

SEASONAL VARIATIONS OF THE PHYTOPLANKTON IN THE WHITE NILE AT KHARTOUM, SUDAN

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Abstract: The variation in numbers of the major planktonic algae in the surface water of the White Nile at Khartoum has been studied over a period of one year (May 2000–May 2001). In terms of biomass, the phytoplankton was dominated during the cold and warm months by diatoms and blue–green algae (cyanobacteria) and to lesser extent green algae. In terms of number of species chlorophycean algae outnumbered all other groups. Euglenophyceae and Dinophyceae were meagerly represented in the open water. No member of the Xantophyceae or Chrysophyceae was encountered in the plankton of the White Nile. *Aulacoseira granulata* and its variety *angustissima* and *Anabaena flos–aquae* f. *spiroides* were the most important taxa. *Planktolyngbya* (formerly *Lyngbya*) *limnetica*, *Anabaenopsis cunningtonii* and *A. tanganyikae*, which constituted important components of the phytoplankton in the early 1950s, either disappeared or maintained themselves in reduced numbers during the present study

Keywords: Sudan, White Nile, tropical rivers, phytoplankton, diatoms, cyanobacteria *Aulacoseira granulata*, *Anabaena flos-aquae*.

Introduction

Brook (1954) presented a systematic account of the phytoplankton of the White Nile. Brook and Rzóška (1954) studied the effect of Gebel Aulia dam on the development of the phytoplankton and zooplankton in the White Nile. Rzóška *et al.* (1955) studied the seasonal plankton development in the White Nile near Khartoum. Prowse and Talling (1958) gave a detailed account of the seasonal growth and succession of plankton algae in the White Nile from 1949 to 1956. Later during 1968–1970 Sinada and Abdel Karim (1984a) studied the phytoplankton of the White Nile near Khartoum and attempted to relate the periodicities of major planktonic algae to certain environmental factors.

Sinada and Abdel Rahman (2012) described in detail the water quality of the White Nile at one location near Khartoum. The present paper deals with the seasonal variations of the major phytoplankton species encountered in the White Nile at the same location during the

*Received July 20, 2015 * Published Aug 2, 2015 * www.ijset.net*

same period, May 2000–May 2001. Therefore in this paper an attempt is made to relate the periodicities of the major members of the phytoplankton to certain physical and chemical factors in the White Nile at Khartoum. Comparisons with findings from previous studies undertaken during the second half of the last century on the same river and studies undertaken elsewhere are made wherever relevant. An updated checklist of the phytoplankton of the White Nile at Khartoum will be published in the future.

Materials and Methods

The sampling site was described by Sinada and Abdel Rahman (2012). Phytoplankton samples were taken at two-week intervals from May 2000 to May 2001. Unstrained water samples were collected from below the surface and preserved in Lugol's solution. Depending on the density of the phytoplankton, aliquots of 2–10 mL were sedimented in chambers by standing for 4 h following the procedure described by Lund et al. (1958). Algae present were enumerated on a Zeiss inverted microscope at a magnification of $\times 200$. Each filament was counted as a unit. The average number of cells per filament was determined from a large number of specimens. Results of phytoplankton biomass were expressed as cells mL^{-1} and as biovolumes ($\mu\text{m}^3 \text{mL}^{-1}$). Biovolumes were calculated from cell dimensions using formulae from Hillebrand et al. (1999).

To determine the species composition of the phytoplankton, net samples were obtained by hand towing a phytoplankton net. The haul was preserved in 4% formalin and left undisturbed until examination.

Results

The phytoplankton of the White Nile was constituted in the main by Bacillariophyceae and Cyanobacteria and to lesser extent Chlorophyceae. In terms of number of species, chlorophycean algae outnumbered all other groups. In terms of biomass Euglenophyceae and Dinophyceae were meagerly represented in the open water. No member of the Xantophyceae or Chrysophyceae was encountered in the plankton of the White Nile.

Seasonal variations of the major components of the phytoplankton

In the White Nile, species belonging to Bacillariophyceae and Cyanobacteria dominated the phytoplankton. Chlorophyceae showed appreciable growth at one time or another.

