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Pollution Special Study (PSS)

Summary Technical Report

by
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2000

Pollution Control and Other Measures to Protect Biodiversity in Lake Tanganyika (RAF/92/G32)
Lutte contre la pollution et autres mesures visant à protéger la biodiversité du Lac Tanganyika (RAF/92/G32)

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

Burundi: Institut National pour Environnement et Conservation de la Nature
D R Congo: Ministrie Environnement et Conservation de la Nature
Tanzania: Vice President's Office, Division of Environment
Zambia: Environmental Council of Zambia

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THE LAKE TANGANYIKA BIODIVERSITY PROTECTION POLLUTION SPECIAL STUDY

Summary

To assess the overall pollution status of Lake Tanganyika, samples and probe readings were taken from a total of approximately 40 sites distributed over the lake from the northern most Rusizi area in Burundi to the Mpulungu area at the foot of the lake in Zambia. The focus was primarily on potential enrichment from sources of inorganic nitrogen and phosphorus and on water quality indicators such as transparency and chlorophyll$_a$ concentrations. However, data on phytoplankton population densities, net phytoplankton size frequency distributions and the diversity of genera were also generated.

The lake can be characterised as one of a conductivity of *ca* 700 _S/cm, a transparency usually exceeding 8m, and chlorophyll$_a$ concentrations (as a measure of phytoplankton abundance) generally around 5_g/l. The pigment value indicates an oligotrophic system at this trophic level, but - as outlined below - not ultra-oligotrophic. The algal levels nevertheless, do not take account of the likely high phytoplankton *production.* On the basis of the PSS sampling coverage, NH_4-N and NO_3-N levels recorded in Burundi are 0.5-1.0 mg/l. Nitrate concentrations in Tanzania are of the order of only one-tenth of these levels. This is not because many of the Burundian sites are riverine; open water sites there are equally rich in these ions. Typical soluble reactive phosphorus concentrations of 0.5mg/l in Burundi contrast considerably with the levels recorded in Tanzania - and Zambia i.e. 7-8 _g/l and *ca* 12.0 _g/l respectively. Note therefore, the high N-to-P weight ratio in Burundi. Total P concentrations (measured in only the anglophone countries) were typically 30_g/l in Tanzania and somewhat less at 12_g/l in Zambia.

Peak levels of 0.8-1.2mg NO_3-N/l in Burundian waters are much the same as those characteristic of shallow eutrophic systems in Europe. The maxima again contrast with ranges of 75-130_g NO_3/l obtained from samples taken elsewhere. The range in maxima recorded in Tanzania was 25-60_g TP/l compared with a smaller excursion of 30-40 _g/l found in Zambia. There are many instances where a particular factor has much the same maximum regardless of the apparent proximity to human impact. As an example, much the same maximum TP level of 45_g TP/l was recorded near such disparate sites as the thronging Ngwenya Market and the far more remote area of the Nsumbu National Park in Zambia. This does not mean however, that a nutrient maximum for example, is attained on the same number of occasions. Detailed time-series data are now available for interrogation and interpretation. The apparent similarity in the levels of a particular nutrient for example, may also indicate rapid mixing of inshore water with the open lake. Chlorophyll$_a$ maxima in Tanzania range from 1.5-7.0 _g/l. This is probably not significantly different from the range of 3-6_g/l found in Zambia, particularly if we exclude the two highest maxima of 13 and 14_g/l associated with the surface blooming of the cyanobacterium *Anabaena flos-aquae* caused by the seasonal nutrient up-welling in e.g. May 1998.

With data still arriving from the regions as late as the end of 1999, substantial sets of information still need to be checked. These mainly concern algal studies comprising (i) arrays of the maximum size and generic identity of net phytoplankton in Tanzania and Zambia, and (ii) algal population density information from the Burundian team. However, other information that still needs to be explored, includes that on the weather records throughout the region, and in Tanzania, a series of Kigoma-Gombe-Kigoma transects of conductivity, water temperature, pH and dissolved oxygen levels.

Although this report is the 'final' one produced by the PSS team, it should also be viewed as a new beginning. In addition to re-checking the present data, we need to produce a more detailed account of temporal and spatial variation in the factors studied. For example, the teams could establish

whether trends in various pollutants or indicators of pollution exist between inshore and offshore sampling sites. The data could also be analysed and interpreted better than they have been so far, by testing hypotheses such as the following:

- phosphorus concentrations are highest at sampling sites near towns and large villages.
- due to rapid water mixing, point-source pollutant concentrations are similar to those measured 100m off shore.
- the taxonomic composition and abundance of the phytoplankton reflect nutrient levels and water stability.

This Coordinator would be interested in collaborating with the regional teams over these and other aspects. He is also keen to help the regional personnel publish the findings of the PSS.

1. INTRODUCTION

This report, along with separate volumes of data graphs and tables, represents the culmination to date, of the Pollution Special Study (PSS) training and research programme. The programme aimed to assess the pollution status of Lake Tanganyika through an extensive series of general field observations, readings from electronic probes (for water temperature, dissolved oxygen, conductivity and pH) and surface water samples for chemical and net phytoplankton analyses. These data will eventually be related to the findings of the Biodiversity Special Study that dealt with higher biota. My fellow consultants were Dr Chris Foxall, Mr Alex Kirika and Miss Nicola Wiltshire (with Nicola working full-time between the Kigoma and the Mpulungu LTBP bases from November1997 to August 1998). Our regional collaborators/trainees were as follows:

Bujumbura : LTBP laboratory

Mr Wilondja Kamalebo - algologist

Bujumbura : INECN laboratory

Mr. Gabriel Hakizimana - PSS Coordinator and analyst
Madame Consolate Musanisoni - analyst
Mme Aline Irimbere - analyst

Uvira : LTBP laboratory

Dr Tshibangu - PSS Coordinator
Mr Mukungwila Kamalebo - algologist
Two other persons yet to be assigned

Kigoma : LTBP laboratory

Dr Francis Chale - PSS Coordinator and limnologist
Ms Grace Bwathondi (50%) - data entry
Mr Kadula (80% of time) - field operative and i/c 'wet' laboratory
Ms Lyoba (50% of time) - analyst
Mr Lyoba - i/c all laboratory facilities
Mr Mfilinge - field operative and microscopy
Mr Muhoza (90% of time) - microscopy
Mr Tegulilwa - microscopy
Mr Wakafumbe (75% of time) - microscopy

Mpulungu : LTBP laboratory

Mr Leonard Mwaba Mwape - Station Director and limnologist
Mr Lawrence Makassa - analyst
Mr Isaac Zulu - algologist
Mr Joseph Chimanga - analyst
The Late, Mr Kosamu Kaweme - fisheries

Arusha : Tanzania Pesticide Research Institute

Mr Johnathan Akhabuhaya (Principal Researcher Officer at TPRI) and colleagues others to be assigned for specific tasks - e.g. designing a sampling regime for pesticides and heavy metals.

This report has been written by the PSS Coordinator. It covers physical, chemical and algal aspects, but generally excludes findings on pesticides, heavy metals and hydrocarbons which are being assessed following a recent pollution inventory organised by with Dr Foxall and Dr Kelly West. Apart from reasonably regular progress reports from the Burundian team, no reports have been received from the Lake region. However, there has been an enormous output of data from the Lake Tanganyika laboratories in Tanzania and Zambia as well as Burundi. This report provides an overview of results rather than detailed methodology. It bears ample evidence of an enormous effort made by all concerned. Consequently, this report can only comment on a small fraction of the large amount of information generated. As an example, we have plotted approximately 300 graphs of temporal variation in physical and chemical factors; these range over time-spans of a few days to many months. Other data sets also only referred to briefly here are as follows:

(i) series of surface water probe measurements taken along transects between Kigoma and Gombe, Tanzania
(ii) data on heavy metals in Burundi
(iii) net phytoplankton size and Genus richness arrays produced by the Anglophone teams
(iv) phytoplankton densities produced by the Bujumbura (Burundi) PSS Laboratory.

Deadlines dictate that this report is the final one from the PSS. However, this Coordinator views it as a beginning of a phase of more intensive analysis, interpretation and, above all, publication. He would also be very happy to be involved in these aspects.

2. GENERAL APPROACH

Following contributions to the successful bid for the GEF Lake Tanganyika Biodiversity Project, the PSS Coordinator made the Study's first visit to the Lake region in November 1995 (see References). The visit was crucial in providing a first-hand appreciation of the challenges of the Project, and the prospects of assessing 'pollution' parameters over the length and breadth of the Lake. The challenges were all the more testing in that, at one and the same time, we needed to train personnel to carry out the following tasks to an acceptable standard:

- appreciating the *raisons d'être* of the work
- assembling the resources and equipment to execute field recording and sampling programmes
- handling the samples appropriately (preservation, protection) and transporting them back to the laboratory
- recording the observations made and logging the samples collected
- analysing the samples and attending to AQC procedures
- logging and checking the results
- reviewing and interpreting the results
- reporting on the findings in a manner appropriate to 'end users' e.g. the public, fishing communities, water engineers and pollution prevention personnel.

The Coordinator's first visit referred to above, was valuable in providing him with an opportunity to scour the FAO Lake Tanganyika Project's library. Along with access to the libraries of the Institute of Freshwater Ecology and the Freshwater Biological Association, these resources underpinned much of the information that was eventually incorporated in the PSS Baseline Review.

With the exception of Dr Francis Chale who eventually headed the Kigoma Laboratory, PSS staff were appointed from existing fisheries institutions in Bujumbura, Kigoma, Mpulungu and Uvira. On account of the war situation, the Uvira PSS laboratory has only now started to produce data. The PSS approach to securing the information necessary for assessing pollution in the Lake, has been by means of 'on-the-job' training between Drs Bailey-Watts and Foxall, Mr Kirika and Miss Wiltshire. This contributed significantly to a reasonable monitoring of physical, chemical and micro-algal aspects of river and lake water sites, maintained over some 40 months. This long-term routine has undoubtedly increased the skills of the trainees. The data accrued will remain useful in providing a benchmark against which change or lack of change in various aspects of water quality can be assessed. [1]

As already indicated, we are still assessing the impacts of pollution status on some aspects of the nature and abundance of the phytoplankton. All aspects of the PSS programme have been achieved by means of following:

- establishing a series of sampling sites ranging from 'pristine' to plainly impacted in all four countries, although data from Congo are only just emerging
- ensuring that the majority of the riparian sites are also those studied by the BioSS team
- incorporating studies on micro-algae (especially phytoplankton) from samples taken at the same spatial and temporal frequencies as those used for our other work.

The present document, along with separate reports such as the Baseline Review, suggests that the PSS did achieve its main goals. It also reviewed to some degree all of these issues in its submissions to the Strategic Action Plan (see 'References'). A major omission concerns Analytical Quality Control (AQC), although samples, Secchi disc and probe readings were taken and analysed in duplicate. Unfortunately, due to a combination of lack of time and inability to

[1] To be outlined in a separate document, although aspects of this were included in our contributions to the Strategic Action Plan

gather appropriate personnel together, we were unable to mount workshops on data analysis and interpretation, as well as those on field sampling practices AQC, and micro-algal population density estimation, species identification and species richness AQCs. The most seriously neglected of these tasks, were those relating to AQC and the last two areas listed above.

In spite of these omissions, the great majority of the results make sense'. These include sustained trends in many dozens of time series graphs relating to lake sites, in contrast to the more erratic plots relating to river sites and effluent outfalls. Examples of such data are featured later in this report.

3. AIMS

The main aim of the PSS was to support the development of the Strategic Action Plan (SAP) to manage the lake, while the aim of the SAP was, and still is, 'to provide for regional management of biodiversity and the livelihoods of present and future generations of lakeside communities'. With this in mind, the PSS endeavoured to provide the following:

- sound information on pollutant levels and their distribution; *this remains to be seen after a thorough analysis of the data, and the relationships between for example, nutrient levels and the nature and abundance of the phytoplankton; we failed most however, in relation to work on hydrocarbon, heavy metal and pesticide pollution, although an inventory of these substances was carried out under the direction of Dr Foxall, and Dr Chale collaborated with Mr Akhabuhaya over some of these substances in molluscs, crustaceans and fish.*

- field and laboratory facilities to carry out the necessary qualitative and quantitative analyses: *there were problems with such vital instruments as spectrophotometers from time to time, but a substantial body of sensible results has been generated*
- regional personnel trained to carry out these duties both now and after the official end of the LTBP: *the PSS teams are capable of carrying out the duties necessary to maintain skeleton monitoring programmes; relatively few crucial requirements are needed to monitor a few sites easily accessed and generally impacted areas, as well as a few remote and less frequently monitored sites; the existing database will provide information on which parameters to include*
- sampling micro-algae at some of the same sites and at the frequencies adopted for gauging nutrients, and exploring the relationship between eutrophication levels and the diversity of species involved in photosynthesis and primary production: *a considerable amount of data analysis remains in order to explore these relationships.*
- linking with the BioSS team to establish whether diversity at one trophic level (e.g. phytoplankton) is paralleled by diversity at other levels (e.g. those of invertebrates and fish): *a considerable amount of data analysis remains in order to explore these interrelationships.*
- contributing suggestions on priority areas of conservation based on PSS findings in mainly off-shore and open water habitats, but also with some attention to shoreline epilithic algal communities: *in its submissions to the SAP, the PSS commented on the relative potential at least, of any habitat - including overtly impacted areas - harbouring 'new' (unrecorded) species.*

4. OBJECTIVES

To achieve these aims, the PSS had the following four key objectives as written in the Baseline Review:

- to obtain sound information representative of the lake wide situation regarding pollution and phytoplankton status (overall abundance and species diversity): *we achieved this by capitalising on (virtually lakeside) working laboratories in all four countries: Bujumbura (Burundi) and Uvira (Democratic Republic of Congo) at the northern end of the lake, and in Kigoma (Tanzania) approximately one-quarter of the distance down the lake on its eastern side, and in Mpulungu (Zambia) at the southernmost point of the lake*
- to identify the main types of pollution and their sources and, where feasible, to gauge their concentrations and loadings: *we have not estimated loadings, although information from the Sediment Special Study on river discharges can be combined with the considerable body of PSS pollutant concentration data*
- to examine the diversity of phytoplankton within polluted/eutrophic areas and at pristine sites of similar physiography: *a considerable set of algal information relating to sampling sites that we consider - on the basis of proximity to human habitation - in both impacted and unimpacted areas has yet to be analysed*
- to assess the effects of pollution on phytoplankton diversity - and thus, the levels of pollution that can be sustained without loss of that diversity: *this has not been explored, but overall sampling coverage was extended to a number of sites situated many kilometres from the laboratory bases: good examples of remote sites are those in the Gombe area in Tanzania and sites some 80 kilometres from Mpulungu, Zambia; in comparison, our sites in Burundi were mainly, though not exclusively in and near Bujumbura Town.*

A second laboratory in Bujumbura is the National Institute for the Environment and the Conservation of Nature (INECN). Together with the much refurbished and equipped Centre Regionale Hydrobiologique (CRH), Uvira, this constitutes as strong a base in the Francophone countries as those in Tanzania and Zambia, although, as already indicated, studies in Uvira have only just begun.

5. FIELD AND LABORATORY METHODS

A separate document describing a number of field and laboratory procedures adopted in the Anglophone laboratories will be available on request from NRI/University of Greenwich. They are similar in all respects to those summarised in **Table 1**. The Bujumbura laboratories used similar methods but attended to a somewhat different suite of analyses. This reflects the greater attention there, to waters and effluents containing industrial contaminants in and around that town.

6. RESULTS AND DISCUSSION
6.1 The physical and chemical database

The physical and chemical database comprises the following:

- information produced by the Burundian PSS team (4) headed by Mr Gabriel Hakizimana, on 13 main sampling sites extending from the Rusizi in the north to the Muha area in the south; the main analytical focus was Cadmium, nitrate-nitrogen, water temperature, ammonium-nitrogen, Lead, pH, phosphate-phosphorus, sulphate, total dissolved solids and electrical conductivity. The total number of analyses/recordings carried out is approximately 1,270.
- to information produced by the Tanzanian team (7) headed by Mr Makassa on 13 main sites extending from the Gombe region in the north to Jacobsens Bay south of Kigoma; the main determinands were suspended solids, electrical conductivity, pH, chlorophyll$_a$, water clarity, dissolved silica, total phosphorus, phosphate-phosphorus, % dissolved oxygen and water temperature. The total number of analyses/recordings is approximately 1,940.
- to information produced by the Zambian team (7) headed by Mr Makassa on 11 main sites extending from Nsumbu Harbour in the north to Mpulungu Ngwenya Market in the south; their results included on % dissolved oxygen, dissolved silica, total phosphorus, phosphate-phosphorus, water temperature, pH and electrical conductivity, chlorophyll$_a$ and water clarity. The total number of analyses and recordings is 2,300.

Table 1. Field and laboratory methods for physical (including weather) and chemical (including chlorophyll$_a$) variables.

DETERMINAND	METHOD OF MEASUREMENT
Daily run of wind	Recording the number of revolutions of a cup-counter anemometer
24-h rainfall	Standard meteorological rain gauge
Maximum and minimum air temperatures	Screened mercury-in-glass maximum-minimum thermometer
Water level	Readings from metric staff-gauge near the laboratories
Water temperature	Mercury-in-glass thermometer
Water transparency	The depth at which a 20-cm diameter, quartered black and white Secchi disc, lowered into the water, disappears
Nitrate-nitrogen	Spectrophotometry following reduction by cadmium to nitrite and reaction with acidified sulphanilamide and N-1-naphthylethylenediamine hydrochloride producing a brightly coloured azo dye
Soluble reactive phosphorus	Spectrophotometry, using the molybdenum blue method (acidic ammonium molybdate with potassium antimony tartrate and ascorbic acid)
Soluble reactive silica	Spectrophotometry, using the molybdenum blue reaction (acidic ammonium molybdate with ascorbic and oxalic acids)
Chlorophyll$_a$	A measured volume of lake water is filtered through a glass-fibre disc which is then steeped overnight in 90% methanol; the subsequent pigment extract is then measured in a spectrophotometer.

The grand total number of physical and chemical analyses thus exceeds 5,500. **Appendix 1** is the

Contents List of the hard copy volume of SigmaPlot graphs and associated data.

Ranges in values of a selection of factors studied in Burundi

This section concentrates on a selection of data on heavy metals, nutrients and overall indicators of water quality such as conductivity, suspended solids and pH.

Lead is of considerable concern in over the world because it is characterised by rapid respiratory uptake. In contrast to the situation regarding the effects of Lead on humans, the threat to aquatic biodiversity is not at all well-documented. The only LTBP data on Lead are those produced by the Burundian team. **Figure 1** gives the results eight sampling sites. Compare these levels with those of 1-3 ug/l characteristic of natural fresh waters. Apart from the figures recorded at the Lake Life Buoy and the Kanyosha River mouth sites, the LTBP levels are much lower than those normally recorded i.e. 100-200 ug/l for waters draining areas of lead mineralisation, and the 100-400 ug/l in mainly particulate form in urban area storm water run off. Concern remains however; a considerable amount of lead is likely to be present in both water and the air in the region, assuming that the vast majority of the thousands of outboard motor boats on the lake are likely to be fuelled by petrol with a Pb concentration of approximately 1g/l. An additional worry is the Lead emitted from cars and trucks. Introduction of lead-free fuels would increase fuel costs, but some of the financial outlay for this could be offset by savings on health-care. Future programmes should monitor Pb levels at quarterly intervals at one or two obviously impacted sites (e.g. the Port) and a site well distanced from this (e.g. the Muha area). The PSS has produced some valuable data on this element, but more assays of the levels in pelagic and benthonic biota are needed.

As a toxic element that can enter the food chain, Cadmium, like Lead, is also of environmental concern. Disposal of waste Cd probably stems primarily from point-sources. Control of this could do two things: enhance the edibility of biota, and improve human health. This project obtained values of 60-70_g dissolved (i.e. *not total*) Cd/l from the Rusizi and Kanyosha Rivers. Other sites registered <10_g/l **(Figure 2**). A search for previous data on the Cd status of the lake proved fruitless, but the Burundian Laboratory's results fit well with concentrations generally expected for natural rivers and lakes, and other uncontaminated waters.

In December 1998, Dr Foxall submitted a rigorously designed plan to survey a number of heavy metals, (as well as pesticides and hydrocarbons), primarily for Burundi, but the proposal was never funded. However, some new data will be gained from an inventory of the nature and approximate discharge rates of industrial effluents (e.g. metal working/electro-plating and paint plants) in all four countries.

Phosphate-phosphorus (soluble reactive phosphorus, PO_4-P or SRP) is normally present in very low concentrations, and particularly so relative to the levels of other nutrients such as nitrate and silica. As a consequence, SRP is often the main nutrient limiting primary biological activity and thus, the production of many other lake biota. This general situation is far removed from the situation in Burundi, with concentrations of *milligrammes per litre* in contrast to tens or hundreds of *microgrammes per litre* encountered elsewhere (**Figure 3**). These levels are characteristic of hypertrophic ponds and tanks in countries such as India. As a consequence, we question their validity. It is unlikely, however that the concentration units are at the microgramme per litre level. First, we doubt that the analytical method for SRP used in Burundi could detect such low concentrations. Second, such concentrations of this nutrient are invariably higher than a few microgrammes per litre in the other countries. An exception might be that similar to the situation recorded at the foot of the lake in southern Zambia, at the time of the seasonal up welling of nutrients. This was marked by an extensive algal bloom consisting almost entirely of the cyanobacterium *Anabaena flos-aquae fa. atekariana* which is very similar to the often toxic *flos-aquae* form in Europe.

Nitrate maxima in Burundi generally decreased from the north (Rusizi area) to the south (Muha) although the absolute maximum value of 2 mg NO_3^-N/l was recorded at the Lake Port site (**Figure 4**). Towards the other end of the range of nitrate concentration maxima are levels of *ca* 0.5 mg/l (e.g. in the Kinyankonge River) and 0.1 mg l^{-1} (Lake Life Buoy). With the exception of the Lake Life Buoy site, the sampling locations constitute an area that is very rich in nitrate, and comparable in this respect with shallow eutrophic systems in Europe. The situation almost certainly stems from runoff of nitrogenous fertilisers from the catchment. In Europe, one would favour limiting fertiliser usage in this situation, but the high-nitrate areas in lake Tanganyika may well be enhancing biodiversity potential, but quantitative information on the relationships between biodiversity and nitrate status is lacking. Assuming the high SRP concentrations referred to above are correct, a particularly striking feature is the very low NO_3^-N/l-to-PO_4^-P weight ratios: these approximate to 1:1 in contrast to 10:1 generally recorded for lake systems. This situation may well be reflected in the algal species composition, but we have not yet examined these features in our database .

Sulphate levels (not plotted) generally decreased from the Ntahangwa southwards. Concentrations of 3-4 mg sulphate/l fit well with previous results of 3-5mg/l recorded by Dr Cohen and his co-workers and in the late 1980's. For some reason, concentrations in the Rusizi and Kinyankonge rivers are clearly much higher than those recorded elsewhere, but concentrations are well below those likely to cause concern over human exposure. This study did not ascertain the relative importance of sulphate originating from geological sources, and that relating to the use of Aluminium Sulphate in water works for example.

Ammonium nitrogen levels are remarkably similar to the oxidised N values. However, whereas nitrate maxima generally decrease from north to south, ammonium-N maxima showed no such trend. The highest concentrations were recorded in the Rusizi, Kanyosha and Muha rivers (**Figure 5**).

Temporal variation in a selection of factors studied in Burundi

Before considering temporal variation in some physical and chemical factors, it is worth considering what further understanding can be gained by plotting the time-series information i.e. as against the range graphs. The latter provide a first impression of the status of the lake with respect to a factor such as the concentrations of total dissolved solids and nutrients, or the pH or conductivity at a sampling site. However, the degree to which the highest or lowest values approximate to other values can only be established by examining the temporal information. In this connection, an easily generated statistic such as the mean figure of a particular array of measurements, can often be very misleading unless the arrays are normally distributed. In the majority of situations involving environmental data such as those produced by the PSS teams, this is not the case.

