Seasonal variations in water quality of a West African river (R. Jong in Sierra Leone)

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ABSTRACT

The River Jong in Sierra Leone was tested monthly at two stations over a one year period for colour, turbidity, conductivity, pH, permanganate values, concentrations of free CO_2, dissolved oxygen, HCO_3^-, Ca^{2+}, Mg^{2+}, Na^+, K^+, phosphate-P, silicate-Si and dissolved iron, and for the presence of Cl^-, SO_4^{2-}, F^-, Mn^{2+}, Cu^{2+}, NH_4^+, NO_2^- and NO_3^-. The river was found to be acidic throughout the year (pH range 5.44-6.76) and possessed a very low dissolved chemical content (conductivity range 10-30 μS cm^{-1}). Levels of all the determinands investigated quantitatively, except phosphate-P, dissolved oxygen and free CO_2, showed a clear relationship with the seasonal variation in rainfall; the major ions reached concentration peaks at the end of the dry season; levels of dissolved iron, colour, turbidity and permanganate values reached later peaks, corresponding to the time of re-emergence of ephemeral streams in the drainage basin. Phosphate-P and the ions qualitatively tested for were not present in concentrations above the detection limits of the methods employed. Some implications of the low ionic content of the R. Jong are discussed.

KEY WORDS : Seasonality — Water Quality — River Jong — Conductivity — Tropical.

RÉSUMÉ

VARIATIONS SAISONNIÈRES DE LA QUALITÉ DE L'EAU D'UNE RIVIÈRE D'AFRIQUE DE L'OUEST (RIVIÈRE JONG, SIERRA LEONE)

La rivière Jong en Sierra Leone a été analysée mensuellement, en deux endroits et sur une période d'un an, pour la couleur, la turbidité, la conductivité, le pH, les valeurs de permanganate, les concentrations du CO_2 libre, de l'oxygène dissous, HCO_3^-, Ca^{2+}, Mg^{2+}, Na^+, K^+, phosphate-P, silicate-Si et du fer dissous, et pour la présence de Cl^-, SO_4^{2-}, F^-, Mn^{2+}, Cu^{2+}, NH_4^+, NO_2^- et NO_3^-. La rivière s'est révélée acide tout au long de l'année (pH variant de 5.44 à 6.76) et elle a une très faible teneur en éléments chimiques dissous (conductivité variant de 10 à 30 μS cm^{-1}). Les niveaux de tous les déterminants étudiés quantitativement, à l'exception de phosphate-P, de l'oxygène dissous et du CO_2 libre, montrent une nette corrélation avec les variations saisonnières des précipitations; les ions majeurs atteignent des pics de concentration à la fin de la saison sèche; les teneurs en fer dissous, la couleur, la turbidité et les valeurs de permanganate présentent des pics plus tardifs, correspondant à la période de réapparition des cours d'eau temporaires dans le bassin hydrographique. Phosphate-P et aucun des ions analysés qualitativement n'était présent en concentration supérieure aux limites de détection des méthodes utilisées. Quelques conséquences du faible contenu ionique de la rivière Jong sont examinées.

MOTS-CLÉS : Variations saisonnières — Qualités de l'eau — Rivière Jong — Conductivité — Tropicale.

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Seasonal influence on the hydrology of tropical rivers is often great and may affect the benthos and plankton markedly (EVISON and JAMES, 1977). The enormous volume of water entering such rivers during the wet season can reduce chemical concentrations to potentially growth-limiting levels for some algae (HOLDEN and GREEN, 1960) and produces a mean chemical content (as total dissolved solids) much lower than the world average (LIVINGSTONE, 1963). The chemical input to tropical rivers from soil leaching is very often negligible due to the advanced state of weathering of soils in their drainage basins.

The River Jong (also known as Taia, Sanden and Pampana at different stretches) originates in the Sula mountains in the North-East of Sierra Leone (9°15′ N, 11°31′ W). The origin is a small lake (Lake Sonfon), the only natural, permanent lake in the interior of Sierra Leone. Lake Sonfon has been described previously (GREEN, 1979). The Jong is approx. 249 km long, entering the sea at Matru, and its drainage basin (Fig. 1) covers an area of approx. 7500 km² (CLARKE, 1969). The predominant soil type in this area is laterite, overlying granite (ODELL et al., 1974). By the end of 1981, no industrialisation or development of sewage disposal had occurred along the length of the river.

