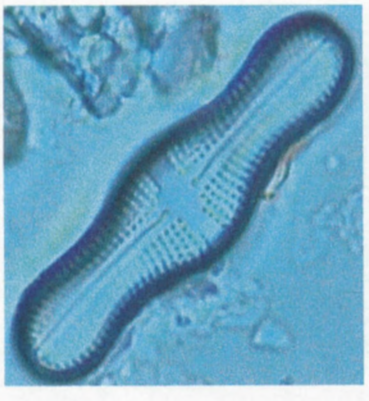
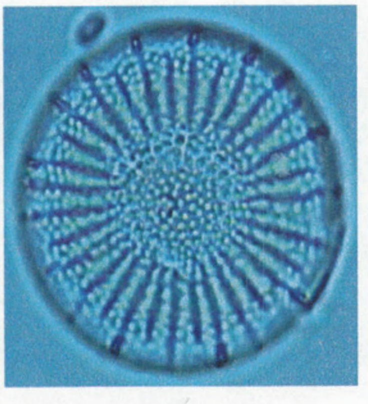
VRIJE UNIVERSITEIT BRUSSEL

Faculty of Science
Laboratory of General Botany and Nature Management

Assessment of water quality using diatoms as bio-indicators in catchments of Lake Victoria, Kenya

Henry B. O. Lung'ayia





Submitted in fulfilment of the requirements for the degree Doctor of Science (Ph.D.)

Promoter: Prof. Dr. Ludwig Triest

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Dedication

To

My wife Pamela

and children Edwin and Gloria

DECLARATION

I hereby declare that the thesis entitled, "Assessment of water quality using diatoms as bio-indicators in catchments of Lake Victoria, Kenya" has been submitted for the degree of Doctor of Philosophy in Science to the Vrije Universiteit Brussel, Brussels, Belgium. It is a record of my original piece of research work carried out in the Laboratory of General Botany and Nature Management of Vrije Universiteit Brussel. No part of this thesis has been submitted for any other degree or diploma.

June 2002 *(Henry B.O. Lung'ayia)*

CERTIFICATE

This is to certify that the thesis entitled "Assessment of water quality using diatoms as bio-indicators in catchments of Lake Victoria, Kenya" submitted for the degree of Doctor of Philosophy in Science to the Vrije Universiteit Brussel, Brussels, Belgium, is a record of bonafide research work carried out by H.B.O. Lung'ayia under my supervision and guidance and that no part of this thesis has been submitted for any other degree or diploma.

June 2002 *(Prof. Dr. Ludwig Triest)*
Promoter

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Samenvatting

In deze verhandeling werd een beschrijving gemaakt van de soortensamenstelling en karakteristieken van de epilithische diatomeeën in de rivieren Nyando, Kibos en Kisat die uitmonden in het Kenyaanse gedeelte van het Victoria-meer. De waterkwaliteit in de rivieren werd geëvalueerd zowel aan de hand van de diatomeeëngegevens op zich als aan de hand van diezelfde gegevens in relatie tot de omgevingsvariabelen. Ook de distributie van diatomeeën in het oppervlaktewater van het Victoriameer werd onderzocht in relatie tot omgevingsvariabelen. De doelstelling hiervan was het testen van het potentiële belang van diatomeeën in het vaststellen van de "ecologische" waterkwaliteit in het Victoria-basin.

Eerst werden soortensamenstelling, soortenrijkdom en soortendiversiteit van de epilithische diatomeeën in de Nyando, de Kibos en de Kisat onderzocht. 224 diatomeeëntaxa (218 soorten), behorende tot 32 genera werden geobserveerd in de drie rivieren. De maximum soortendiversiteit werd gevonden in de minder vervuilde rivier Kibos (bereik 1.3 – 3.4), gevolgd door de intermediair vervuilde rivier Nyando (1.6 – 2.9). De Kisat-rivier met de grootste vervuiling had de laagste diversiteit (0.4 – 2.5). De soortenrijkdom en soortendiversiteit waren significant gecorreleerd met de hoogte, breedte van het rivierkanaal, diepte, stroomsnelheid, debiet en opgeloste zuurstof. Eutrofiëring, een verhoging van het ionengehalte en de instroom van organische componenten verminderden de diversiteit stroomafwaarts, waar enkele pollutietolerante soorten, zoals *Nitzschia palea*, de gemeenschap domineren, dit vooral in de Kisat. Diversiteitsindices voor diatomeeën bleken belangrijk te zijn voor het monitoren van veranderingen in de hele diatomeeëngemeenschap als reactie op veranderingen in de waterkwaliteit.

Daarna werden de gewogen gemiddelden van gekende ecologische indicatorwaarden voor diatomeeën gebruikt voor de determinatie van de waterkwaliteit in de Nyando, de Kibos en de Kisat. De ecologische indicatorwaarden omvatten saprobiteit, zuurstofbehoeften, trofische toestand, stikstofopnamemetabolisme, vochtigheid, pH en saliniteit. Taxa met een gekende ecologische indicatorwaarde waren voortdurend aanwezig met hoge abundanties in alle bemonsterde stations en gedurende de gehele staalnameperiode. De ecologische indicatorwaarden waren sterk gecorreleerd met de relevante omgevingsvariaben. Saprobiteit, zuurstofbehoefte, trofische toestand en stikstofopnamemetabolisme neigden ernaar toe te nemen stroomafwaarts, wijzend op een verhoging van de pollutie in dezelfde richting. De

gegevens van de indicatorwaarden waren in overeenstemming met dezelfde onderzochte omgevingsvariabelen die aantoonden dat de Kisat meer vervuild is dan de Nyando en de Kibos. De ecologische indicatorwaarden voor diatomeeën gebruikt in deze studie werden geschikt bevonden voor het inschatten van de waterkwaliteit in alledrie de rivieren.

Het derde luik van het onderzoek omvatte het relateren van de distributie van epilithische diatomeeën aan de omgevingsvariabelen in de Nyando, Kibos en Kisat. Clusteranalyse door "Two-Way Indicator Species Analysis (TWINSPAN)" toonde een scheiding aan in de diatomeeëngemeenschap tussen twee grote groepen bestaande uit enerzijds de minder aangerijkte rivieren Nyando en Kibos samen en anderzijds de assemblages van de meer vervuilde rivier Kisat. De eerste groep bevatte *Navicula exigua*, *N. schroeteri* en *Gyrosigma scalproides* als indicatorsoorten. Het daaropvolgende splitsen van de data resulteerde in gemeenschappen die ook de verschillen tussen de watertypes reflecteerden, ongeacht de positie van het staalnamepunt. Ordinatie aan de hand van Canonical Correspondence Analysis toonde aan dat de distributie van de diatomeeënsoorten significant beïnvloed werd door het synergetische effect van de onderzochte omgevingsvariabelen. Conductiviteit, alkaliniteit, turbiditeit, opgeloste zuurstof, siliciumgehalte en hoogte werden aangewezen als de voornaamste factoren bijdragend aan de variatie in epilitische diatomeeënassemblages in de drie rivieren. De soorten die de verschillende milieugradiënten weerspiegelden werden geïdentificeerd.

Tot slot werd de distributie van diatomeeën in de oppervlaktewateren van het Victoriameer bestudeerd in verhouding tot de omgevingsvariabelen. 101 taxa behorend tot 29 genera werden geïdentifieerd. Hogere soortenrijkdom en –diversiteit kwamen voor in de baaigebieden van de Nyanza-golf in vergelijking met het open water. Conductiviteit en siliciumconcentratie bleken de soortenrijkdom, -diversiteit en equitabiliteit te beïnvloeden. De diatomeeëngemeenschap werd onderverdeeld in twee grote groepen bestaande uit enerzijds de assemblages van de Nyanza-golf en anderzijds die van het open water. Deze assemblages weerspiegelden eveneens de milieugradiënten. Het open meer werd over het algemeen meer geassocieerd met hogere abundanties ven *Nitzschia acicularis*, die ook de indicatorsoort was voor deze groep. *Aulacoseira agassizii*, *Cyclotella meneghiniana*, *Nitzschia fonticola* en *Cyclostephanos dubius* waren de indicatorsoorten voor de Nyanza-golf. Conductiviteit, alkaliniteit, opgeloste zuurstof en diepte van het meer werden aanzien als de voornaamste omgevingsvariabelen die de variatie in de diatomeeënassemblages duidelijk verklaren.