Graphs highlight trends or the lack of these, and from such information questions ('hypotheses') to explain the patterns can be posed. Contrasts and similarities between data for a particular factor from different sites are best assessed by plotting the results on a common set of vertical and horizontal axes. Time has not allowed to do this so far, but it is hoped that the regional teams will endeavour to do so.

Figure 6 shows two peaks of *ca* 0.6 mg SRP/l. Generally however, values are at, or near 0.2 mg/l. An encouraging feature of this graph (along with many others produced by the PSS) is the number increases and decreases in SRP comprising three or more consecutive sampling occasions. This adds credibility to the results. In contrast, runs of values in which the levels of a particular factor increase and decrease on alternate sampling occasions are generally less plausible. Exceptions could arise however, in the case of a site influenced by a pulsed, point-source input of a pollutant.
At values ranging generally between 0.3 and 1.0 mg/l, the Kinyankonge River is very rich in ammonium-N (**Figure 7**). Nevertheless, sustained trends suggest that these analyses are correct. Note however, the sampling interval in this case is approximately one month.

At ≥9.0 units the majority of the pH values featured in **Figure 8** are similar to those recorded in many African lakes. In contrast, the Bujumbura Port pH data suggest that values as low as 6 units can occur. We assume that these low values result from acidic effluent in the vicinity at the time of sampling.

Fluctuations in the concentrations of total dissolved solids should mirror the changes in conductivity. The data from the Lifebuoy site in Bujumbura (**Figures 9** and **10**) show that the two methods of analysis do result in parallel fluctuations during the period from June 1998 to February1999. After that time however, the patterns differ. Nevertheless, major fluctuations in TDS levels at the effluent outfall (**Figure 11**) coincide with those illustrated in the two previous Figures. Whatever the cause of the massive swings in TDS levels, a comparison between Figures 9-11 and **Figure 12** suggests that the cause was not evident at the sampling point between the two effluent outfalls in that vicinity.

Ranges in the values of a selection of factors studied in Tanzania

Thirteen sampling sites were established in Tanzania. These extended from the Gombe area in the north to Jacobsens Bay in the south. The majority of these sites are in the lake, but there are also three small running waters: Gombe Stream, the Kibirizi River near Kigoma and the very small Rubengara Drain near the TAFIRI laboratory. The array of sites also includes (i) the very remote and apparently unimpacted areas such as the most northerly and the most southerly shown in **Figure 13**, and (ii) the much more congested areas such as those of the Docks. Of the whole array of factors investigated in Tanzania (listed previously), those considered under the umbrella of 'pollution' or pollution indicators are as follows: nitrite-nitrogen, SRP, TP, water clarity, total suspended solids, dissolved silica and, as an index of total phytoplankton biomass, chlorophyll$_a$.

In sharp contrast to the nitrate-rich situation in Burundi, most of the NO_3-N concentrations recorded in Tanzania were less than 100 _g/l and thus approximately one-tenth of those recorded at the sampling sites in Burundi (**Figure 13**). Exceptions to this situation are as follows: the

Gombe Stream (max. 150 _g/l), the Kigoma Pier and the Docks (140), and a single value of 560_g/l in the small Rubengara Drain issuing from houses at the south of Kigoma. The lowest maximum concentration was recorded at Jacobsens Bay situated at the remote southern-most site sampled in Tanzania. Another single analysis, of the Kibirizi River, produced a value of 9_g/l. The low nitrate situation is remarkable considering the sampling zone includes potentially pollutant-rich areas as the docks, the oil jetty and the somewhat enclosed TAFIRI Bay. It is possible that the some of the low concentrations in those types of sites are due to denitrification. The low values in areas such as Gombe may simply reflect a relatively untouched environment.
Phosphate-phosphorus concentrations in Tanzania are also low (**Figure 14**). Maximum values are < 12 _g/l with the exceptions of the Gombe Stream (23_g/l), and the single Rubengara Drain value of 73 _g/l. Albeit based on single analyses, the Kibirizi River and the lake at Gombe site TG3 are also very low in SRP i.e. 4.6 and 4.7_g/l respectively.

Total phosphorus maxima ranged from 17.5 _g/l at Gombe lake site TG3, to 60 _g/l at Jacobsens Bay. Minimum values are generally less than 10 _g/l and some sites registered less than 5 _g/l **(Figure 15)**. As elsewhere in Lake Tanganyika, research on the partitioning of particulate and dissolved P components would improve our understanding of phosphorus bio-availability and/or physical and chemical sequestration.

As probably to be expected, water clarity at the Docks, Jetty and Pier monitoring sites in Kigoma are generally much lower than those recorded in many of the other sites (**Figure 16)**. It is probable that with the exception of continually wave-washed fringing zones the lake, the light climate is very special. Secchi disc reading maxima ranged from 8-16m. This indicates a considerable depth zone in which planktonic and attached algae can photosynthesise.

Many limnologists view water clarity as one of most useful overall indicators of water quality. This is largely because this factor can be assessed effectively using materials that are likely to be available in the most primitive of laboratories. There are just two components: a rope, and a 20-cm diameter metal disc with a central hole through which the rope can pass and be knotted above and below the disc. The rope must be at least 20m long for work in the generally clear waters of Lake Tanganyika. It should also be marked at 25-cm intervals for reading the depth Secchi Disc Reading (SDR) at which the disc just disappears from view. Discs are usually painted in black-and-white quarters. After, minimal tuition in the use and recording of the SDR values and the approximate locations of the readings, it is possible that boatmen would agree to take measurements throughout the lake.

Chlorophyll$_a$ provides a convenient index of overall phytoplankton abundance. In the predominantly nutrient-poor and essentially clear waters of Lake Tanganyika, pigment concentrations of a few microgrammes per litre would be expected. This prediction is supported by the data (**Figure 17**). The pigment maxima range from just over 6 _g/l in TAFIRI Bay and the water supply intake site, down to 1.5_g/l at the more remote Nondwa Point. Lowest values range from fractions of a microgramme per litre at the water supply intake, TAFIRI Bay, and even the Docks, Kigoma Pier and the oil jetty as well as Nondwa Point and the Gombe sites.

Silica is not usually viewed as a 'pollutant' in the same way as the other nutrients studied, but it is important in controlling the productivity and abundance of diatoms and other silica-bearing algae such as chryso-flagellates. These organisms, and the diatoms in particular, thus compete for N and P resources with the other algae. 27 July 2000. Deployments of glass slides on wave-washed piers and submerged structures, as well as and natural substrates yielded visible accumulations of attached al diatoms within a few days. Few of these samples have been analysed, but they indicate in the Kigoma area at least, nutrient-rich micro-environments.Diatoms are also prominent in the plankton, but their production and biomass accumulation (though not necessarily species-richness) may be restricted by the relatively low N and P levels.

Dissolved silica (SiO_2) maxima of between 2 mg/l and 6 mg/l accounted for virtually all of the sites sampled (**Figure 18**). The exceptions are the considerably higher concentrations recorded in the Kibirizi River and the Rubengara Drain.

Temporal variation in a selection of factors studied in Tanzania

Figure 19 displays a set of data that appears less convincing than many of the other time-series graphs. This is probably due to the comparatively long sampling interval adopted for this remote site at Gombe sampled every five weeks. Otherwise, there are instances where increases or decreases in the $chlorophyll_a$ values were sustained over two or three sampling visits. The majority of the concentrations fall within a band of 1.5-4.0 _g./l, which would be generally expected for this oligotrophic lake. These concentrations are similar to those recorded in Zambia. Ideally, we should have organised analyses of $chlorophyll_a$ in all three countries, but unfortunately no pigment analyses were undertaken in the Bujumbura laboratories.

Nitrate-N concentrations often increased or decreased on a number of consecutive sampling periods at the Kigoma Pier site (**Figure 20**). In contrast to many other graphs showing such trends, these data comprise two main phases within a run of information beginning in May 1998 and ending in June 1999. The first phase is dominated by the sharp and sustained increase of approximately 110_g/l to a maximum of 130 _g/l, and a decrease to approximately 60 _g/l. Excluding the sharp increase to nearly 130 _g/l again, the second phase is characterised by a long period in which the values generally remain within a band from 40 _g/l and 70 _g/l.

Figure 21 relates to the comparatively remote Nondwa Point sampling site offshore of Kigoma. On account of its comparatively unimpacted position, we would predict low $chlorophyll_a$ levels. This indeed is the case - with values never exceeding 1.5 _g/l. Compare these results with those shown for TP in **Figure 22**; it concerns another site in the Kigoma area, but one that due to its proximity to the oil jetty would be expected to yield indications of high nutrient and/or chlorophyll status. Again, the expectation is borne out by the data with seven TP values exceeding 30_g/l and, in **Figure 23**, a few values exceeding 4_g $chlorophyll_a$/l. The Kigoma Docks would also be expected to reflect relatively high nutrient status, and this is also confirmed by the example of nitrate-N in **Figure 24**; numerous values exceed 80_g/l and a few values reach 130_g/l.

Ranges in the values of a selection of factors studied in Zambia

The Zambian PSS team carried out field and laboratory work at 6 sampling sites in the Mpulungu area at the foot of the lake, and at 4 sites in the Nsumbu area some 80 kilometres north of Mpulungu. Sites thus range from the potentially highly impacted areas within a few hundred metres of the Mpulungu Ngwenya Market and the Port, to the open waters of the Nsumbu

National Park. The sites are almost all situated in the lake, although one of these is situated just off the mouth of the Lufubu River. This section concentrates mainly on water clarity and nutrients.

Maximum water clarity values ranged from 7.2m even off the mouth of the Lufubu River, to 15m at the open water Mpulungu Bay South site whilst minimum readings of < 2m were obtained at the Port and the mouth of the Lufubu (**Figure 25)**. However, the Mpulungu Bay South site also manifested readings as low as 2m on occasions. Overall, the water in Nsumbu Harbour and off the mouth of the Lufubu River are the most turbid areas on occasions. Indeed, readings there rank with those characteristic of shallow, eutrophic, algae-laden lakes in both the Tropics (as at the foot of the lake in May 1998) and the Temperate Zones of the world. At the other end of the range of Secchi Disc readings in Zambia are the values recorded from Kala Bay and the Nsumbu National Park. The spectrum of underwater light conditions is very wide. The LTBP has no data on phytoplankton species richness, but this is likely to be considerable, and attributable in part at least, to relatively sparsely dispersed zones of low-light conditions and the more widespread, clearer, pelagic zone.

The highest concentrations of SRP in the large sampling area in Zambia, were recorded in the Mpulungu region (which included most of the sampling sites in that country); the values ranged from approximately 18_g/l at Mpulungu Port to 24_g/l at Mpulungu site 1(**Figure 26**). This distribution of values contrasts with maxima of between 8_g/l and 14_g/l in the Nsumbu area which includes the National Park. All of the total phosphorus maxima lie within a range of 30-43_g/l (**Figure 27**). The considerable degree to which the total figures exceed the inorganic fractions is remarkable. We know nothing about the phosphorus in particulate and dissolved organic forms, but these fractions could well could be mineralised and sequestered by phytoplankton for example.

Unfortunately, the data produced on dissolved silica in the Mpulungu laboratory are suspect, with concentration maxima at each site being apparently as high as 25-30 mg SiO_2 l^{-1} (**Figure 28**). This contrasts with published values of only 0.3 mg l^{-1}. We are exploring the possibility of obtaining samples still stored in Africa, with the view to repeating the analyses.

Maximum concentrations of $chlorophyll_a$ in Zambian waters ranged from 4-14 _g/l (**Figure 29**) as compared with the span of 4-7_g/l recorded in Tanzania. The two highest concentrations correspond to the apparently impacted sites of Mpulungu ZM1 and Mpulungu Ngwenwa Market. However, the third ranked maximum value was that recorded from the Nsumbu National Park site which we have consistently viewed as relatively unimpacted. Maxima of approximately 5 _g/l were recorded at the mouth of the Lufubu River, the open water Mpulungu Bay South site and off the Nkumbula Isle. All of the Zambian sites included values of < 1_g/l and the majority of the pigment values would be classified as oligotrophic or mildly mesotrophic. It is notable that this suite of $chlorophyll_a$ values is similar to those obtained by Dr Coulter some 12 years ago - perhaps suggesting little increase in enrichment/eutrophication over that period.

Temporal variation in a selection of factors studied in Zambia

The Zambian team produced a valuable set of time-series data with a number of trends sustained over many weeks. **Figure 30** concerns TP at a somewhat impacted site in the Mpulungu area. Total phosphorus levels reflect the situation with a number of reasonably high values e.g. 25_g/l. Chlorophyll$_a$ values of generally less than 4_g/l at another, offshore site in the Mpulungu area are shown in **Figure 31**. **Figure 32** can be compared directly with Figure 30 because both the y and x axes on the two graphs are identical. We would probably have predicted that the Port area would be more 'impacted' than the Mpulungu Bay South site, but in terms of TP, the reverse is indicated, albeit to a minor degree. The Nkumbula Isle however, is only 200 metres off the Mpulungu shore and the suite of TP values recorded from that site are reflected in **Figure 33**.

The sole graph of dissolved oxygen in this report (**Figure 34**) is featured in order to emphasise that many values are much lower than might be generally expected. However, we need to examine these data in more detail; a faulty probe may even be the cause.

The final pair of time-series data included in this report relate to (i) TP levels recorded at a site near Mpulungu town (**Figure 35**) and (ii) chlorophyll$_a$ data from a site offshore from a market (**Figure 36**). Bearing in mind the nature and location of these sites, we would have expected reasonably high TP and pigment concentrations. Even ignoring the outlying peak value in the Market chlorophyll$_a$ graph, the upper values there are higher than those obtained from the Nkumbula Isle for example. However, spatial variation in TP is rather minor throughout the Zambian sampling area, but both the Isle and the Town site maxima are higher than the maximum recorded at the Bay South site.

6.2 The phytoplankton database

We incorporated phytoplankton studies in the PSS programme for two main reasons. First, as the Biodiversity SS was not including these organisms, attention to the lower trophic level would have been ignored, although Mr Mukungilwa Kamelebo initiated investigations on attached algae, in the Congo, and phytoplankton species population densities were estimated by Mr Wilondja Kamelebo in Burundi. All countries were equipped with very good high-power inverted and conventional microscopes and counting chambers. Examples of Wilondja's work are featured below, but no information has been received from Mukungilwa. The second reason for incorporating algal work in Tanzanian and Zambian waters, was to gain some semi-quantitative information on species richness at this low trophic level; sampling for that work was carried out at may of the same sampling sites and at the same frequencies as those adopted for our other water quality monitoring activities.

An additional reason for training and in algal work, recognises the potential environmental indicator value of these microscopic plants. Examples are as follows:

- when large species predominate, it is likely that grazing by zooplankton on small species is heavy
- when a cyanobacterium/blue-green alga such as *Anabaena flos-aquae* dominates the scene (as it did over vast areas in the south of the lake in mid-June 1998), and the algae bear heterocysts that are fixing nitrogen from the gaseous N dissolved in the water, it is likely that the dissolved concentrations of inorganic nitrogen are low
- a preponderance of comparatively 'heavy' diatoms suggests a well-mixed environment; however, some of these algae are often attached to ciliate protozoa (e.g. *Vorticella* species) which distribute the algae even in calm conditions
- algal assemblages dominated by green algae (e.g. Chlorococcales) indicate some of the nutrient-richest conditions
- algal flagellate-dominated phytoplankton are often associated with nutrient-rich and calm environments

Phytoplankton size cannot explain all features of the freshwater environment, but the assemblages of species recorded, and their spatial and temporal dynamics can be viewed as the outcome of interactions between a suite of physical and chemical factors, i.e.

physics + chemistry = biology (phytoplankton)

As indicated in earlier sections of this report, the physical environmental measurements and observations that were made included water movement, temperature, colour/particle content and clarity. Chemical factors included in the PSS programme were nutrients and a small selection of heavy metals.

Selected information on concentrations of phytoplankton - Burundi

This section is important in highlighting the significant contribution to the PSS from Mr W Kamalebo; **Figure 37** is an example of many dozens of his graphs. For a number of the same sites sampled for physical and chemical information, the Figure includes information on the total abundance levels of planktonic algae (expressed in numbers per litre) and a breakdown of the totals into the major algal groups recorded. This particular Figure suggests that cyanobacteria(‘blue-green algae’) dominated the waters at the time. As many of these cyanobacteria are relatively large in algal terms, it is likely that they dominated the scene also in terms of biomass on this occasion. This data set also indicates that diatoms were the next most prominently featured algal group. A third feature is the broad taxonomic range in algae overall, and the preponderance of different flagellates i.e. Cryptophyceae, flagellate Chlorophyceae, Euglenophyceae, Chrysophyceae and Dinophyceae. The full data set is as follows:

· 17 'EXCEL' files as follows but with 4 or 5 dates' quantitative information:

		1	2	3	4	5	6	7
Date		Rusizi mouth 50m	Ntahangwa	Port 3	Port 4	25m collect	Lifebouy	500m out
4.3.99	Total Alg		5040	4880	4400	2400	8480	3280
	Cyano		2720	2960	2480	960	3440	2240
	Chloro		2000	800	640	1120	2880	960
	Bacillario		160	720	880	320	1600	0
	Eugleno		0	400	240	0	240	0
	Dino		160	0	160	0	320	80
	Chryso		0	0	0	0	0	0
	Crypto		0	0	0	0	0	0

A selection of arrays of net phytoplankton genera and their sizes - Tanzania and Zambia

Another type of phytoplankton analysis was trialed in the Anglophone laboratories, and **Figures 38 and 39** illustrate two of the approximately 100 outputs of these analyses. The work recognised that the Zambian and Tanzanian trainees when expressing interest in this aspect had rarely, if ever, examined such small organisms under the microscope. Hence the restricted focus on the generally larger organisms obtained by towing a 30-_m mesh net slowly in a wide circle for 10 minutes within the top three metres of the water column. Each hauls was mixed thoroughly and concentrated, and an aliquot of approximately 20ml was transferred to a pre-labelled, plastic, screw-topped container, and fixed with Lugol's Iodine preservative. The trainees carried out these procedures in duplicate (incidentally, as in the case of all the PSS sampling and analytical activities); they were also encouraged to keep some live material for examining the colour, shape, motility and other features of the organisms.

The quantitative component of the laboratory analysis of each sample was very simple: measuring the greatest dimension of an alga whose central point was nearest the centre of the field of view in the microscope - at each of 50 randomly chosen positions in a Lund chamber counting chamber. The less easily generated component of this work was the identification of each alga. However skills in the identifying organisms to the level of Genus at least, were quite rapid. The following are some arrays of algal lengths and, where it was possible to identify the organism, its abbreviated name e.g. Ped (*Pediastrum*), Ooc (*Oocystis*) and Mic (*Microcystis*). This green algae and blue-green algae dominated sample is indicative of nutrient-rich conditions in Kigoma.

Sample code	TK4		TK4		TK4	
Sample number	A		B		A	
Sample date	02.06.98		02.06.98		02.06.98	
Analyst	Muhoza		Muhoza		Muhoza	
Microscope	O		O		V	
Objective	x40		x40		x32	
Multiplication Factor	2.5		2.5		3.6	
alga1	10	Ped	10	Ooc	18	
alga2	10	Mac	10	Sce	36	
3	12.5	Ped	12.5	Gle	36	
4	15		17.5	Ped	46.8	
5	17.5	Ooc	20	Mic	61.2	
6	17.5	Ped	20	Mel	75.6	
7	22.5	Nav	22.5	Mic	79.2	
8	22.5		25	Mic	79.2	
9	25	Mic	25	Ped	82.8	
10	27.5		30	Mic	90	
11	30	Ooc	30	Mic	90	
and so on						
12	30	Syn	32.5	Mic	90	
49	350	Gon	177.5	Clo	180	
50	375	Cos	362.5	Gon	262.8	

7. POSTSCRIPT

Whilst this report is the ‘final’ one produced by the PSS team, it should also be viewed as the start of a new programme with first a thorough re-check of all the data. The teams should then capitalise on the present database to explore in more detail than hitherto, aspects on temporal and spatial variation in the various factors studied. Questions over the extent to which a plume of a pollutant is dispersed is an example. Other issues of interest include an examination of trends (or lack of these) between inshore and offshore sampling sites; question whether sites near towns or large villages are actually, as expected, more polluted as evidenced from the data. We have hardly explored at all, the relationships between physical and chemical indicators of water quality, and the taxonomic nature, abundance and distribution of the phytoplankton. This Coordinator would be interested in collaborating with the regional teams over these aspects - and above all helping them to publish their findings.

8. REFERENCES: Paper published by the PSS team; reports by the PSS team, and consultancy visits by the PSS Coordinator, Dr Foxall and Mr Kirika.

8.1 Paper published by the PSS team; Reports by the PSS team.

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8.2 Reports by the PSS team:

1. BAILEY-WATTS, A.E., (1995). RAF/92/G32 - *Pollution control and other measures to protect biodiversity in Lake Tanganyika*. Back-to-Office report - Tony Bailey-Watts - Bujumbura (Burundi) and Kigoma (Tanzania), 7-26 November. 3pp. Institute of Freshwater Ecology, Edinburgh.

2. BAILEY-WATTS, A. E., FOXALL, C. and WILTSHIRE, N. J. 1996. *Baseline review - 4: Pollution of International Waters*. (Contribution to UNDP GEF Project RAF/92/G32 - 'Pollution control and other measures to protect biodiversity in Lake Tanganyika'). 60pp with 5 Tables and 2 Figures in text; 3 Appendices.

3. BAILEY-WATTS, A. E. and FOXALL. C. 1996. Report on the Inception Workshop held in Dar es Salaam, Tanzania 23-31 March 1996. *4: Pollution of International Waters*. (Contribution to UNDP GEF Project RAF/92/G32 - 'Pollution control and other measures to protect biodiversity in Lake Tanganyika'). 20 pp with 4 Tables in text.

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5. ALLISON, E.H., BAILEY-WATTS, A.E., DUCK, R.W., FOXALL, C., PATTERSON, G. and PETIT, P. 1996. *Report of the Lake Tanganyika Biodiversity Institution and Resources Assessment Mission to Tanzania, Zaire and Zambia - 8 August to 3 September 1996.* 114 pp including 6 Appendices (GP and TBW edited this report).

6. BAILEY-WATTS, A.E., (1996). RAF/92/G32 - *Pollution control and other measures to protect biodiversity in Lake Tanganyika.* BTO report on mission to Tanzania, Zaire and Zambia - 8th August to 3rd September, 1996. 8pp. Institute of Freshwater Ecology, Edinburgh.

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8.3 Consultancy visits by the PSS Co-ordinator with either Dr Foxall or Mr Kirika, or both

(i) Visit (**2-29 November 1995**) to Bujumbura (Burundi) and Kigoma (Tanzania) to obtain information and review literature as part of preparation of *Baseline review - 4: Pollution of International Waters*. (Contribution to UNDP GEF Project RAF/92/G32 - 'Pollution control and other measures to protect biodiversity in Lake Tanganyika' - , hereafter 'LTBPP').

(ii) LTBPP: Visit (**23-31 March 1996**) to Dar es Salaam, Tanzania: Inception Workshop.

(iii) LTBPP: Institutional resource assessment mission **8 August-5 September 1996** to

Tanzania and Zaire.

(iv) LTBPP: Mission to Tanzania and Zambia **30 May-29 June 1997** to finalise selection/nomination of personnel.

(v) LTBPP: Technical Steering Committee Meeting, for Burundi and the Democratic Republic of the Congo, **12-17 September 1997**, Bujumbura, Burundi.

(vi) LTBPP: *'Field and Laboratory Methods Training Workshop'* Kigoma, Tanzania, 18 flagellate September-3rd October 1997. TBW a main presenter and trainer on this Workshop. Continued training **4-12 October 1997**.

(vii) LTBPP: Kigoma, Tanzania. Continued training and expansion of activities (in limnological field and laboratory methods) of Tanzanian staff appointed to the Pollution Special Study, **28 November-17 December 1997**.