Bacillariophyceae:

Several diatoms contributed appreciably to the total phytoplankton at different times of the year, thus: *A. granulata* var. *angustissima* (O. Müller) Simonsen, *A. distans* (Ehrenberg) Simonsen, *Aulacoseira nyassensis* var. *victoriae* (O. Müller) Simonsen, *A. ambigua* ?,

Cyclotella spp., *Ulnaria* (formerly *Synedra*) *acus* (Kützing) M. Aboal, *Fragilaria* spp., and *Navicula* spp. *Cocconeis placentula* Ehrenberg was encountered in the net samples in appreciable numbers.

***Aulacoseira granulata* (Ehrenberg) Simonsen, (Fig. 1a)**

A. granulata was the second major species in the White Nile in the present study contributing an annual average of 17.6% to total algal biomass and 19.6% of total diatom biomass. Data on the seasonal variation in *A. granulata* on a biovolume basis are shown in Fig. 1a. The densities of this diatom varied between a minimum of $4.3 \times 10^3 \mu\text{m}^3 \text{mL}^{-1}$ (3 cells mL^{-1}) and a maximum of $17.5 \times 10^5 \mu\text{m}^3 \text{mL}^{-1}$ (1224 cells mL^{-1}) with an annual average of $225.0 \times 10^3 \mu\text{m}^3 \text{mL}^{-1}$ (159 cells mL^{-1} Fig. 1a). This maximum range of growth coincided with low range of silica (3.5–11.5 mg $\text{SiO}_2 \text{L}^{-1}$), which is an indication of uptake of this nutrient by the diatom and other diatoms

A noticeable decrease in nitrate from 230 to $<100 \mu\text{g NO}_3\text{-N L}^{-1}$ was associated with the increase in the density of *Aulacoseira granulata* from 3.0×10^5 to $17.5 \times 10^5 \mu\text{m}^3 \text{mL}^{-1}$ (208–1224 cells mL^{-1}). A similar result was found by Abdel Karim and Saeed (1978) in the Gebel Aulia dam reservoir 45 km south Khartoum.