CHAYTOR (1969) studied the hydrology and some chemical characteristics of the Jong at Njala over the period 1966 to 1968. However, CHAYTOR's water chemistry data did not indicate the significant seasonality which would be expected for a river subject to the extreme seasonal variation in rainfall which occurs in Sierra Leone and no significant correlation between water quality and hydrology was observed. At Njala, the Jong is approx. 120 m wide and varies from a minimum depth (mid-river) of approx. 1.2 m at the end of the dry season, to a maximum depth of approx. 6.7 m in the wet season.

Mean total annual rainfall in Sierra Leone is high and increases from approx. 2500 mm at Lake Sonfon to approx. 3500 mm at Matru (BOWDEN, 1980). Rain falls almost entirely in a wet season lasting from May to November. During the dry season, the cumulative net deficit between rainfall and potential evapotranspiration reaches a peak, at Njala, in April (ODELL et al., 1974); virtually all of the tributary streams of major rivers dry up completely by this time.

The present study was undertaken to determine the manner and extent of seasonal variations in water quality of the R. Jong and to attempt to define any observed relationships so that they may be investigated with respect to other tropical rivers.

METHODS

Preliminary water samples were obtained from the R. Jong at Njala and tested using standard methods (A.P.H.A., 1981; GOLTERMAN, 1969), over the period May to July 1979, in order to obtain an estimate of physical and chemical water quality and to identify appropriate methods of analysis. From August 1979 to July 1980, samples were then obtained, on the same day each month, from two locations : Njala (8°05′ N, 12°04′ W) and Momenga (approx. 2 km down-river from Njala). Four samples were taken at each location, at each sampling time—a glass Winchester-type bottle (capacity approx. 2.5 l) and a polyethylene bottle (capacity approx. 500 ml) were filled completely; a sample for dissolved oxygen was taken and a separate sample for dissolved iron obtained. The dissolved oxygen sample was taken first, according to the method of DREW and ROBERTSON (1974) except that sample was preserved by the addition of sodium azide and acid (A.P.H.A., 1981) instead of precipitating manganese hydroxides in the field. For dissolved iron, reagents were added in the field to develop the 1,10-phenanthroline-Fe^{2+} complex (NICOLSON, 1966), which is very stable, in order to avoid any post-sampling precipitation of ferric oxides. Water temperature and river level (the latter at Njala only) were recorded at the time of sampling.

Laboratory analysis was initiated within 3 h of sampling and performed as follows.

The dissolved oxygen determination was completed.

Free CO_2 concentration was determined on the first sample removed from the Winchester-type bottle, by titration with 0.0227 M Na_2CO_3 (A.P.H.A., 1981).

pH and conductivity were recorded with Griffin (U.K.) meters.

Bicarbonate concentration was determined by a conductometric titration (GOLTERMAN, 1969) with 0.005 M HCl.

Permanganate values (P.V.) were determined according to W.P.R.L. (1969). Both 3 min and 4 h values were determined; the 3 min value was considered to represent the amount of readily oxidisable inorganic material in samples and the 4 h value the amount of readily oxidisable inorganic plus organic material present (KLEIN, 1959).

Colour, both apparent and true, was determined by visual comparison of natural and centrifuged sample, respectively, with platinum-cobalt (Pt-Co) standards (A.P.H.A., 1981), at the natural sample pH.