(viii) LTBPP: Continued training, expansion of activities (in limnological field and laboratory methods) and appointing of Lake Tanganyika regional staff to the Pollution Special Study: plying between Uvira (Congo) and Bujumbura (Burundi) **16-28 May**, Kigoma (Tanzania) **29 May-2 June**, Mpulungu (Zambia) **3-15 June** and Lusaka (Zambia) **16 June 1998**.

9. ACKNOWLEDGEMENTS

The late Dr Keith Banister was of considerable help to myself and colleagues over the early years of the Project. Dr (now Professor) George Hanek was valuable in providing the PSS Coordinator with an opportunity to scour the FAO Lake Tanganyika Project's library in Bujumbura, and for accommodating me on that and many other visits. He was also kind enough to involve me in a meeting of that FAO Project. Along with access to libraries of the Institute of Freshwater Ecology and the Freshwater Biological Association, these experiences proved immensely valuable in providing much information that was eventually incorporated into the PSS Baseline Review.

Alongside our African hosts, Dr Foxall and Alex Kirika designed and organised the laboratories. All PSS Consultants were also heavily involved in organising other field and laboratory facilities - and training of personnel in all aspects of the Study. I thank these consultants and the regional personnel for their support and friendship. Last but not least, I greatly appreciate the help and support from Sheila Bailey-Watts and Sue Daplyn in the UK and the Lake Region.

APPENDIX 1. Contents List of the hard copy volume of the SigmaPlot graphs and associated data.

The Lake Tanganyika Pollution Special Study

BURUNDI

ammonium nitrogen
Cadmium
conductivity
Lead
nitrate-nitrogen
pH
phosphate-phosphorus
sulphate
total dissolved solids
water temperature

The time-series graphs for each site are presented generally in order from north to south. The title of each Figure is the abbreviated site name. Each factor (e.g. nitrate-nitrogen, total dissolved solids) is shown on the vertical axis. Each of the three countries produced results from approximately 12 sampling sites and data on at least 10 factors at each site. Thus, hundreds of time-series graphs varying in start and end date have been generated. As a consequence, we have drawn all graphs (including those for which data may still be missing) on a standard 3-year time axis from 1 January 1997 to 31 December 1999. The sampling sites are as follows:

TANZANIA

PHYSICAL AND CHEMICAL RESULTS

suspended solids
conductivity
pH
chlorophyll a
water clarity
dissolved silica
total phosphorus
phosphate-phosphorus
nitrate-nitrogen

The time-series graphs for each site are presented generally in order from north to south. The title of each Figure is the abbreviated name of the sampling site, while the factor (e.g. nitrate-nitrogen, total dissolved solids) is shown on the vertical axis. Each of the three countries produced results from approximately 12 sampling sites and data on at least 10 factors at each site. Thus, hundreds of time-series graphs varying in start and end date have been generated. As a consequence, we have drawn all graphs (including those for which data may still be missing) on a standard 3-year time axis from 1 January 1997 to 31 December 1999. The sampling sites are as follows:

ZAMBIA

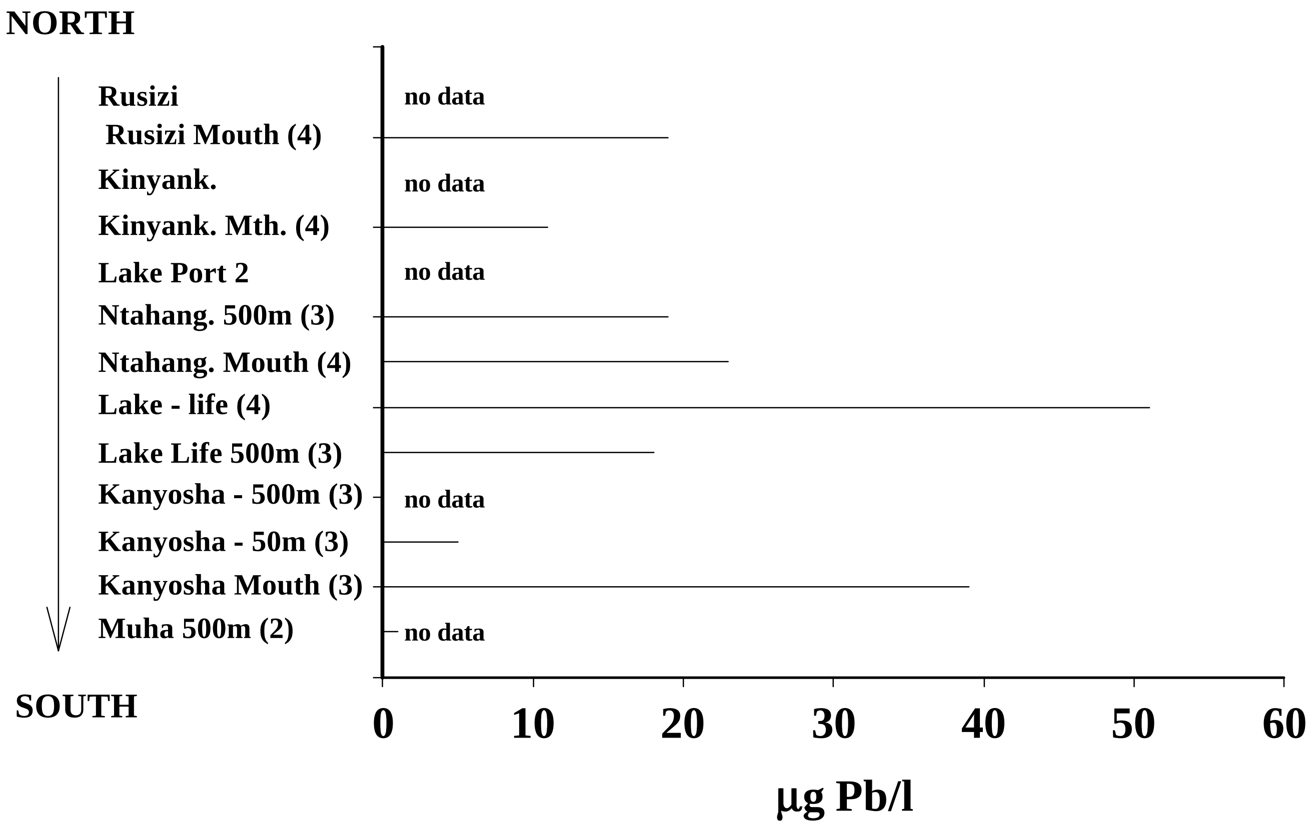
dissolved oxygen
water clarity
dissolved silica
total phosphorus
phosphate-phosphorus
water temperature
pH
conductivity
chlorophyll a

The time-series graphs for each site are presented generally in order from north to south. The title of each Figure is the abbreviated name of the sampling site, while the factor (e.g. nitrate-nitrogen, total dissolved solids) is shown on the vertical axis. Each of the three countries produced results from approximately 12 sampling sites and data on at least 10 factors at each site. Thus hundreds of time-series graphs varying in start and end date have been generated. As a consequence, we have drawn all graphs (including those for which data may still be missing) on a standard 3-year time axis from 1 January 1997 to 31 December 1999. The sampling sites are as follows:

APPENDIX 2: Representative concentrations and levels of a small range of factors at a selection of sampling sites perceived as impacted or unimpacted on the basis of proximity to human habitation in Burundi, Tanzania and Zambia; nd denotes no data. Unless otherwise indicated, nutrient and chlorophyll values are expressed in microgrammes/l and water clarity values are given in metres.

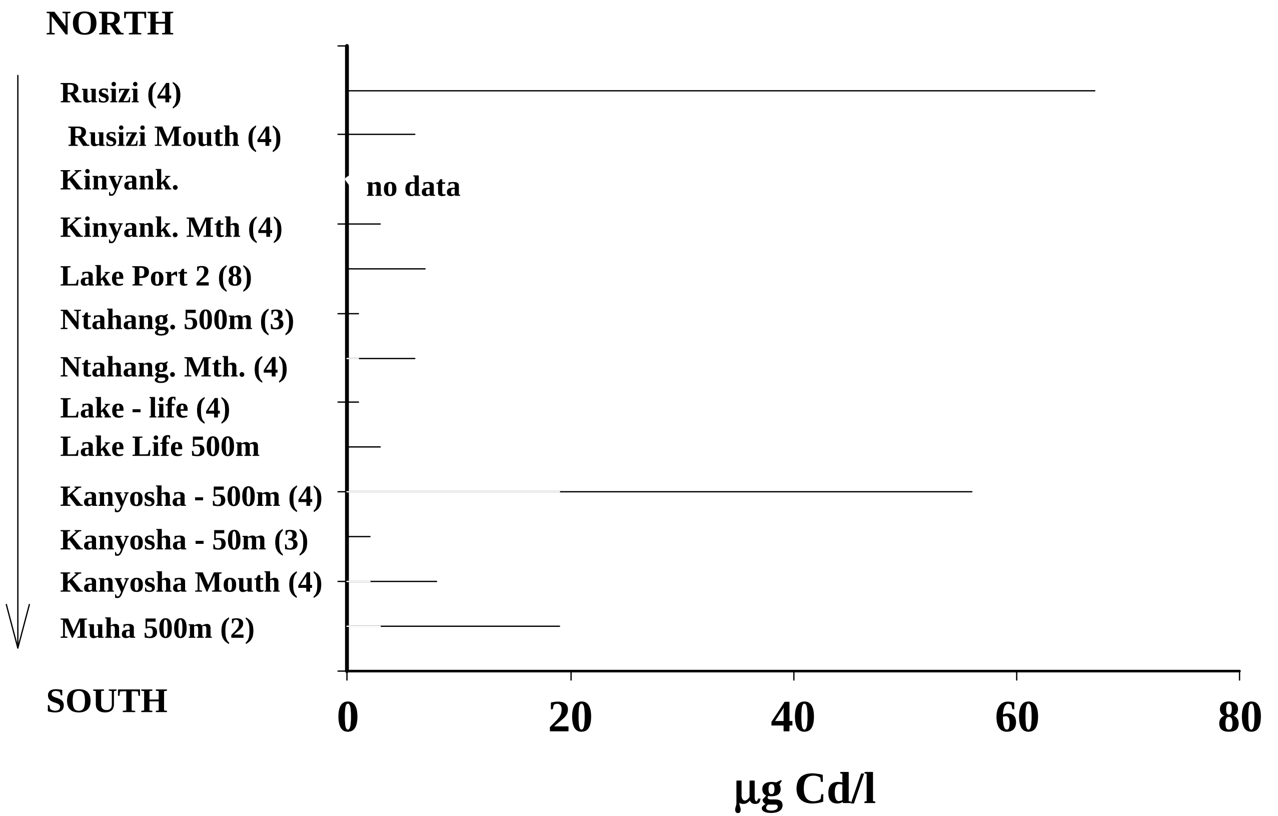
COUNTRY	BURUNDI	TANZANIA	ZAMBIA	BURUNDI	TANZANIA	ZAMBIA
factors	impacted site - 1	impacted site - 1	impacted site - 1	unimpacted site - 1	unimpacted site - 1	unimpacted site - 1
	Rusizi Mth RRMTH 400 TDS mg/l <10mg SRP/l 100_g NO_3-N/l 100_g NH_4-N/l	**Kigoma Pier TK3** 70_g NO_3-N/l 6_g SRP/l 17_g TP/l 1.5 mg SiO_2/l	**Ngwenya Mkt ZM4** 4_g chlorophyll$_a$/l 25_g TP/l	**Muha area** 200 mg TDS/l 1.75 mg SRP/l 1 mg SiO_2/l 100<50_g NH_4-N/l	**Gombe TG1** 60_g NO_3-N/l 3.3_g chlorophyll$_a$/l 1.3 mg SiO_2/l 3_g SRP/l 15_g TP/l	**Nsumbu Nat. Park ZN2** 2.5_g chlorophyll$_a$/l 20 mg SiO_2/l- ?? 20_g TP/l
factors	impacted site - 2	impacted site - 2	impacted site - 2	unimpacted site - 2	unimpacted site - 2	unimpacted site - 2
	RKKMTH 350 mg TDS/l 1 mg SRP/l 400_g NO_3-N/l	**Docks TK4** 80_g NO_3-N/l 2.5_g chlorophyll$_a$/l 1.5 mg SiO_2/l 5_g SRP/l 12_g TP/l	**Mpulungu Town ZM1** 5_g chlorophyll$_a$/l 25_g TP/l	**500m off Lifebuoy** 50_g SRP/l 300 mg TDS/l <10_g SRP/l 1.75 mg SiO_2/l	**off Nondwa Pt TK2** 1_g chlorophyll$_a$/l 1.5 mg SiO_2/l 5_g SRP/l 35_g TP/l	**Kalomo ZKL** 2.2_g chlorophyll$_a$/l 25 mg SiO_2/l- ?? 22_g TP/l
factors	impacted site - 3	impacted site - 3	impacted site - 3	unimpacted site - 3	unimpacted site - 3	unimpacted site - 3
	between 2 effluents 330 mg TDS/l 300_g SRP/l <100_g NO_3-N	**Off oil jetty TK1** 4.5_g SRP/l 20_g TP/l 60_g NO_3-N/l 3_g chlorophyll$_a$/l 2 1.5 mg SiO_2/l mg SiO_2/l	**Mpulungu Port ZM2** 3.5_g chlorophyll$_a$/l 22_g TP/l	**nd**	**Jacobsen's Bay TJ** 3_g chlorophyll$_a$/l 2 mg SiO_2/l 4_g SRP/l 30_g TP/l	**Nkumbula Isle ZM3** 3.3_g chlorophyll$_a$/l 25_g TP/

Figure 1: range in Lead levels at 13 sampling sites extending from the Rusizi to the Muha - Burundi



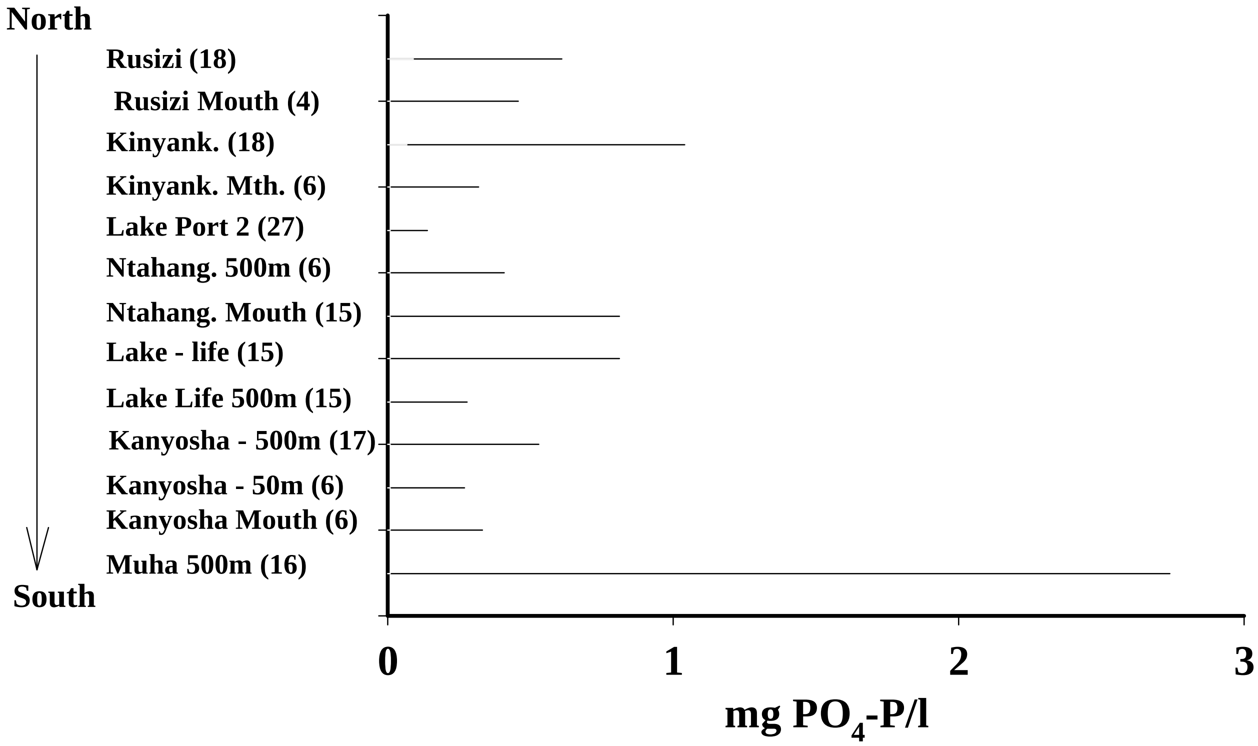
Figures in brackets are the numbers of sampling dates

Figure 2: range in Cadmium levels at 13 sampling sites extending from the Rusizi to the Muha - Burundi



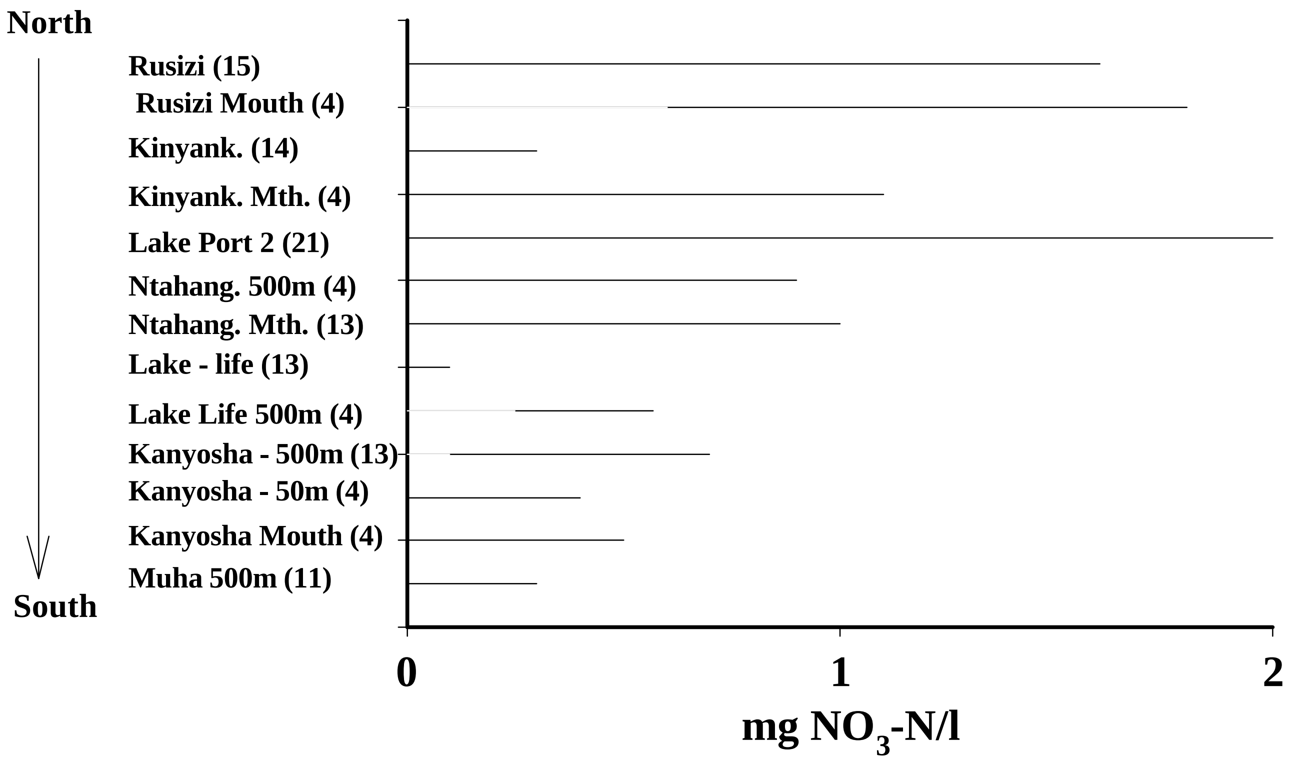
Figures in brackets are the numbers of sampling dates

Figure 3: range in phosphate concentrations at 13 sampling sites extending from the Rusizi to the Muha - Burundi



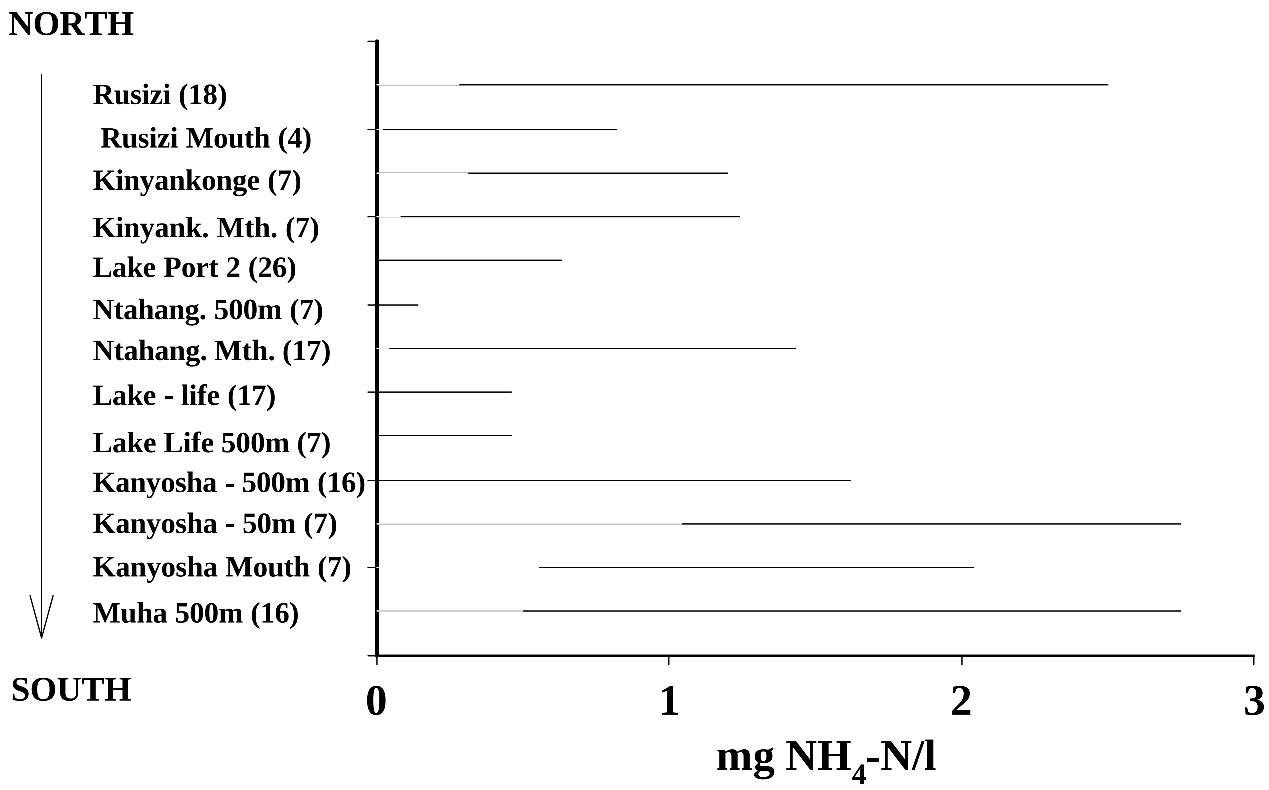
Figures in brackets are the numbers of sampling dates

Figure 4: range in nitrate nitrogen concentrations at 13 sampling sites extending from the Rusizi to the Muha - Burundi



Figures in brackets are the numbers of sampling dates

Figure 5 : range in ammonium nitrogen levels at 13 sampling sites extending from the Rusizi to the Muha - Burundi



