GCP/RAF/271/FIN-TD/56 (En) December 1996

LIMNOLOGICAL SAMPLING DURING A SECOND ANNUAL CYCLE (1994-1995) AND SOME COMPARISONS WITH YEAR ONE ON LAKE TANGANYIKA

by

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OF THE UNITED NATIONS

Bujumbura, December 1996

PREFACE

The Research for the Management of the Fisheries on Lake Tanganyika project (LTR) became fully operational in January 1992. It is executed by the Food and Agriculture Organization of the United Nations (FAO) and funded by the Finnish International Development Agency (FINNIDA) and the Arab Gulf Programme for the United Nations Development Organizations (AGFUND).

LTR's objective is the determination of the biological basis for fish production on Lake Tanganyika, in order to permit the formulation of a coherent lake-wide fisheries management policy for the four riparian States (Burundi, Tanzania, Zaire and Zambia).

Particular attention is given to the reinforcement of the skills and physical facilities of the fisheries research units in all four beneficiary countries as well as to the build-up of effective coordination mechanisms to ensure full collaboration between the Governments concerned.

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Publications of LTR are issued in two series:

* a series of technical documents (**GCP/RAF/271/FIN-TD**) related to meetings, missions and research organized by the project; and

* a series of working papers (**GCP/RAF/271/FIN-WP**) related to more specific field and thematic investigations conducted in the framework of the project.

For both series, reference is further made to the document number (**01**), and the language in which the document is issued: English (**En**) or French (**Fr**).

For bibliographic purposes this document should be cited as follows:

Plisnier P.-D. Limnological Sampling During A Second
1996 Annual Cycle (1994-1995) And Some Comparisons With Year One On Lake Tanganyika.
GCP/RAF/271/FIN-TD/56(En): 48 p

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Summary

Most of the events noted during the limnological cycle described in 1993-94 (Plisnier *et al*, 1996) were confirmed in 1994-95 with the tilting of the epilimnion by the SE winds during the dry season and upwelling from return deep currents in the south during the dry season. Stratification index differences between the north and south were generally similar in both years. Upwelling of deep water in June to September could be observed near Mpulungu when values of the stratification index (SI) were < 1. Higher concentrations of phosphorus (TP and TDP) in surface waters of Mpulungu were noted during the upwelling.

Oscillations of the water masses were deduced from the behaviour of several parameter concentrations at the end of the dry season. Chimbanfula waves were observed near the shores of Mpulungu in October 1994. Presence of internal waves throughout the whole year, at all LTR stations, were inferred from measured parameter fluctuations. Pulses of turbidity were observed and supported the suggestion that nutrient rich water displacement by internal waves were tied to pulses of phytoplankton and bacterial production.

The amplitude of hydrodynamics has however apparently decreased in 1994-95 compared to the previous year. There was a decrease in the tilting of the thermocline this year probably because of weaker winds. Secondary upwelling in the north of the lake was not deduced from available data in 1994-95.

The oscillations of parameters were found to be either similar or sometimes higher in the coastal area compared to the pelagic area. There was no clear difference in nutrient concentration in the coastal area between the dry and wet season.

1. Introduction

A second year of limnological sampling at three stations of the lake ended in July 1995 by LTR. Some changes were made in the methods used in year 2. Horizontal transects were made from the coast to the pelagic area and deeper monthly sampling was undertaken (down to 160 m at Mpulungu and 140 m at Kigoma and Bujumbura/Uvira instead of 100 m during year 1).

Horizontal patchiness (coast-pelagic) was investigated as satellite pictures and historical data have shown important differences between coastal and pelagic environments. It was hypothesised that if water runoff was important for nutrient input, coast-pelagic differences should be emphasised during the wet season (assuming horizontal mixing was slow). Deeper sampling was performed, particularly in the south to examine the thermocline and lower metalimnion.

2. Objectives of the limnological component

The objectives of the year 2 limnological sampling was similar to year 1: to provide limnological monitoring at the three LTR stations of Lake Tanganyika that might be used to compare with the abundance of zooplankton and pelagic fishes. Special attention was given to comparing the present results to those in year 1 and whether these results supported or changed the conclusions about the annual limnological cycle of Lake Tanganyika derived in year 1 (Plisnier *et al*, 1996). Other aspects such as differences between the coast and pelagic and the ionic composition were considered.

2. Material and methods

2.1 General remarks

The 1993-94 practice was continued (Plisnier *et al*, 1996) except for phosphorus where SRP (soluble reactive phosphorus) replaced TRP (total reactive phosphorus) since SRP is commonly used when measuring phosphates in water allowing comparisons with other lakes. Total dissolved phosphorus was determined after filtration on 0.45 µm filter. The results of seasonal sampling of type C (every 50 m down to 300 m every 6 to 8 weeks) and determinations of silicate, calcium, total hardness, sodium, potassium, alkalinity, chloride and sulphate are also presented for the whole 1993-1995 period.

2.2 Sampling types and site description

Site locations are given in Table 1. Below, the differences from year 1 are highlighted. A full description of the methodology has been presented earlier (Plisnier, 1994; Plisnier *et al*, 1996).

2.2.1 Horizontal transect (Sampling H)

Twice per month a horizontal transect (surface sampling) starting at site A of year 1 (= H1, called also A/H1 at *c* 4 km from the shore) was carried out. From A/H1 toward the closest shore, sampling was carried out at site H2 (1000 m from the shore), H3 (500 m from the shore) and H4 (50 m from the shore) along a straight line. Sampling was done on surface water at each site.

2.2.2 Vertical transect (Sampling V and A/H1)

Once per month, all parameters, including nutrients, were measured down to 140 m at Bujumbura/Uvira and Kigoma and down to 160 m at Mpulungu (site V).

At site A/H1, vertical sampling was done every two weeks down to 100 m. This allowed a comparison with sampling site A of year 1.

2.2.3 24 H cycles and seasonal sampling (site B/C)

Site B/C was as last year. However, the frequency of sampling was changed from 6 weeks to 8 weeks. These results are presented elsewhere (Plisnier, in preparation.).

Seasonal sampling for cations/anions was done at the same time as in year 1 (12.00 H) every 50 m from 0 to 300 m (with repetition). Mean and median values at each depth are given for the period August 1993 to May 1995 (Table A.2).

2.3 Instrumentation and analyses

Most of the instruments and methods have been described earlier (Plisnier *et al*, 1996). A summary of the methods used is presented in Table 2. Total hardness, calcium, alkalinity and chloride were analysed by titrimetric methods (Table 3). Magnesium (Mg^{2+}) was calculated from the difference between total hardness and calcium. Precision was *c.* 1 mg/l. Sodium and potassium levels concentrations were measured by flame absorption in Burundi or Finland.

3. Results

3.1 The annual limnological cycle in 1994-95

The summary of the limnological cycle proposed last year (Plisnier *et al*, 1996) is compared below with that of 1994-95.

The tilting of the epilimnion by the SE winds during the dry season was apparently less important in 1994-95 as the previous year. From July to September, the mean thermocline depth was 70 m at Bujumbura/Uvira and at Kigoma (compared to 74 and 83 m in 1993-94). In the south, the epilimnion was greatly reduced at this time as last year. Winds data were not obtainable for 1994-95. Therefore limnological changes couldn't be compared with changes in the climate.

Upwelling from deep currents returning to the south during the dry season was apparently less important in 1994-95 as the surface temperature was higher during the dry season of 1994-95 (24.6°C) compared to year 1 (24.4 °C). This coincides with the shallower thermocline in the north.

Differences in the stratification index (Plisnier *et al*, 1996) between the north and south was similar in both years (Fig.A.3.2). There was more variation at Mpulungu (low stratification (SI<1) during the dry season and high stratification (SI >3) during the wet season). Compared to August 1993, Mpulungu stratification was slightly higher in August 1994 which probably indicated decreased upwelling intensity.

During upwelling, total phosphorus (TP and TDP) increased in the surface waters (Fig. A.4.4). Mean water transparency decreased to 8-10 m compared to 10-12 m during the wet season.

When the SE winds ceased, oscillations of the water masses were detected from observing isopleths of several parameters concentrations. This were particularly well observed from pH and turbidity fluctuations at Mpulungu (Fig. A.3.8), dissolved oxygen at 40 m and ammonia at 100 m at Bujumbura/Uvira (Fig. A.3.5) and turbidity at Kigoma (Fig. A.3.6).

Chimbanfula waves were observed near the shores of Mpulungu in October 1994. They probably corresponded to the surge at the beginning of oscillations of the metalimnion in September-October. Coulter (1991) suggested that such a surge could cause a "local severe mixing". They seem to occur along all the shores in the southern area and come from the north. Just before the waves, the fishermen pull their boats well away from the lake edge to avoid damage. In some places, crops bordering the shore may be damaged. Quantities of stones can accumulate on the most exposed shores.

As year 1, internal waves throughout year, at all the stations of LTR, were inferred from fluctuations of temperature, pH, conductivity, turbidity, total phosphorus, phosphates, ammonia, nitrates and nitrites (Figs 1,2,3 and A.3.4 to A.3.9). Pulses of turbidity again suggested that internal waves displaced vertically nutrient rich water giving rise to outbursts of phytoplankton and bacterial production.

Turbidity increased near the thermocline at Bujumbura/Uvira at 80 and 100 m depth in June-July 1995. The origin of the turbidity is unknown but a bacterial 'plate' or chlorophyll production are possible causes.

In the northern stations, the oscillations of pH and conductivity were lower than in year 1 (Figs A.3.4 and A.3.6). Secondary upwelling at the north of the lake could not be deduced from the 1994-95 data. Most of the hydrodynamic events that were previously noted (Plisnier *et al*, 1996) were also observed in 1994-95 but their amplitude was generally reduced compared to year 1. This seems to correspond to important inter-annual variation in the hydrodynamics of the lake.

3.2 Vertical profiles in the pelagic area

The vertical profiles for each measured parameter are detailed in Appendix A.2. The median of each profile is generally similar to year 1. However, variations about the mean was generally less for most of the parameters. The decreased occurrence of extreme values suggests that turbulence had been lower. Decreased thermocline depth in the north in 1994-95 probably corresponded to decreased potential energy induced by lower winds.

3.3 Horizontal comparison (shore-pelagic)

There is no clear increase of nutrients near the coast during each season which could show that runoff waters don't influence in an important way the trophic conditions of the lake. However, it is possible that the fast utilisation of available nutrients does not allow their detection by the present methods.

Variation detected in pelagic area was also well detected in the coastal area. Examples are provided at Figures 1, 2 and 3. In some cases, there was more variability in shore than in the pelagic (eg: isopleths of turbidity at 50 m from shore at Bujumbura in Figure 1B shows dampening not observed in the surface water of the pelagic). Conductivity and silicates changing at Kigoma showed dampening near the shore (Figs 2E and 2F). This indicates that waves can be detected by sampling near the shore

3.4 Major cations and anions

Kilham and Hecky (1973) classified Lake Tanganyika as belonging to the sodium-potassium-magnesium bicarbonate type which also includes Lakes Albert, Edward and Kivu. Beauchamp (1939) noted that the water contained very little NaCl but had a high percentage of $NaHCO_3$ derived from the surrounding volcanic rocks. Concentrations of cations and anions measured during the present study, as in previous studies, were in the following order of importance: cations $Mg^{2+}>Na^{+}>K^{+}>Ca^{2+}$ and anions $HCO_3^{-}>Cl^{-}>CO_3^{2-}>SO_4^{2-}$. The only slight difference to this order was noted at Kigoma where the order of the anions was: $HCO_3^- > CO_3^{2-} > Cl^- > SO_4^{2-}$.

The ionic diagrams (following Maucha representation in Symoens, 1968), every 50 m down to 300 m, are given in Figure.A.2.7.

4. Discussion

4.1 Comparison between the two years

The median value of each parameter was similar to those of year 1. The main difference was the decreased variation of some parameters eg conductivity in 1994-95 compared to the 93-94. This difference was particularly important in the north. A possible explanation is that the dynamics of the system had been decreased due to a smaller accumulation of epilimnion water in the north in the preceding dry season in 1994 compared to 1993. The thermocline depth from July to September showed some differences at Bujumbura/Uvira (*c.* 70 m in 1994-95 compared to 74 m in 1993-94). At Kigoma, a marked difference was noted between the two years: the average thermocline depth between July and September was 83 m in 1993 but only 70 m in 1994. This seemed to indicate less accumulation of warm water in the north in 1994 and less potential energy to redistribute through water movements in 1994-95. Detailed continuous meteorological data were unfortunately not available.

Other observations suggest that upwelling was less important in 1994-95: the surface water temperature during the dry season at Mpulungu shows a higher median value (0.2 °C). Ammonia concentration were less at Mpulungu than in the previous year.

Some variations of parameters in the south were however more important in 1994-95. Turbidity and pH illustrate this (Fig. A.3.8). A direct relationship between the amplitude noted in the north and the south of the lake was difficult to establish from the available data. A detailed comparison with hydrodynamics data is necessary to better understand the ecosystem as well as a higher frequency of measurements. Increased efforts to collect continuous and comparable meteorological data are needed also.

4.2 Internal waves and pulse production

Upwelling in the south is an important process but is geographically localised and restricted to a few months. Other processes such as the internal waves and turbulence are lake wide and have no interruption during the year.

At each station, internal waves peaked alternately with increased turbidity suggesting a pulse production in the lake when deeper nutrient rich waters were able to reach the photic zone. The thermocline influenced by the strong vertical trophic "gradient" in the lake was displaced vertically by internal waves. This might be (besides turbulence) a main cause for the high patchiness in the biotic environment. The dampening of isopleth of parameters such as conductivity over a annual cycle in 1993-94 (Fig. 4C) was rather similar to fluctuations in biomass of phytoplankton and protozoa in 1975 (Hecky and Kling, 1981) when the annual cycle is shown starting in September or August (Figs 4A and 4B) when hydrodynamics are important because the end of the SE winds induces re-distribution of tilted layers of water. High variation was noted between August-September and November-December. At these times of the year, algae blooms have been observed in the north of the lake (Symoens, 1955, Dubois, 1958). Internal loading of nutrients probably results from hydrodynamic events whose amplitude could be dependent of the energy input by the winds and the stratification of the water column. Inter-annual differences in amplitude of the variation is probably linked to inter-annual differences in the weather. In this respect, long and uninterrupted data series of limnological and meteorological parameters are essential to understand ecosystem functioning and its changes over time. Fluctuation in the weather induce differences in the physical environment of the lake and influence production in the epilimnion. This is likely to be a main cause for spatial and temporal changes in the biomass of organisms on small and extended time scales.

5. Conclusions and recommendations

The 1994-95 annual limnological cycle was similar to the previous year. However the amplitude of variation generally decreased. In particular, the following were noted in 1994-95:

- less tilting of the epilimnion by the SE winds;
- decreased upwelling intensity in the south;
- decreased amplitude fluctuations of parameters;
- a secondary, northern upwelling could not be detected.

Internal waves were deduced in 1994-95 but variation in their amplitude was reduced, particularly in the north of the lake.

Differences in wave amplitude in the north and the south remains to be investigated as it appeared from year 2 observations that the differences were not directly proportional. Some parameters such as pH and turbidity showed significant fluctuations in year 2 in the south of the lake which were opposite to the general trends observed in the north.

There was generally no clear increase of surface nutrients in coastal compared to pelagic waters, even during the wet season. Limnological sampling in coastal waters should include 24 h cycles of measurement. Primary production studies are also needed in both coastal and pelagic areas. A fast assimilation of available nutrients is likely in both systems.

Fluctuations of measured parameters near the coast are similar to those in the pelagic suggesting that internal waves influence conditions in coastal area also. Pulse production is likely along the coast as well. Frequent sampling would allow detailed analysis of internal waves characteristics and result in a better understanding of patchiness in the lake. This is an important observation as a representative continuous sampling programme can be made from areas close from the shore. These areas present less sampling difficulties. A high frequency of measurements of parameters such as transparency, water temperature, pH, conductivity and turbidity (every day) near the shore (*c.* 50 meters) is highly advised as well as the continuous meteorological recording near the lake at each station. This should considerably enhance the understanding of the lake ecosystem on a monthly, seasonal and inter-annual time scale. Several years of continuous observations will be required to determine differences in the limnological environment whose basic characteristics have been identified during the two years of sampling.

Location	Sampling sites	Latitude	Longitude
Buj-Uvi.	A/H1	3°28.00' S	29°17.00'E
	B/C	3°45.00' S	29°15.00 E
	V	3°28.68' S	29°16.18 E
Kigoma	A/H1	4°51.26' S	29°35.54'E
	B	4°50.69' S	29°34.65'E
	V	4°51.50' S	29°34.50'E
Mpulungu	A/H1	8°43.98' S	31°02.43'E
	B/C	8°34.45' S	30°50.10'E
	V	8°41.22' S	30°59.80'E

Table 1 : Coordinates of sampling sites as recorded by GPS.

Parameters	Methods	Precision and units
Ammonia	Nessler (*)	+/- 0.01 mg/l (NH3-N)
Nitrates	Cadmium reduction	+/- 0.01 mg/l (NO3-N)
Nitrites	Diazotization (*)	+/- 0.001 mg/l (NO2-N)
Total phosphorus	Acid persulphate (*)	+/- 0.01 mg/l (P04---)
Orthophosphates	Ascorbic Acid (*)	+/- 0.01 mg/l (P04---)
Sulphates	Sulfa Ver 4 (*)	+/- 1 mg/l (SO4--)
Silica	Heteropoly blued Silicomolybdate	+/- 0.001 mg/l (SiO2) +/- 0.1 mg/l (SiO2)

Table 2 : Parameters measured by spectrophotometry methods (Hach Drel 2000) with corresponding precision and units
(*) USEPA approved (United States Environmental Protection Agency).

Parameters	Methods	Precision and units
Total hardness	EDTA titration	+/- 1 mg/l (CaCO3)
Calcium	EDTA titration	+/- 0.1 mg/l (CaCO3)
Alkalinity	H2SO4 titration	+/- 1 mg/l (CaCO3)
Chloride	Silver nitrate	+/- 0.1 mg/l (Cl-)

Table 3 : Parameters measured by titrimetric methods with corresponding precision and units.