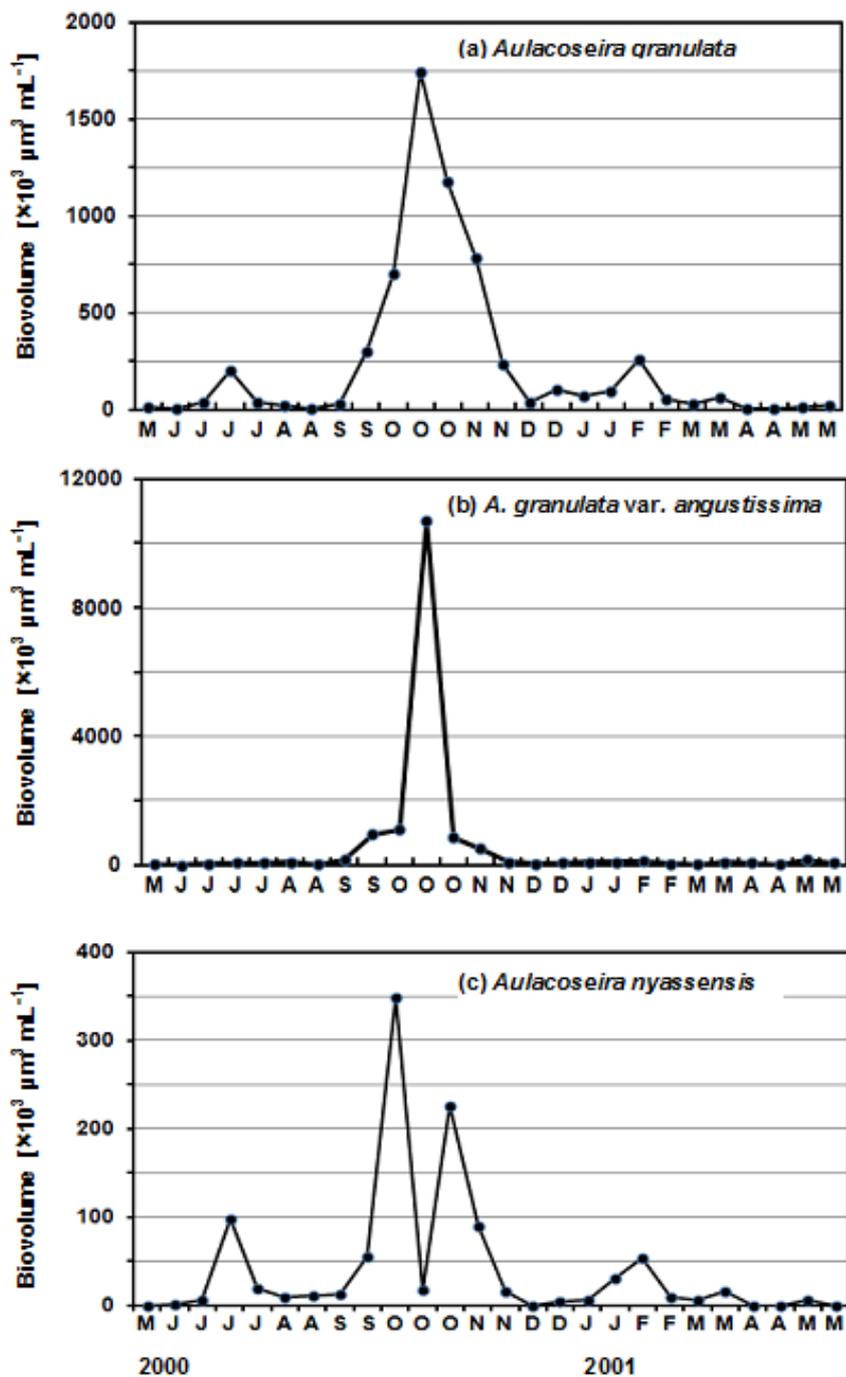


Fig. 1 Seasonal changes in the densities of (a) *Aulacoseira granulata*, (b) *A. granulata* var. *angustissima* and (c) *A. nyassensis* in the surface water of the White Nile during May 2000-May 2001

***Aulacoseira granulata* var. *angustissima* (O. Müller) Simonsen, (Fig. 1b)**

Populations of *A. granulata* were heterogeneous with respect to cell size. The more narrow and long cells were assigned to the variety *angustissima* (Prowse and Talling, 1958). *A. granulata* var. *angustissima* was the most dominant alga during the present study contributing more than 45% of the total algal biomass, more than 50% of diatom biomass and 66.3% of Centrales biomass. Data on the seasonal variation in cell volumes of this variety are presented in Fig. 1b. The biovolume of this alga varied between $3.1 \times 10^3 \mu\text{m}^3 \text{mL}^{-1}$ and $10.7 \times 10^6 \mu\text{m}^3 \text{mL}^{-1}$ ($7\text{--}24440 \text{ cells mL}^{-1}$) with an annual average of $5.8 \times 10^3 \mu\text{m}^3 \text{mL}^{-1}$ ($1331 \text{ cells mL}^{-1}$). Like *A. granulata*, the variety maintained low numbers from May to August. The maximum growth occurred in mid-October when a peak of $10.7 \times 10^6 \mu\text{m}^3 \text{mL}^{-1}$ ($24440 \text{ cells mL}^{-1}$) was recorded at the same time as the peak of *A. granulata*. It is interesting to note that the profuse growth of the variety *angustissima* declined abruptly two weeks later and the diatom maintained low biomass throughout winter and summer, whereas it took *A. granulata* about eight weeks to record the minimum winter value (see Figs. 1a, b). *A. granulata* var. *angustissima* favours the same conditions as *A. granulata* (see above). It is tempting to suggest that the broad species is more resistant to conditions unfavorable to the narrow form, a suggestion in contradiction with that of Prowse and Talling (1958). The latter authors found that the proportion of narrow and elongated cells in the total *Aulacoseira* population is generally small during periods of population increase, becoming larger during population decline. They suggest that the narrow form is more resistant to conditions unfavorable to the species.

***Aulacoseira nyassensis* var. *victoriae* (O. Müller) Simonsen (Fig. 1c)**

Data on the seasonal variation of *A. nyassensis* expressed as cell volume are shown in Fig. 1c. Its biomass varied between $0.9 \times 10^3 - 34.8 \times 10^4 \mu\text{m}^3 \text{mL}^{-1}$, average $38.5 \times 10^3 \mu\text{m}^3 \text{mL}^{-1}$ ($1\text{--}407 \text{ cells mL}^{-1}$) with contribution of 3% of total biomass and over 3% of total diatom biomass. Two peaks of $34.8 \times 10^4 \mu\text{m}^3 \text{mL}^{-1}$ ($407 \text{ cells mL}^{-1}$) and $22.6 \times 10^3 \mu\text{m}^3 \text{mL}^{-1}$ ($264 \text{ cells mL}^{-1}$) were recorded during October (Fig. 1c). *A. nyassensis* var. *victoriae* maximum growth in the range of $5.5\text{--}34.8 \times 10^4 \mu\text{m}^3 \text{mL}^{-1}$ ($64\text{--}407 \text{ cells mL}^{-1}$) coincided with low concentrations of silica in the range of $3.5\text{--}11.5 \text{ mg SiO}_2 \text{ l}^{-1}$.