Figures in brackets are the numbers of sampling dates

Figure 6. Rusizi River SRP levels

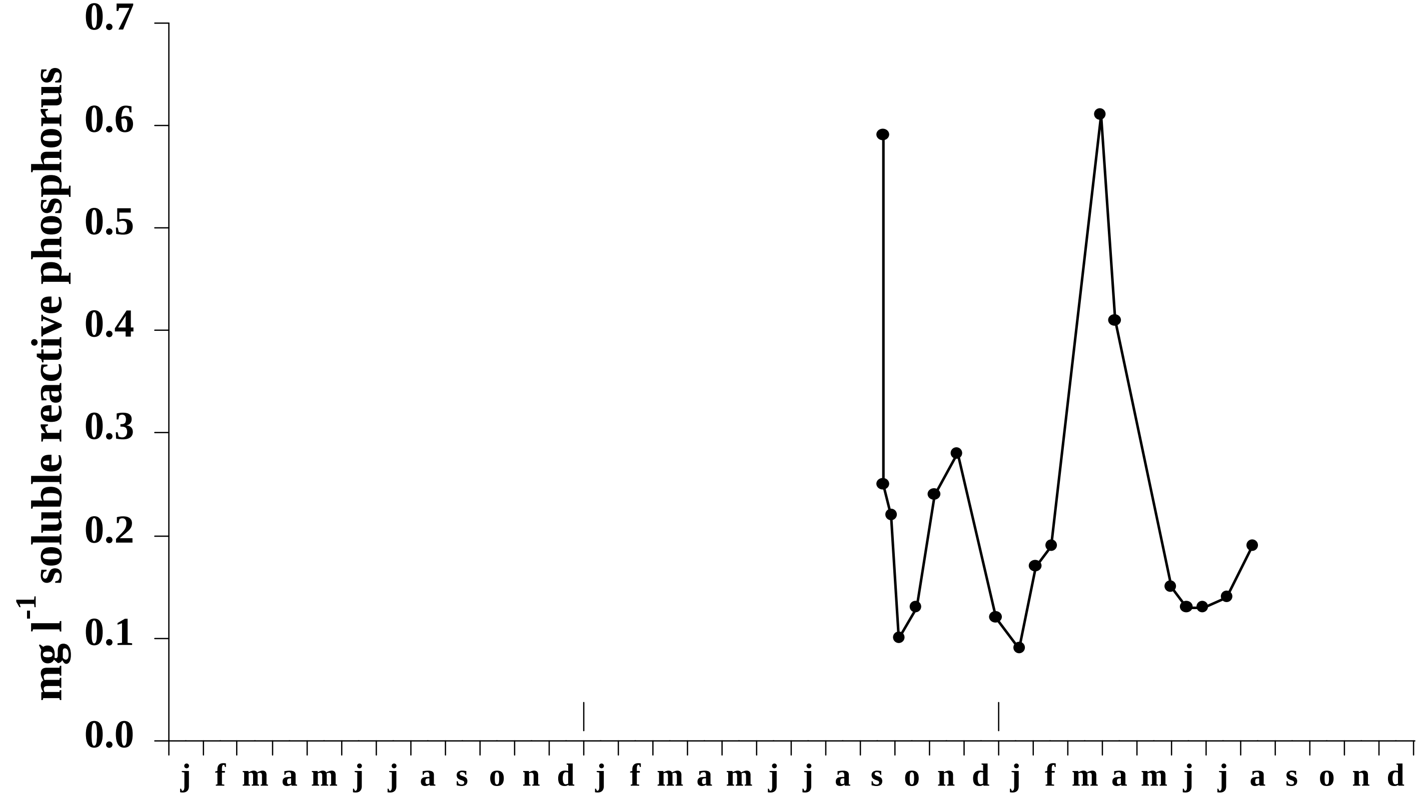


Figure 7: Kinyankonge River ammonium-N levels

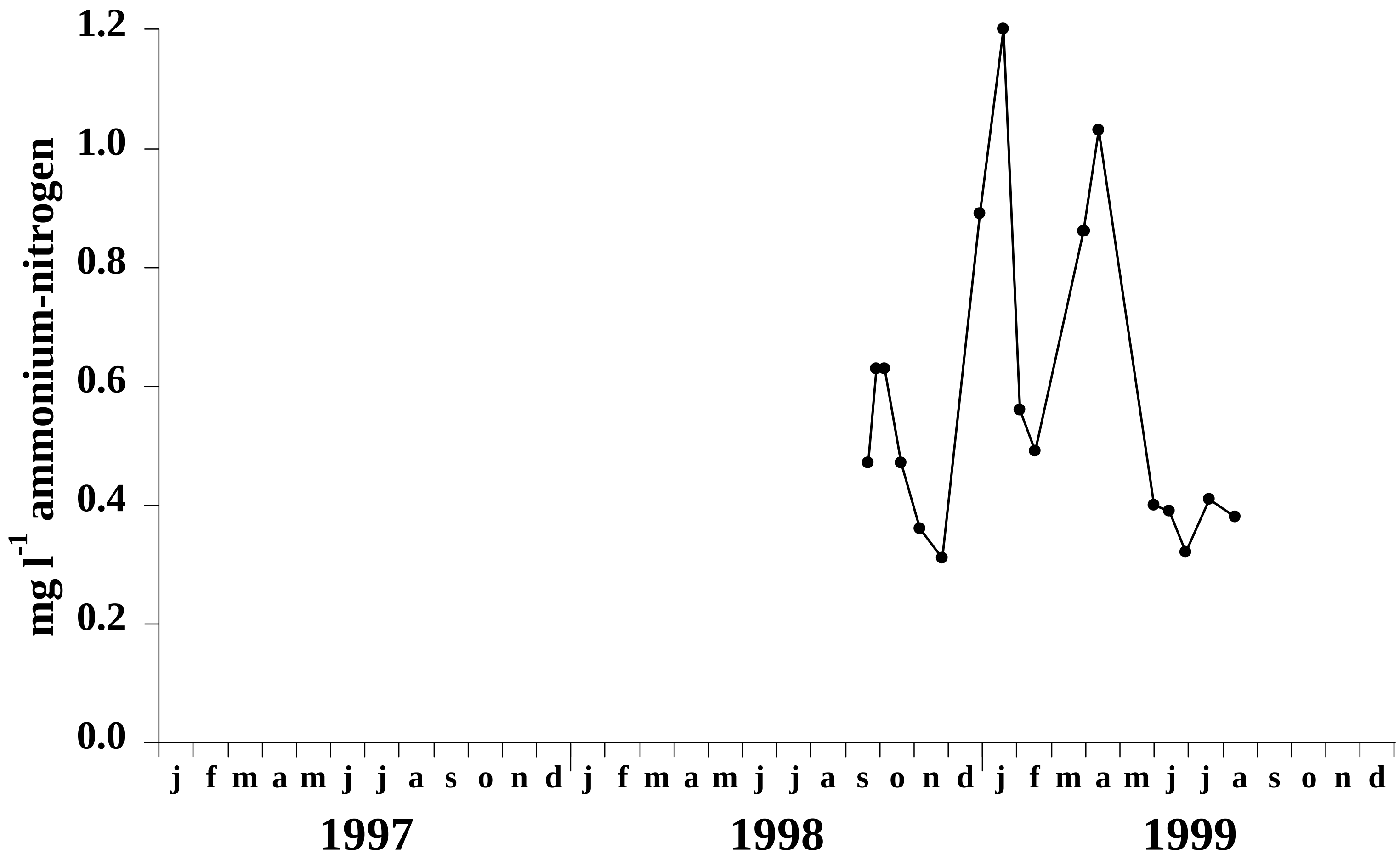


Figure 8: pH variation at Bujumbura Port (all sites)

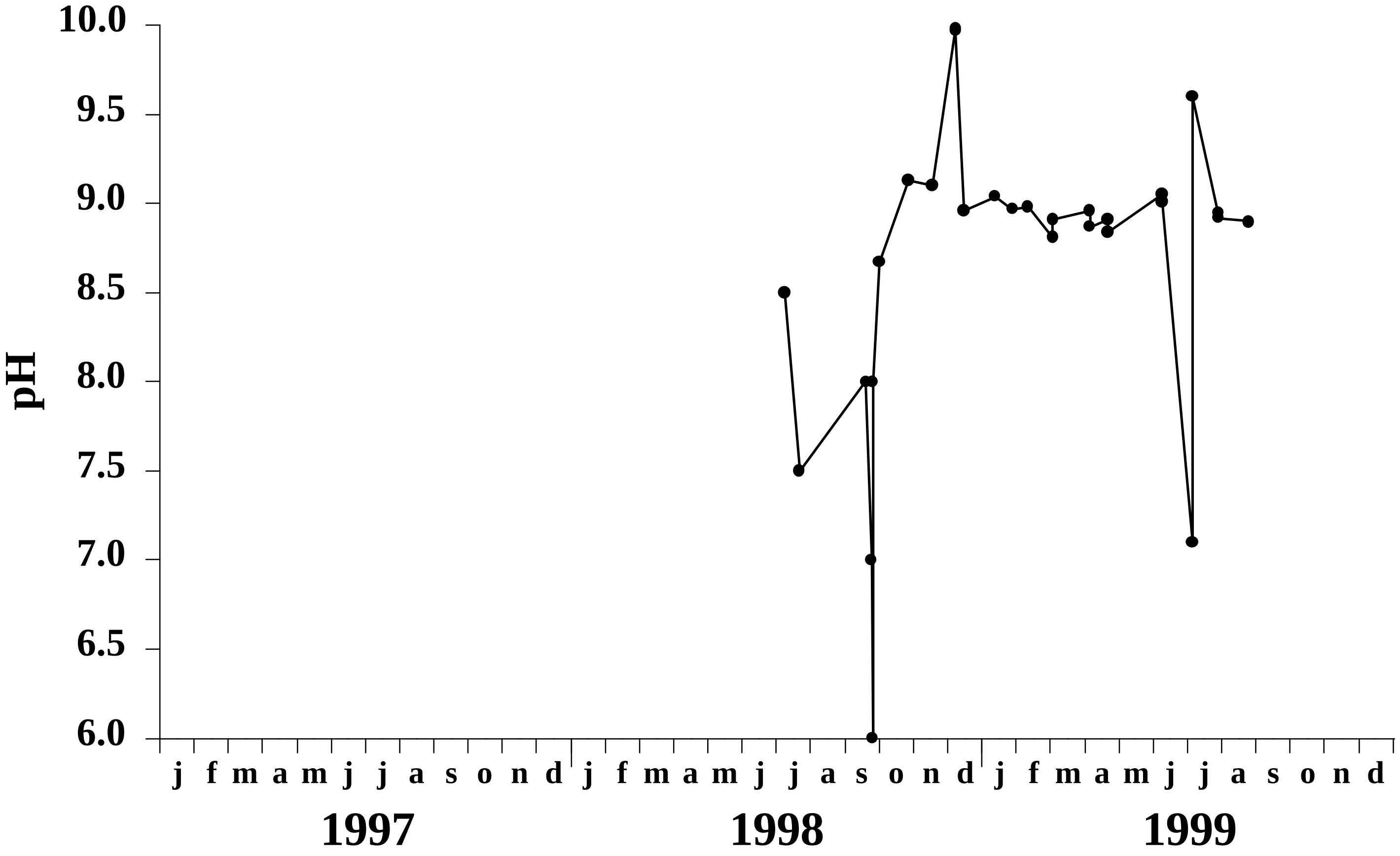


Figure 9: Total dissolved solids variation at the LBOY site

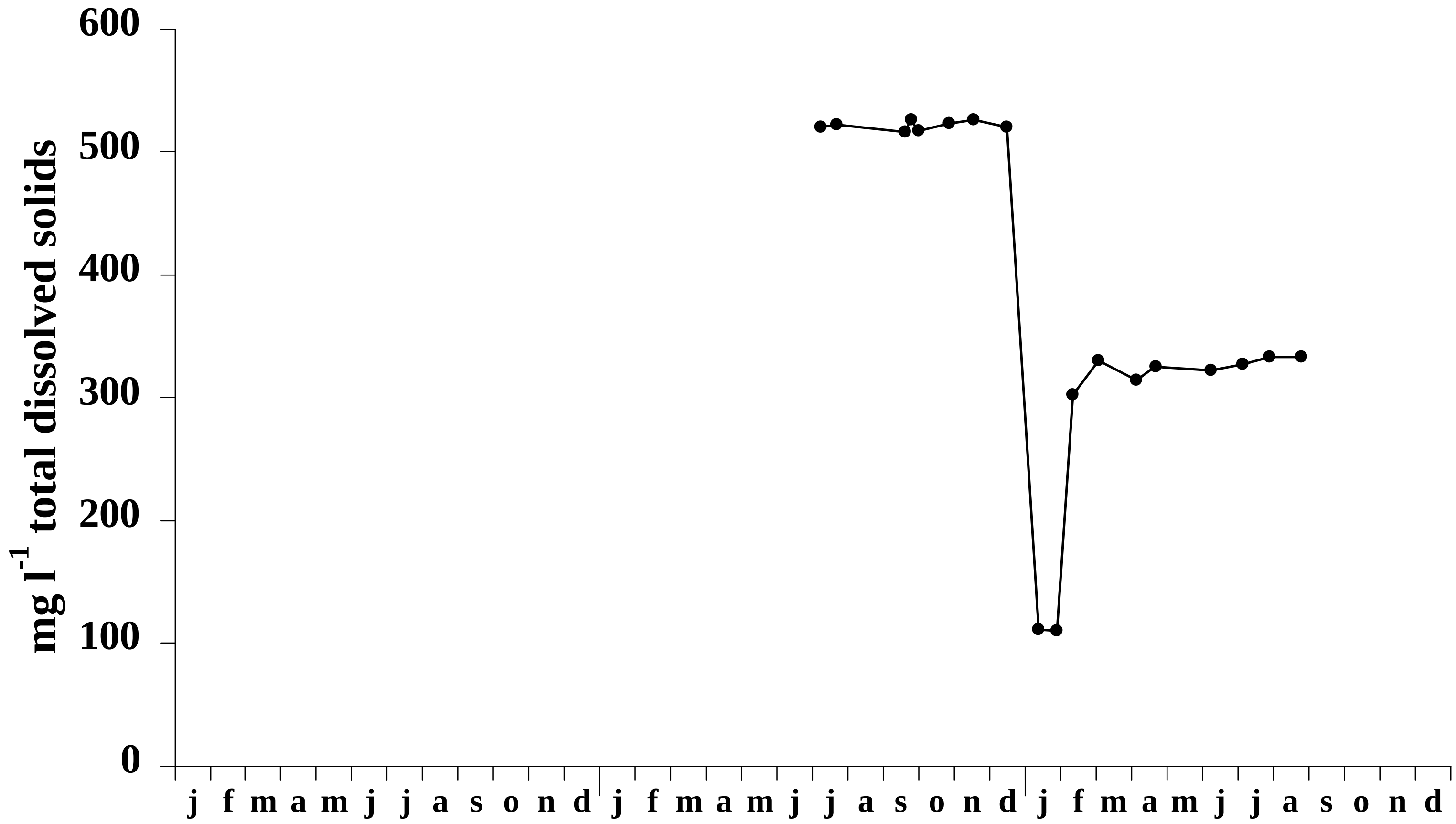


Figure 10: Variation in conductivity at the LBOY site

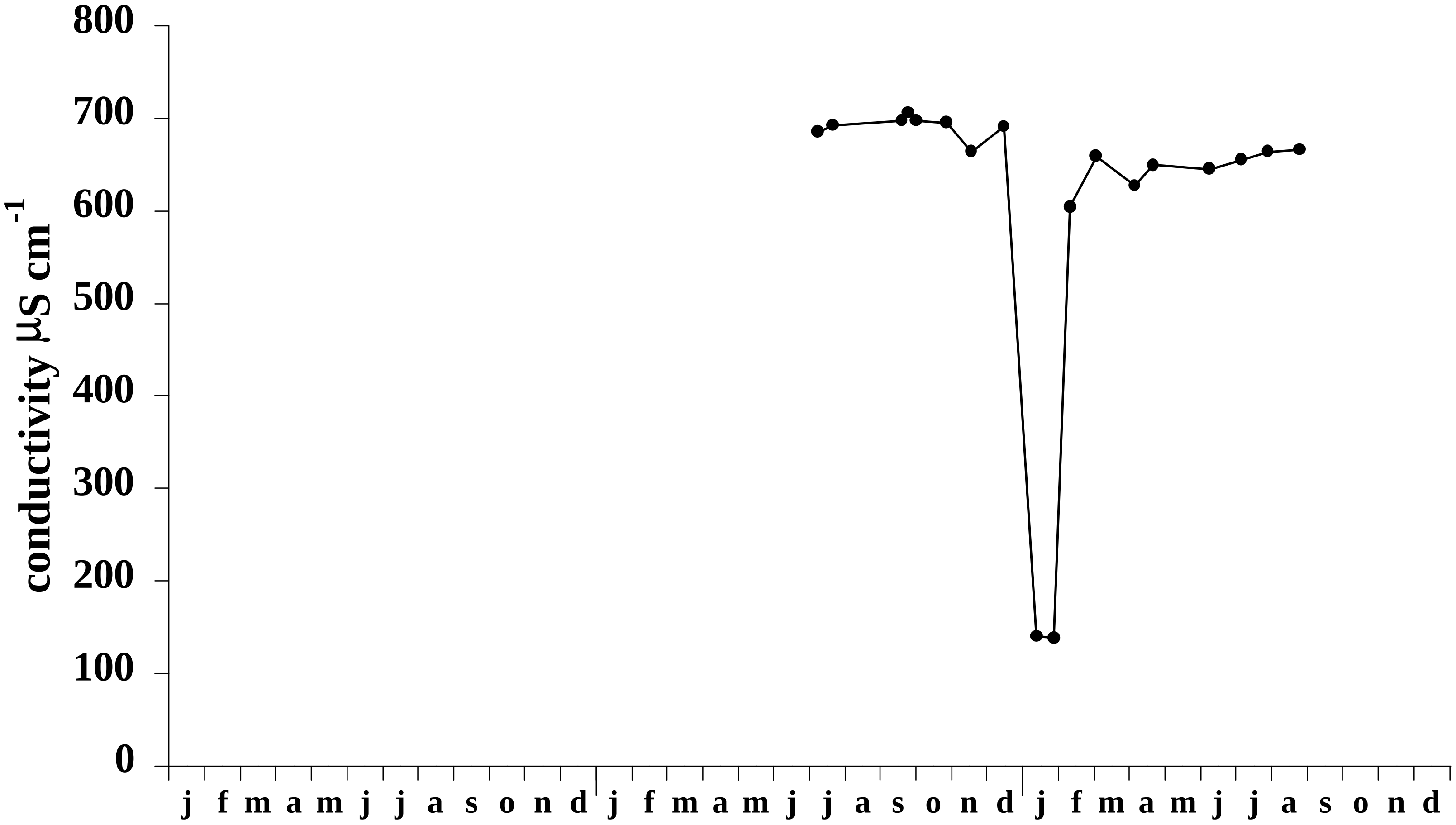


Figure 11: TDS variation in the lake at effluent outfall #1

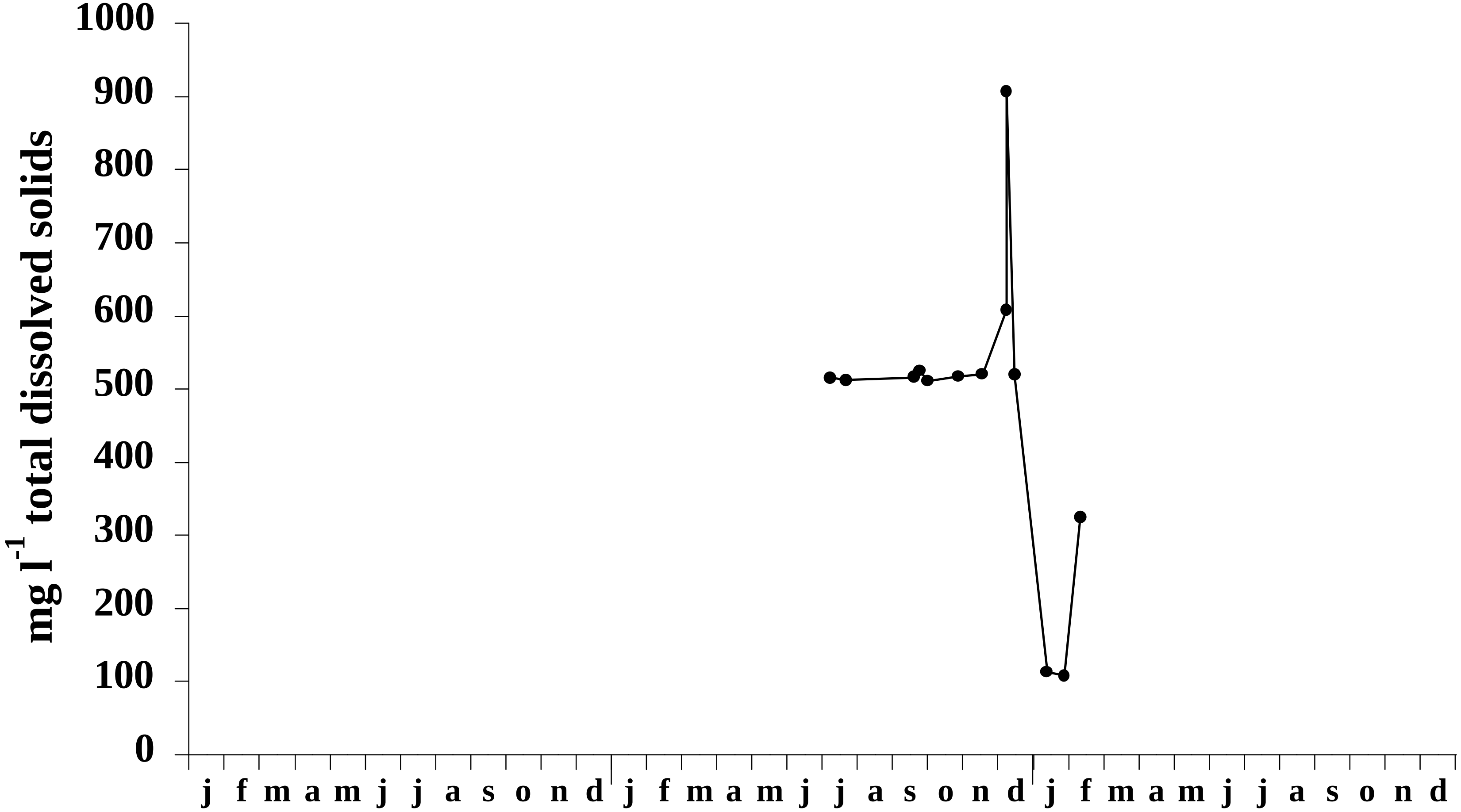


Figure 12: TDS variation in the lake at a point between the two effluent outfalls