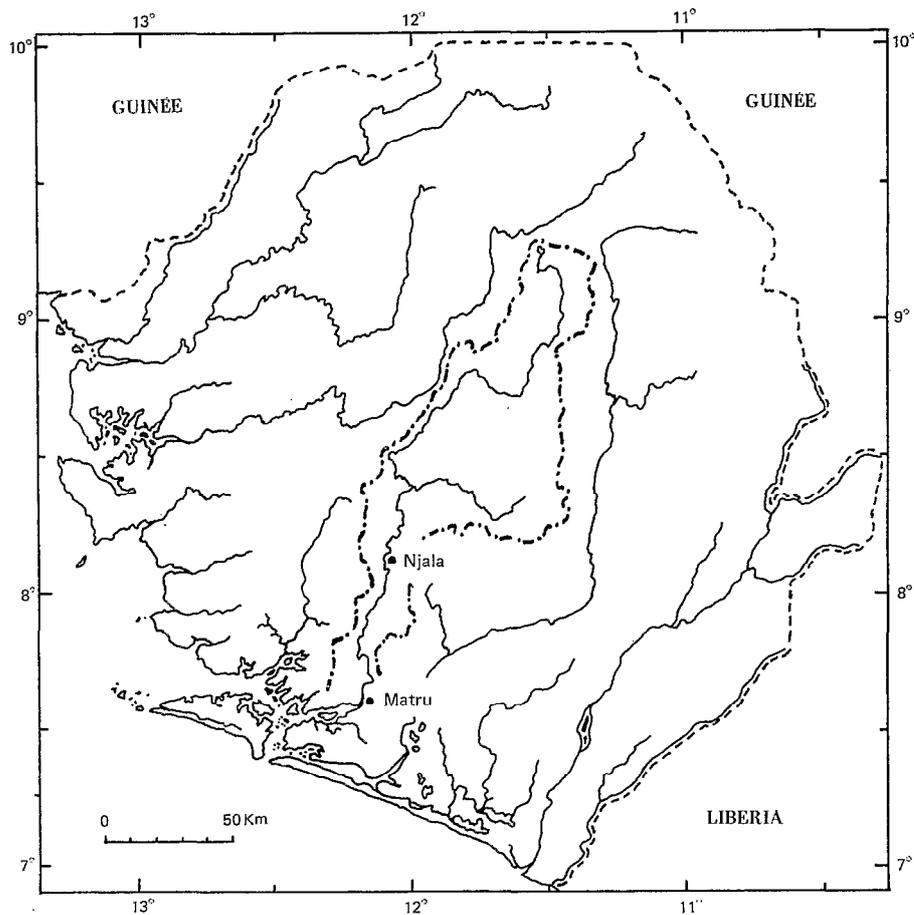Turbidity was determined by visual comparison

FIG. 1. — Principal hydrography of Sierra Leone, indicating drainage basin of R. Jong (—.—.—)
Hydrographie de la Sierra Leone présentant le bassin de drainage de la rivière Jong (—.—.—)

of sample with kaolin standards of known nephelo-metric turbidity units (NTU).

Sodium and potassium concentrations were determined by flame photometry.

Calcium and magnesium concentrations were determined by titration with EDTA. Because of low results, a very dilute (0.001 M) titrant was employed and a spectrophotometer used to determine the end-point.

Silicate-Si concentration was determined by reaction with molybdate (GOLTERMAN, 1969).

Phosphate-P concentration was also determined by reaction with molybdate (A.P.H.A., 1981).

The colour developed in the dissolved iron sample was read against standard solutions at 508 nm.

Of the above determinations, those for sodium, potassium and silicate-Si concentrations, and conduc-

tivity, were performed on sample from the poly-ethylene container. All others (except those for dissolved oxygen and dissolved iron concentrations), including those described below, were performed on sample from the glass Winchester-type bottle.

Qualitative tests were then performed for the presence of the following ions (Preliminary testing had indicated that these ions were not present in high enough concentrations to warrant more detailed, quantitative tests).

Chloride was estimated by titration with mercuric nitrate (GOLTERMAN, 1969). Inability to detect any visual difference against a blank after the addition of 0.10 ml titrant was recorded as a negative result.

Sulphate was estimated by turbidimetry after addition of $BaCl_2$ (A.P.H.A., 1981). A negative

result was recorded if an increase in absorbance of < 0.010 occurred.

Fluoride was estimated by the colour extinction method using SPADNS reagent (A.P.H.A., 1981). A negative result was recorded if a decrease in absorbance of < 0.010 occurred against a distilled water blank.

Manganese, copper, ammonium, nitrite and nitrate ions were estimated by spot-tests described by FEIGL and ANGER (1972).

The detection limit of each of the above qualitative tests was initially determined by the use of standard solutions of the relevant ion.

Daily rainfall and temperature data over the study period were obtained from the meteorological station situated at Njala.

As it was apparent at the start of the investigation that the R. Jong possessed a very low dissolved chemical content, conductivity readings of rainfall at Njala were recorded from May to July 1979.

RESULTS

Rainfall and mean air temperature during the study period (Fig. 2) were typical for the area (ODELL et al., 1974). The study was initiated (August) during the wet season, which lasted until November. A dry season then followed, of approx. 5 months duration, and the wet season began again in May. April is included in the dry season as, although there was 134 mm of rainfall, 130 mm of this occurred in only three storms and potential evapotranspiration still exceeded the total month's rainfall.

The level of the R. Jong (Fig. 2) followed closely the pattern of rainfall.

