	30
Aspirators - 25 litre	20	2	40
Beakers			
10ml	1.4		
100ml	1.2		
250ml	1.3		
600ml	2		
1000ml	3		
2000ml	6		
Benchkote paper (50 metres)	70	2	140
Pipette dropping bottles (125ml)	2	20	40
Bottles - W/N - plastic 500ml	0.5	200	100
1000ml	0.5	200	100
Bottles (amber) W/necked			
500ml	2.0	200	400
250ml	2.0	200	400
Wash bottles - polythene 250ml	1.0	10	10
Balance brushes	4.0	5	20
Beaker brushes	0.5	10	5
T/tube brushes	0.5	10	5
Bunsen burners	6.0	10	60
Centrifuge tubes	4	25	100
Clamps, retort	4	20	80
Burettes	8	20	160
Cling film (300 metres)	8	3	24
Cuvettes, plastic (x100)	5	10	50
glass			
Cylinders, measuring, glass			
10ml	8	10	80
25ml	8.5	10	85

50ml	8.5	10	85
100ml	10	10	100
250ml	14	10	140
500ml	17	10	170
1000ml	19	10	200
Cylinders, measuring, plastic			
25ml	1.5	10	15
50ml	1.5	10	15
100ml	2	10	20
250ml	4	10	40
500ml	4	10	40
1000ml	5.5	10	55
2000ml	19	10	190
Filter papers various sizes	2.5 (av)	40	100
GF	15 (av)	40	400
Filtration flasks			
250ml	6	10	60
500ml	7	10	70
1000ml	9	5	45
Magnetic followers	1	10	10
Mortar and pestle, ceramic	15	4	60
Pipettes, bulb, glass			
10	1.5	10	15
25	2.5	10	25
50	3	5	15
Pipettes, graduated, glass			
0.1	2	10	20
0.2	2	10	20
0.5	2	10	20
1.0	1	10	10
5	1	10	10
10	1	10	10
Pipette fillers	7	5	35
Pasteur pipette (1000 box)	6	3	18
Test-tube rack	5	5	25

Polythene bags (various sizes)			100
Scalpels	2	15	20
Scissors	3	5	15
Trays	6	10	60
Eppendorf pipettes (up to 10ml)	250	3	750
tips - range			300
safety specs	2	10	20
filtration equipment (Whatman)	30	5	150
Tripods	6	10	60
Polystyrene bottles (10)	70	3 packs	210
Desiccator, polypropylene (vacuum)	60	3	180
Aluminium dishes (1000)	40	1 pack	40
Flask, conical			
100	2	20	40
250	3	30	90
500	3	10	30
Flasks, volumetric, glass			
10	4	10	40
25	4	10	40
50	4	10	40
100	5	10	50
250	7	20	140
500	9	10	90
Forceps (polypropylene)	1	10	10
Funnels 45mm	5	10	50
100mm	6	10	60
Gauzes/asbestos centre	1	10	10
Gloves latex (box)	10	10	100
Spatulas micro	3	10	30
larger	3	10	30
Sealing tissue (roll)	14	5	70
teat pipette (d/bottles)	1	20	20
test-tubes (pk 10)	5	20	100
thermometers (-10 -- +110^{0}C)	9	10	90
timers	1.5	5	75

Burettes (polypropylene?)			
10ml	35	10	350
25ml	35	10	350
Retort stands and clamp	25	20	500

Sub-total £8,277 ∴ £33,108 for whole project

Equipment/resources needed for data logging, analysis, interpretation, and presentation in written and spoken form

Computer hardware - including printers; software, at the very least: the WordPerfect for Windows version 6.0 is needed for general writing; Excel and SigmaPlot for data analysis, other spreadsheet work and good quality graphs and graphics. Much of this is already accounted for under the resources itemised above for planning, but an extra sum should be considered for visual aids and the production of reports, scientific papers, slides and overheads.

Sub-total £10,000 for whole project

Other equipment/resources

E-mail; fax and phone links. Electrical plugs/sockets (multi-plug systems); current stabilising and/or other measures to protect electrical and electronic equipment.

Sub-total £10,000 for whole project

GRAND TOTAL: £ 794,020

Appendix C: Issues arising from the scientific review for the Pollution Special Study, with a bearing on Social-economic studies.

We have given very little thought to these issues so far. However:

- Reynolds and Greboval (1988) discuss whether the introduction of the Nile Perch (*Lates niloticus*) to Lake Victoria have been beneficial (in apparently improving the commercial fishery for example), or a disbenefit (by marginalising the artisinal fisherfolk).

- Deelstra references commonly concern the potentially harmful effects of fish contiminated with pesticide residues.

- Eskeland, G. S. 1992. Policy instruments for pollution control in developing countries. *The World Bank Research Observer*, 7: 145-169.

- Alabaster, J. S. 1981. Review of the state of aquatic pollution of East African inland waters. *United Nations Food and Agriculture Organisation Report,* CIFA/OP9. Considers among other things: action on technical cooperation to evaluate and disseminate information, satisfy training needs, and foster legislation and research on the prevention of water pollution. May refer to consequences (not costed though) of not doing something about this.

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