De resultaten van dit onderzoek verschaffen een bijdrage aan de kennis over de potentiële diversiteit en ecologie van de tegenwoordige diatomeeën in het Victoria-basin. Eveneens verschaft deze studie bewijs dat diatomeeën als nuttige indicatoren voor de waterkwaliteit kunnen dienen en dat ze kunnen gebruikt worden voor zowel monitoringprogramma's als beheersdoeleinden.

Summary

In this thesis a description is made of species composition and characteristics of epilithic diatoms in rivers Nyando, Kibos and Kisat draining into Lake Victoria (Kenya part). The water quality of the rivers is evaluated by examining the diatom data alone and in relation to environmental variables. The distributions of diatoms in surface waters of Lake Victoria were also examined in relation to environmental variables. The aim was to asses the potential of diatoms in determining the "ecological" water quality and in supporting management decisions and conservation strategies for these aquatic ecosystems.

First, species composition, richness and diversity of the epilithic diatoms in rivers Nyando, Kibos and Kisat were investigated. 224 diatom taxa (218 species) belonging to 32 genera were recorded from the three rivers. Maximum species diversity was observed in less polluted river Kibos followed by Nyando with medium pollution levels and Kisat the most polluted had the lowest values of diversity. Species richness and diversity were significantly correlated with altitude, width of the river channel, depth, current velocity, volume of discharge and dissolved oxygen. Eutrophication, increase in ionic content and organic loading reduced diversity downstream where a few species tolerant to pollution, such as *Nitzschia palea* dominated the community especially in Kisat. Diatom diversity indices were found to be important in indicating changes in whole diatom assemblages in response to changes in water quality.

Secondly, weighted means of known diatom ecological indicator values were used in determining the water quality in rivers Nyando, Kibos and Kisat. The ecological indicator values included Saprobity, Oxygen requirements, Trophic state, Nitrogen uptake metabolism, Moisture, pH and Salinity. Taxa with known ecological indicator values occurred consistently in high abundance in all stations sampled and throughout the sampling period. The ecological indicator values had strong correlations with the measured environmental variables, which they are known to reflect. Saprobity, Oxygen requirements, Trophic state and Nitrogen uptake metabolism tended to increase downstream showing increase in pollution in the same direction. The data from the indicator values was in agreement with the one of measured environmental variables in confirming that Kisat is more polluted than Nyando and Kibos.

The diatom ecological indicator values used in this study were found to be suitable for assessing water quality in the three rivers.

The diatom "Indice de polluo-sensibilite" (IPS) or pollution sensitivity index was evaluated and was found to give nearly the same information as the known diatom ecological indicator values. The results of the IPS showed that on average, weakly polluted to moderately polluted waters occurred in Kibos and moderate to heavily polluted waters occurred in Nyando. The whole of Kisat was heavily polluted and pollution levels were more acute downstream after the Kisumu industrial area.

In the third investigation, the distribution of the epilithic diatoms was assessed in relation to environmental variables in rivers Nyando, Kibos and Kisat. Cluster analysis by Two-Way Indicator Species ANalysis separated the diatom community into two major groups comprising the less polluted waters of Nyando and Kibos together, from assemblages of the more polluted Kisat. The group of kibos and Nyando had *Navicula exigua, N. schroeteri* and *Gyrosigma scalproides* as indicator species. Subsequent splitting of the data resulted in assemblages also reflecting different water quality irrespective of the position of the sampling station. Ordination by Canonical Correspondence Analysis revealed that diatom species distributions were significantly influenced by overall effect of the measured environmental variables. Conductivity, alkalinity, turbidity, dissolved oxygen, silicate and altitude were identified as the main factors contributing to variation in diatom assemblages in the three rivers. Species reflecting various environmental gradients were identified.

Finally, the distributions of diatoms in the surface waters of Lake Victoria were studied in relation to environmental variables. 101 taxa belonging to 29 genera were identified. Higher species richness and diversity occurred in the Nyanza gulf and bay areas when compared to the open lake. Conductivity and silicate were found to influence species richness, diversity and evenness. The diatom community was separated into two main groups comprising assemblages of the Nyanza Gulf and the ones from the open lake. These assemblages also reflected environmental gradients. The open lake was generally associated with higher abundance of *Nitzschia acicularis* that was also the indicator species for this group. *Aulacoseira agassizii, Cyclotella meneghiniana, Nitzschia fonticola and Cyclostephanos dubius* were indicator species for the Nyanza Gulf. Conductivity, alkalinity, dissolved oxygen and lake depth were identified as the main environmental variables that significantly explain variations in the diatom assemblages in Lake Victoria.

The results of this study are a contribution to knowledge on potential diversity and ecology of the present day diatoms in the Lake Victoria basin. Further, they provide evidence that diatoms can be useful indicators of water quality in the basin and that they can be employed in monitoring studies and for management purposes.

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Chapter 1

General introduction

1.1. GENERAL INTRODUCTION TO DIATOMS

1.1.1. What are diatoms?

Diatoms are small unicellular algae with cell walls mainly made of silicon dioxide. They are either unicellular and free-living or attached to a substratum, benthic or planktonic or colonial and joined to each other to form chains. A few species are symbiotic. Some species can move actively and some are free floating and are transported by water currents. Over 100,000 diatom species from freshwater to marine habitats have been described (Tappan, 1980; Raven *et al.*, 1999). They range in size from 0.75 μm diameter to 2 mm. Colonial species can form chains of varying lengths.

Detailed descriptions of the diatom cell and its characteristics are given in Patrick & Reimer (1966) and Tappan (1980) among others. The typical diatom cell consists of a single diploid nucleus that is variable in size depending on the species and is usually rounded or oval in form. The protoplast cytoplasm lines the inside of the cell wall or frustule and extends into cavities and openings in the cell wall where osmotic exchange or active transport takes place. A large central vacuole is surrounded by the cytoplasm. Plastids, mitochondria and storage bodies are found within the cytoplasm. The plastids vary in shape and size from small granules in centric diatoms to large plate-like structures in pinnates. The plastids contain chlorophylls *a* and *c* and accessory carotenoids and and xanthophylls that are involved in photosynthetic and photoprotective processes in autotrophic diatoms (Tappan, 1980).

A siliceous bipartite cell wall or frustule made of polymerised, opaline silica (Raven *et al.*, 1999) is a characteristic and important feature of the diatoms that also distinguishes them from other members of Kingdom Protista. The frustule is clearly visible with the light microscope after removal of the cellular contents and is composed of two

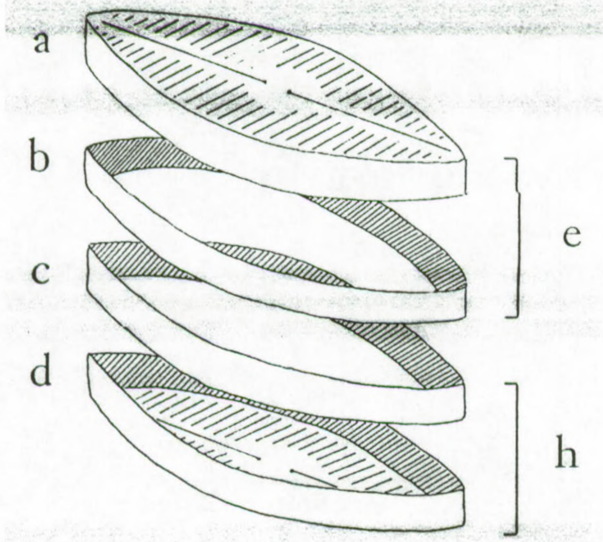

Figure 1.1. Diagram showing main features of a pennate diatom frustule. a, epivalve; b, epicingulum (one or more girdle bands); c, hypocingulum (one or more girdle bands); d, hypovalve; e, epitheca (= epivalve + epicingulum); h, hypotheca (= hypovalve + hypocingulum). (adapted from Kelly, 2000).