The majority of the water quality variables investigated exhibited seasonal fluctuations directly associated with the variation in climate. Such variables were associated either with surface run-off, particularly at the start of the wet season (Fig. 3, a to d), or with the reduction of river volume during the dry season (Fig. 3, e to l). From the former group of variables, levels of dissolved iron, colour and permanganate values displayed remarkably similar fluctuations over the period April to July. In fact, throughout the year, dissolved iron levels were significantly correlated both with the levels of true colour (r = 0.848; p < 0.001) and permanganate values (r = 0.616 for the 4 h values, 0.577 for the 3 min values; both significant at p < 0.05). Turbidity values reached a peak in July, the last month of sampling (a sample taken in August 1980, at Njala, gave a result of 8 NTU, showing a return to normal levels); otherwise, little variation of values was observed.
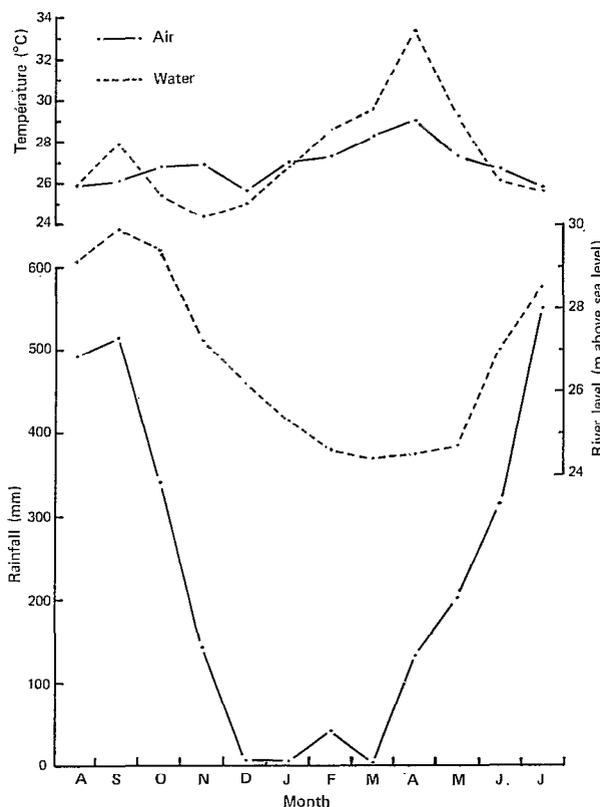
The levels of the major ions investigated (Na^+, Ca^{2+}, Mg^{2+}, K^+, HCO_3^- and silicate-Si) were all associated with river volume, rising from constant values during the wet season to concentration peaks occurring at the time of lowest river depth (March to April). Variation in conductivity readings reflected this pattern. The actual levels of the major ions were extremely low. pH values were seen to fluctuate with the levels of the major ions, highest values occurring during the dry season.