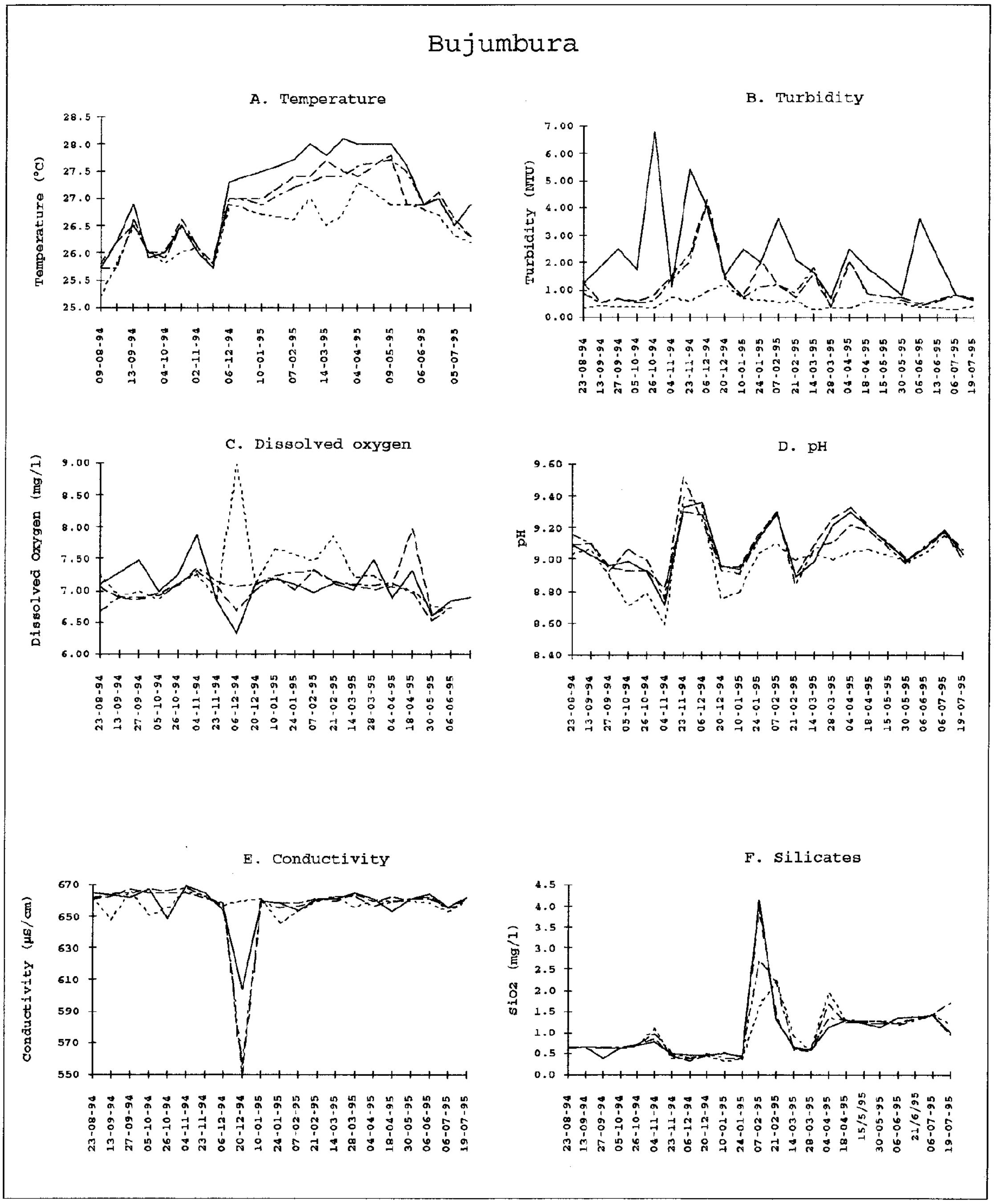


Figure 1 Changes in surface temperature, turbidity, dissolved oxygen, pH, conductivity and silicates at 4 sites (horizontal transect at H1, H2,H3 and H4) at Bujumbura/Uvira station from August 1994 to July 1995.

H1	(>4 km from the shore)
H2	(1 km from the shore)
H3	(500 m from the shore)
H4	(50 m from the shore)

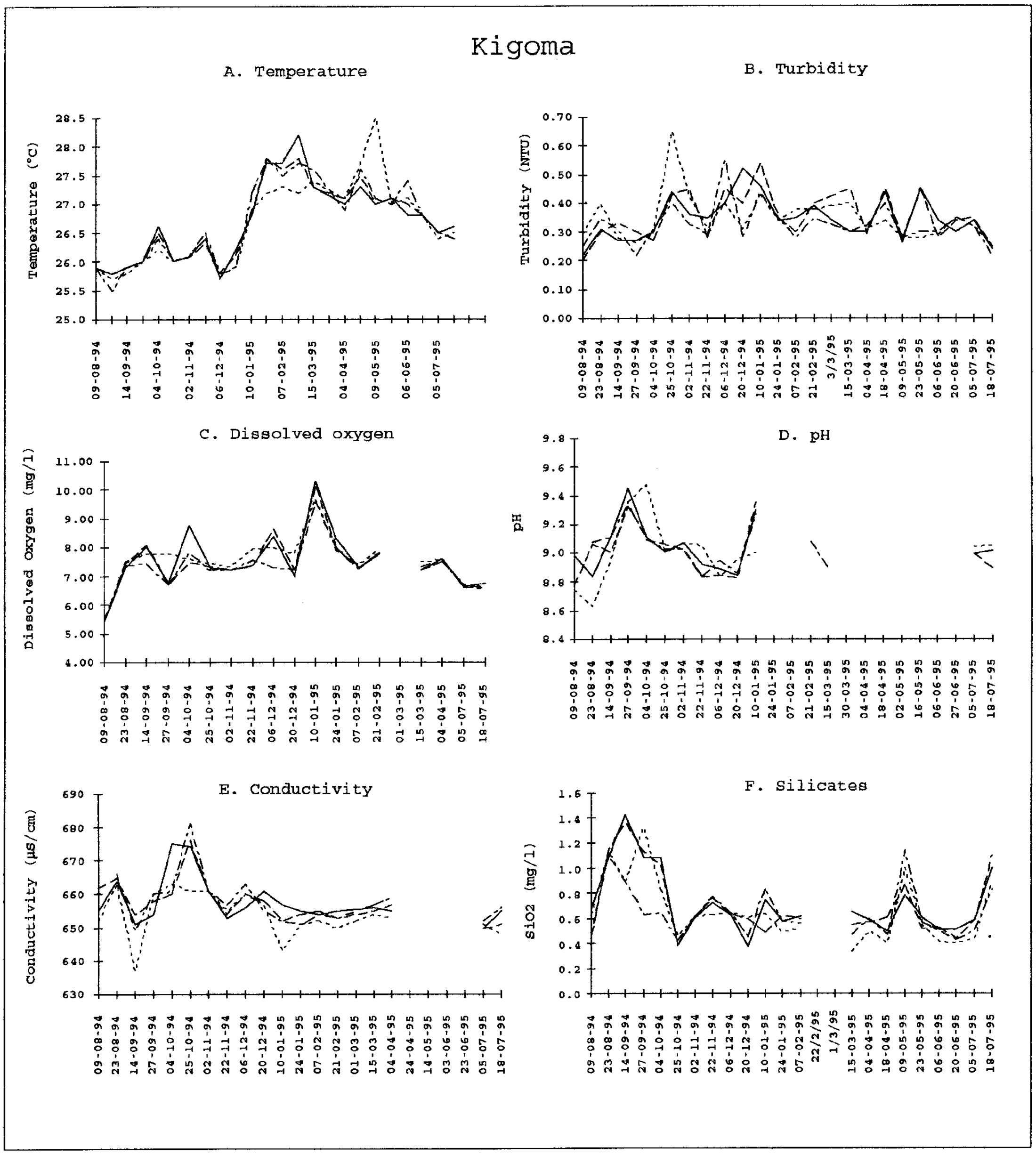


Figure 2 Changes in surface temperature, turbidity, dissolved oxygen, pH, conductivity and silicates at 4 sites (horizontal transect at H1, H2, H3 and H4) at Kigoma station from August 1994 to July 1995.

H1	(>4 km from the shore)
H2	(1 km from the shore)
H3	(500 m from the shore)
H4	(50 m from the shore)

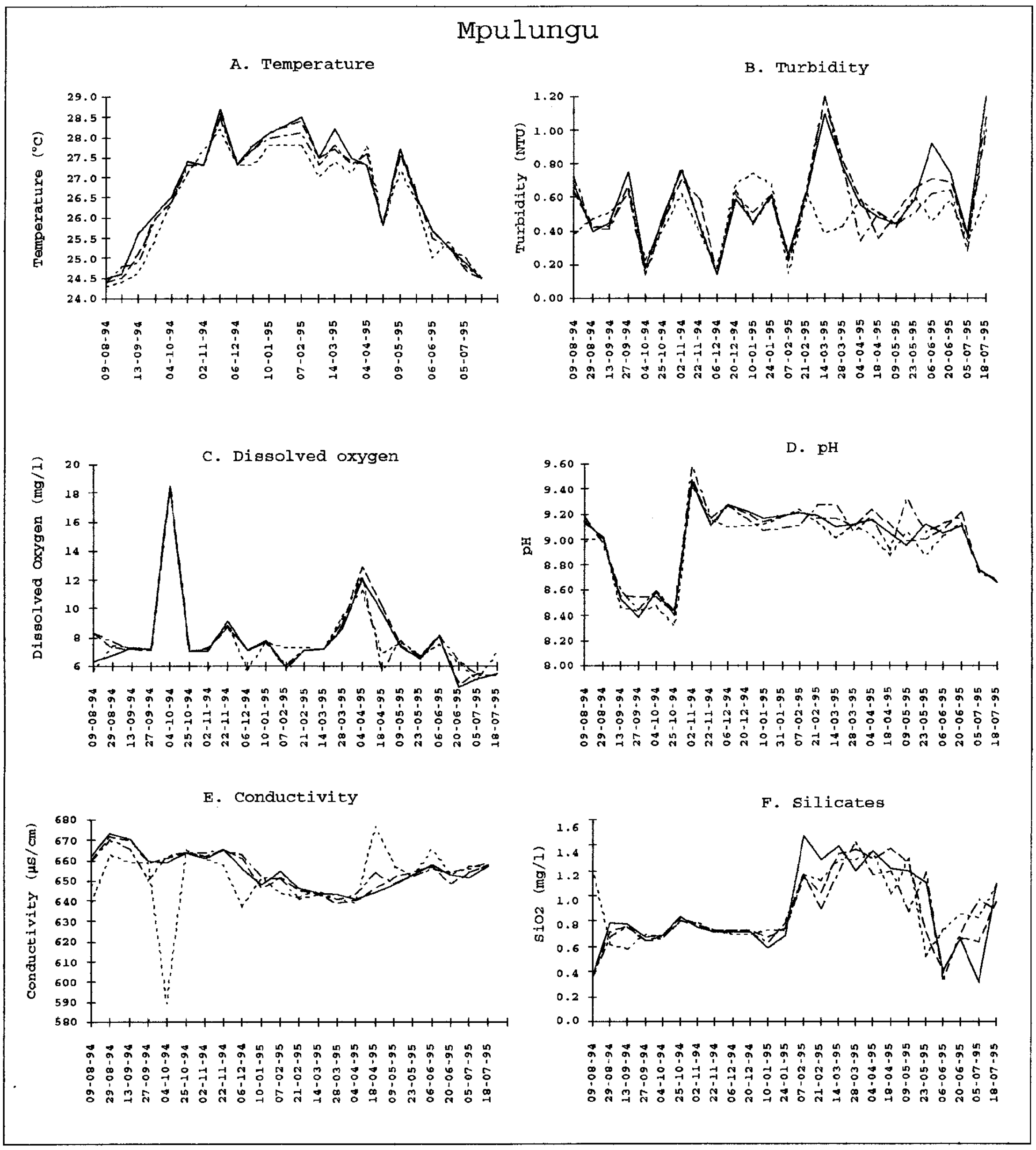


Figure 3 Changes in surface temperature, turbidity, dissolved oxygen, pH, conductivity and silicates at 4 sites (horizontal transect at H1, H2,H3 and H4) at Mpulungu station from August 1994 to July 1995.

H1	(>4 km from the shore)
H2	(1 km from the shore)
H3	(500 m from the shore)
H4	(50 m from the shore)

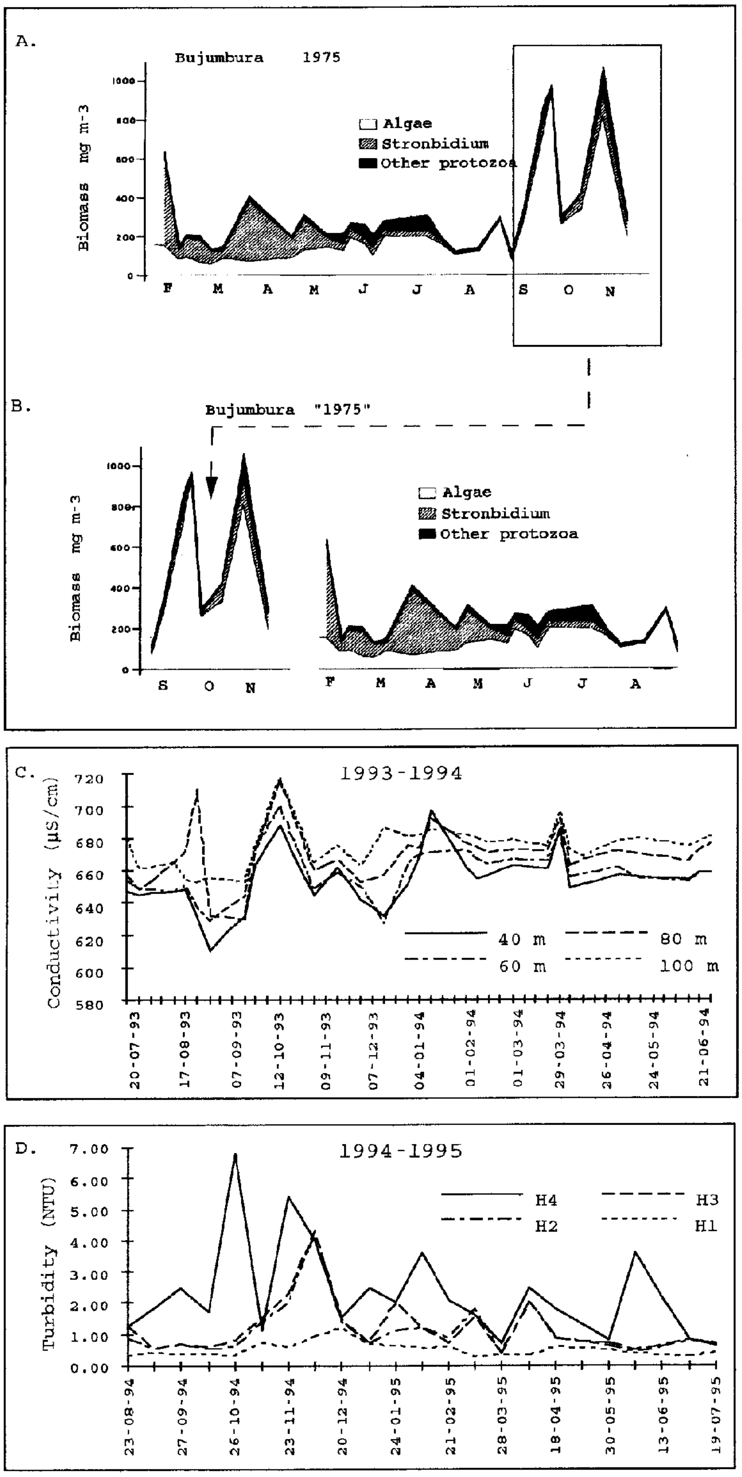


Figure 4 (A) Phytoplankton and protozoan abundance near Bujumbura in 1975 (Hecky and Kling,1981),(B) same as (A) if sampling would have started in September (modified after Hecky and Kling, 1981) (C) Changes in conductivity (µS/cm) at 4 depths of Bujumbura in 1993-1994 (D) Changes in turbidity at 0 m in four sites (from pelagic H1 to H4 at 50 m from the shore).

6. Appendices

A.1 Means, medians, maximum and minimum values of parameters.

The values of each parameter measured at site A/H1 or V of each station are presented in Table A.1. In this table means were calculated for the 0 to 100 m water column. More specific data are given in the following sections. Median values are compared graphically in Figures A.1.1 and A.1.2 using the "box and whiskers" representation (Tuckey, 1977).

Yearly median values were as follows. For **temperature** at Bujumbura/Uvira, 25.8 °C, was close to that at Kigoma, 25.7 °C, but higher than at Mpulungu, 24.7 °C. (24.5 °C in 1993-94). As in the preceding year, variation was higher in Mpulungu (Fig A.1.1). **Transparency** was lower at Bujumbura/Uvira (8.2 m) and Mpulungu (11.2 m) than Kigoma (13.0 m). This order is similar to the preceding year. **pH** was similar to previous observations: Bujumbura/Uvira and Mpulungu (9.0) and Kigoma (8.8). Minimal values for each station were generally higher than year 1. for each station. Variation was similar in Bujumbura/Uvira and Kigoma stations (standard deviation was *c.* 0.2) and slightly higher in Mpulungu (Stdev 0.3). **Conductivity** was 662 at Bujumbura/Uvira and Kigoma and 659 µS/cm at Mpulungu. Those values were comparable to year 1. Conductivity amplitude was similar at each station. **Turbidity** was higher at Bujumbura/Uvira and Mpulungu, 0.42 and 0.35 NTU respectively than at Kigoma, 0.26 NTU. This was a similar observation to year 1. **Total phosphorus** was 0.07 at Bujumbura/Uvira, 0.05 at Kigoma and 0.05 mg/l $PO4^{3-}$ at Mpulungu. Phosphates measured from filtered water were 0.05 at Bujumbura/Uvira, 0.04 at Kigoma and 0.04 mg/l $PO4^{3-}$ at Mpulungu. The values were similar to year 1 except Kigoma whose median value was halved. **Ammonia** had a median value of 0.01 at Bujumbura/Uvira and 0.00 at the other stations. As in year 1, individual measurements were sometimes high. They could occasionally reach 0.95 at Bujumbura/Uvira, 0.15 at Kigoma and 0.06 mg/l NH_4-N at Mpulungu. At each station, ammonia showed less variation (Figure A.1.2**).** **Nitrates** were similar to year 1: 0.05 at Bujumbura/Uvira, 0.08 at Kigoma and 0.07 mg/l NO_3-N at Mpulungu. At Bujumbura/Uvira and Kigoma, median values of **nitrite** were the same as year 1: 0.002 and 0.004 mg/l NO_2-N. Nitrite was slightly higher at Mpulungu, 0.003 mg/l NO_2-N.