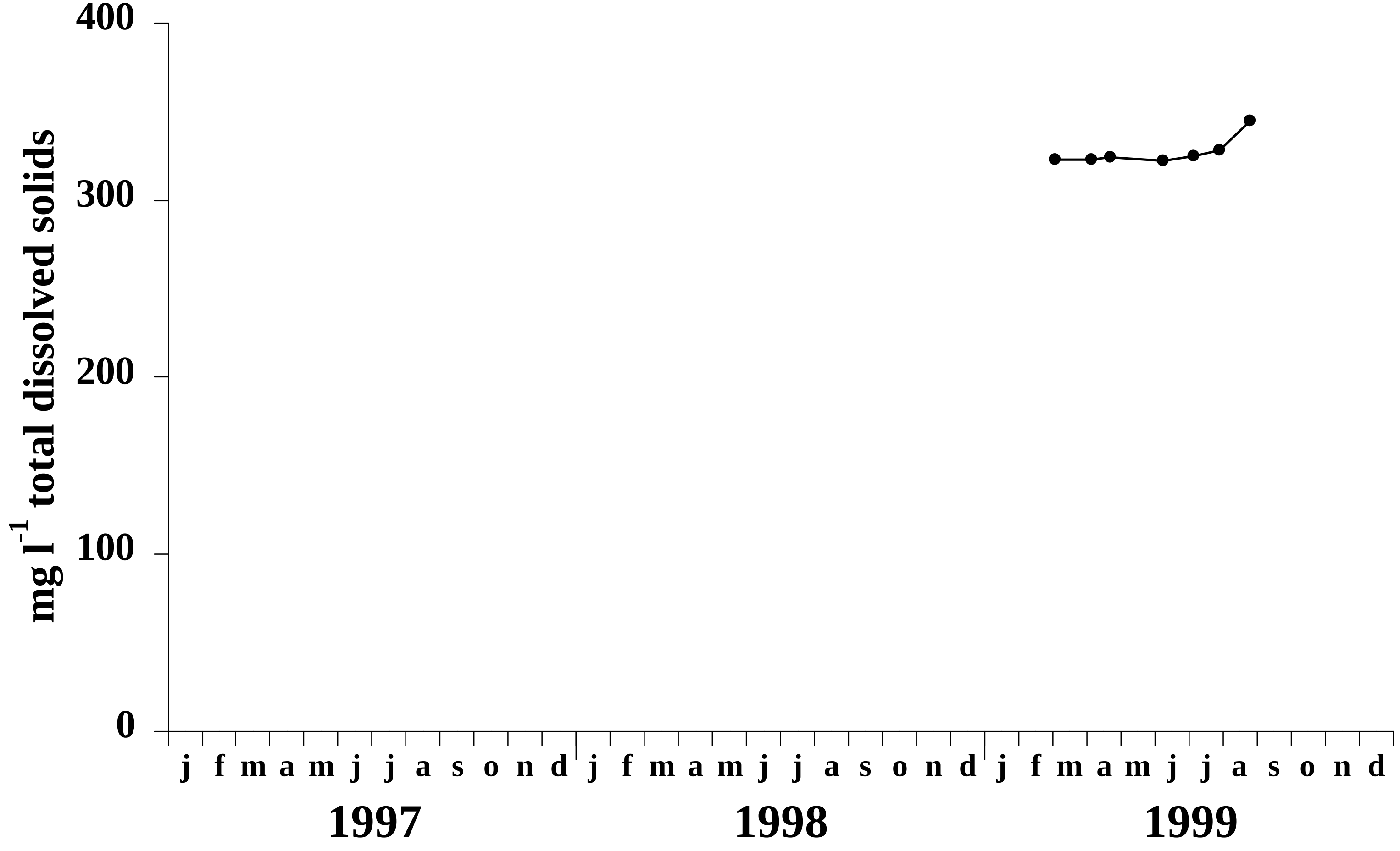
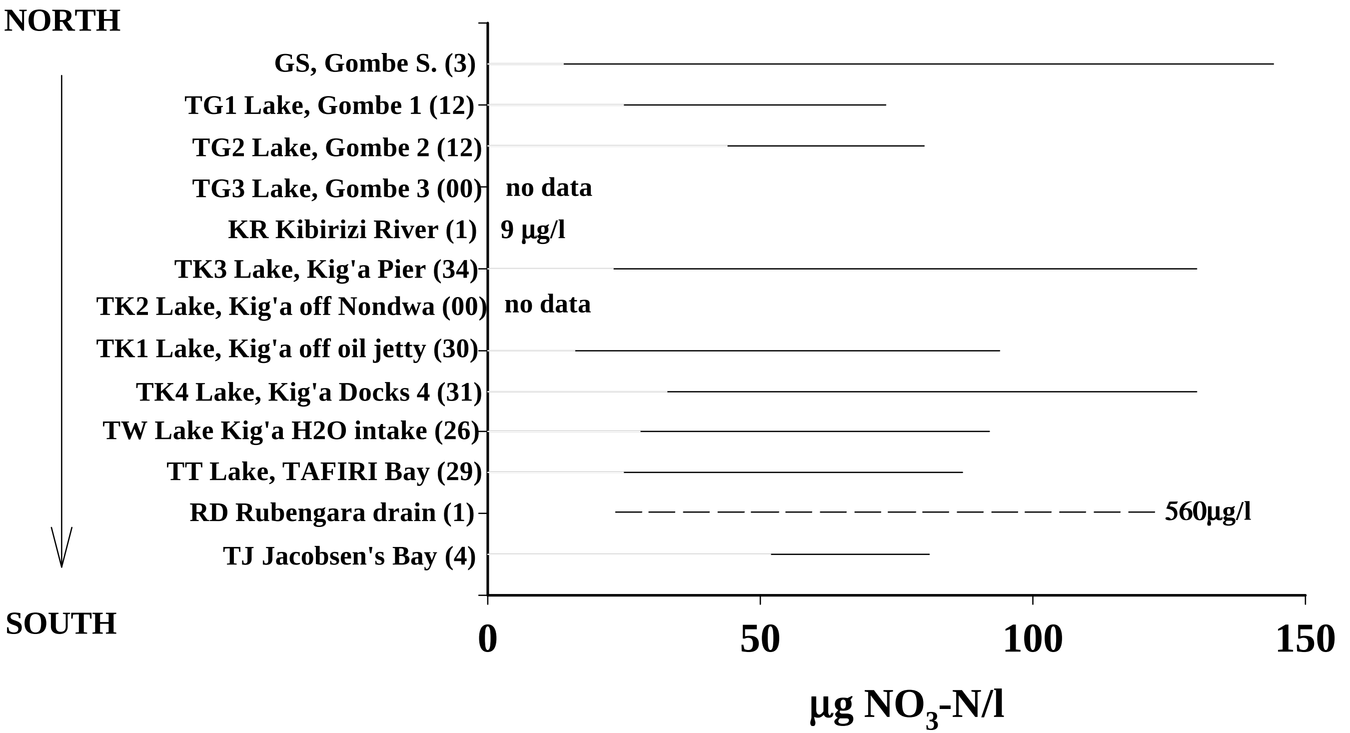
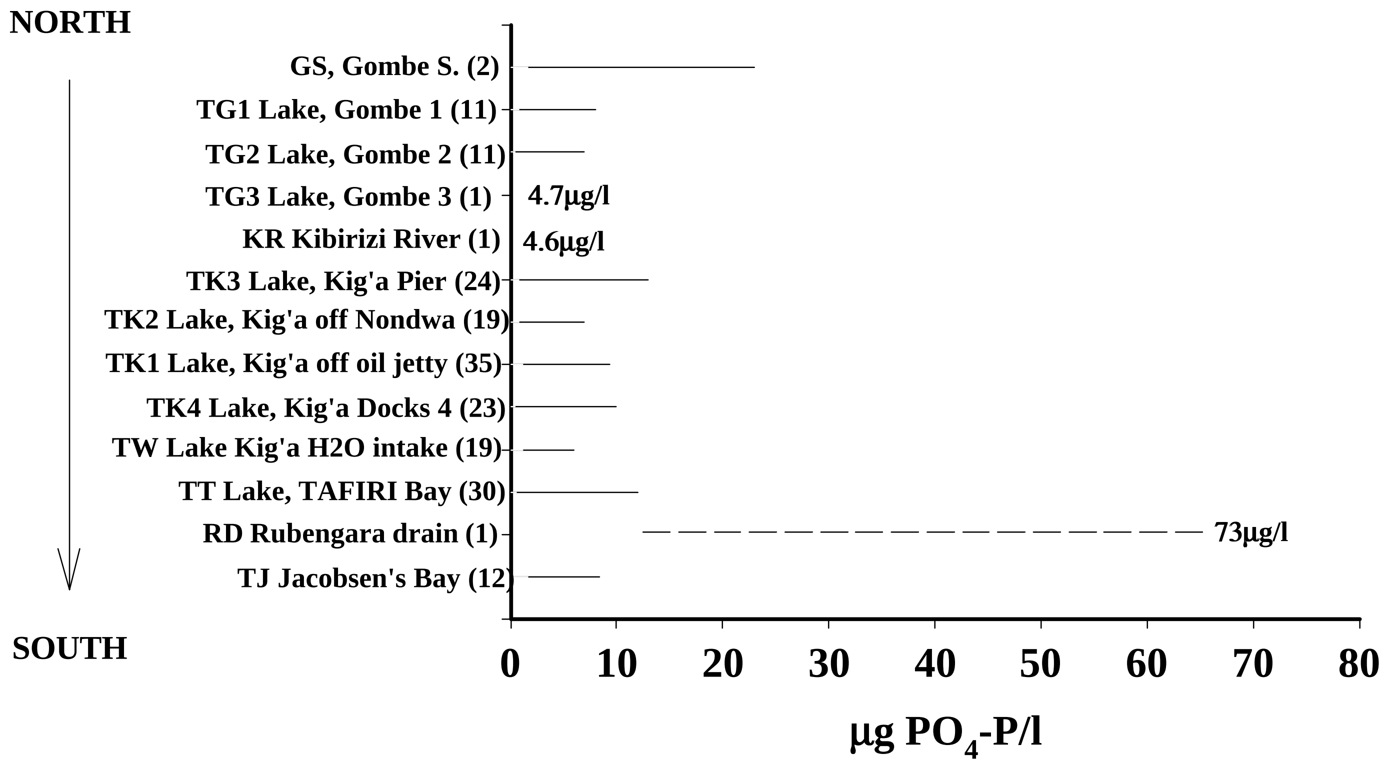


Figure 13: range in nitrate-N concentrations at 13 sampling sites extending from the Gombe Stream to Jacobsen's Bay - Tanzania



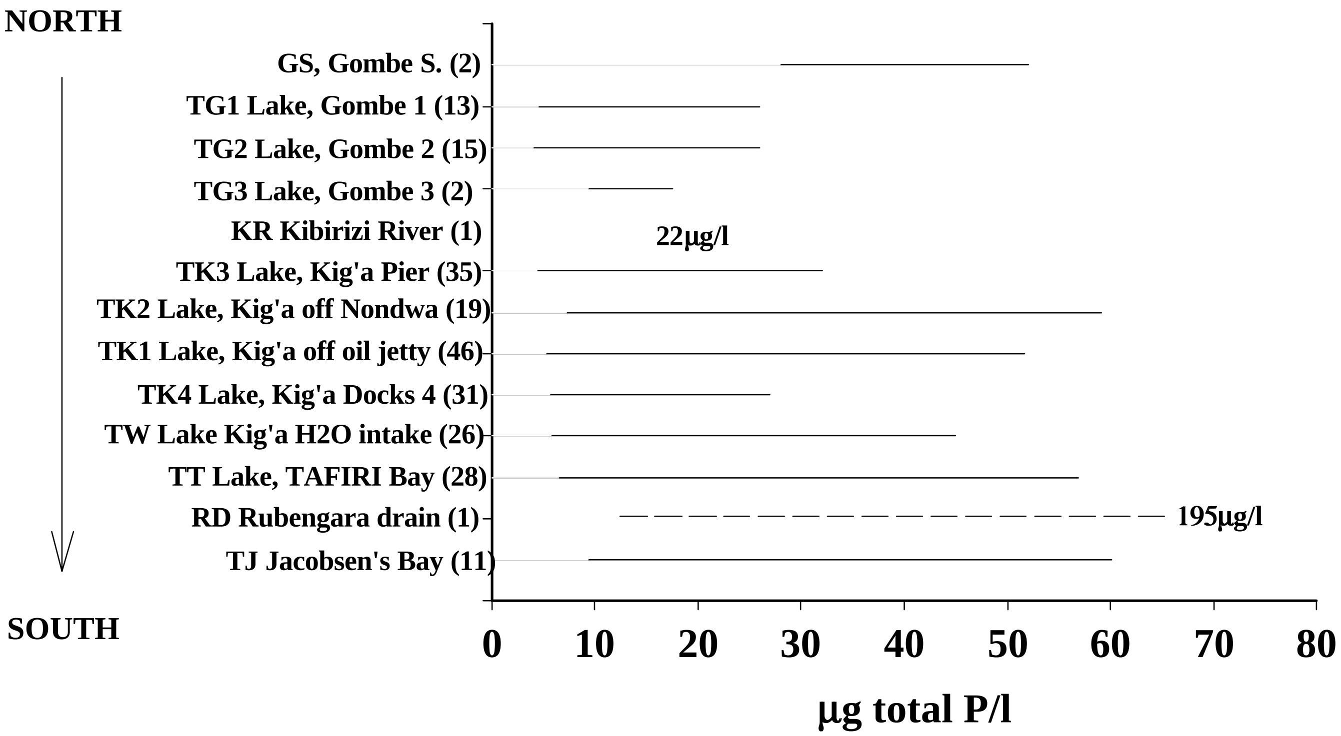
Figures in brackets are the number of sampling dates

Figure 14: range in phosphate phosphorus concentrations at 13 sampling sites extending from the Gombe Stream to Jacobsen's Bay - Tanzania



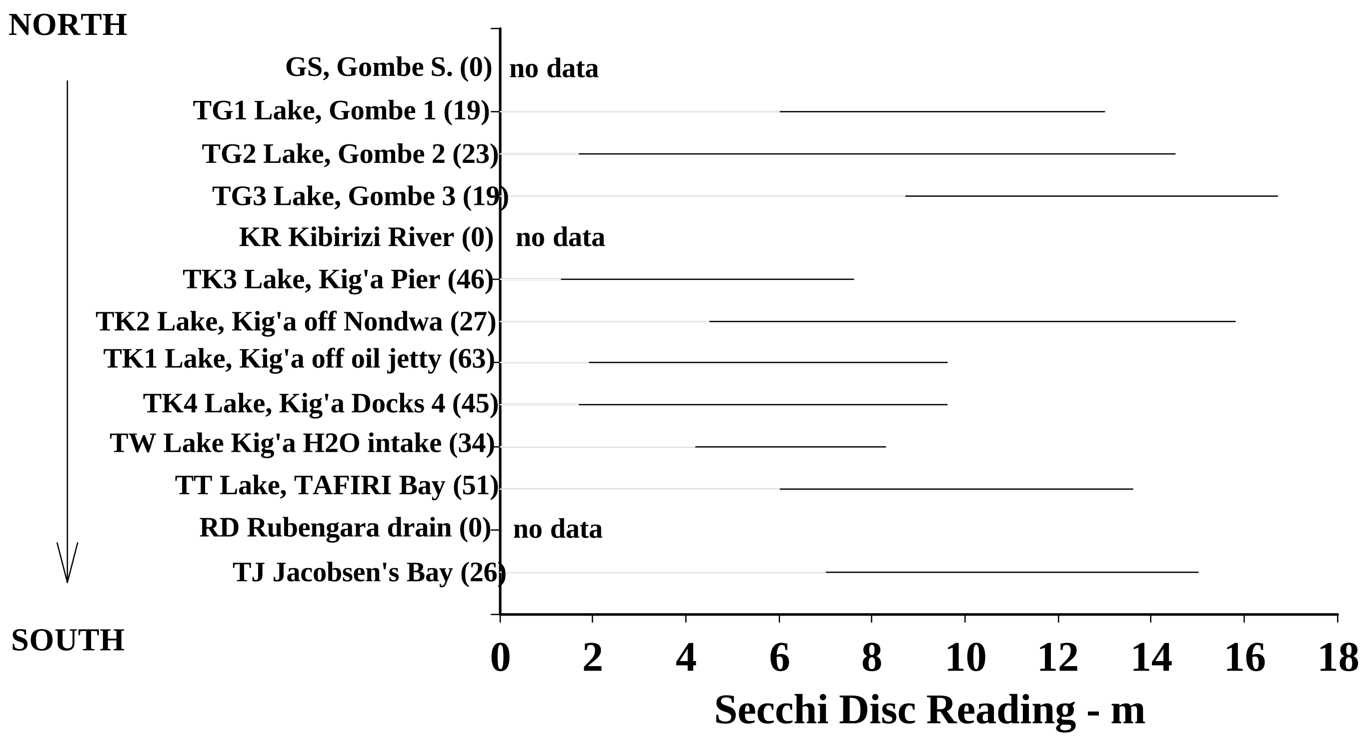
Figures in brackets are the number of sampling dates

Figure 15: range in total phosphorus concentrations at 13 sampling sites extending from the Gombe Stream to Jacobsen's Bay - Tanzania



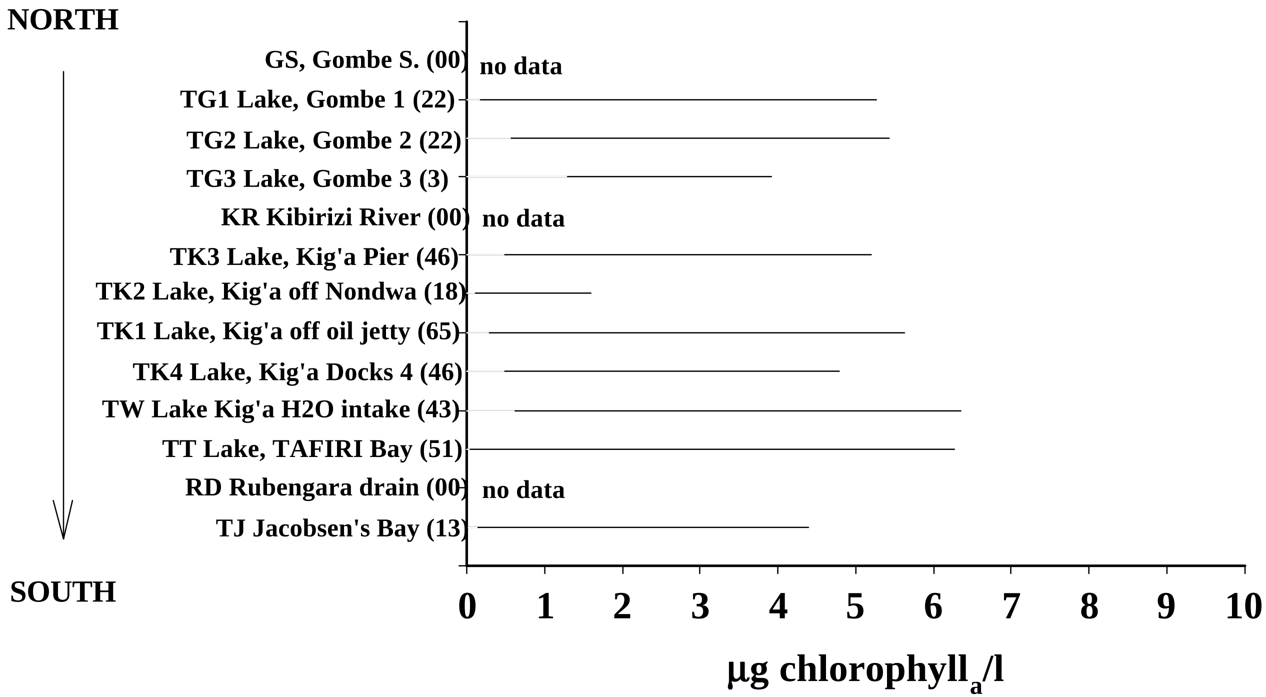
Figures in brackets are the number of sampling dates

Figure 16: range in water clarity at 13 sampling sites extending from the Gombe Stream to Jacobsen's Bay - Tanzania



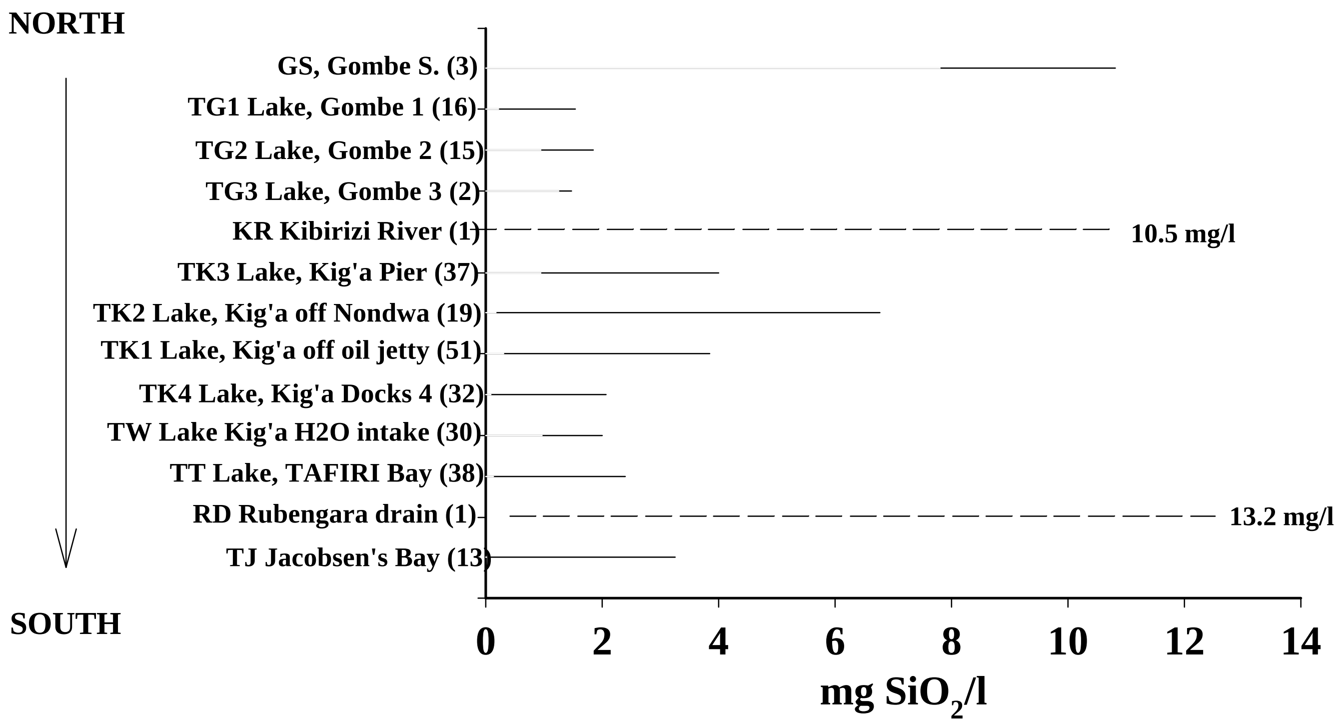
Figures in brackets are the number of sampling dates

Figure 17: range in chlorophyll$_a$ concentrations at 13 sampling sites extending from the Gombe Stream to Jacobsen's Bay, Tanzania



Figures in brackets are the number of sampling dates

Figure 18: range in silica concentrations at 13 sampling sites extending from the Gombe Stream to Jacobsen's Bay - Tanzania