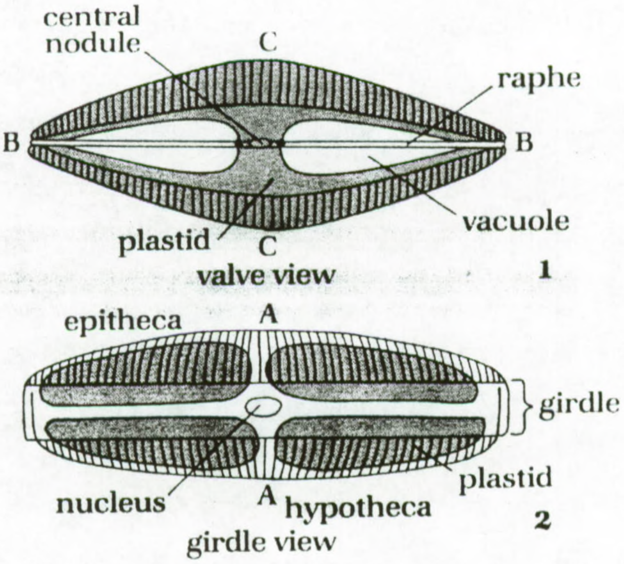

Figure 1.2. Frustule morphology of a pennate diatom: AA, pervalvar axis; BB, apical or sagittal axis; CC, transapical or transverse axis. 1. valve view showing median slit or raphe at each end, separated at the centre of the valve by central nodule; plastid and vacuole of the cell interior also indicated. 2. Girdleview showing epitheca, girdle, and hypotheca, and position of nucleus and plastid. (adapted from Tappan, 1980).

overlapping parts or valves which fit together like the two halves of a petri dish (Kelly, 2000). Each valve has one or more girdle bands or cingulum that help them to effectively cover and protect the middle of the cell (Figure 1.1). The upper valve together with its girdle bands forms the epitheca which is slightly larger and overlaps the lower and inner one or the hypotheca. The valve view is the view directly on the face of the valve and the girdle view is the side view through which also the girdle bands are visible (Figure 1.2).

The valve surface has a variety of minute and finely shaped depressions and pores, hyaline areas and in some cases thickened ribs and other processes arranged in unique patterns and structure These structures are genetically determined and their appearance, number and arrangement are the basis of systematics of most taxa of diatoms. Usually, they enable distinction and identification to taxon, species and even variety level (Patrick & Reimer, 1966). A thin mucilaginous organic substance that also enables diatoms to adhere to substrates covers the cell wall.

Recent studies show that in addition to silica, the diatom cell wall contains organic substances including proteins. Biological synthesis of silica occurs within silica deposition vesicles (SDV) or nanospheres and precedes the formation of a new valve during cell division. This processes through which silica is precipitated and deposited is controlled genetically and is regulated by the proteins frustulins and silaffins (Kröger *et al.*, 1999). Frustulins bind calcium ions (Ca^{2+}) whereas silaffins have a high affinity for silica, and a combination of these substances with silica seem to provide the structural strength of the diatom cell wall. The silicious nature of the cell wall is resistant to most chemicals and this makes it to preserve well in fossil deposits.

Two broad groups of diatoms are generally recognized basing on the symmetry of the frustule in relation to their axis. They are: the Centrales (centric diatoms), which have radial symmetry and the Pennales (pennate diatoms) with bilateral symmetry. However, this classification is still reviewed as modern methods of studying diatoms unveil new and additional information. Variations in numerous characters and life cycles of diatoms has resulted in recent classification into orders and sub-orders.

1.1.2. Classification of diatoms

The diatoms belong to Phylum Bacillariophyta in the Kingdom Protista (Raven *et al.*, 1999). The variety and extent of their taxonomy is mainly based on the shape and size of the frustule in addition to its fine structure, the presence or absence of perforations, elevations, spines and other processes. Revisions of the taxonomy are a continuous process in order to accommodate new information from scanning electron microscope (SEM) or other modern techniques of identification. For example, Medlin *et al.* (1993) used 18S RNA molecules to show that diatoms are monophyletic but major groups within the phylum are not. Table 1 gives a summary of the classification of the diatoms as outlined by Tappan (1980) with some inputs from Raven *et al.* (1999).

1.1.3. State of the art

The oldest remains of diatoms can be traced in geological deposits dating back to Jurassic and Devonian periods (Barber & Haworth, 1981). However, the oldest well preserved and substantial records are marine forms from Cretaceous period onwards (Patrick and Reimer, 1966; Tapan, 1980; Barber & Haworth, 1981). Freshwater forms are reported from Miocene onwards. The worldwide distribution of diatoms is shown by presence of fossil diatoms in all continents.

For a long time, diatoms have been of great interest due to possession of beautiful and ornamental structure of their siliceous shells. These features greatly fascinated earlier microscopists, naturalists and scientists who patiently observed, drew and described the miniature organisms. Stoermer & Smol (1999) divide the history of ecological studies on diatoms into three eras: exploration (1830-1900), systematisation (1900-1970) and objectification (1970 to present).

Table 1.1. Classification of diatoms (Tappan, 1980; Raven *et al.*, 1999)

Phylum Bacillariophyta Engler & Gild 1924

I. Class Centrobacillariophyceae Silva 1962

A. Order Eupodiscales Bessey 1907

1. Family	**Melosiraceae Kützing 1844**
2.	Thalassiosiraceae Lebour 1930
3.	**Coscinodiscaceae Kützing 1844**
4.	Asterolampraceae H.L. Smith 1872
5.	Actinodiscaceae Kützing 1844
6.	Stictodiscaceae Schütt 1896
7.	Hemidiscaceae Hendey 1937
8.	Eupodiscaceae Kützing 1844

B. Order Rhizosoleniales Silva 1962

1. Family	Pyxillaceae Schütt 1896
2.	**Rhizosoleniaceae Petit 1889**
3.	Chaetoceraceae H.L. Smith 1872

C. Order Biddulphiales Krieger 1954

1. Family	Biddulphiaceae Küizing 1844
2.	Hemiaulaceae Heiberg 1863

II. Class Pennatibacillariophyceae Silva 1962

A. Order Fragilariales (G.S. West) Silva 1962

1. Family	**Diatomaceae Dumortier 1823**
2.	Protoraphidaceae Simonsen 1970

B. Order Eunotiales Silva 1962

1. Family	**Eunotiaceae Kützing 1844**

C. Order Achnanthales (G.S. West) Silva 1962

1. Family	**Achnanthaceae Küitzing 1844**

D. Order Naviculales Bessey 1907

1. Family	**Naviculaceae Kützing 1844**
2.	Auriculaceae Hendey 1964
3.	**Cymbellaceae Kützing 1844**
4.	**Gomphonemiaceae Kützing 1844**
5.	**Epithemaceae Grunow 1860**
6.	**Nitzschiaceae Grunow 1860**

E. Order Surirellales (West) Silva 1962

1. Family	**Surirellaceae Kützing 1844**

* Taxa represented in our samples are mentioned in bold character.

Among the pioneer diatomists listed in Barber & Haworth (1966) in the nineteenth century are Ehrenberg, Ralf, Kützing, William Smith, Grunow, Cleve, Schmidt, van Heurck, Cleve-Euler who between 1838 and 1955, produced illustrations and descriptive accounts on diatoms from various regions of the world and from different habitats. In the early twentieth century are names of Hustedt, Aleem and Behre among others. Recent classical accounts include those of Krammer and Lange-Bertalot (1986, 1988, 1991a, b) and many other publications by numerous authors. Present day diatomists are continuously updating information on various aspects of diatoms.