	At site A/H1						At site V						
Buj.-Uvi.	SD	T°	pH	C.	D.O	Turb.	T. P.	T.D.P	S.R.P	NH4-N	NO3-N	NO2-N	SIO2
Median	8.2	25.8	9.0	662	6.6	0.42	0.07	0.05	0.05	0.01	0.05	0.002	1.40
Max	13.1	27.3	9.6	684	9.0	5.20	0.23	0.23	0.49	0.95	0.17	0.009	3.45
Min	4.3	24.0	8.5	646	0.0	0.14	0.00	0.00	0.00	0.00	0.03	0.000	0.45
Mean	8.5	25.6	9.0	665	4.5	0.57	0.08	0.06	0.07	0.04	0.06	0.002	1.63
Stdev	2.3	0.9	0.2	8.5	3.1	0.53	0.06	0.05	0.09	0.11	0.03	0.002	0.76
N	21	210	203	203	204	203	62	57	63	70	70	70	63

Kigoma	SD	T°	pH	C.	D.O	Turb.	T. P.	T.D.P	S.R.P	NH4-N	NO3-N	NO2-N	SIO2
Median	13.0	25.7	8.8	662	4.7	0.26	0.05	0.06	0.04	0.00	0.08	0.004	0.58
Max	18.7	28.5	9.8	688	9.7	0.65	0.23	0.52	0.29	0.15	0.47	0.030	5.00
Min	10.6	24.0	8.5	637	0.0	0.13	0.00	0.00	0.00	0.00	0.03	0.000	0.11
Mean	13.6	25.6	8.9	662	4.4	0.27	0.07	0.08	0.05	0.02	0.10	0.005	0.86
Stdev	2.0	1.0	0.2	8	2.6	0.07	0.06	0.08	0.05	0.04	0.06	0.005	0.81
N	23	253	220	242	198	253	84	77	84	84	84	84	83

Mpulungu	SD	T°	pH	C.	D.O	Turb.	T. P.	T.D.P	S.R.P	NH4-N	NO3-N	NO2-N	SIO2
Median	11.2	24.7	9.0	659	5.9	0.35	0.05	0.05	0.04	0.00	0.07	0.003	0.82
Max	16.5	28.2	9.6	678	18.4	0.84	0.25	0.16	0.27	0.06	0.18	0.009	3.60
Min	7.0	23.7	8.3	589	2.2	0.07	0.00	0.00	0.00	0.00	0.02	0.001	0.27
Mean	11.2	25.2	8.9	657	6.2	0.37	0.07	0.06	0.06	0.00	0.08	0.003	1.09
Stdev	2.8	1.2	0.3	9	2.3	0.16	0.06	0.04	0.05	0.01	0.04	0.002	0.72
N	26	275	276	276	264	274	70	63	70	77	77	77	70

Table A.1 Median, maximum, minimum, mean, standard deviations and number of measurements at each station, site A/H1, 0 to 100 m, from August 1994 to July 1995 for SD, T°, pH, C, D.O. and turbidity at site V for TP, TDP, SRP, NH4-N, NO3-N, NO2-N and SiO2 (Secchi disk (SD) in m, temperature in °C, conductivity in µS/cm at 25 °C, turbidity in NTU, TP, TDP and SRP in mg/l (PO4---), ammonia in mg/l NH4-N, nitrates in mg/l NO3-N, nitrites in mg/l NO2-N, silicates in mg/ l SiO2).

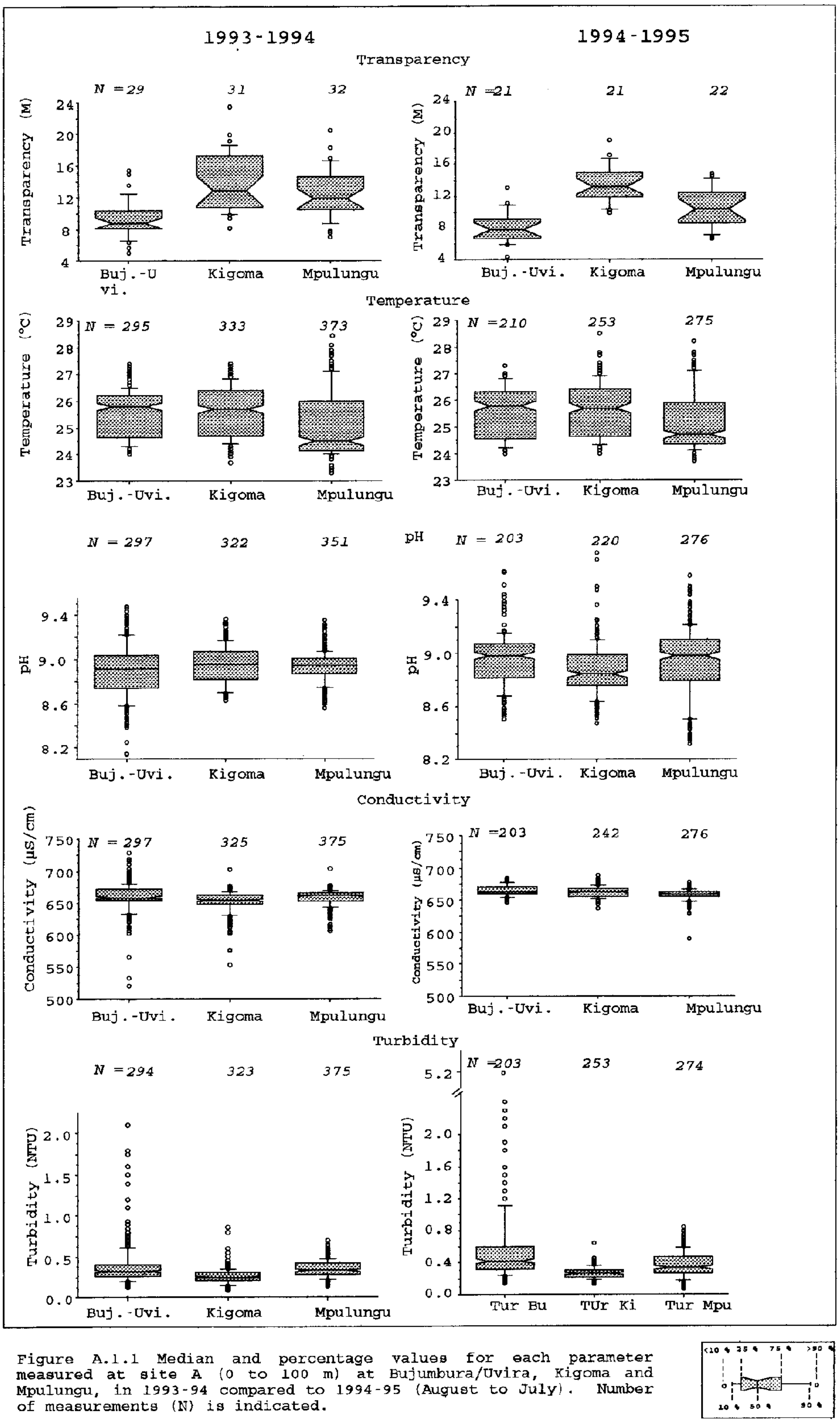


Figure A.1.1 Median and percentage values for each parameter measured at site A (0 to 100 m) at Bujumbura/Uvira, Kigoma and Mpulungu, in 1993-94 compared to 1994-95 (August to July). Number of measurements (N) is indicated.

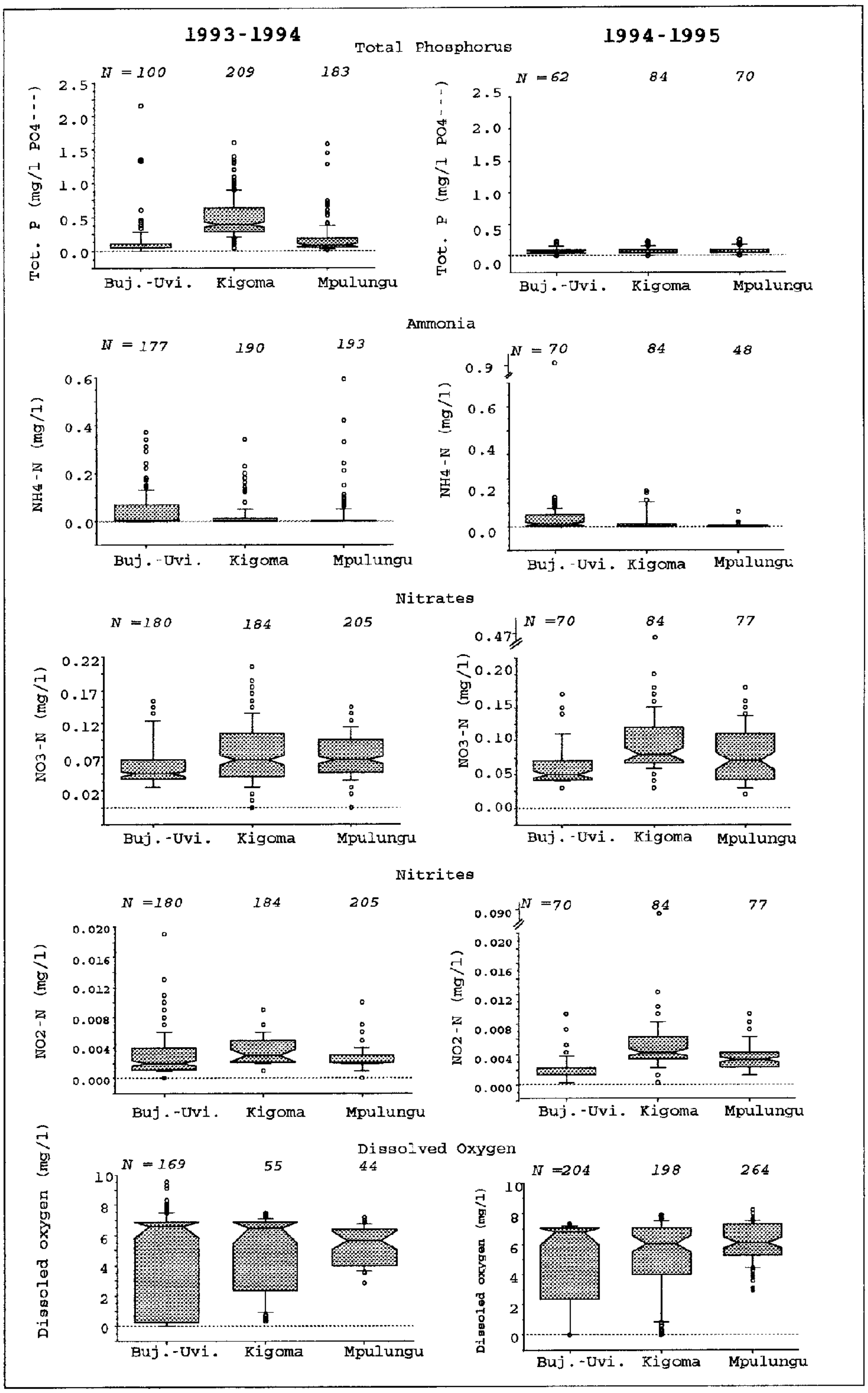
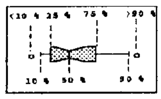


Figure A.1.2 Median and percentage values for each parameter measured at site A (0 to 100 m) at Bujumbura/Uvira, Kigoma and Mpulungu, in 1993-94 compared to 1994-95 (August to July). Number of measurements (N) is indicated.



A. 2 Parameter changes with depth

A.2.1 Temperature

Temperature (Fig. A.2.1) showed a similar median profile in 1994-95 as in the previous year. Four layers were identified: the epilimnion between 0 and 35 m at each station, the upper-metalimnion (including the thermocline) between 35 and 90 m at Bujumbura/Uvira and Kigoma and 35 and 70 m at Mpulungu, the lower metalimnion, 250-300 m and the hypolimnion >250-300 m at each station.

A.2.2 Conductivity

Conductivity profiles were very similar in both year (Fig. A.2.1): median *c.* 660 µS/cm near the surface and 690 µS/cm at 300 m at each station. The main difference was observed in the variation around the mean values at Bujumbura/Uvira and Kigoma. The variation was less in 1994-95 compared to the previous year.

A.2.3 pH

Profiles of pH from 0 to 300 m depth (Fig. A.2.3) were similar in both years. A decrease between surface waters (pH *c.* 9.0) toward deeper waters (pH *c.* 8.6) was observed. However, as for conductivity, variation around the mean at each depth was generally less at the northern stations in year 2. Variation around the mean was more important at Mpulungu.

A.2.4 Dissolved oxygen

Dissolved oxygen showed less variation below the oxycline at each station in year 2 than in previous year (Fig. A.2.1). At Kigoma, there appeared to be two types of oxycline: the main oxycline at *c.* 70 m but also a rapid decline of DO between 0 and 20 m depth which was not observed in year 1. However, the data from 1993-94 were not complete as they did not encompass the whole year and the differences noted here may not be statistically significant.

A.2.5 Ammonia, nitrates and nitrites

Ammonia values were generally < 0.05 mg/l in 1994-95 in the epilimnion and upper metalimnion (Fig. A.2.2). Values were less variable than in 1993-94 at each station. This may have resulted from decreased turbulence in the water column with less occurrence of deeper water mixing in the epilimnion.

Profiles of nitrate were similar in both years. It increased near the oxycline: *c.* 70-80 m at the northern stations and between 60 and 140 m at Mpulungu. As for ammonia, the variation around the mean was less at Bujumbura/Uvira and Kigoma (Fig A.2.2) than Mpulungu.

Nitrites were similar between years. More variation were noted at Kigoma than at the other stations (Fig. A.2.2).

A.2.6 Phosphorus (TP, TDP, SRP)

All phosphorus measurements (TP, TDP and SRP) showed an increase with depth (Fig. A.2.3). This was particularly noticed at Bujumbura/Uvira below the thermocline. Variation around the means may be important however and future measurements should confirm those preliminary results with the use of improved methods. The estimates of phosphorus were not very reliable due to the methods available in the field.

A.2.7 Silica

Silica (at sites C) increased from the surface, <1 mg/l, to *c.* 10-15 mg/l SIO_2 at 300 m at each station (Fig. A.2.6). Reduction in the upper photosynthetic zone probably resulted from the fixation of silica by diatoms (Beauchamp, 1939) while increase in the deeper areas was probably due to progressive re-dissolving while organisms were slowly sedimenting (van Meel, 1987).

A.2.8 Calcium

Cations stimulate phosphate uptake by some blue green algae. Calcium ions in particular cause a pronounced reduction in the half-saturation concentration for orthophosphate uptake by increasing active transport of phosphorus into the cells (Wetzel, 1983). Productivity of freshwater has been linked with the concentration of calcium. During the present study, surface calcium concentrations were similar at each station, 11.2 mg/l at Bujumbura/Uvira, 10.9 mg/l at Kigoma and 11.6 mg/l at Mpulungu and were comparable to earlier measurements (Hecky *et al*., 1978) (Table A.2). The concentration of calcium increased with depth (Fig. A.2.5). As in most other African waters, calcium was low in concentration compared with other cations.

A.2.9 Magnesium

Mean concentrations of surface magnesium was 43.2 mg/l at Bujumbura/Uvira, 42.9 mg/l at Kigoma and 41.2 mg/l at Mpulungu (Table A.2). Concentrations increased with depth (Fig.A.2.5).

A.2.10 Sodium and potassium

Mean concentrations of surface sodium were 66.5 mg/l at Bujumbura/Uvira, 65.0 mg/l at Kigoma and 63.9 mg/l at Mpulungu (Table A.2). These were similar to the measurements of Hecky *et al.* (1978), Van Meel (1987) and Craig *et al.* (1974).

Mean concentrations of surface potassium were 32.7 mg/l at Bujumbura/Uvira and Kigoma and 33.0 mg/l at Mpulungu (Table A.2). Profiles of medians and centiles indicated an increase of potassium with depth (Fig A.2.5).

A.2.11 Alkalinity

Total alkalinity generally relates to bicarbonates and carbonates as the contribution of other anions is often considered as negligible (Talling and Talling, 1965; Kilham and Hecky, 1973).

Alkalinity of Lake Tanganyika was mainly represented by bicarbonate at each sampling station (5.6 to 6.2 me/l) (Table A.2). There were few carbonates present. Kigoma had a higher proportion of carbonates (1.02 me/l) than recorded at Bujumbura/Uvira (0.19 me/l) and Mpulungu (0.06 me/l). Alkalinity recorded at Bujumbura/Uvira and Kigoma was slightly lower than previously recorded by Kufferath (Symoens, 1968) but similar to those measured by Craig *et al.* (1974) and Degens and Kulbicki (Van Meel, 1987). Alkalinity values recorded at Mpulungu were similar to those reported for Lake Tanganyika generally. An increase in alkalinity with depth was noted at each station (Fig. A.2.6). Some lower values (< 5 me/l) have been recorded at 100 m at Bujumbura/Uvira. Van Meel (1987) noted also that alkalinity increased with depth. He noted that deep waters were richer in CO_2 (as found in the sea).

A.2.12 Chloride

There was considerable variation in the concentration of chloride at each station, particularly at Mpulungu. Mean surface values were 34.3 mg/l at Bujumbura/Uvira, 31.5 mg/l at Kigoma and 38.1 mg/l at Mpulungu (Table A.2). Concentrations were higher than from previous data (Hecky *et al*., 1978) (Table A.2). There was no detectable difference in vertical profiles of chloride (Fig. A.2.6).

A.2.13 Sulphates

Mean surface sulphate concentrations were 3.3 mg/l at Bujumbura/Uvira and 0.8 mg/l at Kigoma and Mpulungu (Table A.2). At Bujumbura/Uvira, high concentrations of sulphates were sometimes measured (Fig. A.2.6). Kilham and Hecky (1973) reported occasional high concentrations such as 13.9 mg/l on August 11 1969 in the south of the lake. H_2S is known to be significant in the hypolimnion of the lake (Edmond *et al*, 1993).