Figures in brackets are the number of sampling dates

Figure 19: temporal variation in pigment levels at Kigoma site TG2

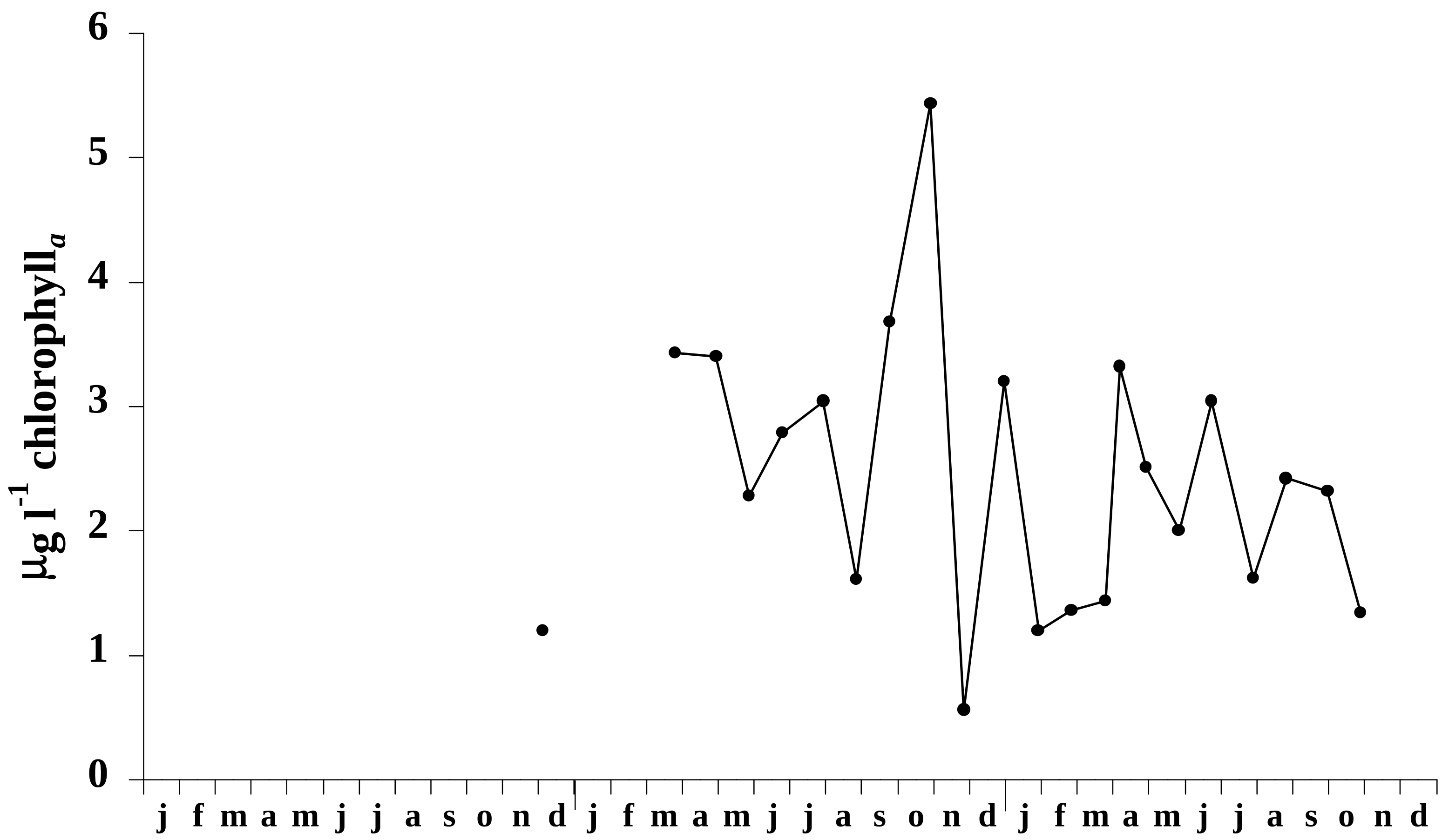


Figure 20: variation in nitrate-N concentrations
at the Kigoma Pier site TK3

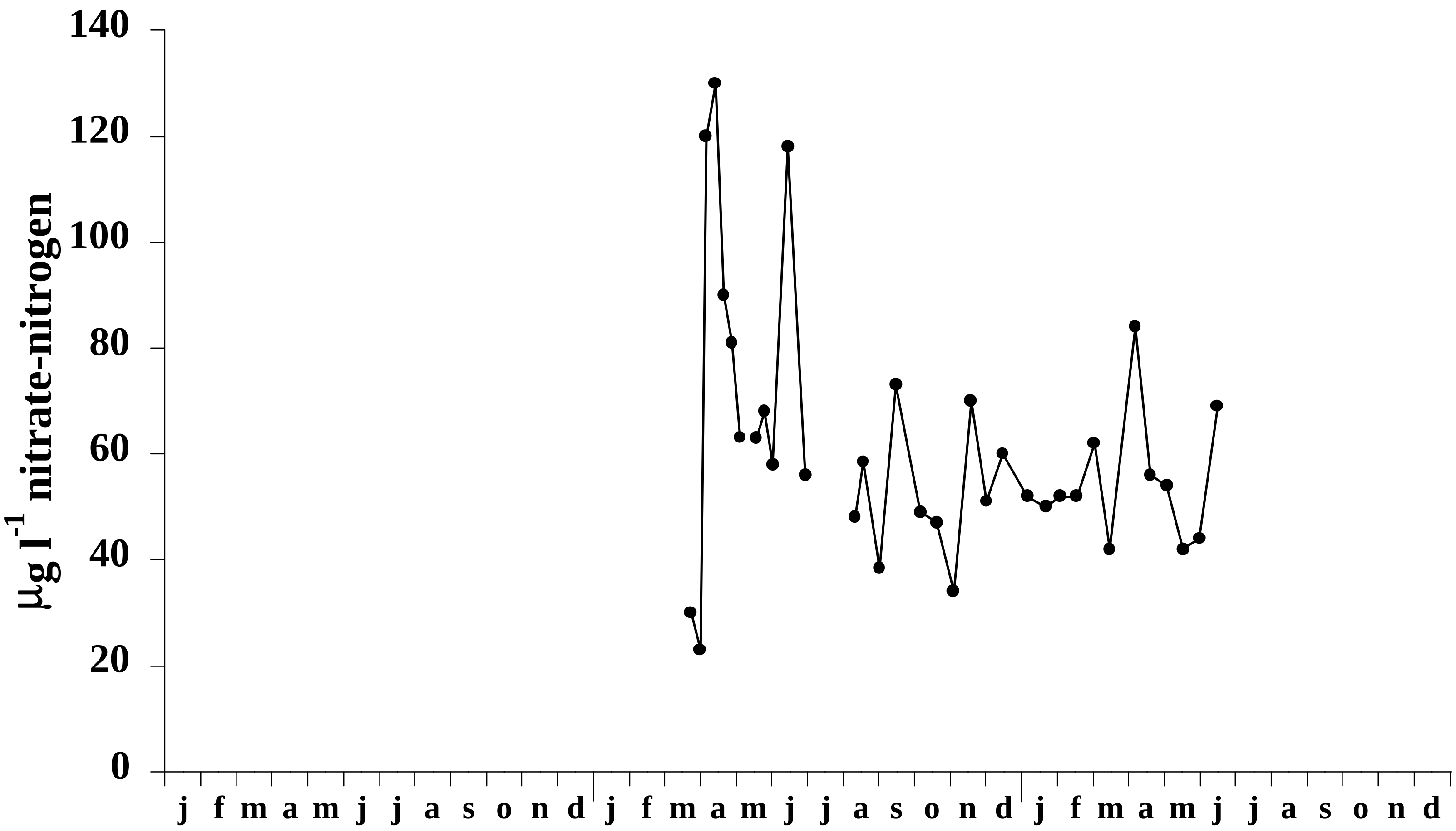


Figure 21: variation in chlorophyll$_a$ levels off Nondwa Point (Kigoma siteTK2)

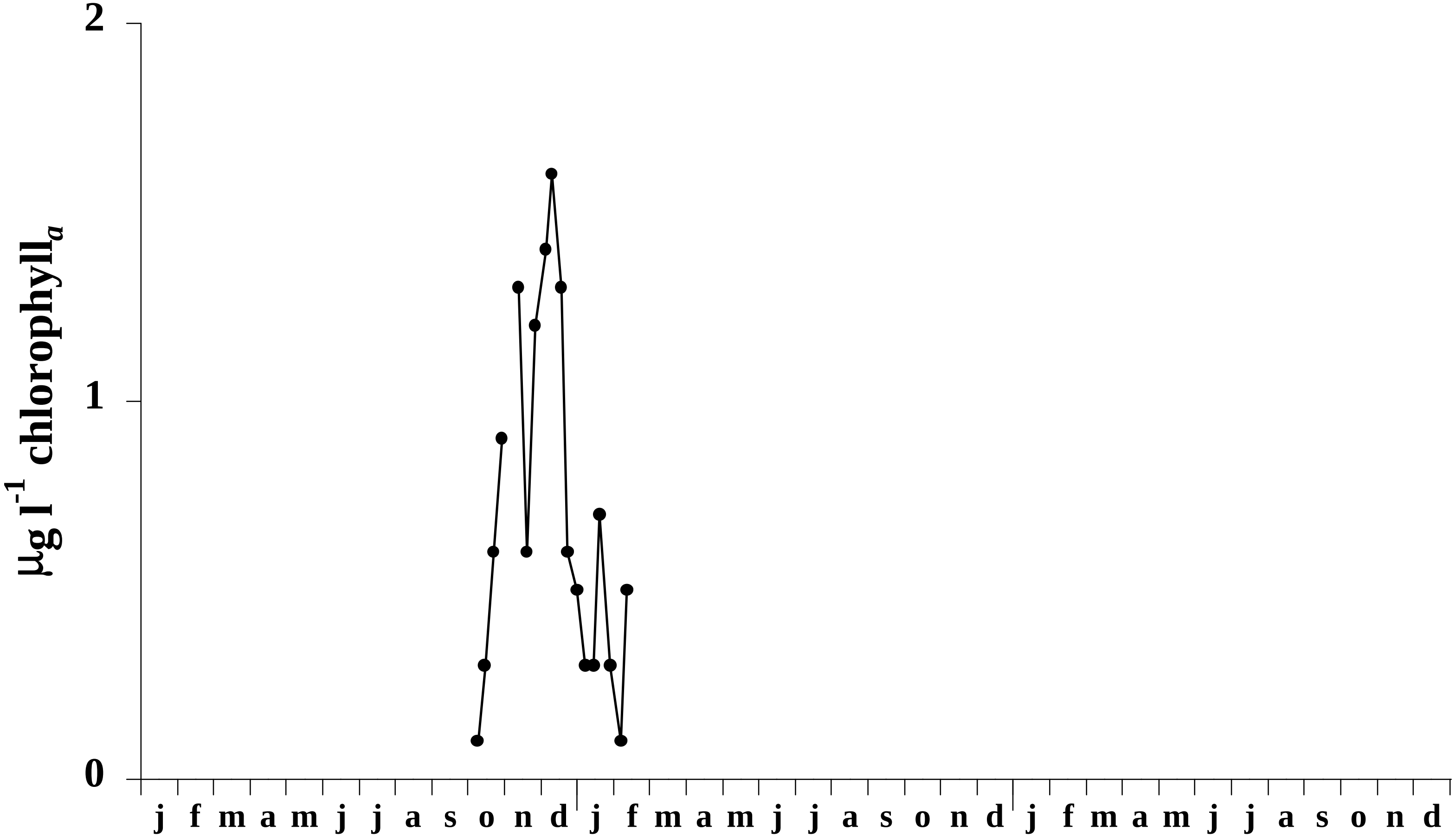


Figure 22: temporal variation in total phosphorus levels at site TK1 (off the Kigoma oil jetty

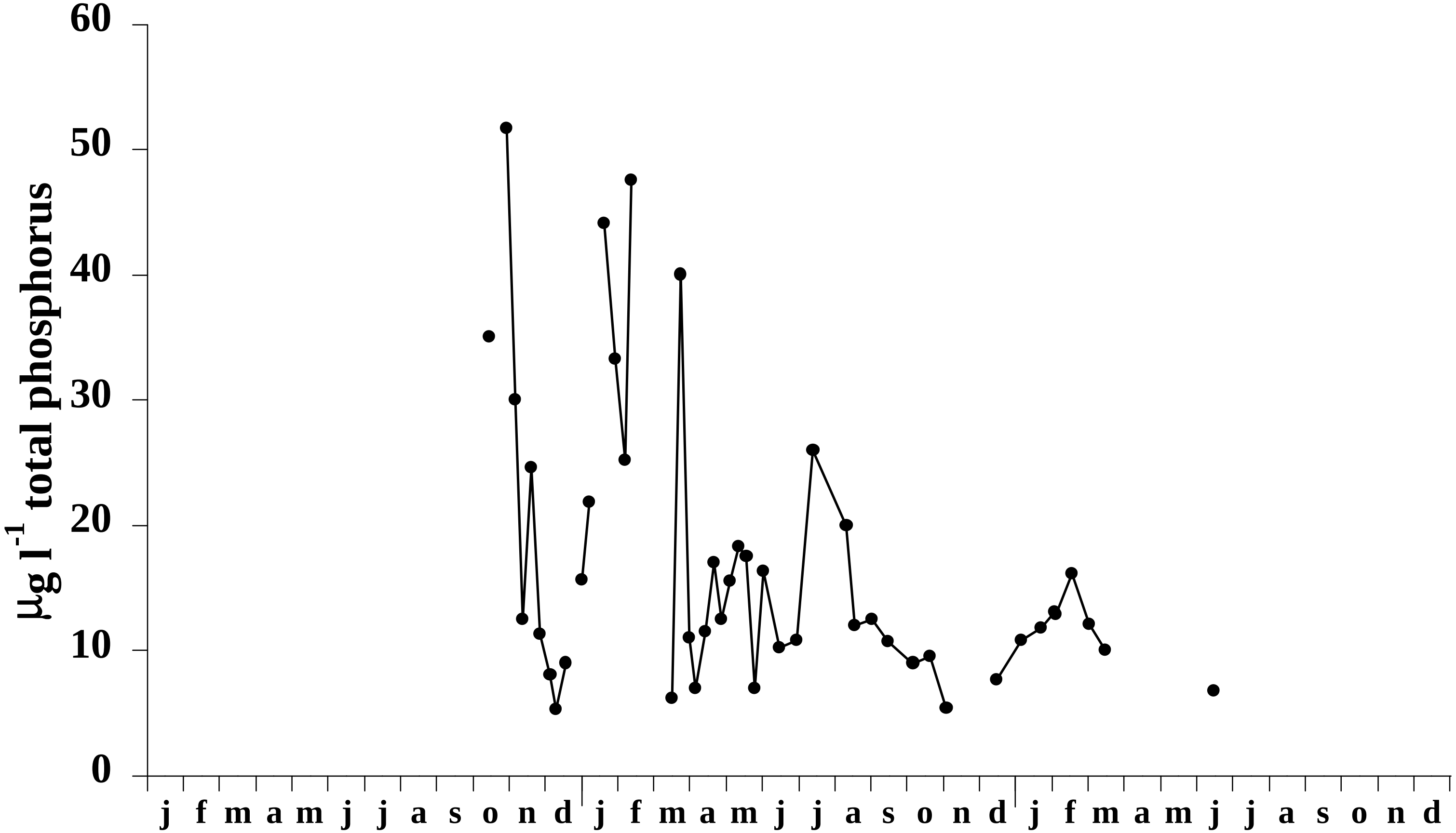


Figure 23: temporal variation in chlorophyll$_a$ concentration off the Kigoma oil jetty site (TK1) - Tanzania

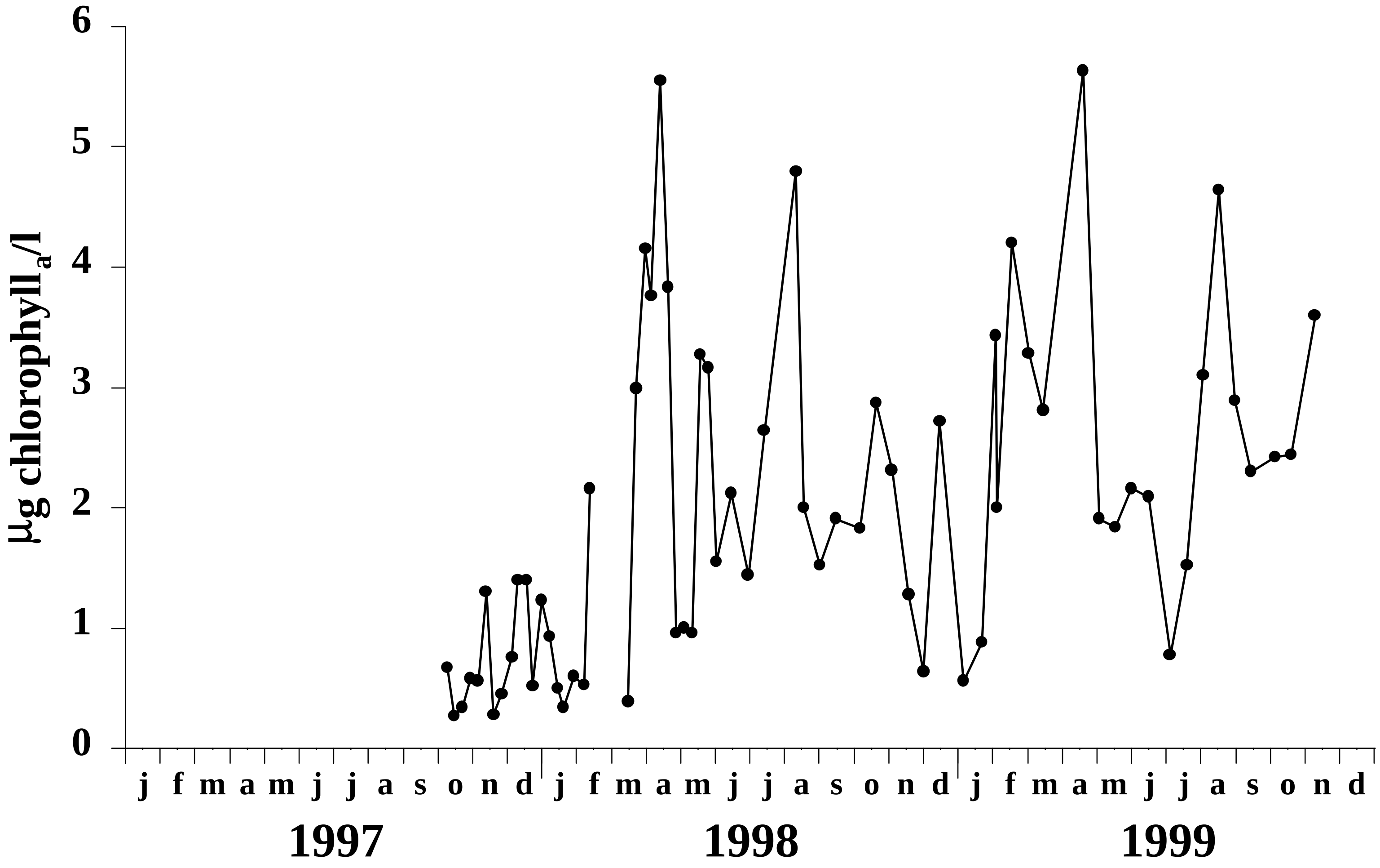


Figure 24: variation in nitrate-N concentrations at the Kigoma Docks (site TK4)

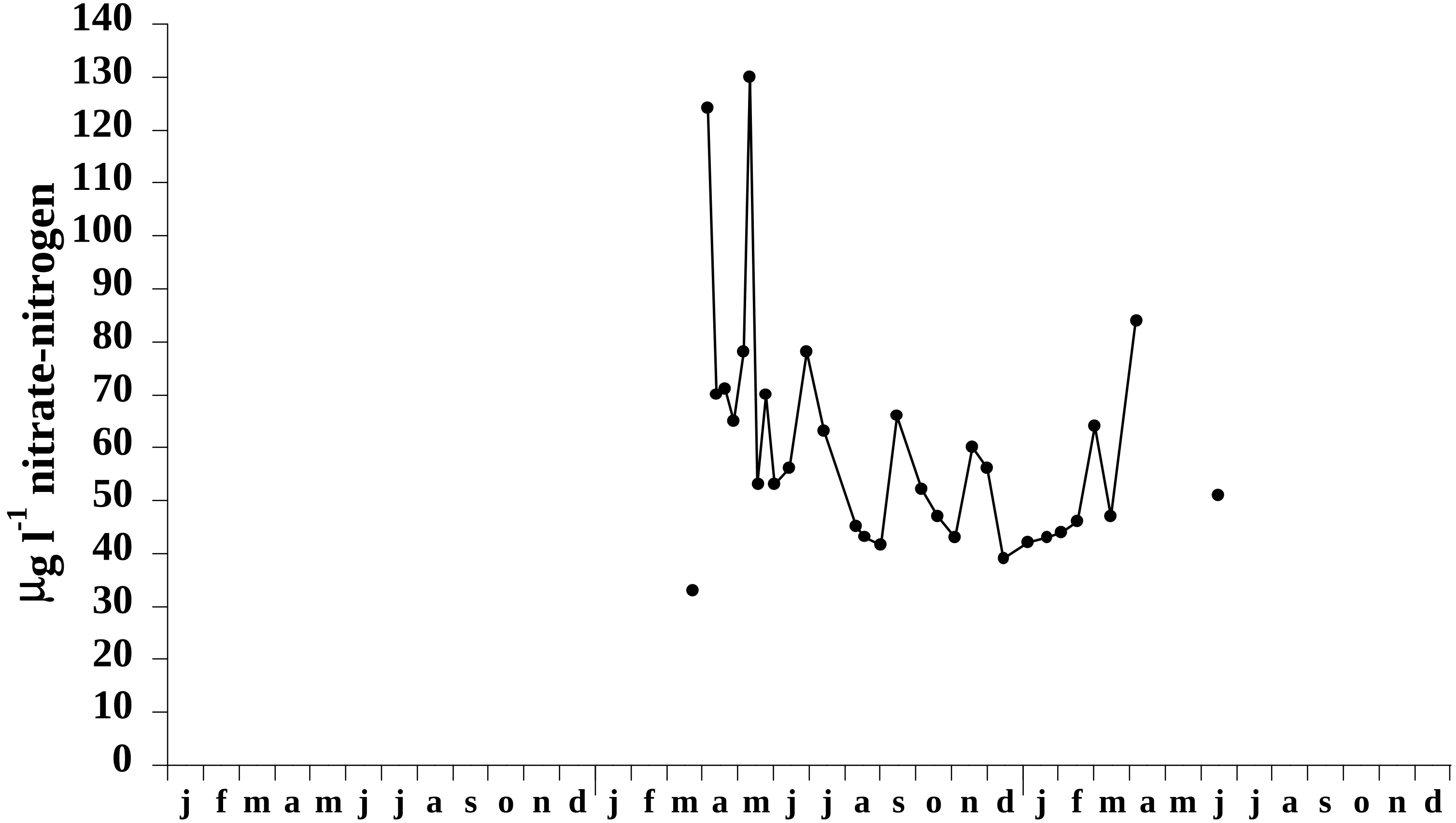


Figure 25: range in water clarity values at 10 sampling sites extending from Nsumbu Harbour to Mpulungu Ngwenya market - Zambia