General and very interesting information on diatoms can also be found on the internet at several websites including:

http://www.calacademy.org/research/diatoms/
http://www.indiana.edu/~diatom/diatom.html
http://www.indiana.edu/~diatom/branch.html
http://www.ucmp.berkeley.edu/chromista/bacillariophyta.html
http://www.ucmp.berkeley.edu/chromista/diatoms/diatomlh.html,
http://www.microscopy-uk.org.uk/mag/wimsmall/diadr.html,
http://www.microscopy-uk.org.uk/mag/art97b/diatom.html
http://www.umich.edu/~phytolab/GreatLakesDiatomHomePage/top.html,
http://www.calacademy.org/research/diatoms/
http://www.comet.net/gek/phytoc.htm and http://hjs.geol.uib.no/Diatoms/index.html-ssi

The earlier studies on diatoms focussed mainly on morphological descriptions of the diatom shells both of fossil and living material, discovery of new taxa, their life cycles, physiology and observations of their distributions (Stoermer & Smol, 1999). Light microscopy was the basic tool and descriptions of organization and fate of cytoplasmic organelles were used in basic identification and classification of living genera. The size, shape, structure of the cell walls including patterns of striations and processes became more important in identification and taxonomy of the diatoms.

The morphological characteristics of the diatoms came to be understood in much finer detail a few decades ago when transmission electron microscope (TEM) and scanning electron microscope (SEM) came to be used for diatom identification. These modern microphotography instruments increased the resolution of the diatom structure, revealing many features, mainly of the cell wall never seen before and resulting in new terminologies and even re-classification. Emerging new microscopy techniques together with new culture techniques have unravelled the morphology and physiology of diatoms even further.

Occurrence of diatoms has been linked with habitat and environmental variables with great success. Simple indices using various systems were developed including those based on halobion, saprobion, pH and temperature (Prygiel & Coste, 1993). In addition, the more modern methods of stratigraphy based on fossil diatom material has enabled reconstruction of past environmental and ecological events.

Recent emphasis is the use of computer technology and other techniques to determine in a multivariate statistical approach factors that influence occurrence, distribution and growth of modern as well as fossil diatoms. Results from such studies are used to answer many ecological and environmental questions.

1.1.4. Physiological characteristics of diatoms

Diatoms vary considerably in their physiological processes. Although they are mainly autotrophic, a few may be heterotrophic (Patrick & Reimer, 1966). In autotrophic forms, the principal pigments which are directly or indirectly associated with photosynthesis are chlorophyll *a* and *c* and carotene α, β, and ε and xanthophylls. Lipids and water-soluble polysaccharides are the main reserve storage products and they are usually stored in vacuoles (Raven *et al.*, 1999). The amounts of duration of light for optimum photosynthesis vary with species. The various depths in oceans and lakes at which various species live evidence this.

Heterotrophic diatoms can utilize organic compounds for growth in the dark, or in light in the absence of CO_2. These are mainly pinnate diatoms that live on the bottom of the sea in relatively shallow habitats. They absorb dissolved organic carbon from dead and decaying organic matter. A few diatoms are obligate heterotrophs and lack plastids and therefore chlorophyll and cannot photosynthesise. Heterotrophy is important for species living in deeper water, high altitude or survival after sinking below light zone.

Edlund & Stoermer (1997) give an overview of the diatom life histories. The most common type of reproduction is by vegetative reproduction in which mitotic asexual division of the chromatophore occurs. Due to unequal size in the two valves of the frustule, division of the frustule produces two halves with one sibling cell being larger than the other. Because the rigid silica cell wall constraints vegetative cellular growth, successive divisions results in a general reduction or diminution in size of cells of a population. Cells of a filament divide simultaneously. In nature, the alteration of day and night induce the cell division process. The division occurs during the light period and several divisions may occur more than once in a day.

Due to monoecious nature of diatoms, single clones are capable of sexual reproduction (Tappan, 1980). In some species sexual reproduction occurs when the size of the cells decrease to a critical level during successive generations (Raven *et al.*, 1999). In others especially centric diatoms, sexual reproduction may occur when the cells grow to 30-40% of their maximum size and when external environmental conditions become unfavourable (Tappan, 1980; Edlund & Stoermer, 1997). Critical environmental factors that can induce sexual reproduction include temperature, light, nutrients, trace metals organic growth factors and osmolarity.

The normal diatom cell is diploid and meiosis occurs during formation of the gametes that are haploid. Sexual reproduction is mainly oogamous especially in centric diatoms. In araphid and biraphid diatoms, sexual reproduction is through isogamy or anisogamy (Edlund & Stoermer, 1997). The gametes fuse to form a zygote or auxospore, which grows to a maximum size of the cell.

Vegetative cells of some diatoms survive unfavourable environmental conditions such as low or high temperature, desiccation and nutrient limitation by forming resting spores (Tappan, 1980). These spores may be exogenous or isolated from the parent cell, semiendogenous with one valve enclosed in the valve of the parent cell or endogenous within the parent cell. Some benthic diatoms form resting stages, which have heavy frustules. Improvement of the environmental conditions initiates growth to full cell size.

Growth of diatoms is largely manifested by cell division, the rate of which is determined by the conditions of the environment, including temperature, amount of light, nutrients and the genetic make-up of the species. The mineral requirements are similar to those of most plants. In addition, some diatoms require vitamins and certain organic substances for their physiological processes.

Like other algae, diatoms can concentrate external material through adsorption to cell walls and external surfaces, precipitation or active transport across the cell membranes (Patrick & Reimer, 1966; Center, 1996). Preferential accumulation of lighter materials such as univalent rather than divalent ions may help diatoms have a control over their specific gravity. Internal movements in diatoms involve shifts of nucleus in auxospore germination and change in shape of chloroplasts. Active external movement is due to rotation of the cytoplasm in the raphe and only diatoms with raphe can move actively.

1.1.5. Where are diatoms found?

The distribution of diatoms is worldwide and they occur in all types of water, salty or freshwater. They occur in moist and even dry habitats where environmental conditions, especially light for photosynthesis, are suitable for their growth (Tappan, 1980; Patrick and Reimer, 1966). They can be divided broadly into marine forms and freshwater forms.

The variety and extent of occurrence of diatoms depends on the substrata, habitat and geographical location. In terms of habitats and mode of life, the diatom communities are broadly categorised as plankton or periphyton. Plankton communities are free floating and passively move with water currents. They are usually found in deep seas but there are also fresh water forms that are commonly benthic or neritic species, which spend the vegetative part of their life cycle afloat. Many species found in the plankton of freshwater also occur in littoral habitats. Plankton diatoms vary in size from small forms or nanoplankton to large forms or net plankton. They have numerous modifications and adaptations that aid in floatation. Such adaptations include those that increase their surface area, thin-walled cells, hair like shape and formation of long chains, branching and presence of a large central vacuole with cell sap of low specific gravity.

Periphyton (or benthic) diatoms live on or in the substratum and most of them posses raphes that enable them to move about. This flora is often well developed in lakes and ponds and in streams and rivers in places where the current is not too swift. This group can be subdivided further into subgroups: epiphyton, epipsamon, epipelon, endopelon, epilithon, endozoic and epizoic. Epiphyton live and grow by attaching themselves to other plants by secretion of gelatinous mass or stalks to the substratum. Epipsamon live and grow on sand; epipelon live and grow on mud (sediment); endopelon grow within mud and epilithon grow on rocks and surfaces of hard substratum. Endopelon types live and grow within cavities of rocks; epizoic types grow on animals and fouling types grow attached to objects placed in the water body. In addition to these common categories, there are those diatoms that live in aerial habitats (aerophilic) including moss, trunks of trees, damp stones and leaves and in the soil and spray zone of lakes and even on dry rocks.