***Aulacoseira distans* (Ehrenberg) Simonsen**

The biomass of *A. distans* varied between 0.3×10^3 and $6.4 \times 10^4 \mu\text{m}^3 \text{mL}^{-1}$ ($2\text{--}1080 \text{ cells mL}^{-1}$) except in June when it was virtually absent. The annual average biomass was $18.9 \times 10^3 \mu\text{m}^3 \text{mL}^{-1}$ ($124 \text{ cells mL}^{-1}$). It contributed 1.5% to total phytoplankton biomass and 1.7% of the

total diatom biomass. The highest peak of $16.4 \times 10^4 \mu\text{m}^3 \text{ mL}^{-1}$ (1080 cells mL^{-1}) occurred in early October, declined abruptly to $14.6 \times 10^3 \mu\text{m}^3 \text{ mL}^{-1}$ (96 cells mL^{-1}) in November. This diatom was first reported in the White Nile by Sinada and Abdel Karim (1984a) when they studied the river during 1968–1970. They observed maximum development of this diatom during lower temperature and therefore regarded the diatom as a winter species. This relationship is not evident in the present study. However, in conformity with Sinada and Abdel Karim (1984a) *A. distans* preponderated during period of low nutrients. Its maximum growth $16.4 \times 10^4 \mu\text{m}^3 \text{ mL}^{-1}$ (1080 cells mL^{-1}) coincided with lower concentrations of nutrients ($0.07 \text{ mg PO}_4\text{-P L}^{-1}$, $0.13 \text{ mg NO}_3\text{-N L}^{-1}$ and $3.5 \text{ mg SiO}_2 \text{ L}^{-1}$).

***Aulacoseira ambigua* (Grun.) Simonsen**

An *Aulacoseira* tentatively identified as *A. ambigua?* showed appreciable growth during the present study though not as abundant as the previous *Aulacoseira* spp., contributing only 0.3% to the total phytoplankton biomass. The abundance of this diatom varied between $2.6 \times 10^3 - 43.8 \times 10^3 \mu\text{m}^3 \text{ mL}^{-1}$ (12 – 204 cells mL^{-1}) with an annual average of $3.6 \times 10^3 \mu\text{m}^3 \text{ mL}^{-1}$ (57 cells mL^{-1}). It was virtually absent during the rainy season and summer. High temperature was perhaps the major factor adversely affecting the growth of this diatom.

***Navicula* spp. (Fig. 2a)**

The genus *Navicula* was represented in the White Nile by more than one species which were counted together. The biomass of *Navicula* fluctuated between 3.6×10^3 and $87.6 \times 10^4 \mu\text{m}^3 \text{ mL}^{-1}$ (3–731 cells mL^{-1}) with an annual average of $14.0 \times 10^4 \mu\text{m}^3 \text{ mL}^{-1}$ (117 cells mL^{-1} ; Fig. 2a), contributing 11% to total phytoplankton biomass and more than half of the total Pennales biomass (52.3%). *Navicula* spp. exhibited strong correlation with silica. The maximum growth which varied between 5.4 and $8.8 \times 10^5 \mu\text{m}^3 \text{ mL}^{-1}$ (452–731 cells mL^{-1}) coincided with low silica concentrations $3.5\text{--}11.5 \text{ mg SiO}_2 \text{ L}^{-1}$, a condition which perhaps indicates consumption by this diatom.

***Ulnaria acus* (Kützing) M. Aboal and *U. acus* var. *radians* (Fig. 2b)**

The genus *Ulnaria* (formerly *Synedra*) was represented by *Ulnaria acus* and its variety *radians* which were counted together. They contributed 2.0% to the total biomass, 2.2% of diatom biomass and 4.5 of Pennales biomass. The biomass of *Ulnaria* varied between 3.0×10^3 and $27.1 \times 10^4 \mu\text{m}^3 \text{ mL}^{-1}$ (1–158 cells mL^{-1}) with annual average $25.5 \times 10^3 \mu\text{m}^3 \text{ mL}^{-1}$ (14 cells mL^{-1} Fig. 2b). There is a similarity between the seasonal variation of *Ulnaria* and *Fragilaria*.