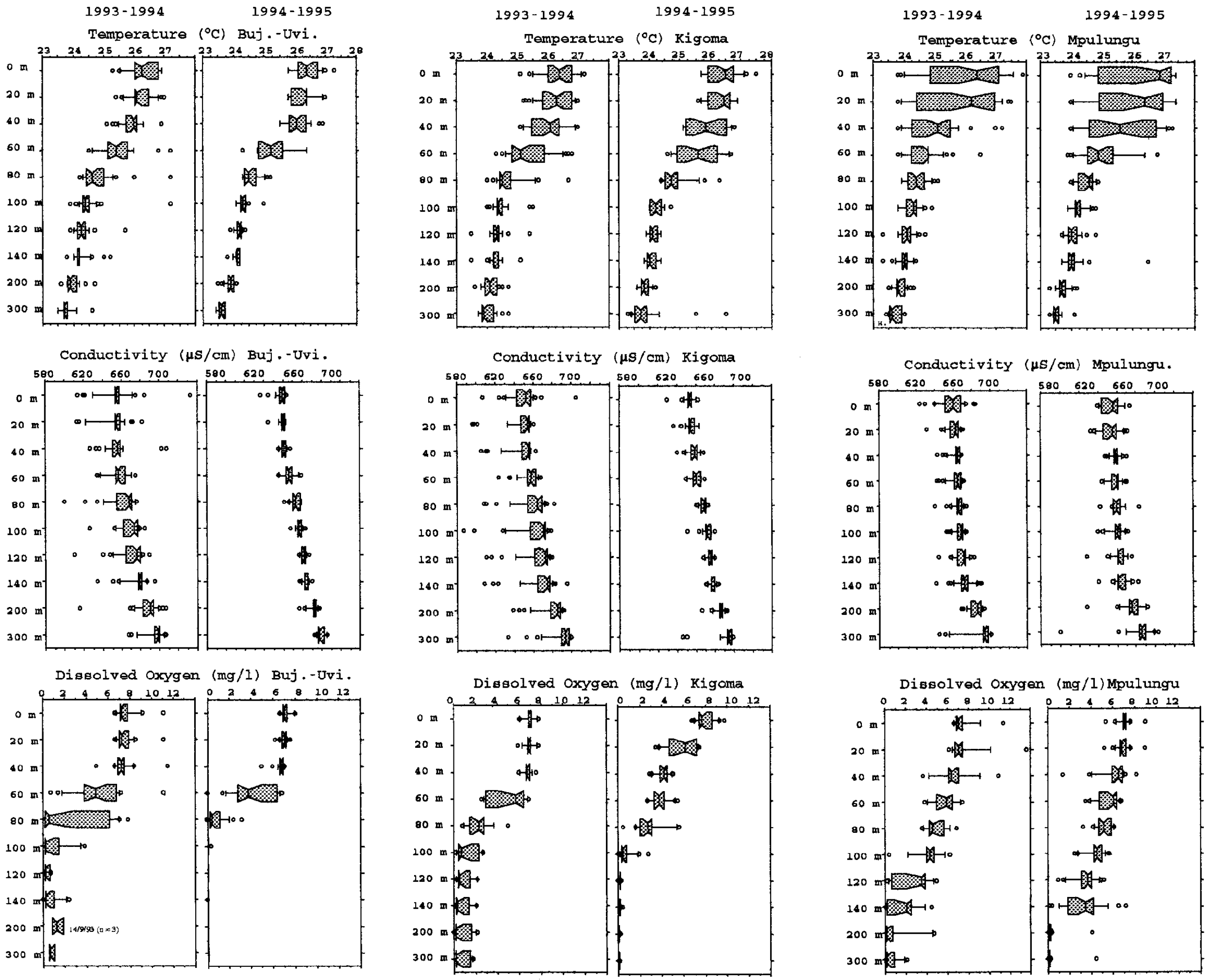
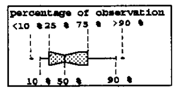


Figure A.2.1 Median and percentile values of temperature (°C), conductivity (µS/cm) and dissolved oxygen (DO, mg/l). Sampling was carried out at site B, 0 to 300 m, Bujumbura/Uvira, Kigoma and Mpulungu over 24 h every 6 weeks from August 1993 to July 1994 and every 8 weeks from August 1994 to July 1995 for temperature and conductivity. In 1993-94, only a few measurements of D.O were made at Kigoma and Mpulungu.



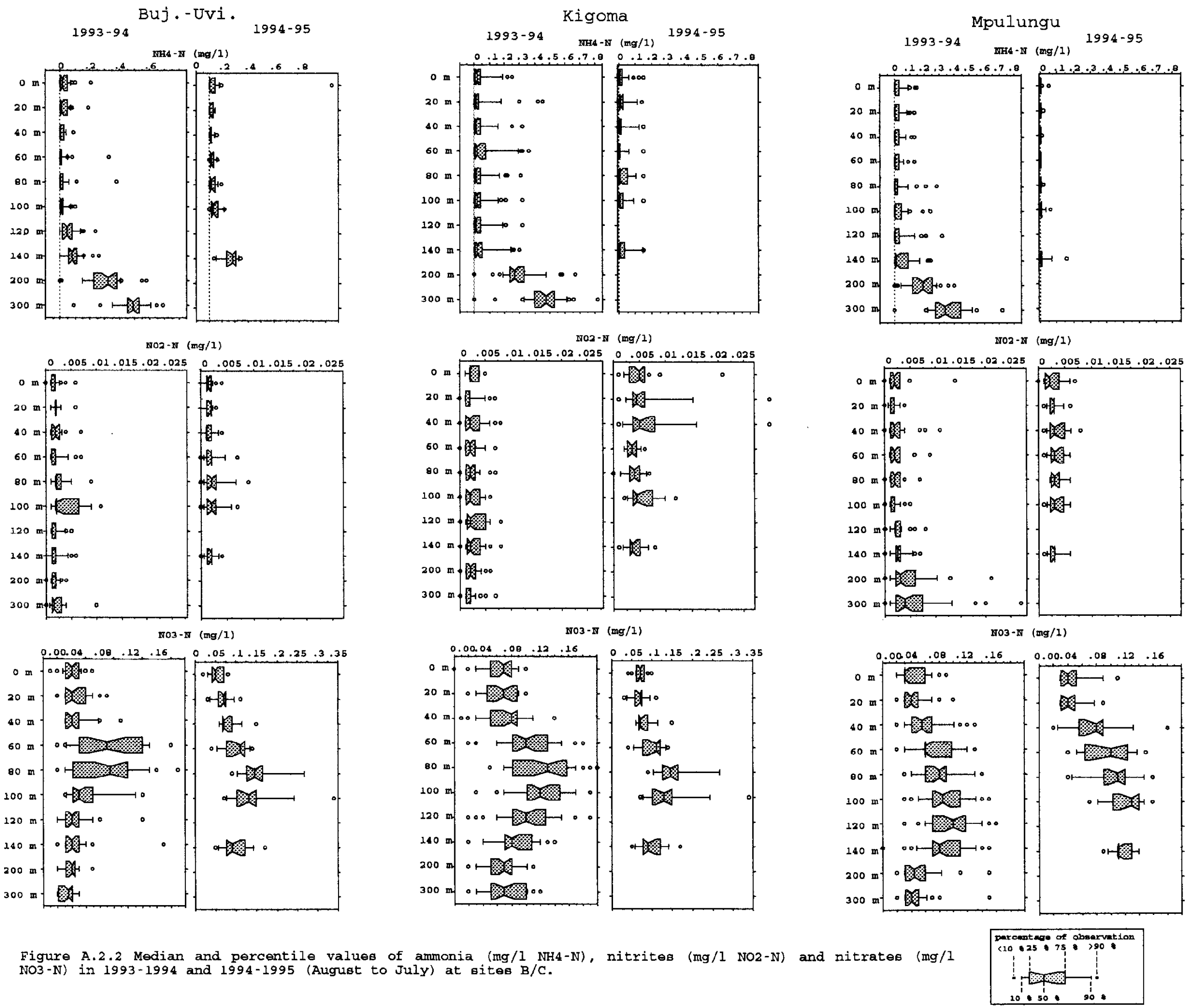


Figure A.2.2 Median and percentile values of ammonia (mg/l NH4-N), nitrites (mg/l NO2-N) and nitrates (mg/l NO3-N) in 1993-1994 and 1994-1995 (August to July) at sites B/C.

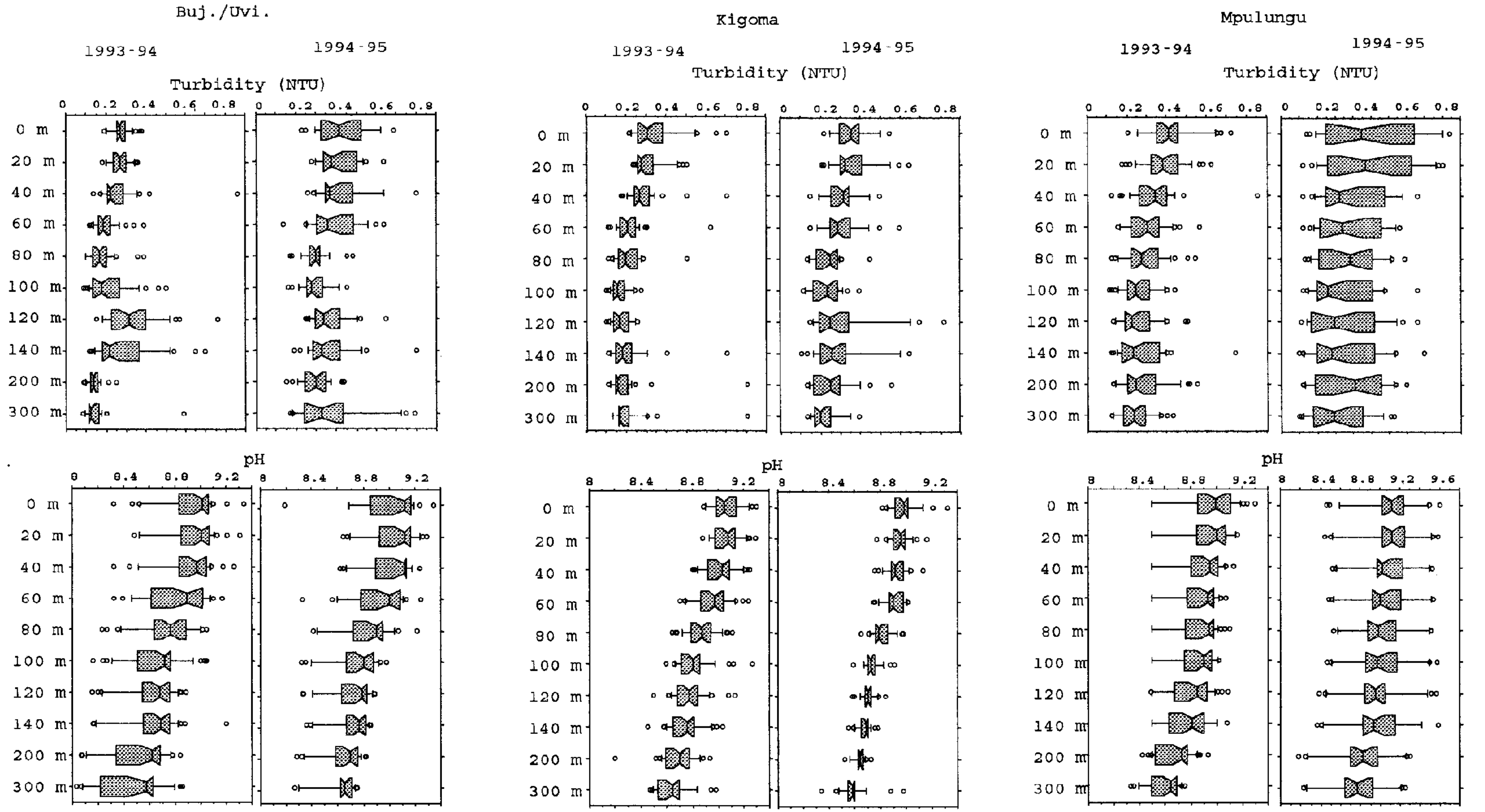
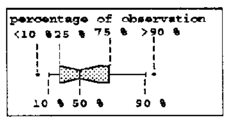


Figure A.2.3 Median and percentile values of turbidity (NTU) and pH in 1993-94 and 1994-95 (from August to July) at sites B/C.



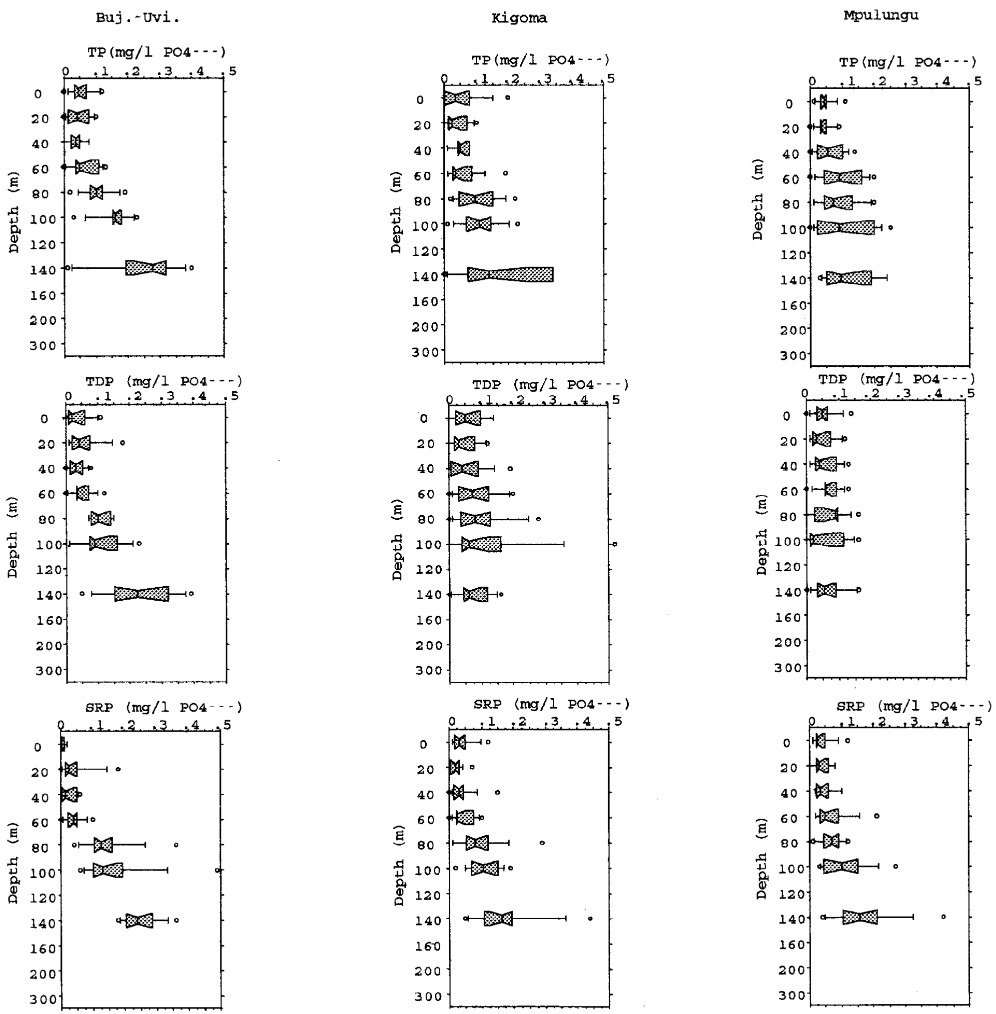
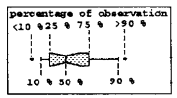


Figure A.2.4 Median and percentile values of total phosphorus (mg/l PO4---), total dissolved phosphorus (mg/l PO4---) and soluble reactive phosphorus (mg/l PO4---) from August 1994 to July 1995 at site V of Bujumbura/Uvira, Kigoma and Mpulungu.



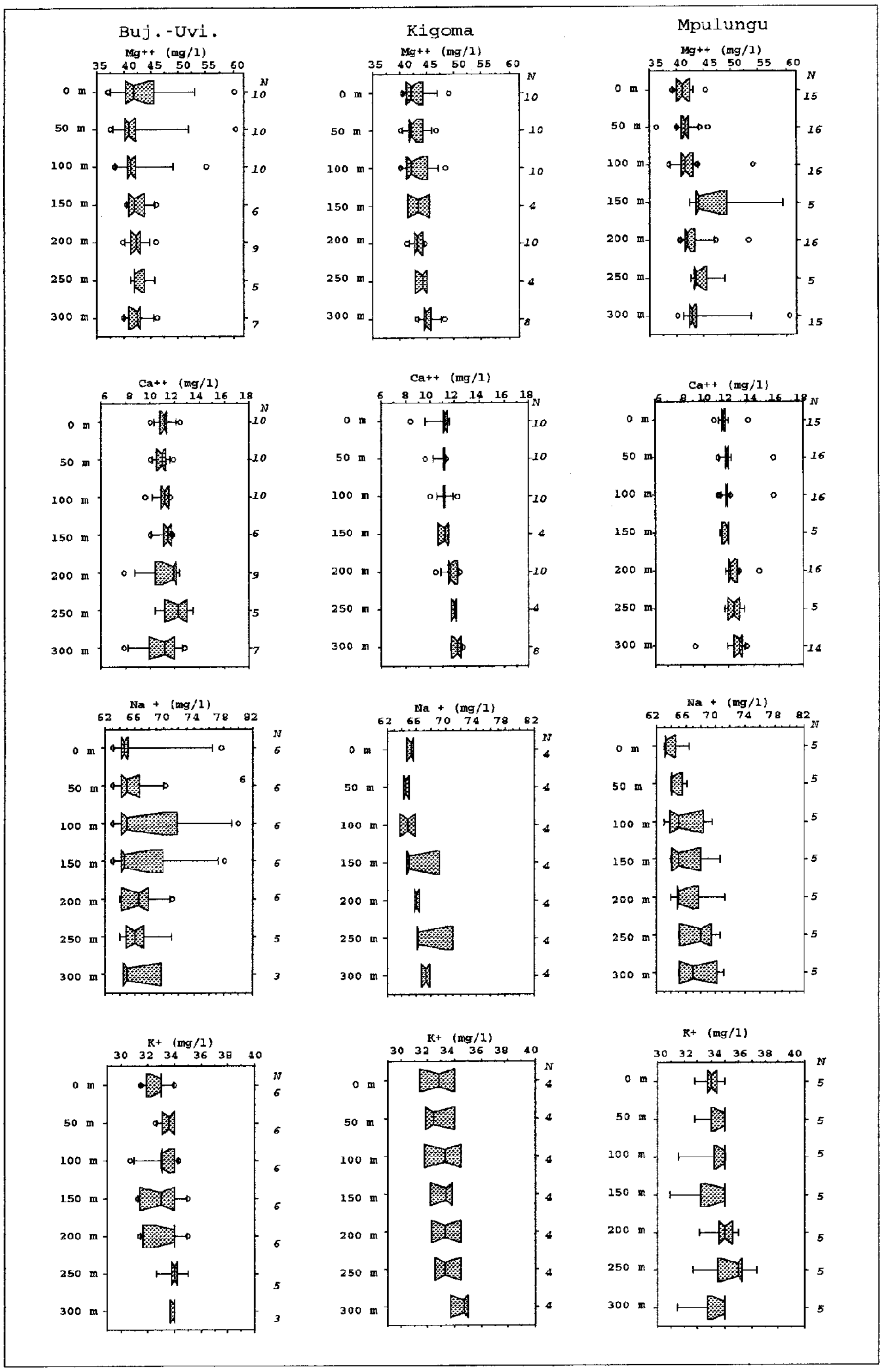
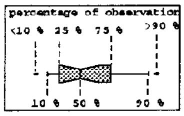


Figure A.2.5 Medians and percentiles of magnesium (Mg++), calcium (Ca++), sodium (Na+) and potassium (K+) in mg/l. Sampling took place at site B (from 0 to 300 m) of each station every 2 to 3 months for most of the parameters from August 1993 to May 1995. Number of observations (N) at each depth is indicated.