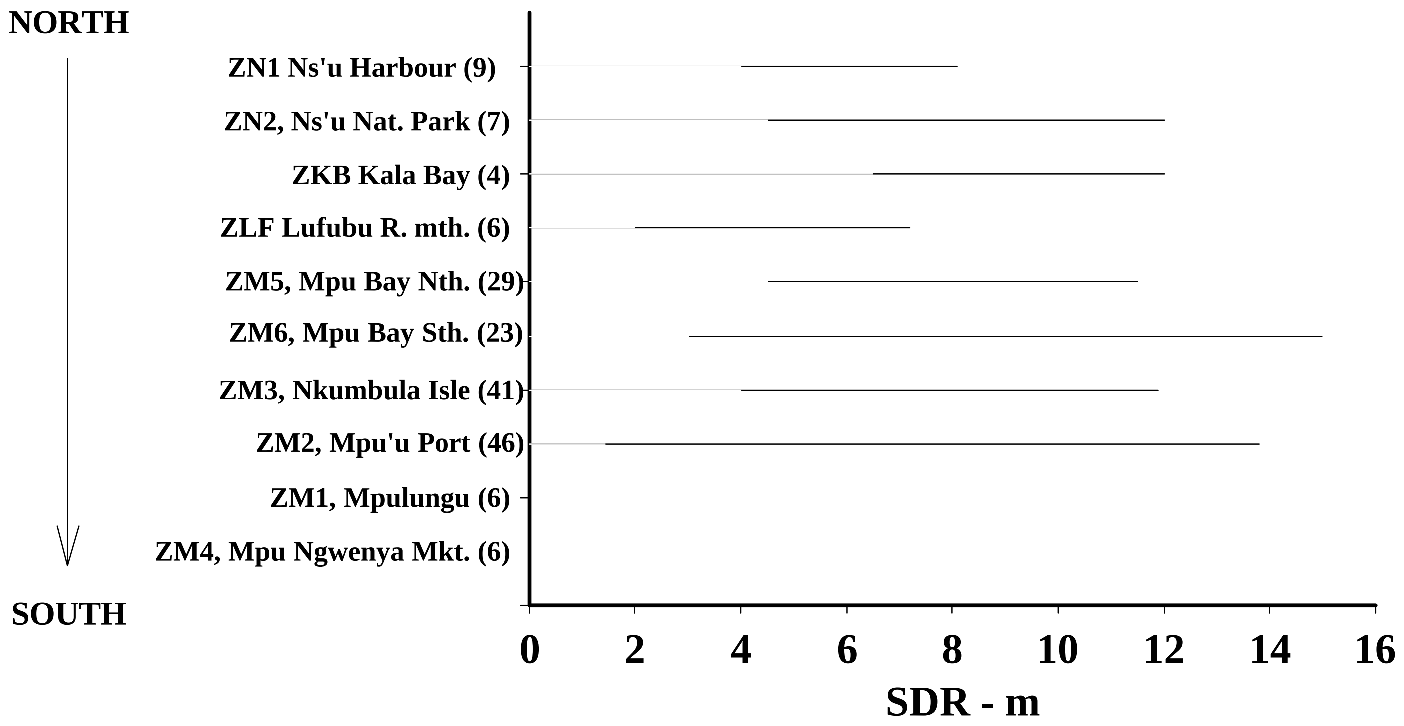
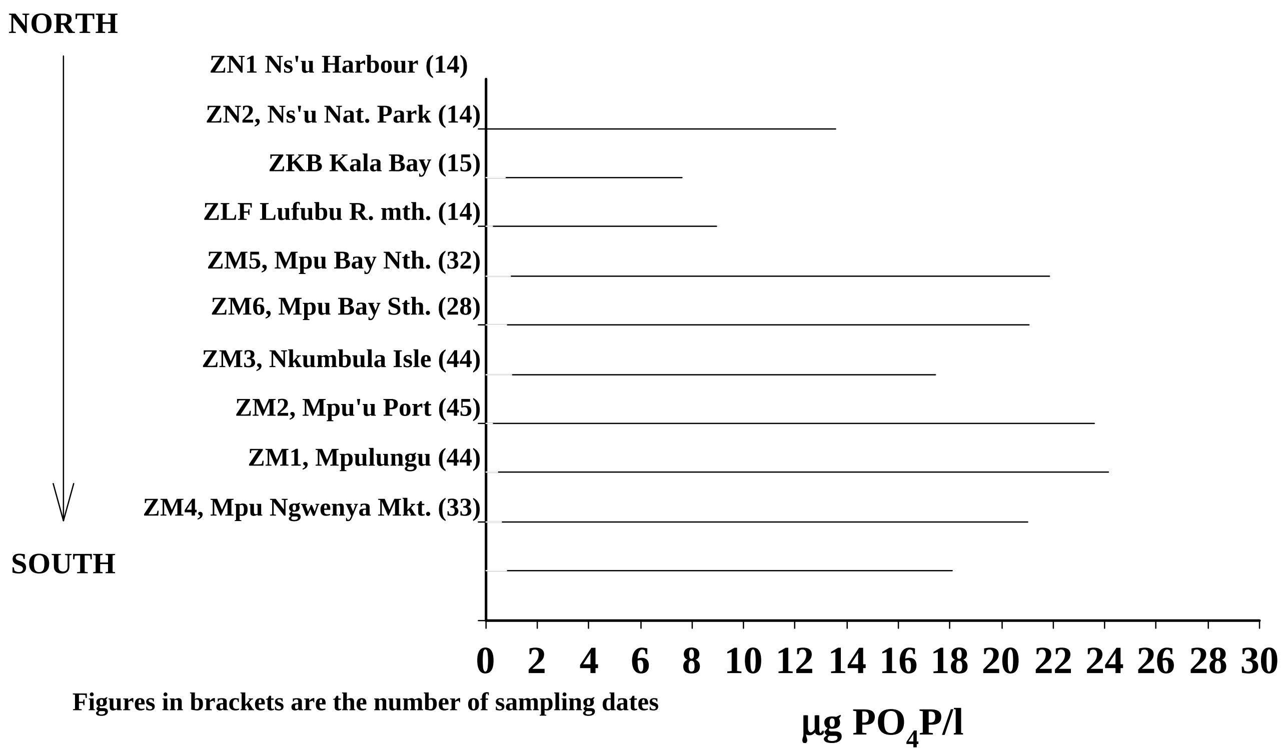
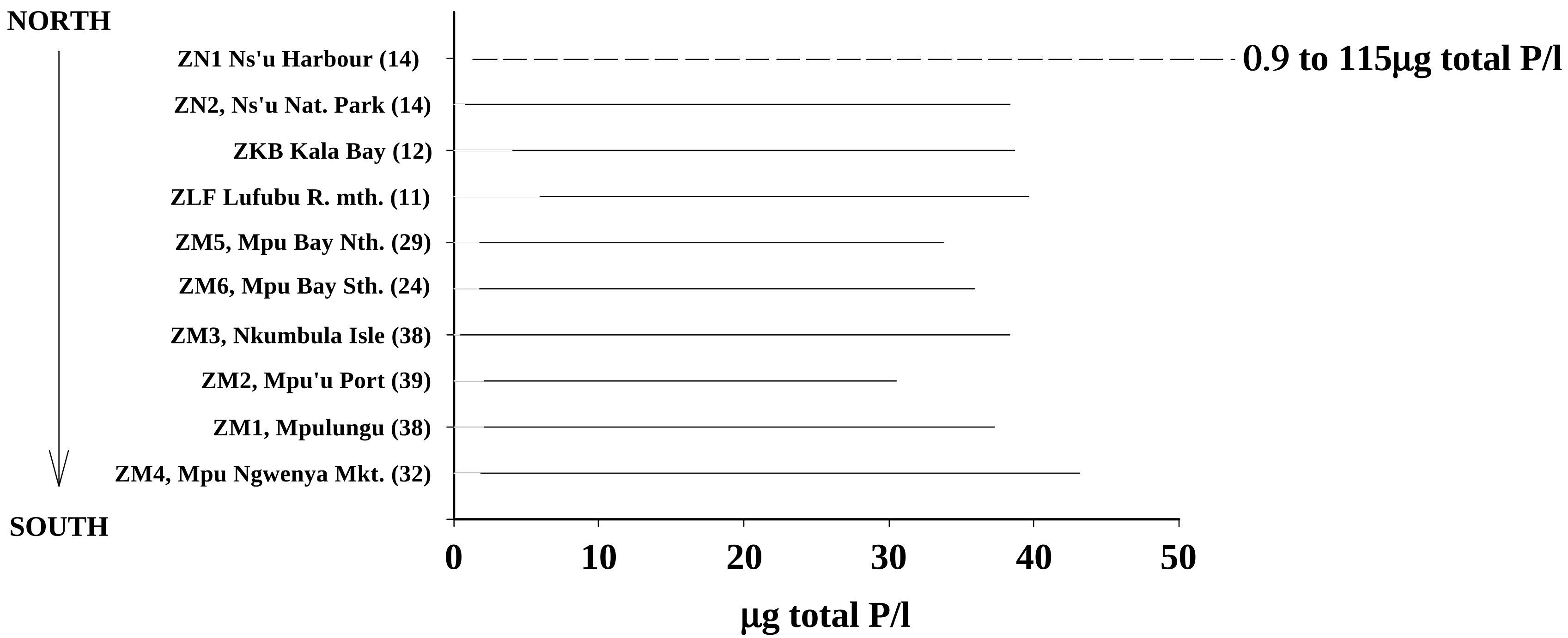


Figure 26: range in phosphate phosphorus concentrations at10 sampling sites extending from Nsumbu Harbour to Mpulungu Ngwenya market - Zambia



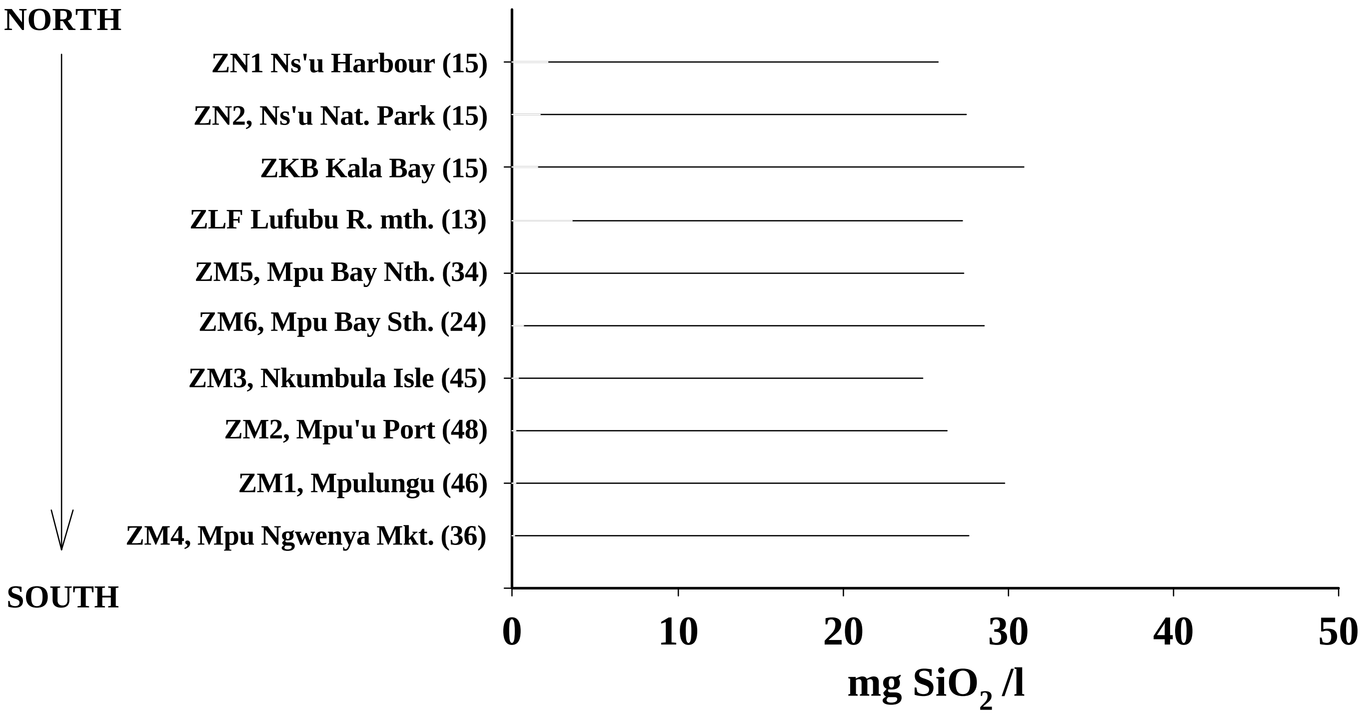
Figures in brackets are the number of sampling dates

Figure 27: range in total phosphorus concentrations at 10 sampling sites extending from Nsumbu Harbour to Mpulungu Ngwenya market - Zambia



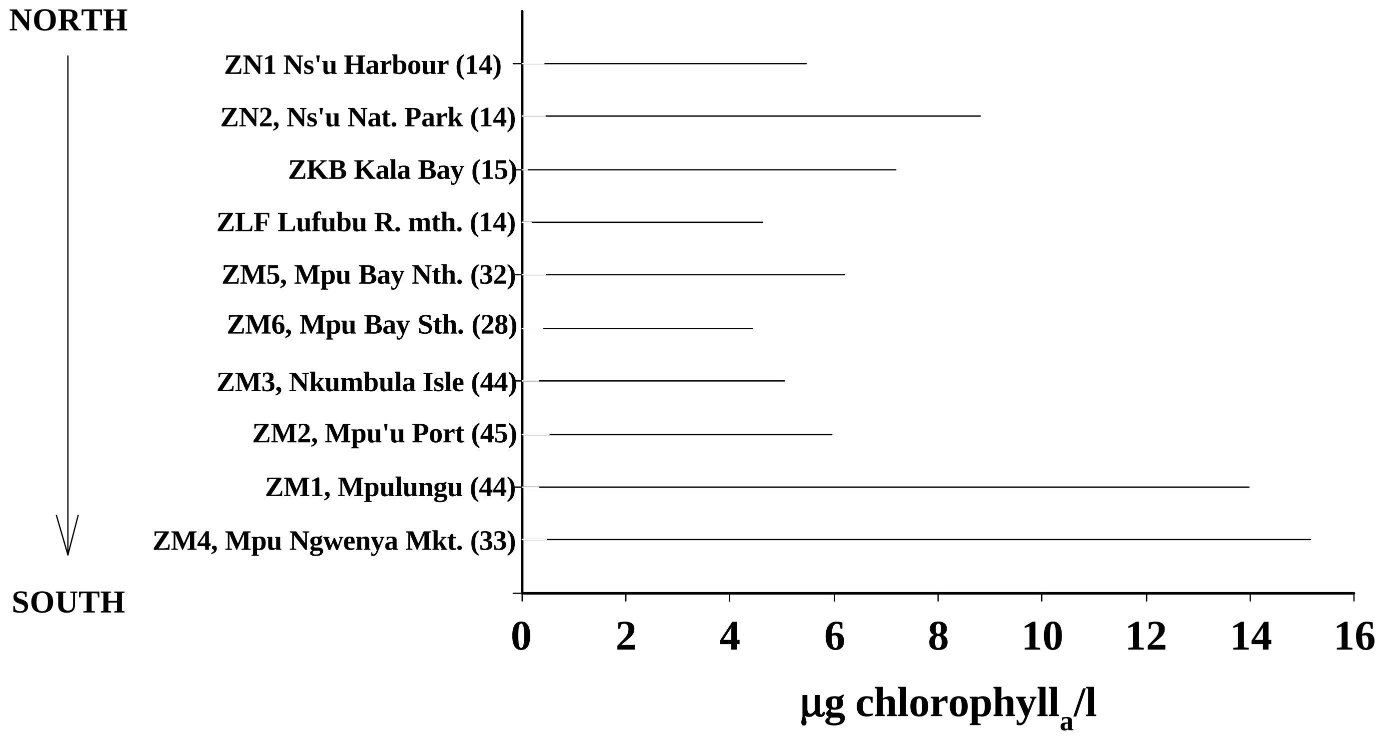
Figures in brackets are the number of sampling dates

Figure 28: range in silica concentrations at 10 sampling sites extending from Nsumbu Harbour to Mpulungu Ngwenya market - Zambia



Figures in brackets are the number of sampling dates

Figure 29: range in chlorophyll$_a$ concentrations at 10 sampling sites extending from Nsumbu Harbour to Mpulungu Ngwenya market - Zambia



Figures in brackets are the number of sampling dates

Figure 30: variation in total phosphorus concentrations at the Mpulungu Bay South site - ZM5

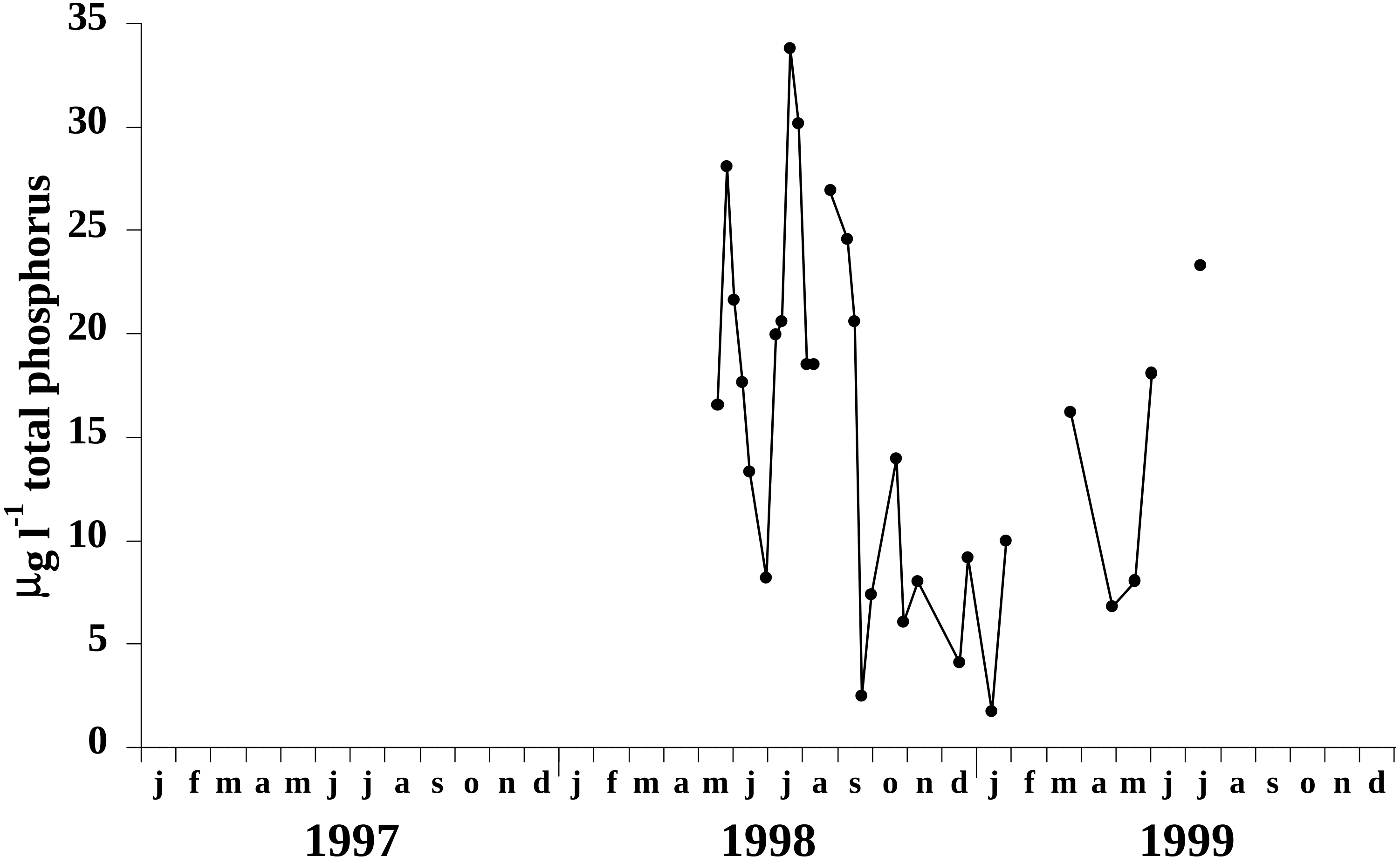


Figure 31: changes in the concentration of chlorophyll$_a$ at the Mpulungu, Nkumbula Isle (site ZM3)

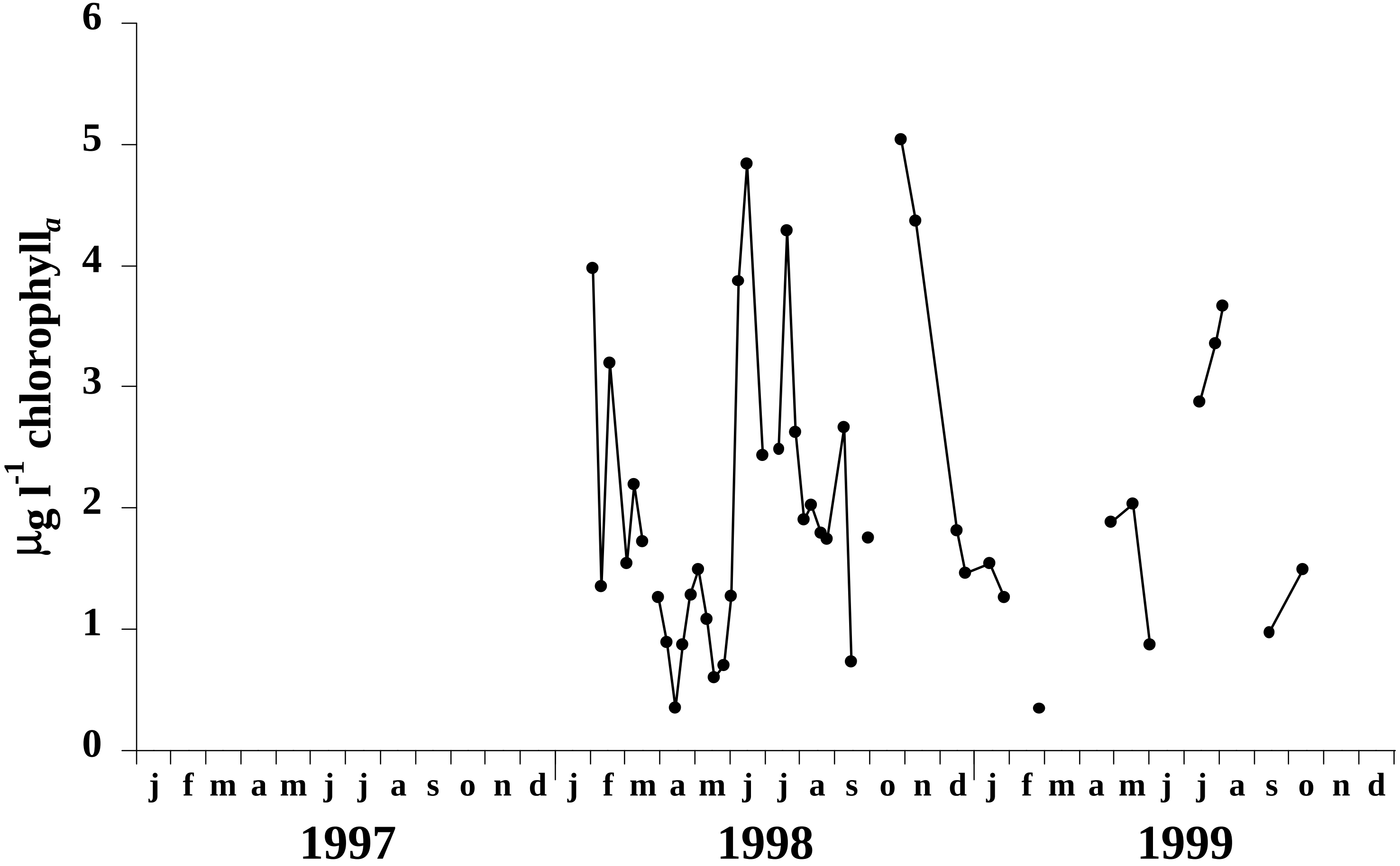


Figure 32: changes in total phosphorus concentrations at the Mpulungu Port (site ZM2)

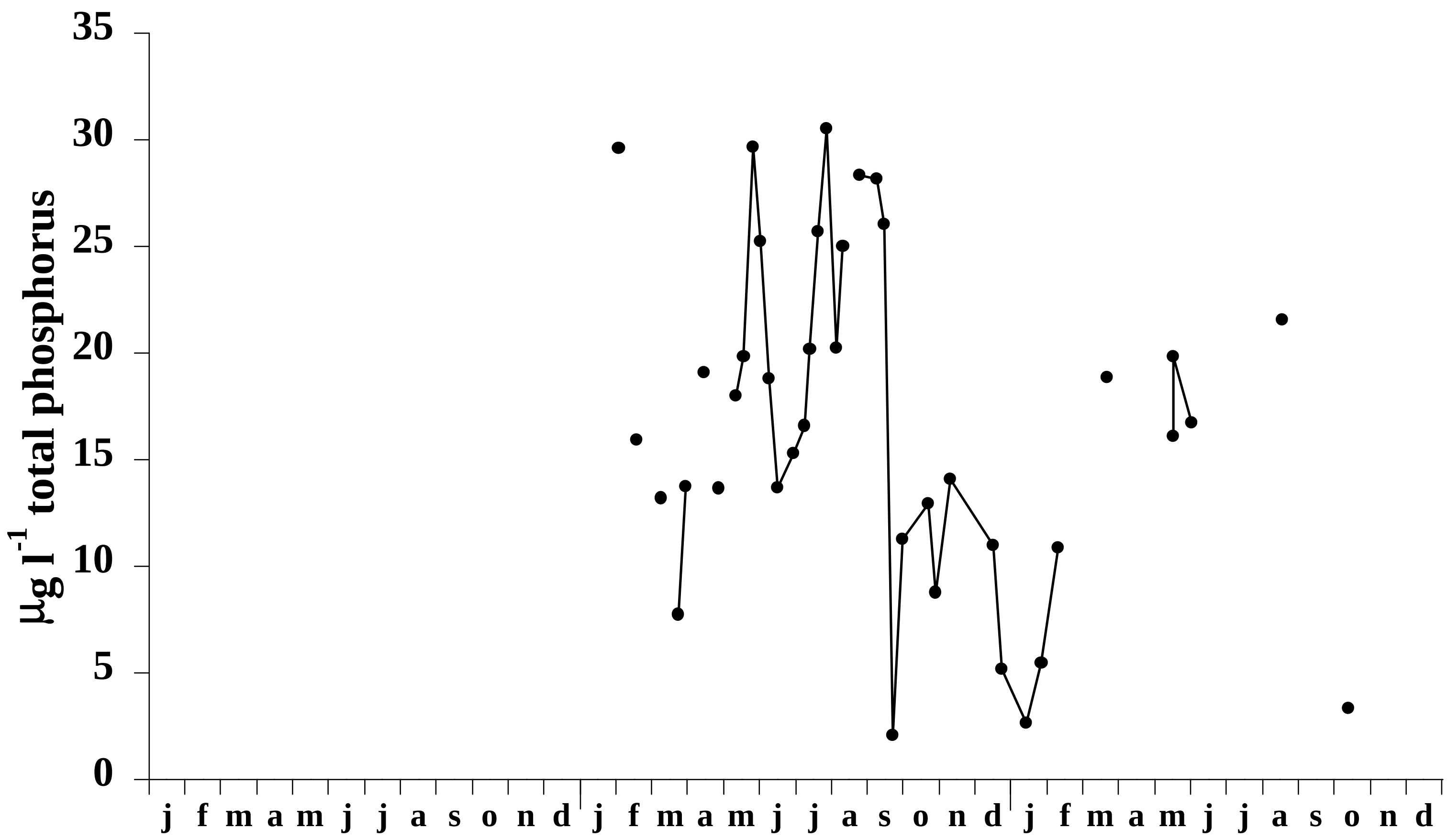


Figure 33: changes in total phophorus at the Nkumbula Isle, Mpulungu (site ZM3)