U. acus var. *radians* showed appreciable growth in the present study of the White Nile as was reported by Prowse and Talling (1958). Sinada and Abdel Karim (1984a) did not record any appreciable growth of this diatom in the White Nile.

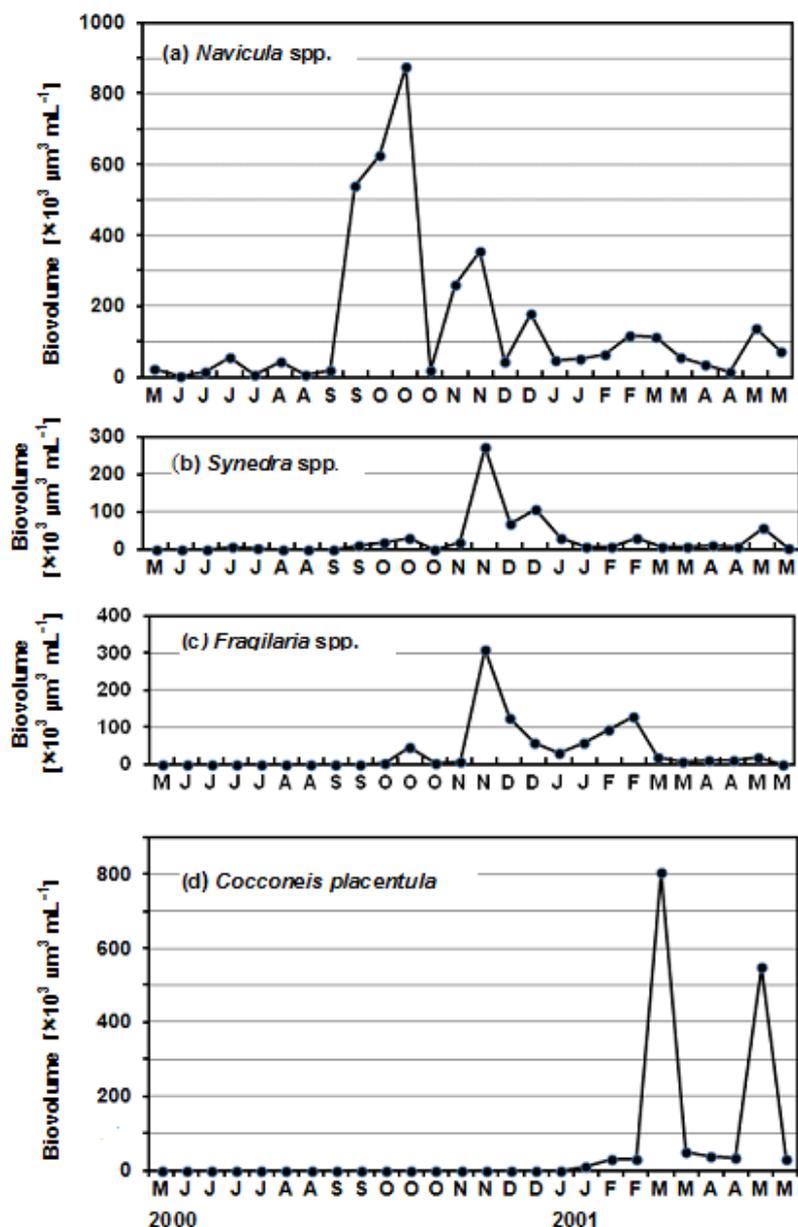


Fig. 2 Seasonal changes in the densities of (a) *Navicula* spp., (b) *Synedra* (*Ulnaria*) spp., (c) *Fragilaria* spp. and (d) *Cocconeis placentula* in the surface water of the White Nile during May 2000-May 2001

Fragilaria spp. (Fig. 2c)

The genus *Fragilaria* was represented by several species, thus: *F. capucina*, *F. crotonensis*, *F. producta* and an unidentified species of *Fragilaria*. All species of *Fragilaria* were counted together. *F. capucina* was more abundant than the other species. Data on the seasonal

variation in *Fragilaria* expressed volume are presented in Fig. 2c. It contributed 3.3% to the total phytoplankton biomass, 3.7% of diatom and 15.9% of Pennales biomass. Its biomass was in the range $2.9\text{--}3.9 \times 10^3 \mu\text{m}^3 \text{mL}^{-1}$ ($1\text{--}106 \text{ cells mL}^{-1}$) with an annual average of $42 \times 10^3 \mu\text{m}^3 \text{mL}^{-1}$ (12 cells mL^{-1}).