In lakes, the diatom flora consists mainly of planktonic, benthic, and epiphytic species. The degree of development of these various types depends on the physical conditions present. If a broad littoral is present, epiphytic and benthic forms flourish. Planktonic forms are found in deep waters but they may also develop in large rivers. The kind of species detected in the various habitats depends on whether the water is eutrophic, oligotrophic or dystrophic.

1.1.6. Ecological factors that influence distribution of diatoms

Among the most important chemical and physical factors that influence the distribution of diatoms, include light, temperature, turbidity, hydrogen ion concentration and sodium chloride (Patrick & Reimer, 1966; Tappan, 1980). Other factors include calcium, iron, silicon, nitrogen, sulphur, copper, boron and manganese. However, there is interdependence of these environmental factors and they may act synergistically to determine growth of diatoms (Mechling & Kilham, 1982).

Various groups of diatoms are physiologically adapted to different kinds and amounts of light. Improved light conditions generally favours growth of most species. Most have a wide temperature tolerance and their latitudinal distribution is not as closely related to temperature itself as to various temperature related or other kinds of seasonal changes, for example, changes in solubility of CO_2, O_2 and salts, pH, nutrients, amounts and duration of light.

Most diatoms prefer neutral pH. Low pH slows down growth and very few species live at pH of less than 3.5, whereas high alkaline conditions increase the solubility of silica resulting in corrosion of the diatom shells.

Diatoms may generally be classified into those, which are specific for certain salt conditions, and those, which are euryhaline or indifferent. Polyhalobiens can withstand salt concentrations greater than that of the sea. Euhalobien species develop best in water with medium salt concentration whereas; the oligohalobien species have their optimum condition in water with a very low salt concentration.

Some diatoms prefer high nitrogen (nitrate, nitrite or ammonia) concentration and others prefer low nitrogen: phosphate ratio. Species that are favoured by nitrogen include *Diatoma vulgarae, Gomphonema parvulum, Nitzschia palea* and *Aulacoseira granulata* (Partric & Reimer, 1996). Phosphorus is also required for growth by diatoms and cell cultures of some species cannot divide if available phosphorus falls below a certain minimum amount. Enrichment of Kootenay Lake in British Columbia with nitrate and phosphate has been found to enhance growth of diatoms in (Yang & Pick, 1996).

Silicon is important in diatom growth. It is used in the formation of the cell wall, and nucleus and cell in divisions. The silicon is used in the form of $Si(OH_4)$ and diatoms efficiently extract it from the dilute solution in nature sometimes lowering its concentration to very low levels that may also result in a negative correlation between diatom abundance and silicon (Yang & Pick, 1996).

Calcium is preferred by some species, e.g., *Synedra* spp., *Achnanthes minutissima, Gomphonema olivaceum*, some *Cymbella* spp., and *Diploneis* spp. (Patrick & Reimer, 1966). Iron is a selective factor in diatom growth and iron-rich waters have many species. Sulphur favours some species, e.g., *Cyclotella meneghiniana, Surirella* spp., *Achnanthes affinis* and *Cymbella ventricosa*. Copper can also be tolerated in small amount by some species, e.g. *Fragilaria virescens, Synedra ulna, Achnanthes affinis,* and *Navicula viridula*. In addition to the physical and chemical factors that determine diatom growth, others factors of importance include boron required by some species for cell division; and manganese for formation of valves and vitamins B_{12}.

The distribution of most diatoms is mainly determined by the natural environmental conditions within which the diatoms are considered as indigenous. The degree of endemism varies from place to place and many of these species, genera and more inclusive taxa may occur only in certain areas or regions. However, many diatoms are cosmopolitan and occur in a wide range of habitats and may be found in many parts of the world.

1.1.7. Applications and uses of diatoms

Diatoms are important components of biodiversity in aquatic ecosystems and play fundamental roles of carbon fixation, oxygenation of surface waters and linkage in biogeochemical cycles (Tappan, 1980; Stevenson & Pan (1999).

Primary production by the diatoms is estimated to account for 20 to 25% of all organic carbon fixed on planet earth in addition to excreting large amounts of organic compounds in solution (Tappan, 1980). The abundance and the high production make diatoms a major source of food for aquatic microorganisms, animals, and a temporary sink for CO_2 as well as a source of atmospheric oxygen. Species such as *Thalassiosira pseudonana* are used as live foods in mariculture of bivalves such as oysters to which they provide essential carbohydrates, fatty acids, sterols and vitamins (Raven *et al.*, 1999).

The occurrence in great abundance, wide distribution and well-preserved siliceous walls make diatoms suitable for a number of practical applications both as fossil and living organisms. Direct applications include use of fossilised diatom remains in archaeology (Juggins & Cameron, 1999) industry (Harwood, 1999), oil and gas exploration (Krebs, 1999) and forensic applications (Peabody, 1999).

Diatom frustules accumulated over many years form diatomaceous earth that is used in polishing silver and as filtering and insulating material (Raven *et al.*, 1999). Fossil diatoms are used as indicators to decipher the effects of long-term ecological perturbations such as climate changes (Bradbury 1999; Denys & De Wolf, 1999; Douglas & Smol, 1999; Fritz *et al.*, 1999; Snoeijs, 1999; Spaudling & McKnight, 1999).

The siliceous cell walls of diatoms preserve well in stratigraphic deposits and provide taxonomically specific fossils. Since limnetic ecosystems are very sensitive to natural and anthropogenically induced environmental changes, this makes sediments therein potential reserves for long-term records of such changes. The use of diatoms in reconstruction of history has been refined even further by improved techniques for sampling and chronological control of sedimentary records (Moser *et al.*, 1996). Advanced sediment coring and sectioning has made it possible for sediments to be discerned to an annual and seasonal basis. ^{210}Pb dating is used for examining records going back 100 years. Much older records are analysed by use of mass spectroscopy. Such microfossil records can be used for geographical research in reconstruction of climate, hydrology, geomorphology, biogeography, water quality assessment and bio-monitoring.

In addition to the siliceous cell wall, diatoms possess other characteristics that make them suitable for reconstruction of history and monitoring of the present environments. They live in a great variety of habitats and their distributions are affected by several environmental variables including climate change, habitat quality, vegetation change, soil erosion, acidification and eutrophication. The narrow ecological tolerances and optima of many diatoms make them potentially sensitive indicators of the environmental changes.

Ecological and autoecological information of many recent and modern diatom species together with information on environmental variables is usually inferred in reconstruction of past conditions (Kilham *et al.*, 1996). This is also enhanced by development of computer-based multivariate statistical programmes applicable to biological communities also discussed by Jongman *et al.* (2000). Once the important environmental variables influencing diatom distributions are known, transfer functions can be developed leading to mathematical formula that estimate environmental variables from diatom species composition.

Diatoms have been used successfully to monitor lakes, rivers and wetlands in Europe, North America and other temperate areas (Whitton *et al.*, 1991; Pan & Stevenson, 1996; Whitton & Rott, 1996; Christie & Smol, 1993; Prygiel & Coste1993; Dixit *et al.*, 1999; Stoermer & Smol, 1999. Triest *et al.*, 2001). Aspects that are monitored include acidification, eutrophication, organic pollution and general water quality. Diatoms have also been used as indicators of water quality in Asian countries (Jüttner *et al.*, 1996) and interest is increasing in other parts of the world.

1.1.8. Why diatoms are used for monitoring aquatic ecosystems

Monitoring and assessment of aquatic ecosystems using biological organisms is receiving greater emphasis now than before. This is because these organisms give a true representation of the state of the ecosystems that they live in. Therefore, conservation, protection and management of the biological organisms themselves are major objectives.

Preferred organisms include fish, zooplankton, macrophytes, macro-benthos, riparian birds and diatoms (Dixit *et al.*, 1999).