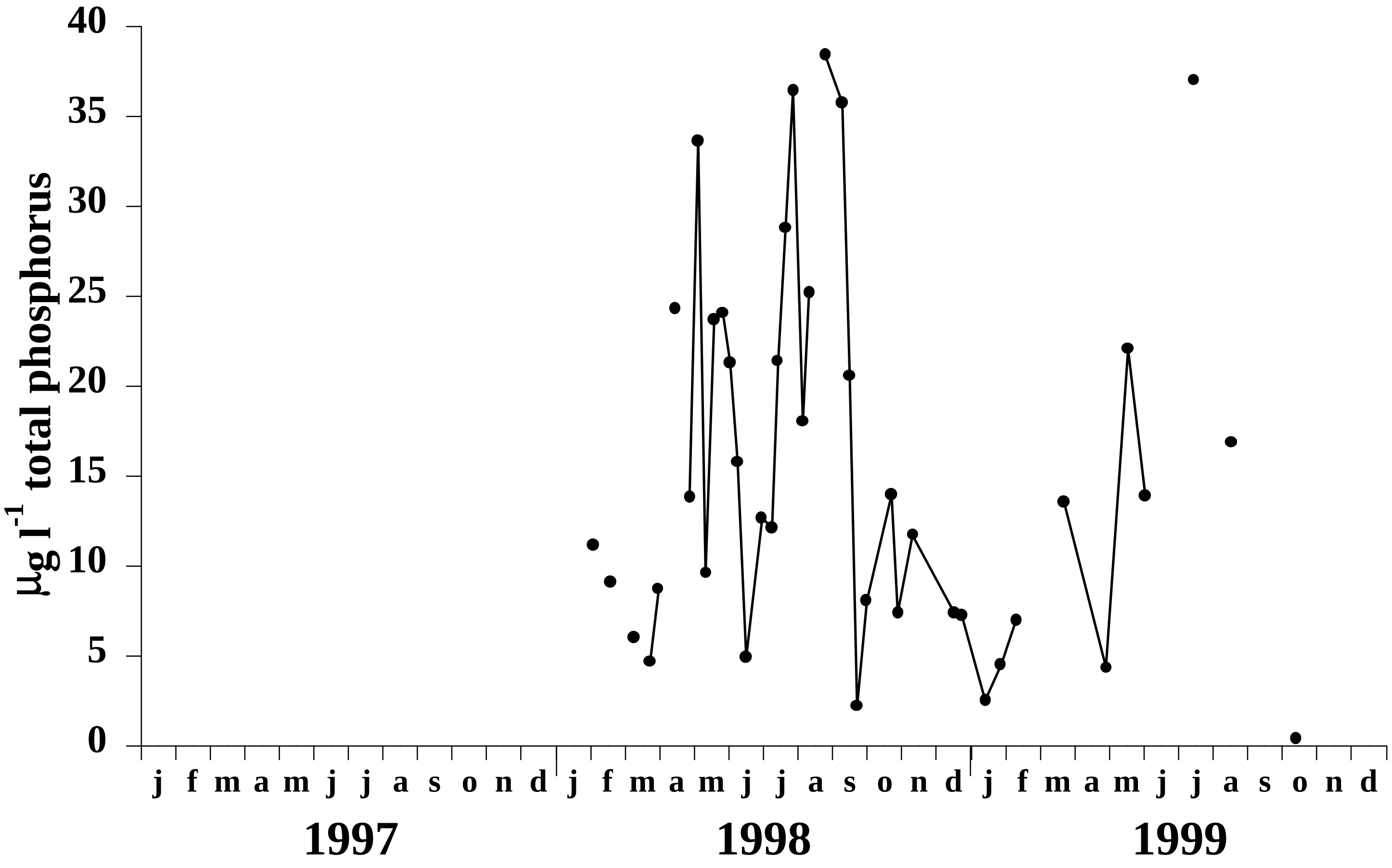


Figure 34: fluctuations in dissolved oxygen at Mpulungu Port site (ZM2)

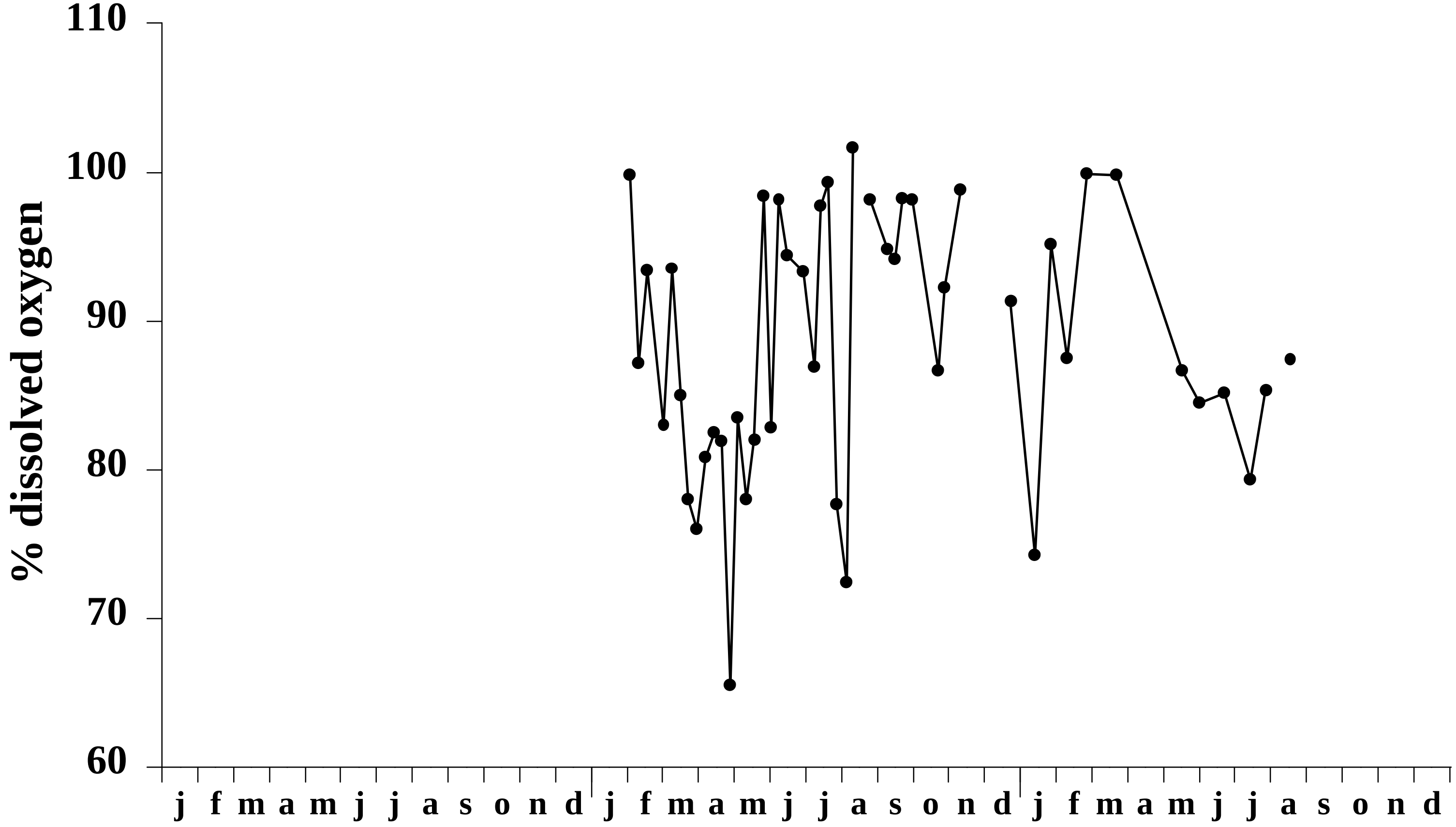


Figure 35: changes in the concentration of total phosphorus at the Mpulungu Town site (ZM1)

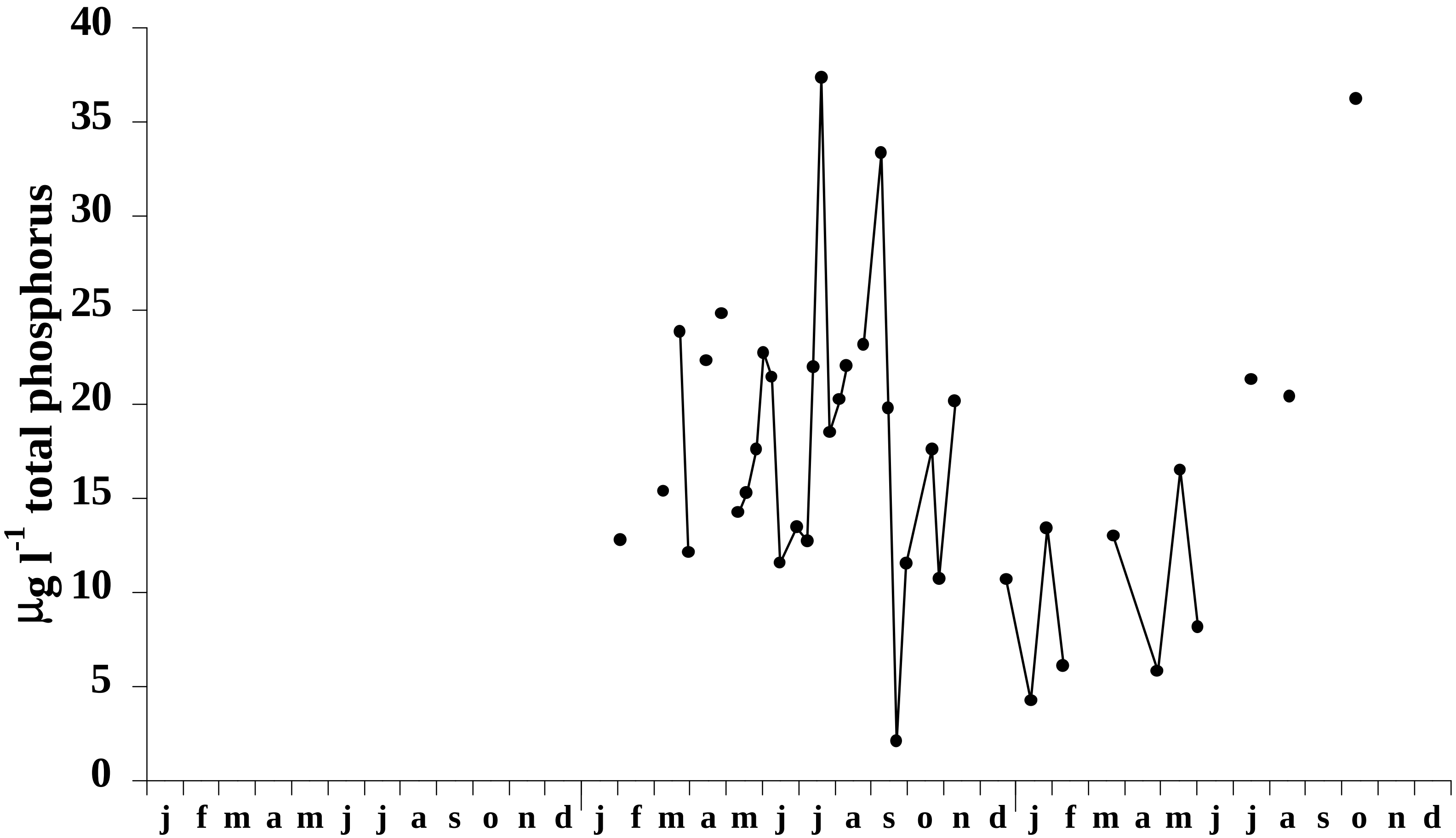


Figure 36: variation in chlorophyll$_a$ concentrations at the Mpulungu Ngwenya Market (site ZM4)

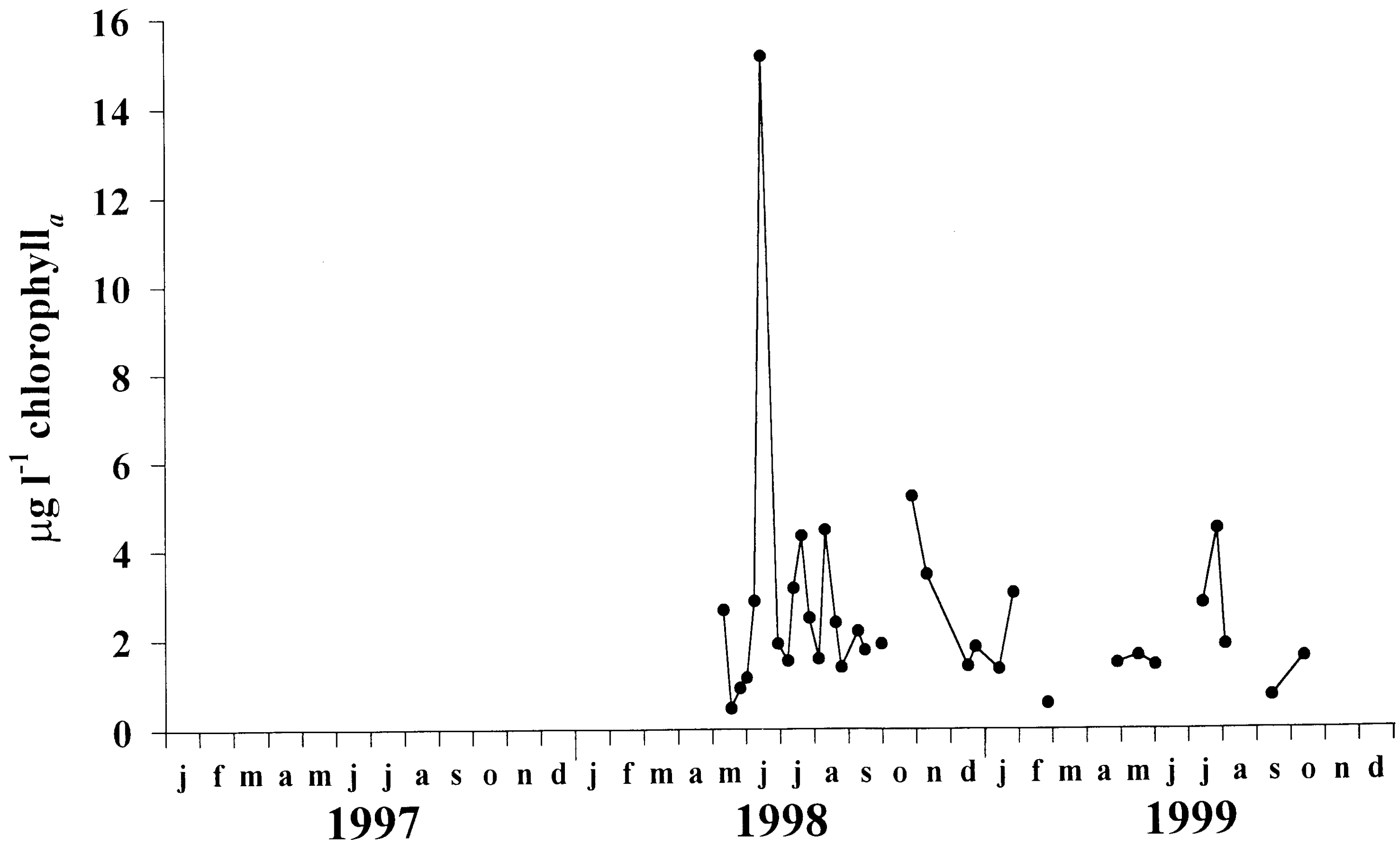


Figure 37:Lake Tanganyika phytoplankton size distribution: material collected with a 30-µm net Mpulungu site ZM3t, 9 June 1998

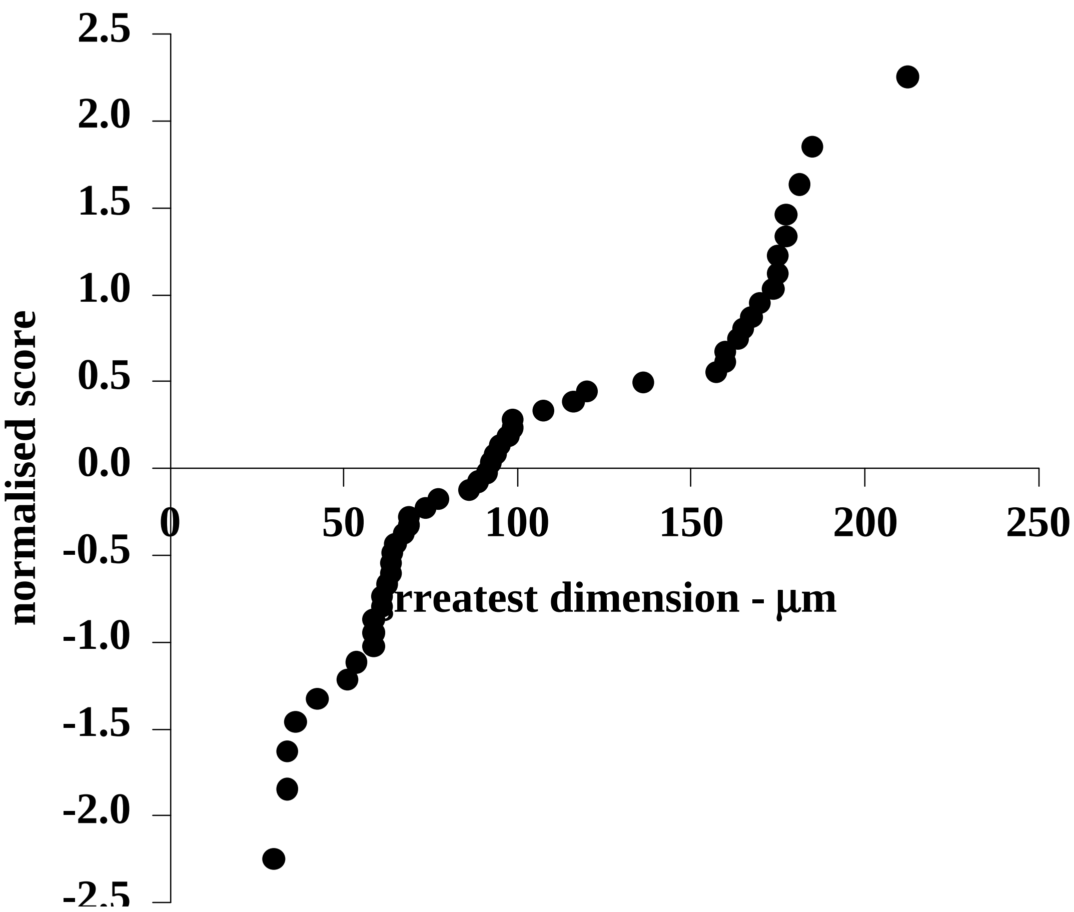


Figure 38: Nsumbu (Zambia) net phytoplankton size spectra and species numbers:results from two investigators

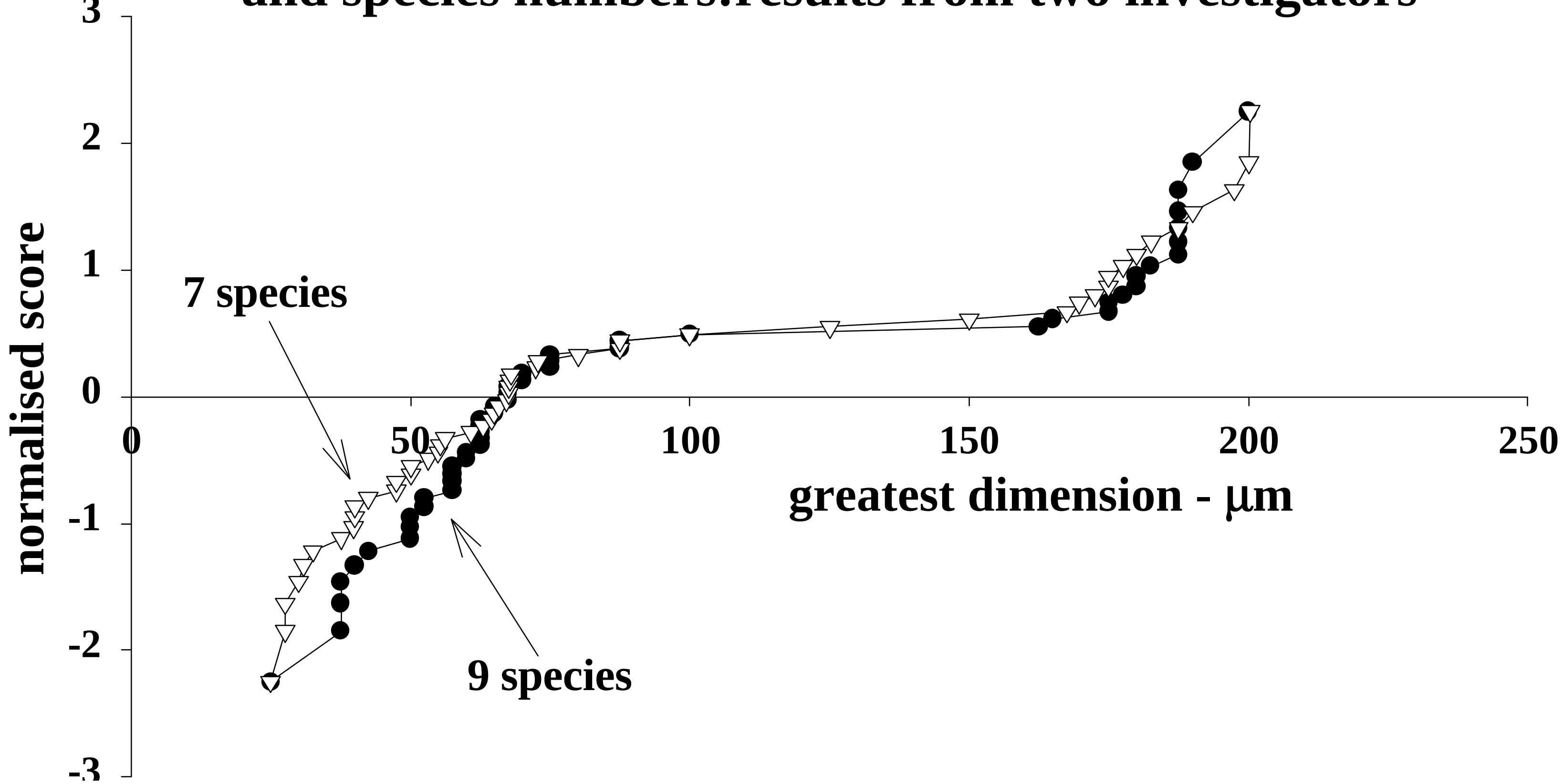


Figure 39: net phytoplankton size spectra
Nsumbu *2*
12 February 1998