Maximum value of $31.0 \times 10^4 \mu\text{m}^3 \text{mL}^{-1}$ ($106 \text{ cells mL}^{-1}$) coincided with the lowest concentration of nitrate ($0.05 \text{ mg NO}_3\text{-N l}^{-1}$) and low concentration of silica ($6.5 \text{ mg SiO}_2 \text{ l}^{-1}$) in late November. When nitrate increased to $0.23 \text{ mg NO}_3\text{-N l}^{-1}$ in late December the total biomass decreased to $5.6 \times 10^4 \mu\text{m}^3 \text{mL}^{-1}$. It seems that the abundance of *Fragilaria* was adversely affected by high temperature but the correlation of this factor was not strong as with nitrate, which showed an inverse relationship.

***Cocconeis placentula* (Fig. 2d)**

Cocconeis was common in running water and mildly alkaline streams (Blum, 1960). Data on the seasonal variation of *Cocconeis placentula* and its variety *lineata* expressed as cell volume are shown in Fig. 2d. It contributed 4.7% to the total biomass. In terms of biomass it was one of the major Pennales diatoms, contributing 22.4% of Pennales biomass but being particularly unimportant during most part of the year. Its presence in the open water was confined to the period February–May when it varied between $10 \times 10^3\text{--}8 \times 10^5 \mu\text{m}^3 \text{mL}^{-1}$ ($10\text{--}804 \text{ cells mL}^{-1}$) and showed an annual average of $60 \times 10^3 \mu\text{m}^3 \text{mL}^{-1}$ (60 cells mL^{-1}). During period of maximum growth in summer, it attained two peaks of $8.0 \times 10^5 \mu\text{m}^3 \text{mL}^{-1}$ ($804 \text{ cells mL}^{-1}$) and $5.5 \times 10^5 \mu\text{m}^3 \text{mL}^{-1}$ ($548 \text{ cells mL}^{-1}$) in March and May respectively. These peaks coincided with declining concentrations of silica to 9.6 and 7.9 mg $\text{SiO}_2 \text{ l}^{-1}$ respectively.

It is apparent that this diatom favours periods of high temperatures since it was virtually absent during cold months. The maximum growth of $8.0 \times 10^5 \mu\text{m}^3 \text{mL}^{-1}$ ($804 \text{ cells mL}^{-1}$) and $5.5 \times 10^5 \mu\text{m}^3 \text{mL}^{-1}$ ($548 \text{ cells mL}^{-1}$) which was maintained during summer coincided with 24.0 and 26.2°C. The minimum total biomass $10 \times 10^3 \mu\text{m}^3 \text{mL}^{-1}$ (10 cells mL^{-1}) occurred when temperature was 15.5°C.

It is surprising to encounter *Cocconeis* in water samples collected from the surface of the river. *Cocconeis* is well known as an attached alga. Zencir et al. (2011) found *Cocconeis placentula* in high densities in samples in the open waters in the phytoplankton of Kirmir River and its tributaries, Ankara, Turkey. It is not unreasonable to assume that some part of the increase in the open water may be due to the resuspension of cells which were living attached to the mud surface at the sampling site.

Cyanophyceae (Cyanobacteria)

Two genera belonging to Cyanobacteria contributed appreciably to the total phytoplankton biomass, thus: *Oscillatoria*, and *Anabaena*.