Levels of dissolved oxygen and free CO_2 (Table I) were relatively constant throughout the study period (free CO_2 concentrations were slightly lower during the dry season) and water temperature followed (although to a greater degree) the variation in air temperature (Fig. 2). With respect to dissolved oxygen, the R. Jong, at the sampling stations studied, did not reach the 100 % saturation level at any time of the year; however, samples were
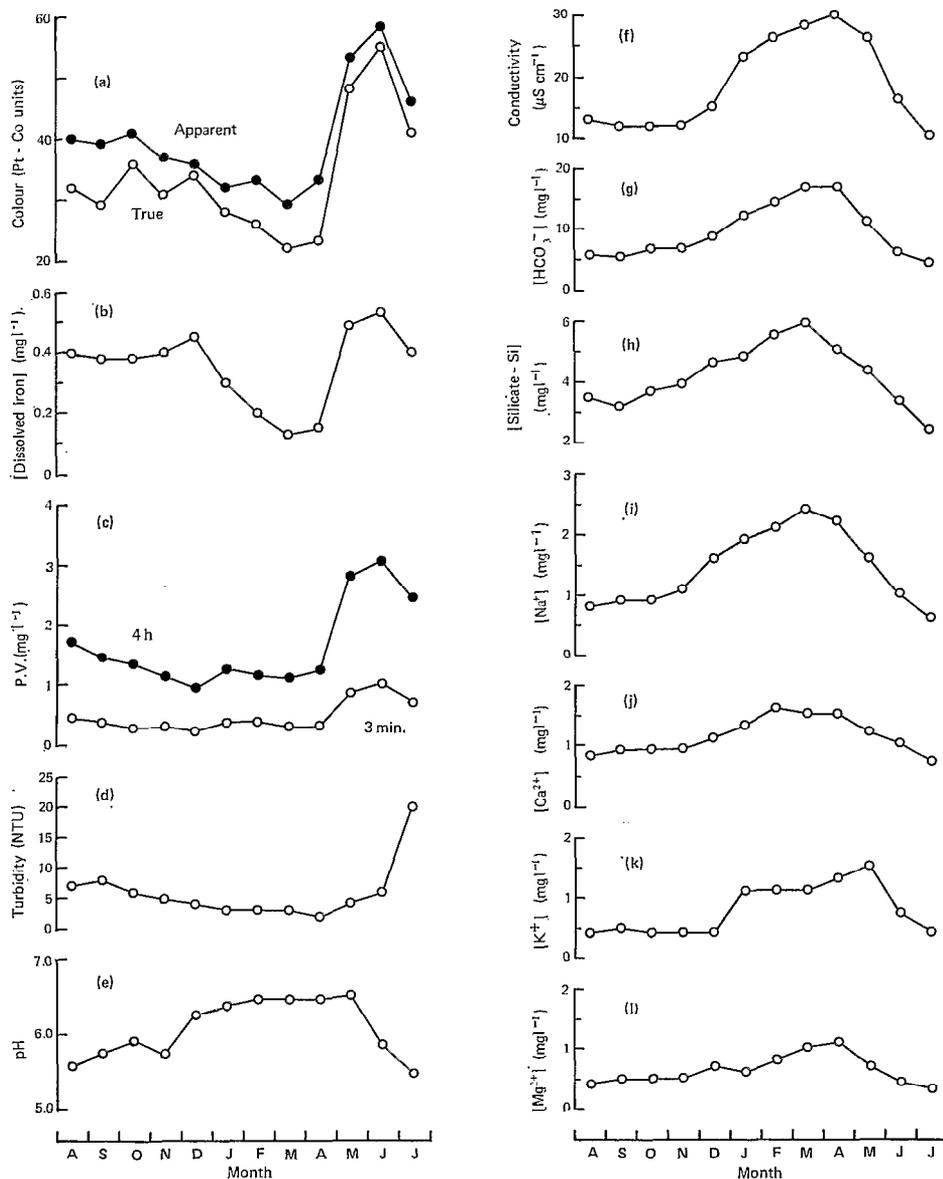
FIG. 3. — Monthly variation of water quality variables associated with surface run-off (a to d) and dry season « concentration » (e to l). Circles represent the means of results at two stations

Variations mensuelles des variables de qualité de l'eau associées à l'écoulement de surface (a à d) et aux « concentrations » de saison sèche (e à l). Les cercles représentent les moyennes des résultats des deux stations

TABLE I

Levels of dissolved oxygen and free CO_2 of the R. Jong over the study period. Figures represent mean values of results at two stations

Teneurs en oxygène dissous et en CO_2 libre de la rivière Jong durant la période étudiée. Les chiffres représentent les valeurs moyennes des résultats des deux stations

Determinand	Unit	A	S	O	N	D	J	F	M	A	M	J	J
Dissolved oxygen	mg l⁻¹	NR*	NR*	6.2	6.3	6.1	6.0	6.2	6.3	5.8	6.2	5.6	6.1
Free CO_2	mg l⁻¹	8.1	9.7	9.9	7.7	6.9	6.1	6.5	6.3	6.9	7.1	6.8	8.0

* NR = No Result.

always taken in the early morning and could account for this.

The following ions did not occur in any sample, at any time, in concentrations above the detection limits of the methods employed (given in parenthesis after each ion): Cl^- (1.0 mg l^{-1}), SO_4^{2-} (2.5 mg l^{-1}), F^- (0.1 mg l^{-1}), Mn^{2+} (0.1 mg l^{-1}), Cu^{2+} (0.1 mg l^{-1}), NH_4^+ (0.2 mg l^{-1}), NO_2^- (0.2 mg l^{-1}), NO_3^- (0.4 mg l^{-1}) and phosphate-P (0.01 mg l^{-1}).

Conductivity values of rain-water declined from an average reading of 9.3 μS cm^{-1} ($\bar{x}$ of 7 samples, 95 % confidence limits ±3.6 μS cm^{-1}, range 3.0 to 15.1 μS cm^{-1}) in May to 3.2 μS cm^{-1} ($\bar{x}$ of 22 samples, 95 % confidence limits ±0.6 μS cm^{-1}, range 0.9 to 6.0 μS cm^{-1}) in July.