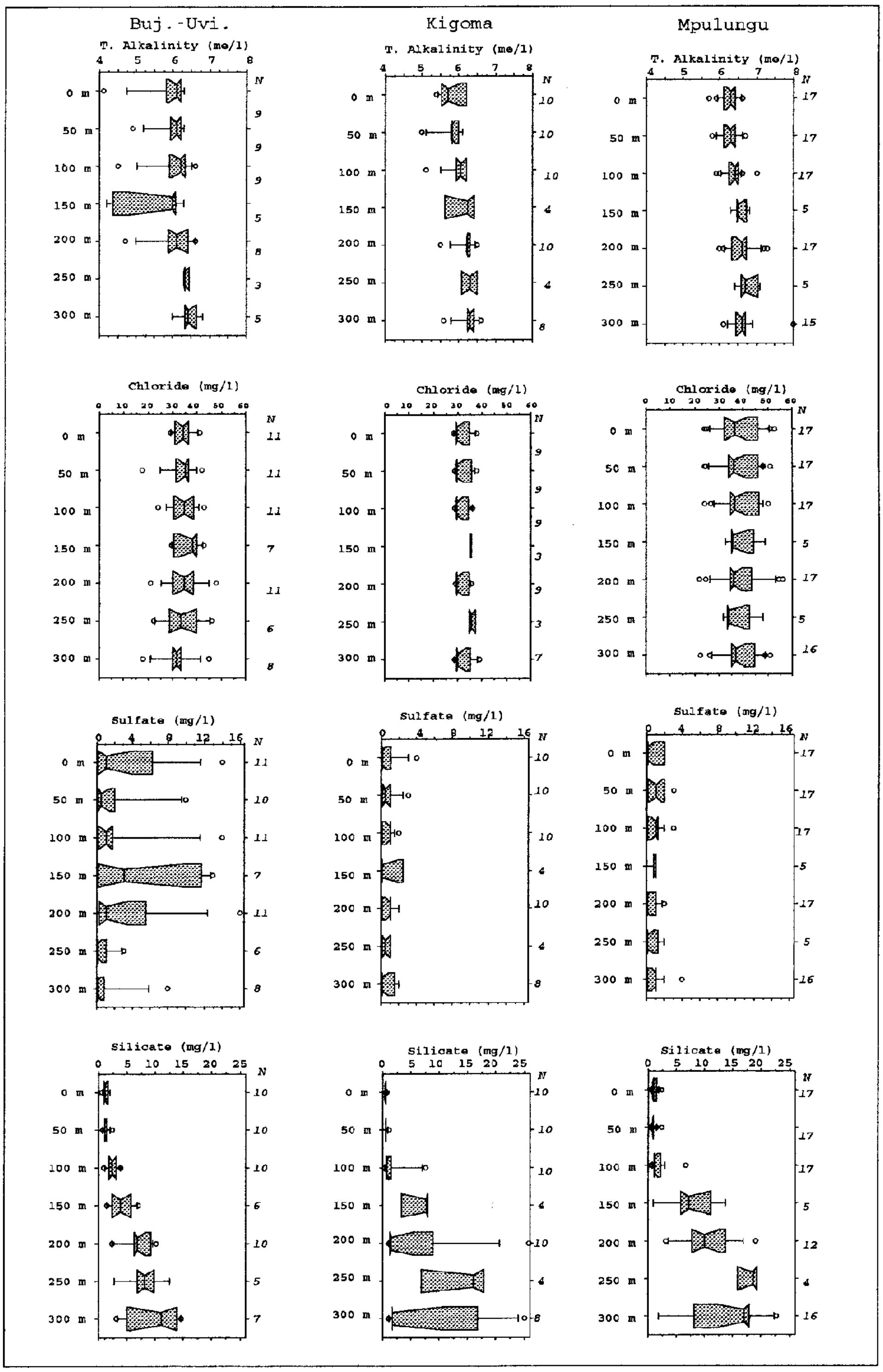
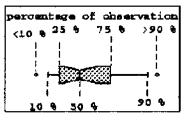


Figure A.2.6 Medians and percentiles of alkalinity (HCO3- and CO3--) in me/l and chloride (Cl-), sulfate (SO4--) and silicates (SiO2) in mg/l. Sampling took place at site B (from 0 to 300 m) of each station every 2 to 3 months for most of the parameters from August 1993 to May 1995. Number of observations (N) at each depth is indicated.



(a.)

Depth : 0m	Buj.-Uvi.			Kigoma			Mpulungu			Buj.-Uvi.		Kigoma		Mpulungu	
	mg/l	me/l	%	mg/l	me/l	%	mg/l	me/l	%	s	n	s	n	s	n
Ca++	11.2	0.56	7.1	10.9	0.54	7.0	11.6	0.58	7.6	0.7	10	0.9	10	0.6	15
Mg++	43.2	3.56	45.4	42.9	3.53	45.6	41.2	3.39	44.6	6.6	10	2.6	10	1.7	15
Na+	66.5	2.89	36.9	65.0	2.83	36.5	63.9	2.78	36.6	5.6	6	0.7	4	1.5	5
K+	32.7	0.84	10.7	32.7	0.84	10.8	33.0	0.84	11.1	0.9	6	1.5	4	0.8	5
Sum Main Cations		7.84	100		7.74	100		7.59	100						
HCO3-		5.62	82.1		4.76	71.2		6.20	84.4	0.7	9	0.8	10	0.4	17
CO3--		0.19	2.8		1.02	15.3		0.06	0.8	0.4	9	0.6	10	0.2	17
SO4--	3.3	0.07	1.0	0.8	0.02	0.2	0.8	0.02	0.2	5.0	11	1.3	10	0.9	17
Cl-	34.3	0.97	14.1	31.5	0.89	13.3	38.1	1.07	14.6	4.0	11	3.7	9	8.7	17
Sum Main Anions		6.85	100		6.69	100		7.35	100						

(b.)

Surface water	North Lake			Central Lake			South Lake			North		Central		South	
	mg/l	me/l	%	mg/l	me/l	%	mg/l	me/l	%						
Ca++	10.7	0.53	7.5	11.0	0.55	7.5	11.0	0.55	7.5	0.4	4	0.2	11	0.2	10
Mg++	37.9	3.12	43.6	38.8	3.19	43.6	39.1	3.22	43.9	1.3	4	0.2	11	0.4	10
Na+	61.7	2.68	37.5	63.1	2.74	37.5	62.9	2.74	37.4	2.4	4	0.6	11	0.4	10
K+	32.0	0.82	11.4	32.8	0.84	11.5	32.2	0.82	11.2	1.6	4	0.4	11	0.4	10
Sum Main Cations		7.15	100		7.32	100		7.32	100						
HCO3- and CO3--		6.66	88.4		6.66	88.4		6.66	87.8						
SO4--	6.3	0.13	1.7	6.3	0.13	1.7	7.6	0.16	2.1	0.4	4	0.5	11	0.3	10
Cl-	26.4	0.74	9.9	26.4	0.74	9.9	27.2	0.77	10.1	0.5	4	1.1	11	1.4	10
Sum Main Anions		7.54	100		7.54	100		7.58	100						

Table A.2 (a.) Main surface waters cations and anions measured at Bujumbura/Uvira, Kigoma and Mpulungu from August 1993 to May 1995 (~~average~~ mean in mg/l and me/l on the left, standard deviation and number of observations are shown on the right) (b.) After data from Hecky et al. (1978) beside alkalinity from Kufferath (in Symoens, 1968).

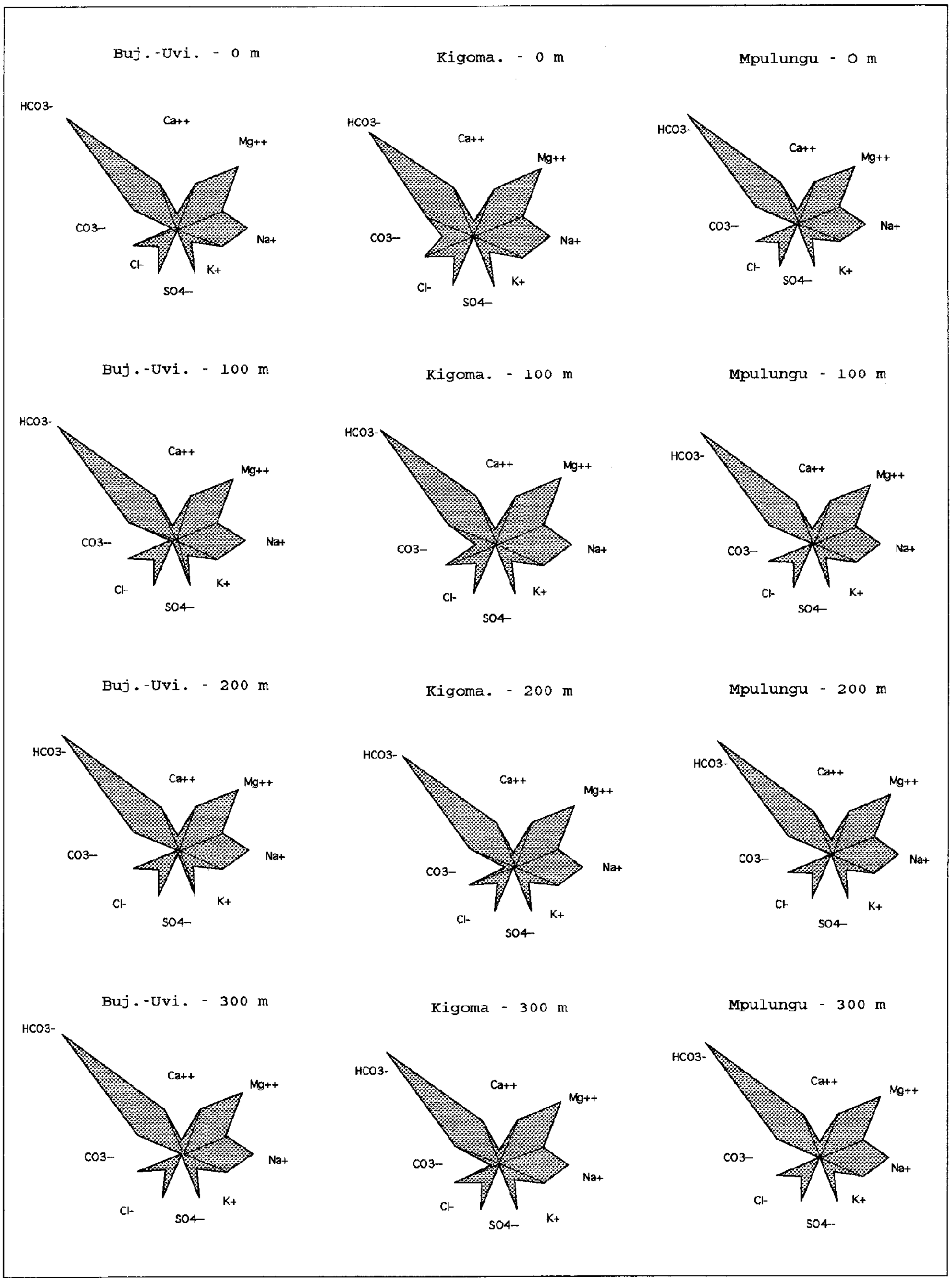


Figure A.2.7 Ionic diagrams (% of mean me/l following Maucha representation in Symoens,1968) of majors cations and anions at depth of 0, 100, 200 and 300 m at site B of Buj.-Uvi., Kigoma and Mpulungu in 1993-95.

A. 3 Parameters changes with season

A.3.1 Temperature

Seasonal water temperature changes at Bujumbura/Uvira (Fig. A.3.4) were similar between years. Fluctuations were important between August and January and decreased from January to July when warming increased.

At Kigoma, the January to July warming was noted (Fig. A.3.6). Waves were more marked there than in Bujumbura/Uvira toward the end of the sampling year (noted in both years).

Mpulungu seasonal temperatures also were similar between years. The temperature in the dry season was low (between 23.8°C and 24.3 °C) at 40 m but increased during the wet season. An important decrease was noted in December. In 1994-95, it was from 26.8 °C to 24.5 °C at 40 m. This was probably due to deep water upwelling resulting from the oscillations of the epilimnion after the end of the SE winds. pH was low at the same time and confirm this hypothesis.

A.3.2 Thermocline depth

Fluctuations of the thermocline depth related to internal waves are observed at Figure A.3.1. The deepening of the thermocline in the northern stations is well observed every year after November-December while the thermocline is getting closer from the surface in the south.

A.3.3 Stratification index

Stratification index (SI) calculated as previously (Plisnier *et al*, 1996) are compared in Figure A.3.2. Stratification increased during the year at both stations in the north which was related to the decrease of the thermocline and the accumulation of warm water toward the north (Fig. A.3.1). Important oscillations were noted in 1994-95 which might be caused by weather conditions The data were unavailable for 1994-95.

At Mpulungu, there was little stratification and no permanent thermocline which corresponded to upwelling of deep water from June to September. Upwelling was observed when SI values were < *c.* 1 (Fig. A.3.2).

A.3.4 Transparency

Transparency was generally similar between years. It showed an increase at the northern stations in the dry season (June-August 1995) (Fig. A.3.3). This was related to the deepening of the thermocline (Fig. A.3.1) and nutrient rich layers.

At Mpulungu, there was less variation in 1994-95 compared to 1993-94. Transparency was relatively low (8 m) at the end of the upwelling period in September-October 1994. This was somewhat later than in the previous year (August 1993).

A.3.5 Conductivity

Conductivity measurements showed the greatest seasonal changes between years. At each station, especially in the north, the fluctuations of conductivity were much decreased (Figs A.3.4 and A.3.6) in year 2.

A.3.6 pH

As for conductivity at the northern stations, pH showed less variation in 1994-95 than in year 1 (Figs A.3.4 and A.3.6). This was less significant than conductivity. At Mpulungu, pH varied from October to November 1994. However measurements were infrequent. A direct relationship of the variability in the north and the south of the lake could not be identified in year 2.

A.3.7 Dissolved oxygen

The variation of dissolved oxygen at Bujumbura/Uvira was similar between years (Fig. A.3.5). Dampening of DO isopleths was well noted at 40 m. At Kigoma variation in DO was observed at 80 m near the thermocline between August and December (Fig. A.3.7) while in Mpulungu some very high values of DO were recorded: *c.* 18 mg/l in the surface water and 14 mg/l at 80 m in October 1994. These could be related to Chimbanfula waves recorded in this month. There are no observations from other parameters to confirm this.

A.3.8 Ammonia, nitrates and nitrites

The presence of ammonia in the epilimnion was regularly detected as in year 1 at Bujumbura/Uvira and Kigoma (Figs A.3.5 and A.3.7). This was probably related to the pulsed input of deeper water accompanying internal waves. The amplitude of the ammonia variation was generally less at the northern stations. At site V at Mpulungu, ammonia was almost never detected (Fig. A.3.9).

Nitrates at Bujumbura/Uvira were relatively similar between years (between 0.05 and 0.15 mg/l NO_3-N at 40 and 80 m) (Fig. A.3.5). Nitrates at Kigoma were slightly higher in year 2 (*c.* 0.15 mg/l NO_3-N) and showed a peak value in November (0.45 mg/l NO_3-N) at site V (Fig A.3.7). This did not correspond to changes in other parameters. At Mpulungu, a general trend of nitrate increase at 40 and 80 m in the dry season was observed in both years. This was probably caused by the thermocline depth getting closer to the surface due to the SE wind. Fewer peaks were noted in

1994-95. This was caused by lower sampling frequency at site V (monthly sampling) in 1994-95.

Nitrites values were higher and more variable at Kigoma and Mpulungu in 1994-95 than in Bujumbura/Uvira (Figs A.3.7, A.3.9 and A.3.5).

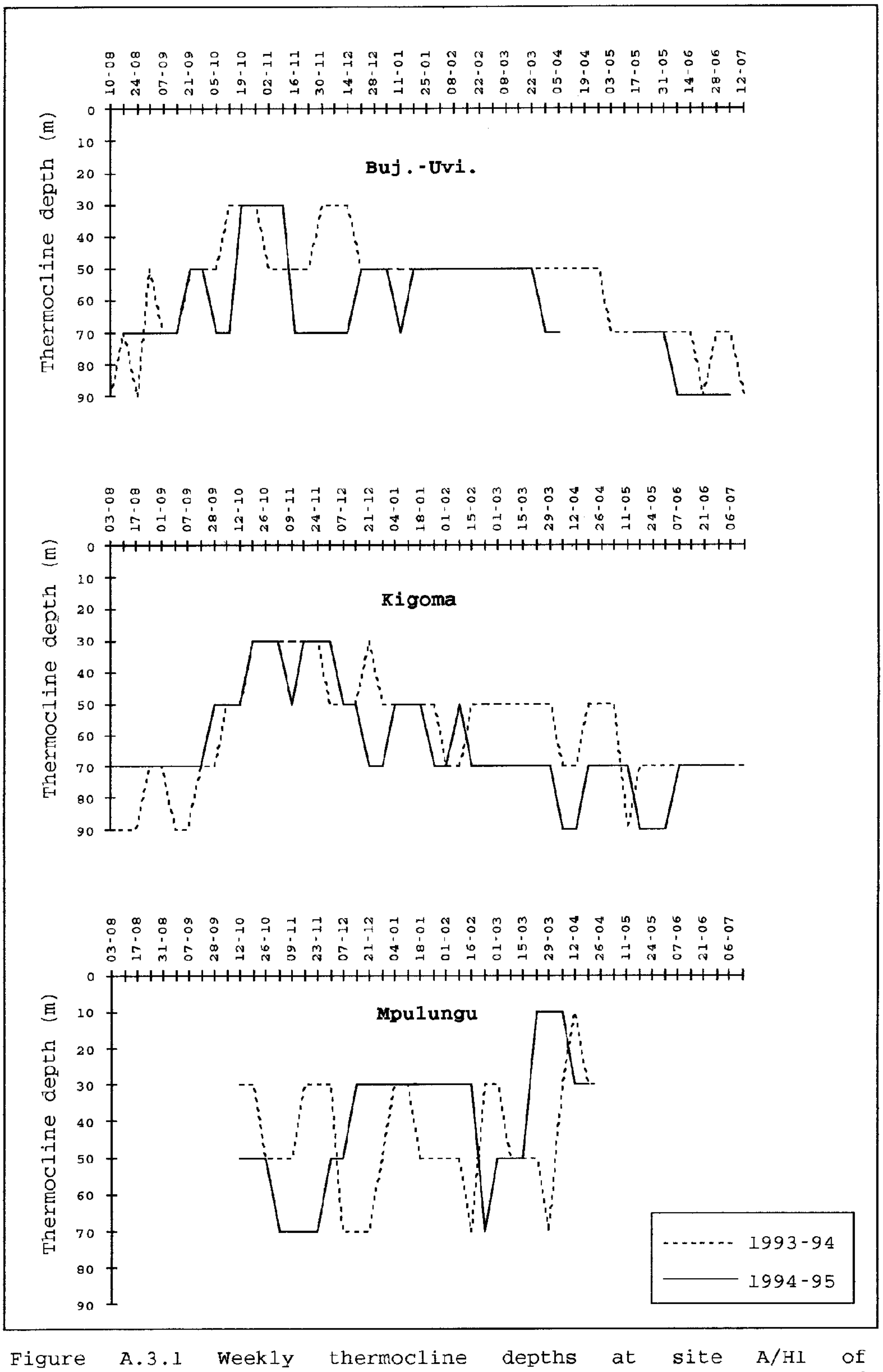


Figure A.3.1 Weekly thermocline depths at site A/H1 of Bujumbura/Uvira, Kigoma and Mpulungu, August to July 1993-94 and 1994-95 (Weeks not sampled are interpolated).