Anabaena flos-aquae (Lyngbye) Brébisson f. *spiroides* (Woron.) Elenkin (Fig. 3a)

Anabaena flos-aquae was the major component of blue-green algae (cyanobacteria) in the White Nile constituting 66.9% of total biomass of blue-green algae and 6.8% of total phytoplankton biomass. It was the first blue-green alga to appear in appreciable number after the wet season in October after a period of absence during the rainy season. Its growth varied between $1.2 \times 10^3 \mu\text{m}^3 \text{mL}^{-1}$ and $12.5 \times 10^5 \mu\text{m}^3 \text{mL}^{-1}$ ($25 - 24564 \text{ cells mL}^{-1}$) with an annual average of $87.1 \times 10^3 \mu\text{m}^3 \text{mL}^{-1}$ ($1726 \text{ cells mL}^{-1}$). From October to November it varied between 10.6×10^4 and $12.5 \times 10^5 \mu\text{m}^3 \text{mL}^{-1}$ ($2098 - 24564 \text{ cells mL}^{-1}$) with an average of $49.6 \times 10^4 \mu\text{m}^3 \text{mL}^{-1}$ ($9777 \text{ cells mL}^{-1}$) attaining its maximum in late October. Sinada and Abdel Karim (1984a) and Rzoska *et al.* (1955) observed this peak in mid-November. In winter the peak declined to an average $9.2 \times 10^3 \mu\text{m}^3 \text{mL}^{-1}$. The periodicity of *A. flos-aquae* appears to be independent of temperature since it preponderated at both high and low temperatures. It dominated the plankton when the nutrients were appreciably high ($0.1 - 0.13 \text{ mg PO}_4\text{-P L}^{-1}$, $0.13 - 0.22 \text{ mg NO}_3\text{-N L}^{-1}$ and $0.13 - 0.35 \text{ mg Fe L}^{-1}$).

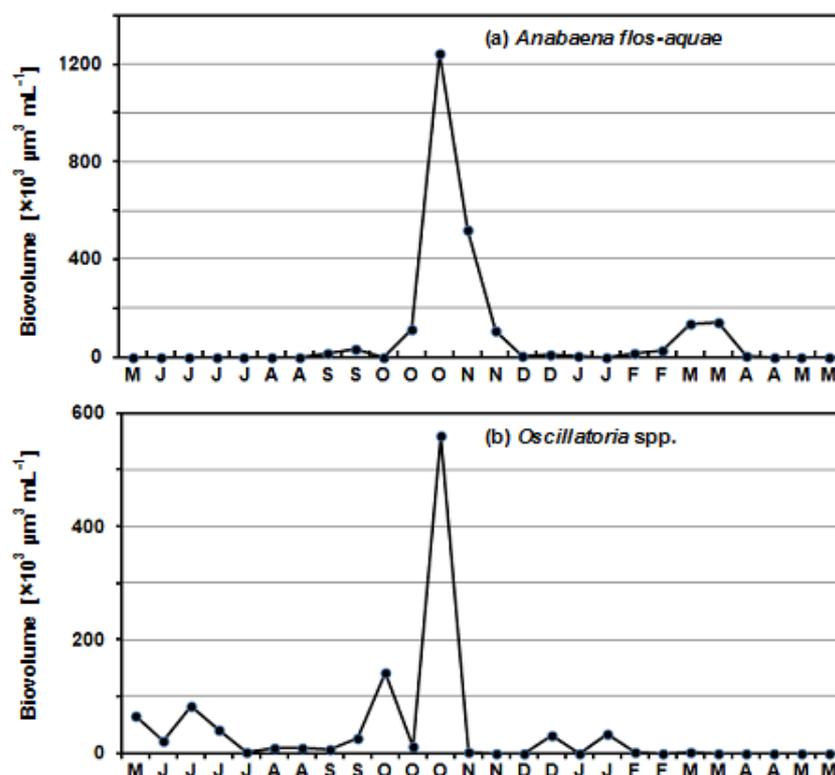


Fig. 3 Seasonal changes in the densities of (a) *Anabaena flos-aquae* f. *spiroides* and (b) *Oscillatoria* spp. in the surface water of the White Nile during May 2000-May 2001

***Oscillatoria* spp. *O. agardhii* Gomont, *O. limnetica* Lemmermann and *O. tenuis* C. Agardh ex Gomont (Fig. 3b)**

Oscillatoria was the second major genus of Cyanobacteria, contributing 29.7% to total cyanophycean biomass and 3% to total phytoplankton biomass. It was represented by 3 species: *O. agardhii*, *O. limnetica*, and *O. tenuis*. The first two were more abundant than the latter. Fig. 3b shows that the total biomass varied between 1.2×10^3 – $56.0 \times 10^4 \mu\text{m}^3 \text{mL}^{-1}$ (30–12180 cells mL^{-1}) with an annual average of $38.6 \times 10^3 \mu\text{m}^3 \text{mL}^{-1}$ (766 cells mL^{-1}). Throughout winter it maintained low numbers (average $7.6 \times 10^3 \mu\text{m}^3 \text{mL}^{-1}$ 405 cells mL^{-1}). Like *Anabaena flos-aquae*, *Oscillatoria* seems to develop its maximum growth when the nutrients were relatively high (0.1–0.13 mg $\text{PO}_4\text{-P L}^{-1}$ and 0.13–0.31 mg $\text{NO}_3\text{-N L}^{-1}$).