DISCUSSION

The distinct differentiation between seasons in Sierra Leone provides an excellent opportunity for the study of factors associated with tropical seasonality. In this study, the seasonality of water quality of a major river was investigated. The majority of the water quality variables studied can be assigned to one of two seasonal influences: dry season "concentration" and wet season (particularly early wet season) run-off.

Variables which are influenced primarily by the effect of concentration of river volume during the dry season are considered intrinsic variables and would be expected to exhibit a significant inverse correlation with river volume. In the absence of data on flow, or discharge, of the R. Jong, and using river depth (calculated from data recorded herein for river levels and based on a minimum depth in March of 1.2 m) as an index of river volume, the following variables were seen to be associated with dry season "concentration" (the linear correlation coefficient, r, between monthly means of each variable and the reciprocals of monthly river depth readings is given in parenthesis; each is significant at p < 0.001): conductivity (0.973), $[HCO_3^-]$ (0.957), $[Na^+]$ (0.936), $[Ca^{2+}]$ (0.933), $[Mg^{2+}]$ (0.898), $[K^+]$ (0.890) and silicate-Si concentration (0.865). The major ions of the R. Jong appear, therefore, to be derived principally from the sediment of the main river bed.

pH values were also significantly correlated with reciprocal river depth readings, i.e. levels of H^+ were directly correlated with river depth. $[H^+]$ is thus considered an extrinsic variable, H^+ being derived principally from rain-water (the range of pH values for 10 samples of rain-water collected in July 1979 was 5.4-6.0).

Variables which are influenced primarily by the effect of rainfall run-off are also considered as extrinsic; these show no significant correlation with variation in river depth. They are marked by an increase in levels during the first period of the wet season, followed by a gradual decline. Colour, dissolved iron concentration, permanganate values and turbidity are considered extrinsic variables associated with this effect.

The very close association between levels of dissolved iron, colour and permanganate values over the period April to July suggests a direct relationship (apart from the common influence of early rainfall), possibly arising from complex-formation of coloured organic material with iron dissolved from lateritic soils by newly extant, acidic, ephemeral streams and the passage of this complexed material into the river. Certainly, the re-emergence of ephemeral streams in the drainage basin is implicated as the major factor influencing levels of these extrinsic variables in the R. Jong.

The generally low permanganate values recorded and the ratios of 4 h/3 min values (mean = 3.4) are typical of an unpolluted water (KLEIN, 1959).

Perhaps the most important feature of the water quality of the R. Jong is the exceptionally low ionic content. This is most marked during the wet season, when the conductivity approaches that of rainfall, and reflects the very advanced state of weathering of local soils. As the amount of rainfall in Sierra Leone tends to increase across the country in a South-Westerly direction (BOWDEN, 1980), it is probable that water sources nearer to the coast than Njala will possess even lower ionic contents. This is particularly relevant as, with the exception of Lake Sonfon, all the lakes of Sierra Leone occur in the coastal region. Thus, whilst GREEN (1979) observed a conductivity of 43 μS cm^{-1} for the out-flowing water of L. Sonfon in April 1976, GERRARTH and DENNY (1979) recorded conductivity values as low as 8.1 μS cm^{-1} for the coastal lakes (sampled in March 1976). In the absence of marine intrusion, these latter values may well be lower in the wet season. At such levels, the concentrations of some inorganic nutrients could indeed be expected to be growth-limiting and an investigation into the primary productivity and species diversity of these lakes should be performed.

Rain-water conductivity, measured at Njala, declined from dry season to wet season, reaching very low levels by July. Relatively high dry season readings have been recorded previously (GERRARTH and DENNY, 1979); these have probably been caused by the solution of chemicals from atmospheric smoke and dust generated by the traditional farming practice of bush-burning which occurs at this time.

The very low concentrations of ions, particularly bicarbonate, in the R. Jong result in this river

possessing a very poor buffering capacity. If this pattern is confirmed for the other major rivers of Sierra Leone (and neighbouring countries influenced by a similar climate), then urban, industrial and agricultural development in the region may have serious deleterious consequences for an aquatic biota possibly already limited by nutrient defi-

ciencies, if such development involves either direct river pollution or air pollution liable to lead to an increase in the acidity of rain-water.

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