Using diatoms as bio-indicators has more advantages that outweigh those of other indicator organisms or even physical and chemical methods. Prygiel (1991) Stevenson & Pan (1999) and Stoermer & Smol (1999) discuss some of the factors that make diatoms good bio-indicators in aquatic ecosystems. Diatoms form an important component of biodiversity and genetic resources in aquatic ecosystems. They are primary producers and in close contact with the physical and chemical environment from which they derive components for their survival. They therefore integrate all information on the physical, chemical and biological parameters providing continuous records of the water quality.

The wide distribution of diatoms and occurrence usually in large numbers in almost all aquatic ecosystems, habitats and various substrata ensures the reliability of using the same group of organisms for routine monitoring and for comparison of many aquatic ecosystems across regions and even continents.

Diatoms are among the most diversified group of organisms and maintain structural and functional attributes that can be linked to the environmental state of the ecosystem. Like most other algae, diatoms have a high growth-rate and turnover time. Many species are ecologically sensitive and respond directly, differently and rapidly to many physical, chemical and biological changes (Stevenson & Pan, 1999). In this way, they provide early warning indicators of environmental change.

The cost of sampling, processing and examination of diatoms are lower than for most other organisms and indices based on diatom composition are more precise and give better predictions (Whitton, 1991; Prygiel & Coste, 1993). The occurrence of diatoms in large numbers allows for rapid sampling and over small areas using very simple equipment. The collected material can be stored in small bottles, take up little space and can easily be transported. Normal preservatives, including formalin solution, are used for long-term storage.

Simple protocols and implements are used for processing of samples from the raw material until the stage of microscopic examination. Permanent preparations in specially embedded mounts on microscope slide allow long-term storage and planning for examination, re-examination and reference at convenience. They are practically easy to use for identification and practice by armature diatomists.

More simplified procedures that allow identification up to generic level can be done by starting diatomists and for routine monitoring purposes (Prygiel, 1991; Chessman *et al.*, 1999). Identification of diatoms is mainly based on details of the siliceous cell wall that are clearly recognized even with a simple light microscope. Distinction is made up to species and sub-species level greatly increasing precision and accuracy of identification and enumeration.

The taxonomy of diatoms is well studied when compared to other algae and other indicator organisms (Whitton, 1991). Classification and identification systems that have been upgraded over the years make it possible for the diatom taxa to be consistently identified and with certainty. There is in existence a large collection of literature on this community as indicators of water quality and ecological requirements of many individual taxons are known from ecological and autoecological studies. From such information, many species have been classified according to their sensitivity or tolerance to various physical and chemical variables. Various indices of environmental conditions have been developed (Prygiel & Coste, 1993; van Dam *et al.*, 1994, Kelly & Whitton, 1995; Kelly, *et al.,* 1995) and can be adapted with modifications for application in various habitats and regions.

Reconstruction of historical environmental conditions is made possible from composition of modern diatoms through predictive models generated with computers and multivariate statistical techniques. In addition, availability of computer software allows for rapid calculation of important diatom indices, environmental relationships and diatom-inference models making the use of diatoms more practical (Lecointe *et al.*, 1993, Dixit *et al.*, 1999).

1.1.9. Limitations of using diatoms as indicators

Routine monitoring using diatoms can be hampered by the occurrence of diatoms in high abundance and in many species creating problems of identification. However, availability of good taxonomic literature that is consistently upgraded over the years makes it possible to identify diatoms at least up to the dominant species with ease. Rapid biological assessment can also be achieved satisfactorily by identification to genera especially by beginners (Chessman *et al.*, 1999).

Empirical methods are used in sampling and the relative abundances replaces absolute abundance in comparisons of communities (Lenoir & Coste, 1996). According to Lenoir & Coste (1996), there is the problem of accounting for contamination of a sample, for example, from upstream-downstream drift. However, water currents help minimise such effects by washing away loosely attached and dead species during spates (Kelly *et al.*, 1998). In studies involving epilithic diatoms, avoidance of surfaces supporting macroscopic growth and knowledge of dominants in an area can also help to minimize the effects of such contamination (Round, 1991a, b).

Oxidation of organic matter is a commonly used method of preparation of frustules and does not distinguish between live and dead specimens. This problem can be solved by using Bengal Rose to stain living diatom cells distinguishing them from dead cells in fixed samples (Sabbe, 1993; Hamels *et al.*, 1998). The relative proportions of the live and dead cell can be used to estimate live cells in oxidised samples, which is gives a true representation of the available abundance and biomass.

1.2. GENERAL INTRODUCTION ON LAKE VICTORIA BASIN

1.2.1. Lake Victoria and its catchments

The Lake Victoria basin is situated between the eastern and western rift valleys of East Africa (Figure 1.3). The catchment of Lake Victoria covers an area of about 185,000 km^2 (Hecky & Bugenyi, 1992) and traverses five countries: Tanzania, Uganda and Kenya, which also share the lake and Rwanda and Burundi. The lake itself covers an area of about 68,800 km^2.

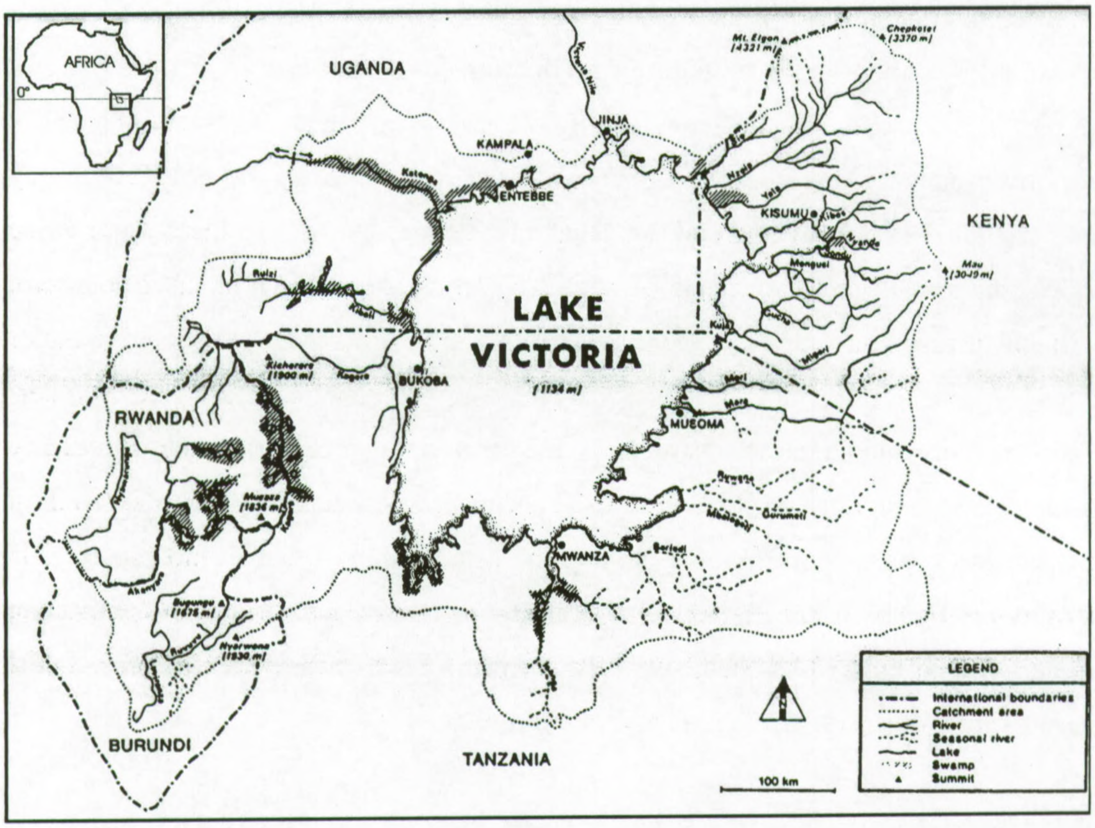

Figure 1.3. Map of Lake Victoria basin showing some topographic features (From Hest, 1988, quoted in Crul, 1995).