Chlorophyceae

Chlorophycean algae rarely contributed appreciably to the total algal biomass. Quantitatively green algae were far less important than diatoms and cyanobacteria contributing < 0.5% to total biomass. However, in terms of species this class of algae was common in the plankton of the White Nile contributing more species than any other class. The number of taxa belonging to green algae collected during the present study was 78 species and varieties, belonging to 37 genera.

Only two genera contributed appreciably to the total algal biomass with 0.4% of the total annual algal biomass being due to *Scenedesmus* spp. and *Crucigenia* spp.

General discussion: Relationship of algal densities to environmental factors:

Inorganic nitrogen and phosphorus were thought to be the major nutrients enhancing primary production even before their estimation was possible. Although they are present in little concentrations in water they play a major part in production, periodicity and determination of species composition.

Orthophosphates are the main source of inorganic phosphorus in aquatic habitats. Since they are usually present in suboptimal concentrations in some aquatic habitats they can be important as limiting factor in a subordinate role to other nutrients (Talling 1965). It is well established that in addition to its utilization, inorganic phosphorus is stored inside algal cells in excess of their immediate needs (Kuenzler and Kuetchum 1962).

During the present study, phosphate did not seem to be a limiting factor in the White Nile at any time in the present study, since it was always present in adequate supply (0.017–0.3 mg $\text{PO}_4\text{-P L}^{-1}$) as found by Sinada and Abdel Karim (1984b). Periods with high concentrations

of phosphate were dominated by cyanobacteria while diatoms were prominent during periods of low concentration of phosphate which was attributable to its uptake by diatoms.

Nitrogen is an essential cellular constituent needed by all living organisms. Gaseous nitrogen is utilized only by a small group of algae, the heterocystous nitrogen fixing cyanobacteria. Other sources of nitrogen are inorganic nitrogen compounds such as nitrate and ammonia. It is possible that the developments of large algal biomass deplete the water of its nitrogen salts and so the change in algal densities are most obvious when nutrient limitation is severe. In aquatic habitats in general the amount of available nitrogen is larger than that of phosphorus. The nitrogen content of algae is much higher than that of phosphorus content. There are some investigations which indicate the importance of nitrogen as a limiting factor. Staub cited in Lund (1965) showed that nitrogen rather than phosphorus limited the massive blooms of *Oscillatoria rubescens* in the Zurichsee. Nitrogen seemed to be the major factor limiting the production in lakes and reservoirs in central Africa because of poverty of nitrogen in many tropical soils (Prowse and Talling 1958; Talling 1965). Low concentrations of nitrate do not necessarily imply lack of nitrogen. Heterocystous cyanobacteria like *Anabaena* spp. may fix gaseous nitrogen.

Summary: Seasonal succession of the major phytoplankters in the White Nile

Most of the major planktonic diatoms showed similar patterns of periodicities. *Aulacoseira granulata*, *A. granulata* var. *angustissima*, *A. distans* and *Navicula* spp. dominated the phytoplankton at the end of the rainy season. The above-mentioned diatoms exhibited their peaks in mid- October simultaneously. As the diatom peaks were declining, the main blue-green algae *Anabaena flos-aquae* and *Oscillatoria* spp. showed sharp increase attaining their maxima at the same time at the end of October. No sooner had the latter blue-green algae declined, than *Ulnaria* spp. and *Fragilaria* spp. attained their peaks in November and December respectively. Throughout winter (January-February) minimum numbers of virtually all algae were maintained. In early March *Cocconeis* sp. peaked in the open water but was replaced in late March by a small summer peak of *Anabaena flos-aquae*. *Cocconeis* sp. attained a second but a smaller summer peak in May.

Acknowledgements

The authors wish to express their gratitude to Mr. R. Ross, Department of Botany, Natural History British Museum, for the identification of *Melosira* (now *Aulacoseira*) *distans*. The funding support from University of Khartoum is appreciated.

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