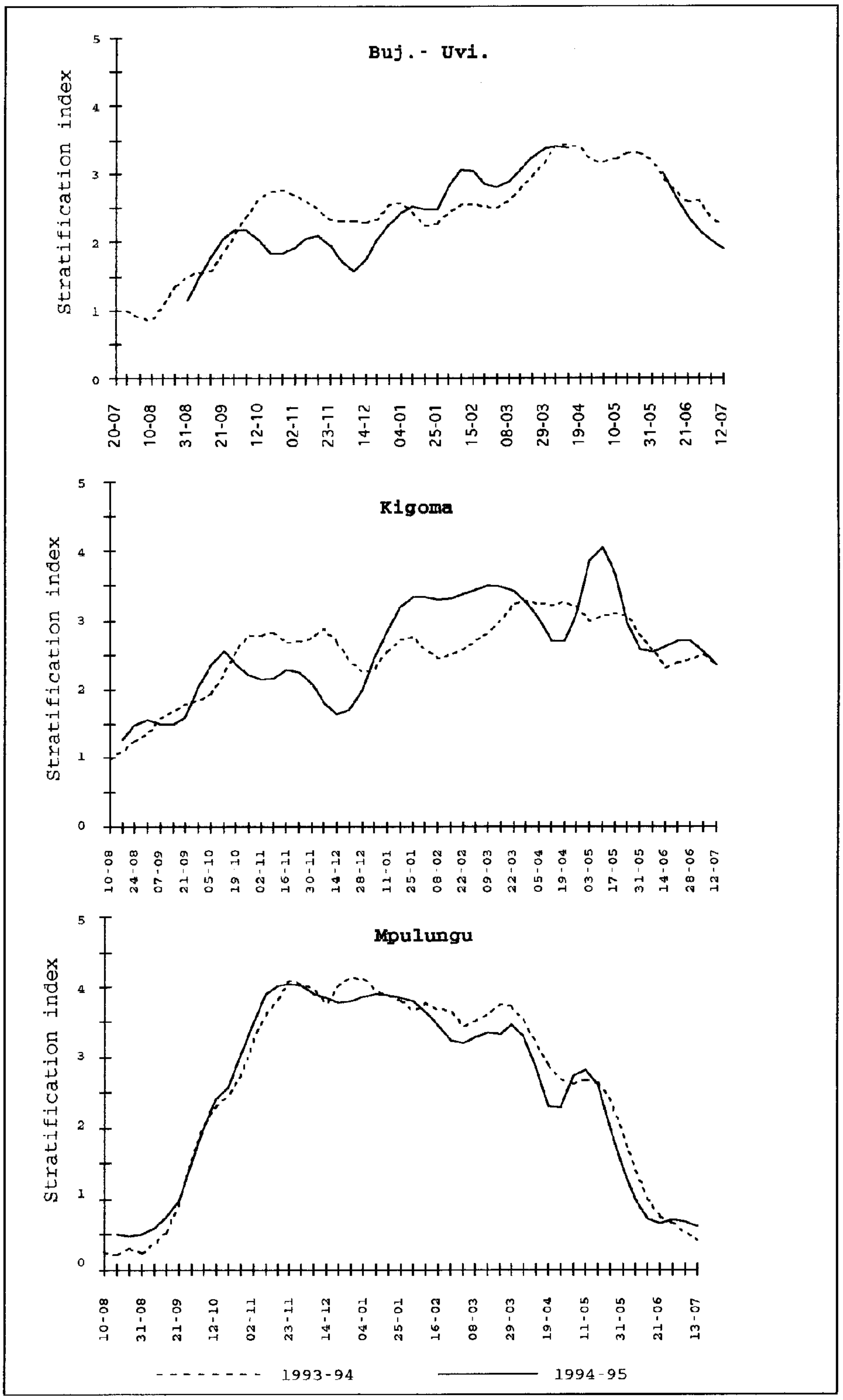


Figure A.3.2 Stratification indices from August to September 1993-94 and 1994-95 at Bujumbura/Uvira, Kigoma and Mpulungu (sites A/H1, 0 to 100 m; running average of 3 weeks; index defined in Plisnier *et al.*, 1996).

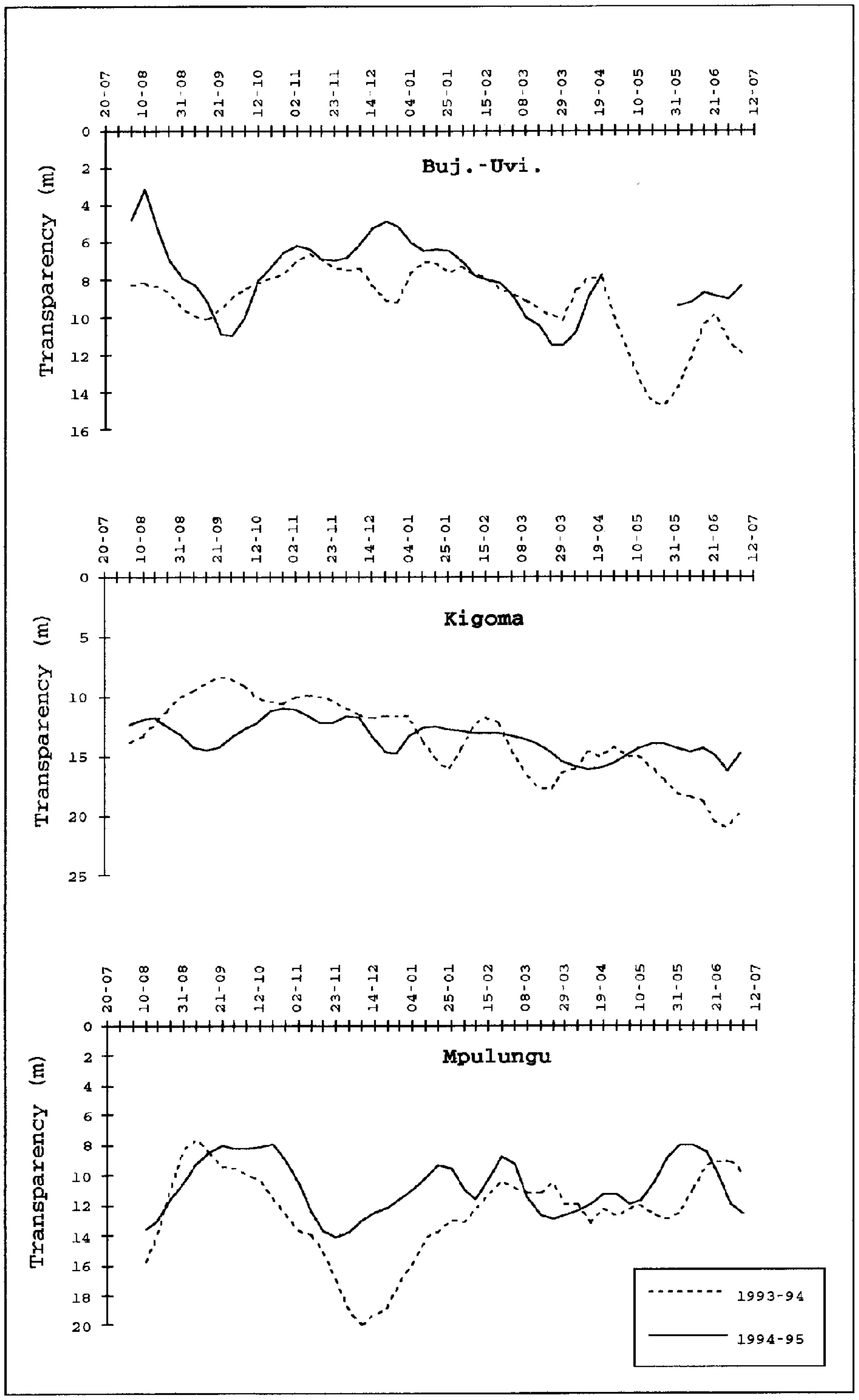


Figure A.3.3 Weekly transparency (secchi disk in m) at site A/H1 of Bujumbura/Uvira, Kigoma and Mpulungu, August to July 1993-94 and 1994-95 (Weeks not sampled are interpolated, running average of 3 weeks).

Bujumbura-Uvira (A)

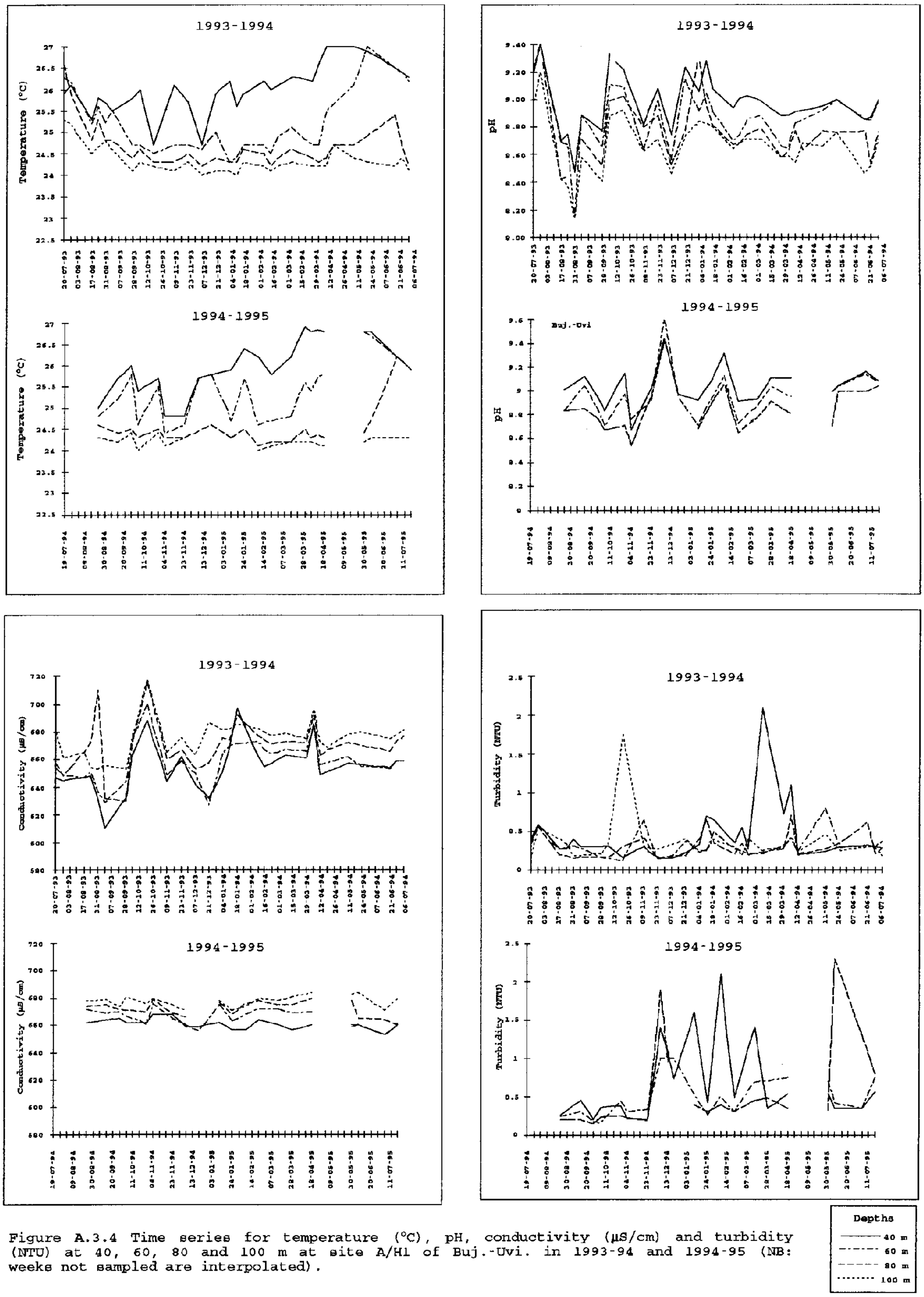


Figure A.3.4 Time series for temperature (°C), pH, conductivity (µS/cm) and turbidity (NTU) at 40, 60, 80 and 100 m at site A/H1 of Buj.-Uvi. in 1993-94 and 1994-95 (NB: weeks not sampled are interpolated).

Bujumbura-Uvira (B)

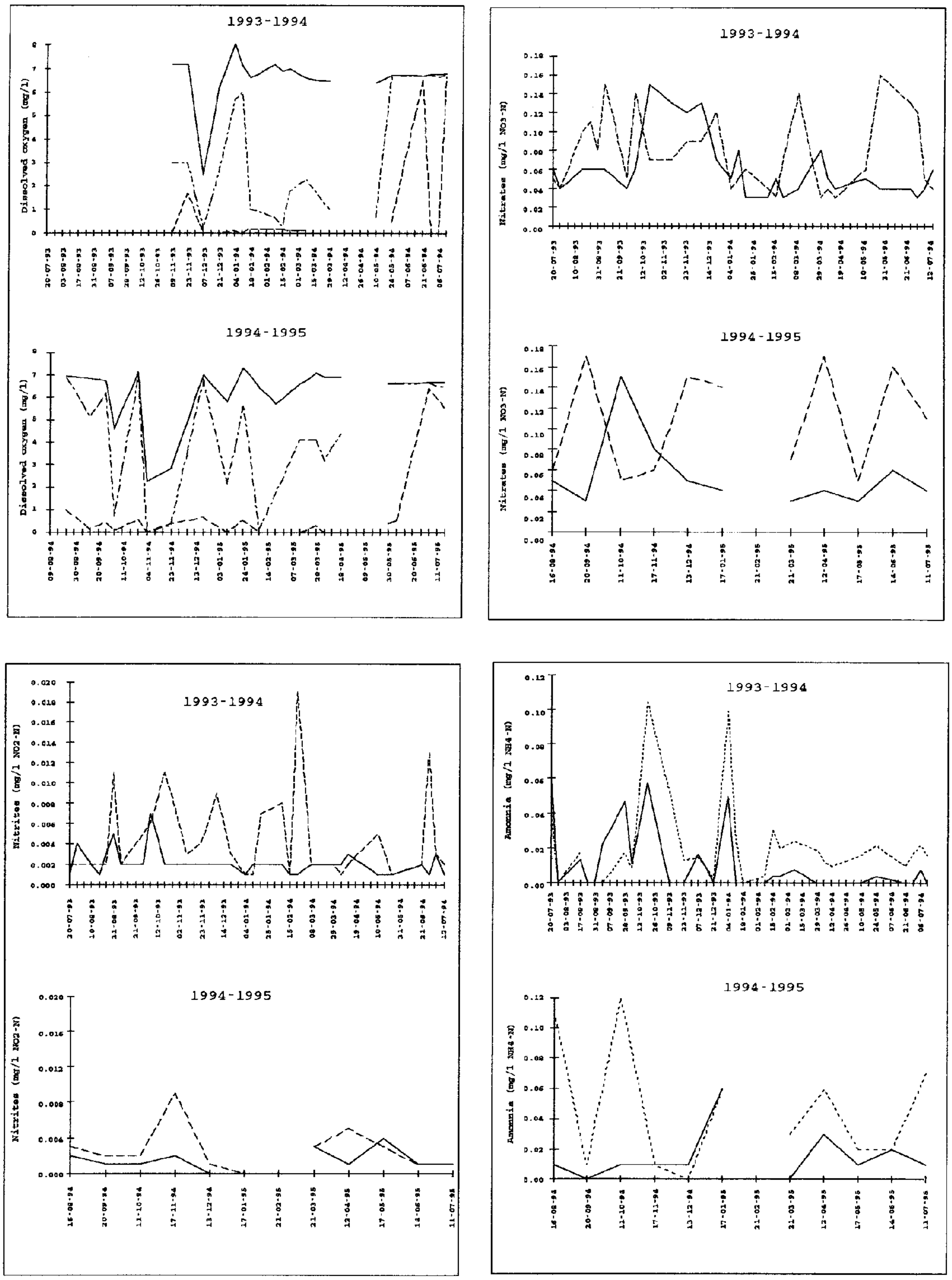
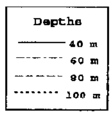


Figure A.3.5 Time series for dissolved oxygen (mg/l), nitrates (mg/l NO3-N), nitrites (mg/l NO2/N) and ammonia (mg/l NH4-N)at 40, 60, 80 and/or 100 m at site A of Buj.-Uvi. in 1993-94 and site V in 1994-95 (NB: weeks not sampled are interpolated in 1993-94).