The Lake's basin overlies Precambrian bedrock and metamorphosed sediments and intrusive and igneous rocks. The north-eastern part occupied by the Nyanza Gulf (also known as Kavirondo Gulf or Winam Gulf) has lacustrine beds of Miocene and Middle

Pleistocene age overlain by tertiary and recent volcanic and sedimentary rocks (Kendall, 1969).

Seismic reflections and biogenic silica profiles place the age of the Lake Victoria basin at about 400,000 years before present (Johnson *et al.*, 1998, 2000) The lake's basin completely dried up during the last glacial maximum and it began to refill with water about 12,400 radiocarbon years ago (Johnson *et al.*, 1998). Prior to and during Miocene, the area that is now occupied by Lake Victoria had an east-west drainage system (Kendall, 1969). Tectonically induced gradual uplift of land along the rift shoulder caused a reversal of the drainage that resulted in formation of swampy lakes, which joined to form Lakes Victoria and Kyoga. A down cutting by water formed a northwards bound outlet through River Nile at Jinja, Uganda.

The climate of the area is of the equatorial type (Walter *et al.*, 1960) and is influenced by effects of the inter-tropical convergence zone (ITCZ). The sun crosses the equator twice each year moving between the tropics. This movement is associated with an atmospheric belt of low pressure that attracts convergence of moisture-loaded winds that cause major bi-annual tropical rainfall. The rainfall peaks occur in March-May and October-November. In addition, a low-pressure zone that prevails over Lake Victoria occasionally lead to creation of convectional rainfall. The annual total rainfall ranges from 630 mm in areas close to the lake to over 2000 mm in the highland areas. Much more rainfall is known to fall directly in the lake accounting for more than 80% of the total water budget of the lake (Johnson *et al.*, 2000). More than 80% of the basins water income is lost through evaporation (Hurst, 1957, quoted by Kendall, 1969).

The seasonal variation in solar radiation is small. Monthly mean air temperatures range from 21.9 °C to 24.3 °C (Burgis *et al.*, 1987). The annual maximum air temperatures range from 25 to 30 °C and annual minimum ranges from 15 to 19 °C. Mophometric and hydrological data of Lake Victoria and its basin are given in Table 1.2.

Table 1.2. Some morphometric and hydrological data of Lake Victoria and Nyanza Gulf (Ochumba, 1990; Hecky & Bugenyi, 1992; Crul, 1995, quoting several authors).

	Lake Victoria	Nyanza Gulf (Kenya)
Catchment area (km^2)	185,000	12,300
Lake area (km^2)	68,800	1400
Volume (V) (km^3)	2,760	13.1
Maximum depth (m)	84	43 (offshore), 6 (inshore)
Mean depth (m)	40	12 (offshore), 4 (inshore)
Max. length (km)	400	70
Max. breadth (km)	240	30
Altitude a.s.l (m)	1,134	1,134
Inflow (I) ($km^3\ y^{-1}$)	20	3.2
Precipitation (P) ($km^3\ y^{-1}$)	100	
Flushing time (V/O) (yr)	140	
Residence time (V/P+I) (yr)	23	19.3
Shoreline length (km)	3,440	500

In mid 19th century, vegetation of the Lake Victoria basin was quite diverse. Savannas of woodlands and grasslands dominated the northern part in Uganda and they were interspersed with forest and swamp (Kendall, 1969). Leguminous woodlands dominated the drier southern parts in Tanzania and in Kenya, with mixtures of savannas and forest. Sedge swamps of mainly *Cyperus papyrus* characterised the fringes of the lake and low gradient floodplain of rivers.

Lake Victoria is the largest lake by surface in Africa and the second largest in the world (Johnson *et al.*, 2000). The lake has a rich and interesting ecological history and a large diversity of organisms including secondary endemics. Most of the 400 species of cichlids reported on lake Victoria are thought to have evolved from a single ancestral species after the lake started refilling more than 12,400 radiocarbon years ago (Meyer *et al.*, 1990; Johnson *et al.*, 2000), and can therefore be considered as secondary endemics. This and many other features make the lake a unique ecosystem that is of interest to many scientists and conservationists from all spheres.

Lake Victoria is a very important water resource in the region and supports the livelihood of millions of people. It is a source of domestic and industrial water supply, source of fish protein and a transportation route. A major hydroelectric power plant is located at the outlet of the lake to the Nile at Jinja. The lake is also increasingly becoming a tourist destination.

Other numerous water bodies are found within the Lake Victoria basin and they include small lakes, dams, ponds, swamps, marshes, streams and rivers. These water bodies form direct or indirect ecological linkages with Lake Victoria and some of them such as Lakes Kanyaboli and Sare are host to biological species that have become rare or have even disappeared from the main lake including *Orechromis esculentus, O. variables* and some *Haplochromis* spp. These small water bodies offer invaluable conservation options and pools for genetic diversity. In addition, they provide vital services including water supply for drinking, domestic purposes and watering cattle; source of fish food and scenic beauty. Unfortunately, these poorly understood and appreciated aquatic ecosystems are undergoing rapid degradation and depletion of their resources.

The Lake Victoria basin supports a large human population with one of the highest growth rates in the world (Hecky & Bugenyi, 1992). Increase in economic activities are characterised by deforestation and destruction of watersheds; intensified cultivation, poor agricultural practises and increased use of mineral fertilizers and pesticides. Fringing wetlands, which are normally buffer zones are increasingly drained and converted into agricultural fields and land for human settlement. Many urban centres, industrial settings and mining activities are poorly planned and most of them commonly lack proper waste disposal facilities. Consequently, runoff from increasingly degraded terrestrial land enhances loading of nutrients and pollutants to aquatic systems.

Consequences of developmental activities in the catchments are manifested in shrinking or drying up of dams, bogs, marshes and other wetlands. Rivers are turning to small volumes of dirty flowing water and the high turbidity is mainly due to suspended sediments from soil erosion processes. Springs, streams and rivers are the sole sources of water for the most of the inhabitants and due to degradation and pollution; water-borne diseases are becoming common (Lung'ayia *et al.*, 2001). The quality of some of the rivers especially those that flow through and near urban areas have deteriorated to very low levels.

The characteristics of the waters of Lake Victoria are indicating increasing levels of nutrient enrichment and pollution (Lehman & Branstrator, 1994; Hecky, 1993). An increase in flux of limiting nutrients stimulates photosynthetic rates that has resulted in an overall increase in algal biomass (Mugidde, 1993). Algal blooms dominated by cyanobacteria are more common (Ochumba and Kibaara, 1989). Increasing levels of anoxia are observed in bottom waters of the lake (Hecky *et al.*, 1994; Lung'ayia *et al.*, 2001) due to a more or less permanent stratification of the water column and increased plant biomass. Frequent large-scale mortalities of fish are partly due to the anoxic conditions in the bottom layers (Ochumba, 1987, 1990).

Alien fish species mainly the Nile perch *Lates niloticus* and several tilapias introduced in the 1950s and early 1960s, coupled with increased fishing activities have caused changes in the trophic structure of Lake Victoria (Ogutu-Ohwayo, 1990; Ogutu-Ohwayo & Hecky, 1991; Witte *et al.*, 1992). A once multi-species fishery largely composed of Haplochromine cichlids that used to form more than 80% of the demersal fish biomass (Kudhongonia & Cordone, 1974) and other indigenous species declined in the 1980s to become rare or they have disappeared from the lake (Witte *et al.*, 1992). The decline of the larger haplochromines started with the introduction of trawlers (Lowe-McConnell (1994). These were followed by decline of smaller haplochromines that shared the same habitats with Nile perch that also predated on them and other rare species. Only the rock-dwelling types and the ones that occupied littorals with plant were thought to have survived but even these have not been spared due to their uncontrolled use as bait fish for long lines and increasing fishing effort (Kaufman & Ochumba, 1993).