Kigoma (A)

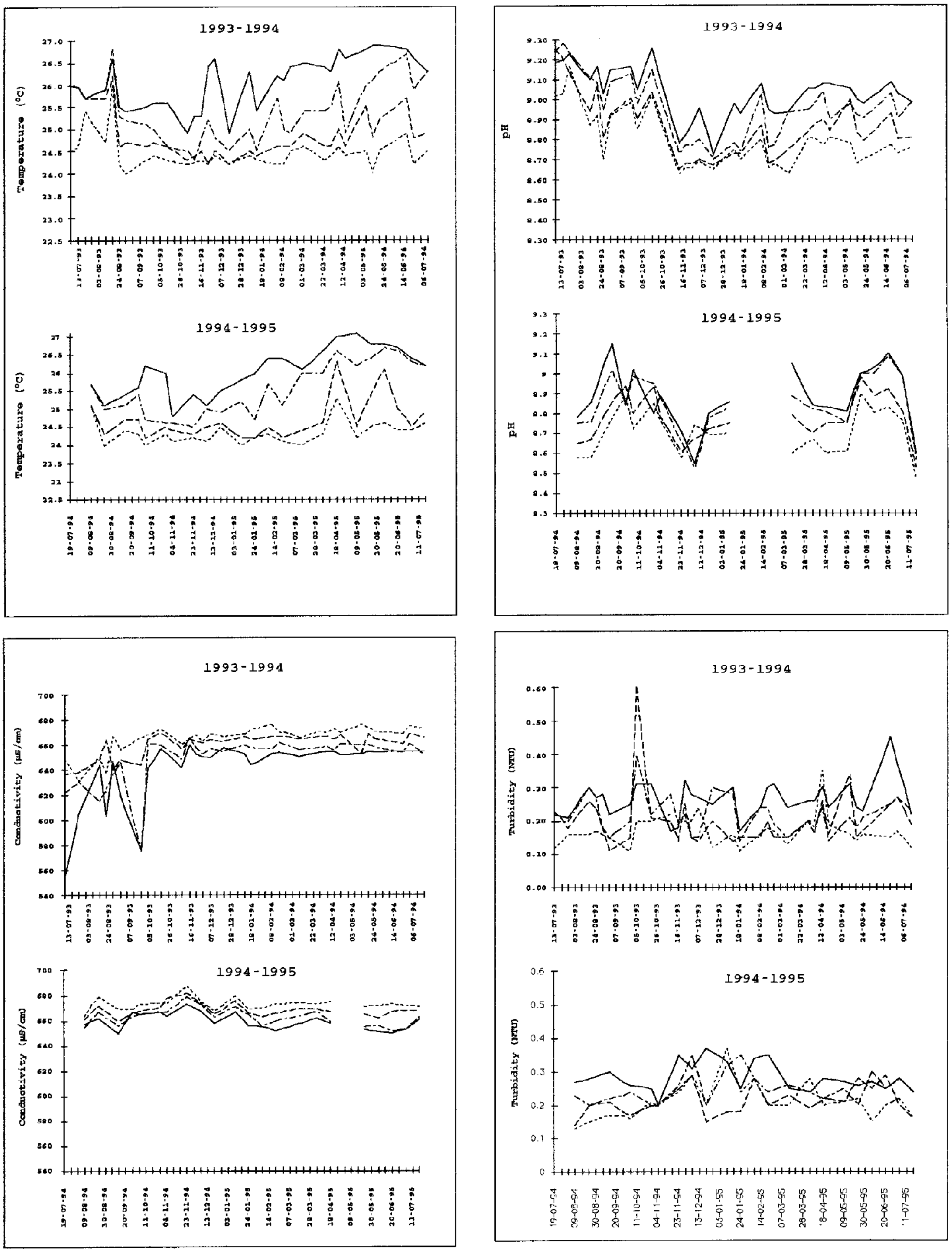
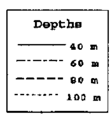


Figure A.3.6 Time series for temperature (°C), pH, conductivity (µS/cm) and turbidity (NTU) at 40, 60, 80 and 100 m at site A/H1 in 1993-94 and 1994-95 of Kigoma (NB: weeks not sampled are interpolated).



Kigoma (B)

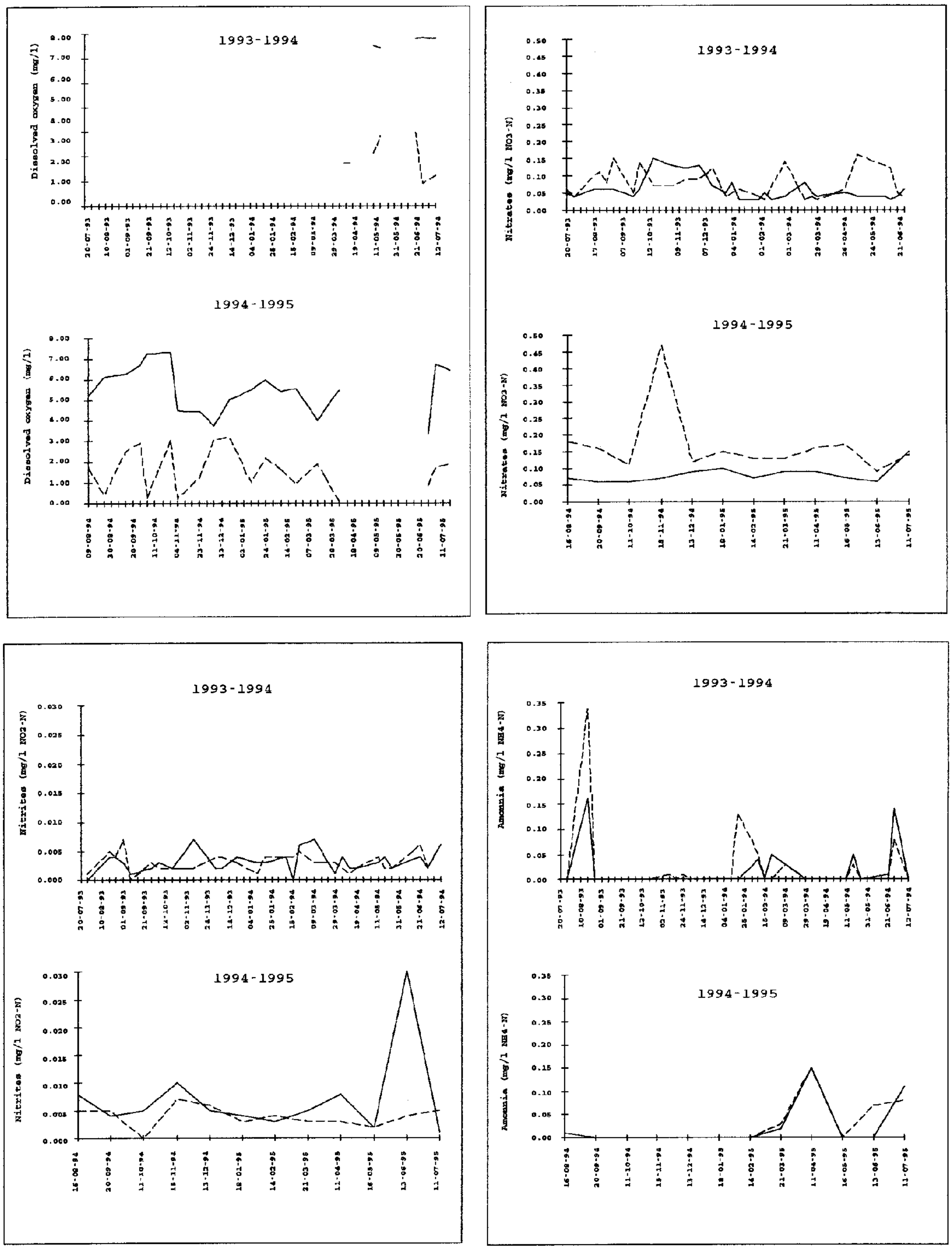


Figure A.3.7 Time series for dissolved oxygen (mg/l), nitrates (mg/l NO3-N), nitrites (mg/l NO2/N) and ammonia (mg/l NH4-N) at 40 and 80 m at site A in 1993-94 and site V in 1994-95 of Kigoma (NB: weeks not sampled are interpolated in 1993-94).

Depths
—— 40 m
----- 80 m

Mpulungu (A)

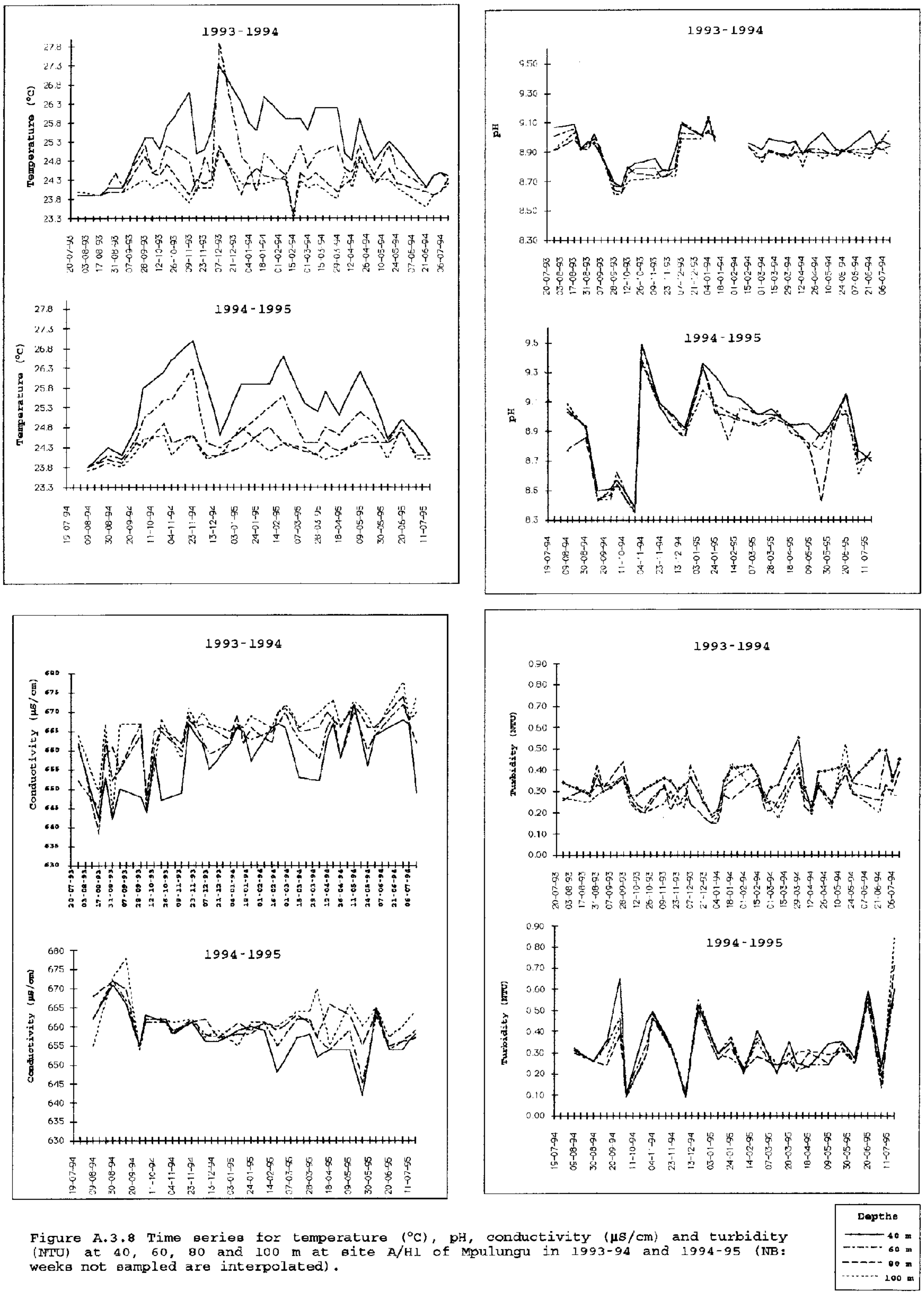


Figure A.3.8 Time series for temperature (°C), pH, conductivity (µS/cm) and turbidity (NTU) at 40, 60, 80 and 100 m at site A/H1 of Mpulungu in 1993-94 and 1994-95 (NB: weeks not sampled are interpolated).

Mpulungu (B)

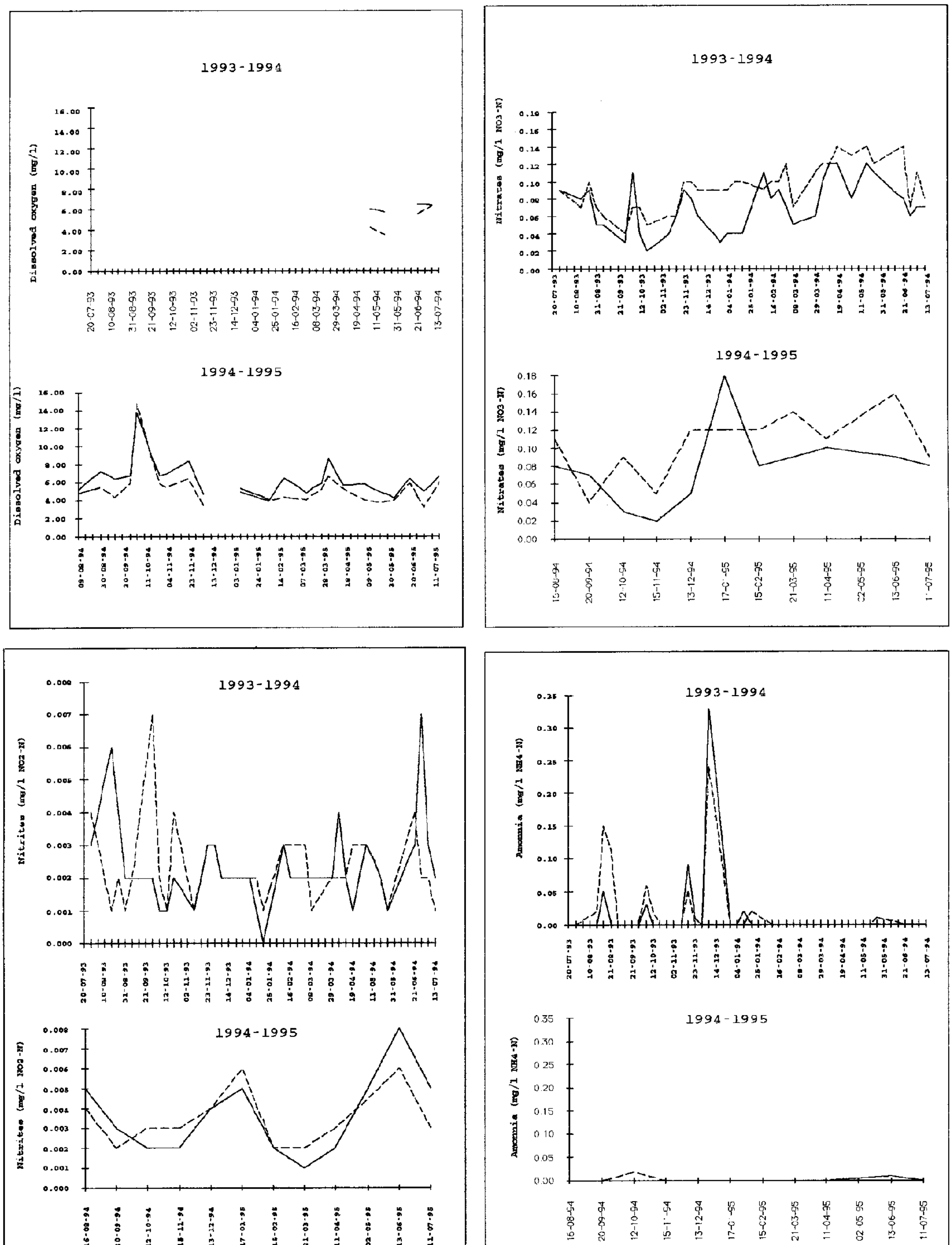


Figure A.3.9 Time series for dissolved oxygen (mg/l), nitrates (mg/l NO3-N), nitrites (mg/l NO2/N) and ammonia (mg/l NH4-N)at 40 and 80 m at site A of Mpulungu in 1993-94 and site V in 1994-95 (NB: weeks not sampled are interpolated in 1993-94, monthly sampling at site V).

Depths
40 m
80 m

A. 4 Horizontal transects (pelagic-coast).

The mean value of each surface water parameter across a horizontal transect (H1, H2, H3 and H4) are presented at Figures A.4.1 and A.4.2.

The most obvious horizontal difference was noted in transparency at Bujumbura/Uvira with a strong decline between the pelagic station H1 (SD=8.4 m) and the H4 station near the shore (SD=2.4 m). Turbidity values increased along this transect as expected. This was probably the consequence of greater mixing. However, silicates did not increase significantly towards the shore. A clear gradient showing other nutrients increase toward the shore could not be detected neither.

Mpulungu transparency also decreased between the pelagic area (mean SD = 11.1 m at site H1) and the coastal area (SD = 7.3 m at site H4). Silicate and other nutrients did not increase significantly towards the coast. TDP slightly decreased near the shore.

At Kigoma, the horizontal gradient was very homogenous between the pelagic and the coast. This might be caused by the topography since deep water is very close to the shore and the pelagic may be found close to the shore.

The reasons for a decrease in transparency near the coast and the apparent lack of a gradient in nutrients between the pelagic and the shore is probably due to the speed of the nutrient intake and the difficulty of nutrient detection if they are assimilated as soon as they enter the system.

A comparison of the horizontal transect between the dry and wet seasons (Figs A.4.3 and A.4.4) showed that the temperature difference between the coast and pelagic was very small at the time of sampling (between 0900-1200 h).

Transparency was higher at all H sites of Bujumbura/Uvira and Kigoma during the dry season compared to the wet season. The reverse was true for Mpulungu. This was probably the result of a deep thermocline in the north and upwelling in the south during this season. Dissolved oxygen at all stations and sites was higher during the wet season that the dry season. pH was lower at Mpulungu during the dry compared to the wet season, probably the consequence of upwelling of deep water. Turbidity showed the greater differential between the pelagic and coastal area during the wet season at Bujumbura/Uvira.

Total phosphorus (TP and TDP) were higher during the dry season at Kigoma and Mpulungu. While this could be explained by upwelling of the nutrients at Mpulungu, there was no obvious reason for the increase at Kigoma beside turbulence during the dry and windy season. Ammonia increased near the coast at Bujumbura/Uvira particularly during the dry season. Movement of water involving mixing near the shore and/or ammonia excreted by organisms could have been the cause. The observations could have been related to the increase turbidity near the shore. Nitrate and nitrite did not show any significant increase near the shore. Runoff water didn't appear to influence nutrient concentration in a detectable way in this area.

Silicate concentrations varied the most at Kigoma and Mpulungu. At Kigoma, higher concentrations were noted during the dry, turbulent season when deeper water may have reached the surface. At Mpulungu, a higher concentration of silicates during the wet season may originate from runoff waters.

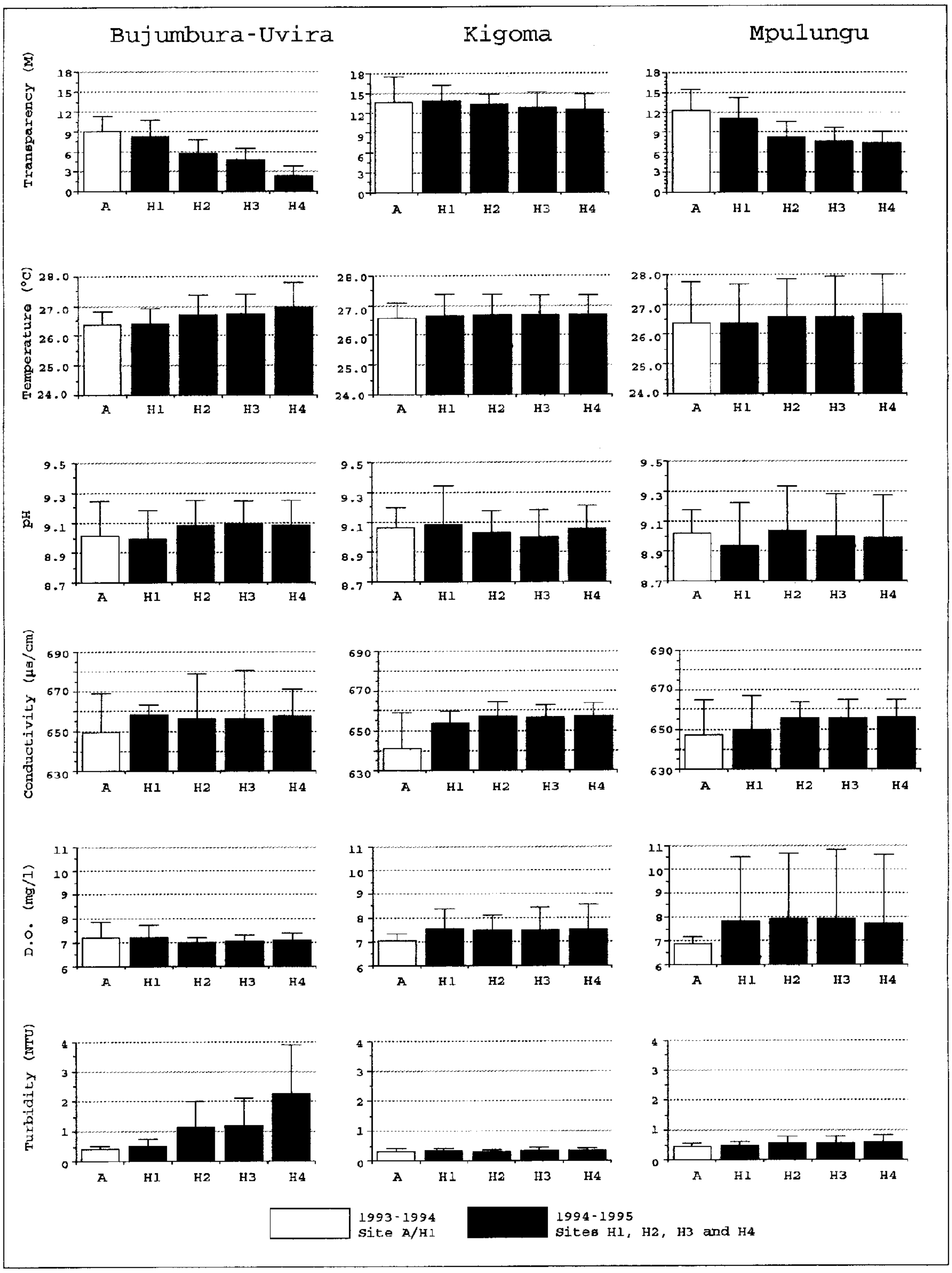


Figure A.4.1 Mean and standard deviation of surface measurement (0 m) for transparency, temperature, pH, conductivity, dissolved oxygen and turbidity at site A (= H1) in 1993-94 and sites H1, H2, H3 and H4 in 1994-95 (Site A/H1 > 4 km from shore, H2 = 1 km from shore, H3 = 500 m from shore, H 4 = 50 m from shore).

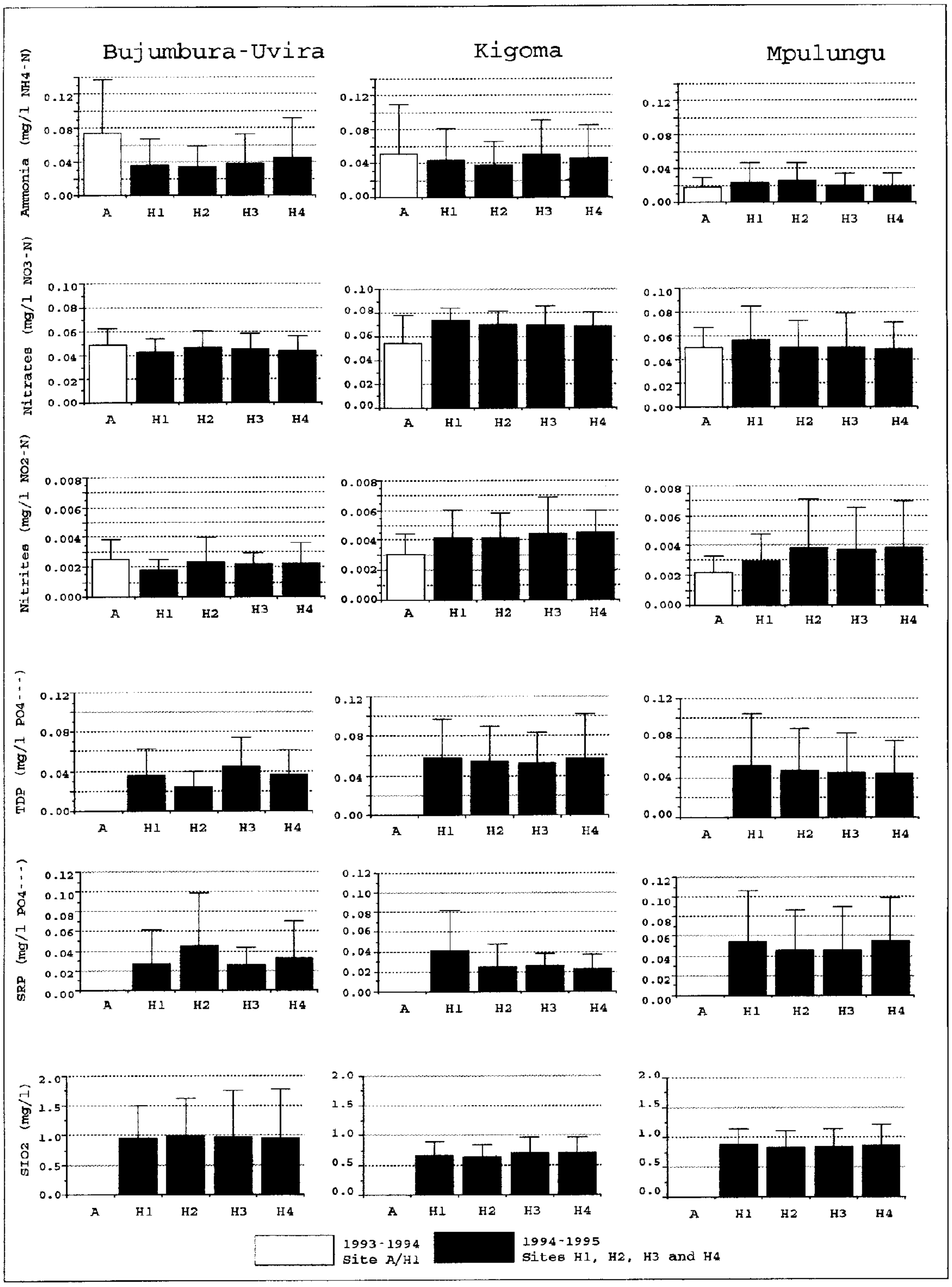


Figure A.4.2 Mean and standard deviation of surface measurement (0 m) of ammonia, nitrates, nitrites, total dissolved phosphorus, soluble reactive phosphorus and silicates at site A (= H1) in 1993-94 and sites H1, H2, H3 and H4 in 1994-95 (Site A/H1 > 4 km from shore, H2 = 1 km from shore, H3 = 500 m from shore, H4 = 50 m from shore).

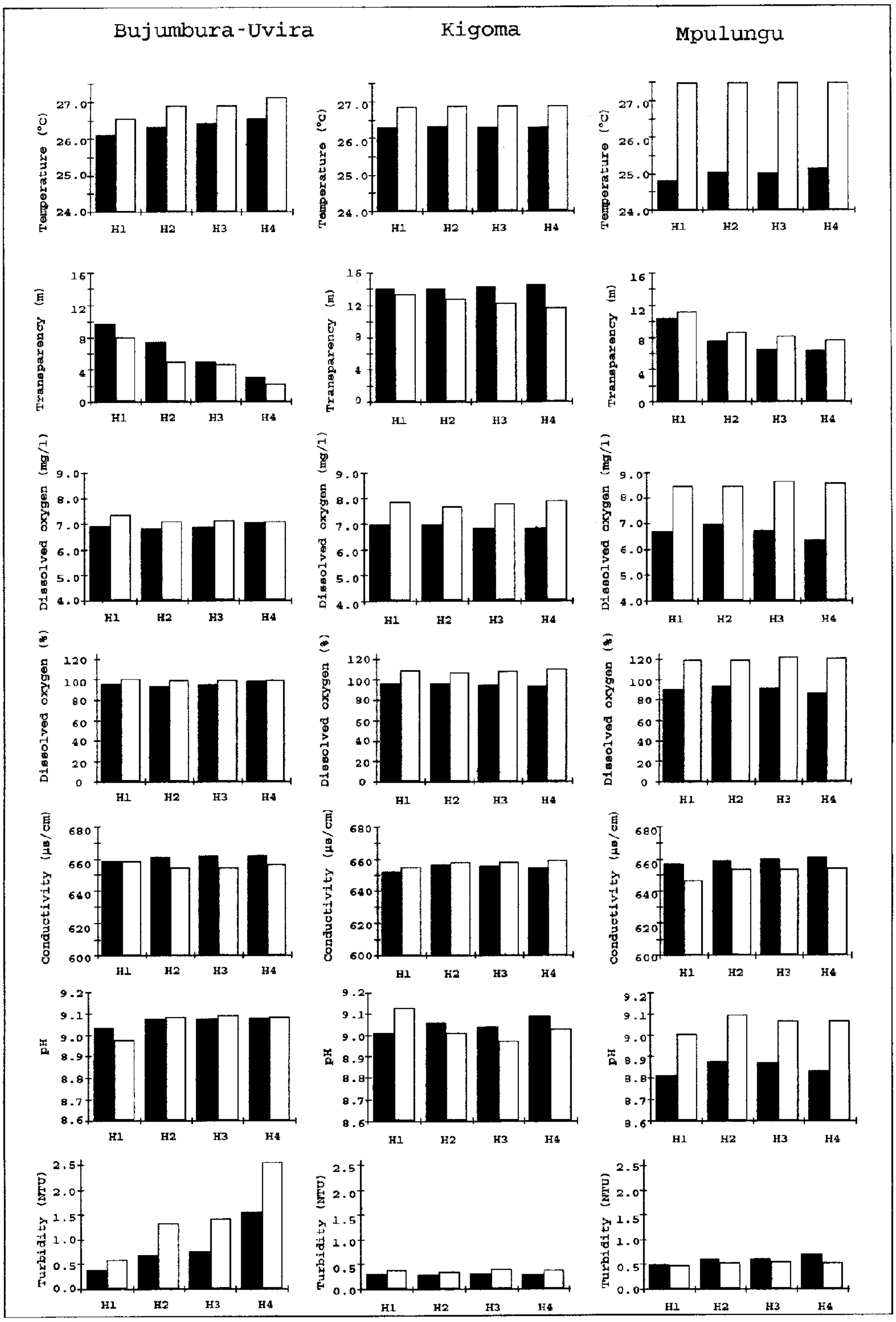


Figure A.4.3 Means of surface measurements during the dry (June-September) and wet season (October-May) for temperature, transparency, dissolved oxygen, conductivity, pH and turbidity at sites H1, H2, H3 and H4 in 1994-95 of Bujumbura-Uvira, Kigoma and Mpulungu stations (distances from shore: H1>=4 km ; H2 = 1 km, H3 = 500 m, H4 = 50 m).

Dry season

Wet season

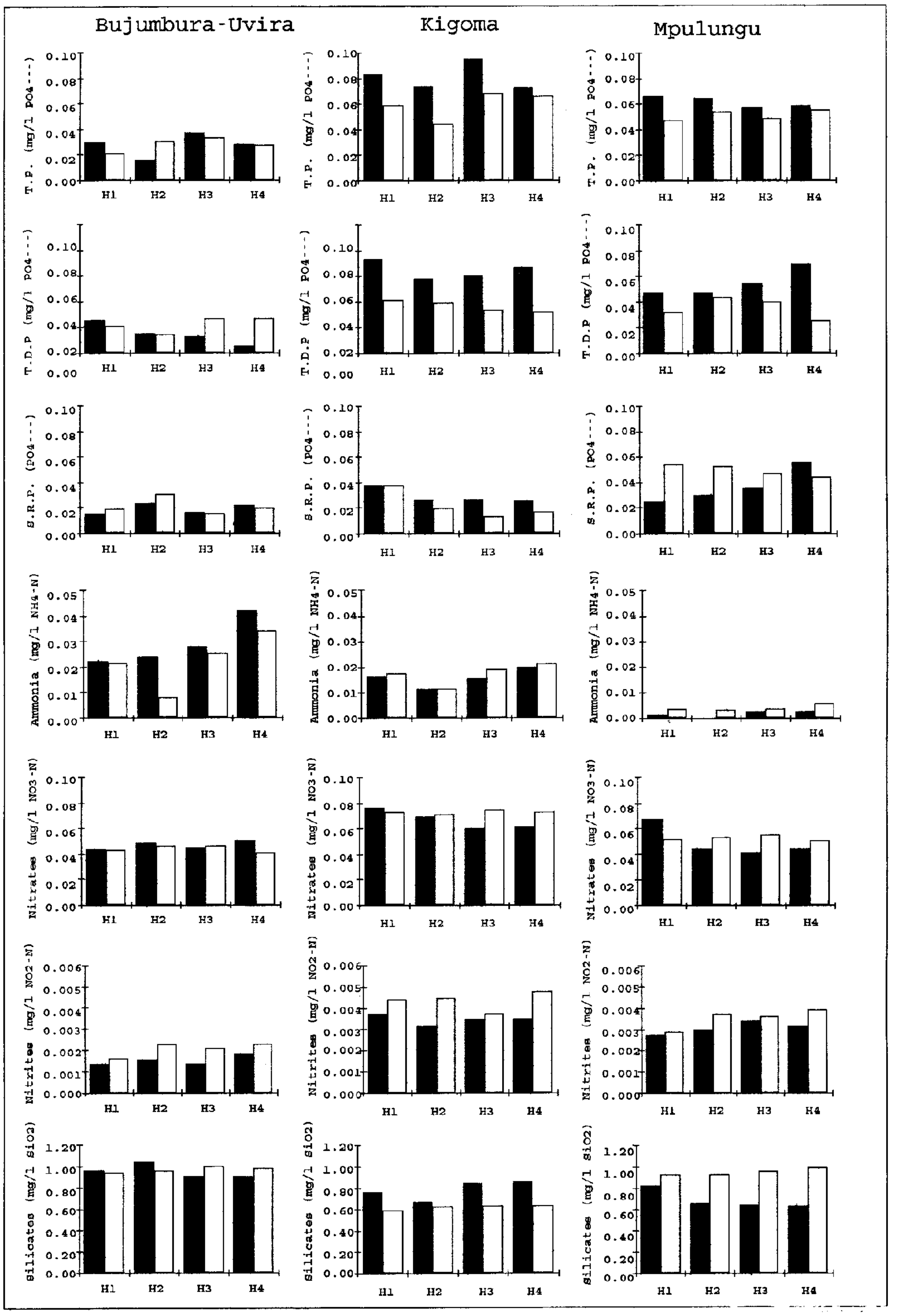


Figure A.4.4 Means of surface measurements during the dry (June-September) and wet seasons (October-May) for TP, TDP SRP, ammonia, nitrates, nitrites and silicates at sites H1, H2, H3 and H4 in 1994-95 of Bujumbura-Uvira, Kigoma and Mpulungu stations (distances from shore: H1>=4 km ; H2 = 1 km, H3 = 500 m, H4 = 50 m).

7. Acknowledgements

Several people have participated with enthusiasm in the programme during sampling and analysis. I sincerely thank them for their involvement in the research. At each station, limnology teams have been involved in regular sampling, sometimes in very rough weather conditions during the day and night. They have also performed a great number of analyses in the laboratories of the project.

At Bujumbura I thank particularly V. Langenberg, E. Coenen, P. Kotilainen., J.M. Tumba, K. Tshibangu, E. Gahungu, P. Paffen, E. Nikomeze, B. Ndimunzigo, S. Nyamushahu, S. Kimbadi, R. Varyianis, I. Rugoreka and P. Sinanka. The LTR station was supervised by Dr G. Hanek.

At Kigoma, sincere thanks are given to D. Chitamwembwa, E.W. Lyoba, D. Lyoba, N. Challe, H. Kurki, M. Chatta, S. Muhoza, A. Kalangali, E. Kadula, O. Kashushu, W. Kisisiwe and M. Agustino. The LTR station was supervised by P. Mannini.

Special thanks in Mpulungu are addressed to L. Mwape, E. Bosma, C. Lukwessa, R. Shapola, L. Makasa, I. Zulu, E. Chipulu, S. Sichivu, K. Kaoma, P. Verburg, J. Chimanga, B. Kassikila and C. Sichamba.

Sodium and potassium were analysed at the "Centre National de Technologie Alimentaire of Bujumbura" with the assistance of A. Bikorimana.

I sincerely thank Dr. J. Kapetsky Scientific Coordinator (FAO), Mrs D. Blessich, Mr. M. Doeff and Mr M. Mann, Project Operation Officers (FAO) for their most valuable assistance and Dr A. Bakun, Mrs J. Collins, Mr A. Gribling as well as other officers of FAO involved with LTR for their support. Acknowledgement is made to Professor O. Lindqvist, Scientific Coordinator and Professor H. Molsä, Kuopio University, Finland, for their support in scientific matters and bibliographic material. Professors J.-C. Descy and J.-C Micha of the Facultés Notre-Dame de la Paix in Namur, Belgium have provided valuable help and advice which I wish to acknowledge here. Very valuable help has been provided by the Belgium-CPGL project of Hydrobiology in Bujumbura. I particularly thank Drs A. Vandelannoote, L. De Vos and L. Risch for their much appreciated collaboration.

I thank also the Project Coordinator Dr G. Hanek for support in implementing the limnological component and Dr J.F. Craig, Senior Scientific Field Coordinator, for advice and guidance. I very much appreciated the help of Dr J.F. Craig in editing this manuscript.

Many others have supported and helped in this research. Although they are not named, they are sincerely thanked.

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