Today, two introduced species, Nile perch and Nile tilapia *Oreochromis niloticus* and one indigenous cyprinid *Rastreneobola argentea* dominate the fish stocks. The Nile perch seem to have replaced piscivorous haplochromines and catfishes (Ligtvoet & Witte, 1991; Lowe-McConnell, 1994). Zooplanktivorous haplochromines were replaced by

Caradina nilotica, an atyid prawn while generalised feeder *Oreochromis niloticus* replaced the indigenous *Oreochromis esculentus* and *O. variabilis.*

A once important river fishery that was based mainly on *Labeo victorianus* and other migratory fishes *including Barbus altianalis, Schilbe mystus, Alestes jacksonii* and *Clarias gariepinus* has totally collapse (Cadwalladr, 1965a; Kibaara, 1981) due to over-fishing and partly due to declining environmental conditions in both the rivers and lake habitats.

Pronounced changes that have been observed in the water quality, flora and fauna of Lake Victoria since 1950s and 1960s seem to have started much earlier. Analyses of sediment cores indicate a change in source of terrestrial minerals from clays to silicate sands and silts in late 19th century, indicating increased erosion from clearing of vegetation for agriculture in the watershed (Lowe-McConnell, 1994; Holtzman & Lehman, 1998). Increasing changes in the regional climate are indicated by high rainfall between 1961 and 1964 that also led to a rise in the lake levels. Inundation of farmlands and vegetation associated with erosion processes and decomposition of the dead plant material contributed to increasing eutrophication in Lake Victoria. The beginning of eutrophication of the lake can be traced back to the 1920s and is mainly due to the increased human activities and disturbance in the watershed as well as air shed (Hecky, 1993; Lowe-McConnell, 1994).

Fluctuations in the climate of the East African region that have involved interchanges between periods of dryness and rainfall are also part of the global climatic changes that are linked to the Antarctic and circumpolar ocean currents (Stager & Mayewski, 1997). The climate is indicating an increasingly warmer regime since the 1960s than before (Hastenrath & Kruss, 1992). This could be the cause of the increasing stability of the water column and stratification in Lake Victoria (Hecky, 1993) with associated consequences including oxygen depletions in the hypolimnion.

Water hyacinth *Eichhornia crassipes* (Mart.) Solms, one of the world's most noxious freshwater weeds invaded Lake Victoria from late 1980s (Twongo, 1992). By mid 1990s, large mats of the plant had spread gradually to cover many parts of the lake, especially on protected shorelines, bays and mouths of rivers. Coverage of water surfaces by the water hyacinth is known to cause negative environmental and ecological effects. They include deterioration in water quality, impairment of biological processes, productivity and biodiversity (Scott *et al.*, 1979; Schouten *et al.*, 1999). The plant hinders human activities such as water abstraction, fishing, water transport, interferes with hydroelectric schemes. In addition, large marts of the plant pose dangers to human health by creating habitats for dangerous reptiles such as poisonous snakes and breeding grounds for mosquitoes.

Measures to control the water hyacinth have involved manual removal, mechanical harvesting and introduction of biological control organisms. The weed re-emerges in areas where it has been removed and it has become an integral part of the lake's ecosystem.

1.2.2. Past studies on diatoms of Lake Victoria basin

Climatic changes and history of Lake Victoria and its basin over the last 17,000 years has been reconstructed from fossil diatoms. Preserved frustules from Pleistocene suggest that lake levels were low during this arid period (Stager, 1984; Kendall, 1969; Richardson *et al.*, 1978; Johnson *et al.*, 2000). Presence of *Thalassiosira rudolfi*, a salt tolerant species indicated alkaline conditions. The lack of other diatoms partly suggested a stratified water column due to low winds or low cloud cover that may have resulted in intense heating. The major producers were green algae including *Botryococcus, Coelastrum* and *Pediastrum.*

Pluvial conditions during Holocene lead to a rise in lake levels accompanied by strong mixing of the water column and accelerated inputs of biogenic silica (Johnson, *et al.*, 1998). *Aulacoseira*, mainly *A. granulata* and *A. ambigua*, and *Stephanodiscus* were the most abundant diatoms in the early parts of this period (Kendall, 1969; Richardson *et al.*, 1978). These species were replaced by *Aulacoseira nyassensis* in the later Holocene when mixing of the water column lessened. Reduction in biogenic silica led to a decline in many diatoms except *Nitzschia* that has increased especially over the last 3,000 to 4,000 years.

The earliest information on living diatoms of Lake Victoria was included in pioneer systematic studies on phytoplankton in the early nineteenth century (lists in Talling, 1987 and Cocquyt & Vyverman, 1994). These were followed, in the mid-century by data on species composition, dominant species and ecology. Talling (1966a, b, 1987) gives baseline accounts on seasonal dynamics and species composition of lake phytoplankton, whereas Akiyama, *et al.* (1977) gives this account for Mwanza Gulf.

Taxonomic descriptions, distribution and ecology of diatoms of the East African region are included in studies by Gasse *et al.* (1983) and Gasse (1986). Cocquyt *et al.* (1993) gives a checklist of all algal taxa in East African Great Lakes (Tanganyika, Malawi and Victoria) in which 215 diatom taxa are recorded for Lake Victoria. According to Cocqyut & Vyverman (1994), 60.2% of the diatom taxa in Lake Victoria are cosmopolitan, 5.2% pantropical and restricted to the tropical region, 20.9% are African and 13.7% are tropical African. The endemic species in the lake include *Rhizosolenia curviseta*, *R. victoriae* and *Fragilaria longissima*.

Attempts have been made to relate diatom assemblages and some environmental factors in different biotopes in East Africa. Hustedt (1949, quoted in Richardson *et al.* 1978) related diatom associations to alkalinity. Richardson *et al.* (1978) used diatom assemblages together with correlations between alkalinity and recent ion content to interpret and trace past history of lakes in the region. Gasse *et al.* (1983) reports a strong relationships between diatom assemblages and chemical factors from samples collected all over East Africa between 1960 and 1984.

In the early 1960s, Lake Victoria had a rich and varied community of phytoplankton (Richardson, 1964; Talling, 1966 a,b; 1987; Gasse, 1983). Diatoms, green algae and cyanobacteria (blue-green algae) were well represented. Clearly defined annual seasonal succession of species occurred in which cyanobacteria dominated the epilimnion during periods of stratification and diatoms replaced them and other forms of algae during isothermal mixing of the water column.

These successions of species have diminished and cyanobacteria seem to persistently dominate (Ochumba & Kibaara, 1989; Hecky & Bugenyi, 1992; Mugidde, 1993; Cocquyt & Vyverman, 1994; Lung'ayia *et al.*, 2000; Kling *et al.*, 2001). *Nitzschia*, particularly *N. acicularis* has replaced *Aulacoseira* as the most important diatom in the open waters of the lake. Such shifts in communities of primary producers can be clear manifestations of the continuously changing environment of the lake that may have far reaching implications on water quality and fish production.

Most of the information on diatoms in the East African region is based on collections from lakes. Whereas, diatom species composition and mechanisms that determine their structure in lotic habitats is poorly known. While lakes and other lentic habitats act as sinks for materials washed from the catchments area, rivers are the main conduits and also transformers of particulate and dissolved forms en route from land to the lake. These ecosystems are increasingly threatened by environmental degradation, human destruction and pollution leading to changes in water quality and loss of biodiversity. Like in Lake, changes in rivers can be detected by monitoring changes in biological organisms such as diatoms.

Rivers and lake are interconnected through continuum and transition areas, and by combining research in the two ecosystems, it may be possible to achieve an understanding of many processes in terrestrial and aquatic environments. Aspects of the biological community structure of these ecosystems can be understood by investigations on environmental conditions as well as biological factors. Such studies are useful in describing changes in the state of the ecosystem and give causative and predictive interrelationships of various elements and available diversity. Gasse *et al.* (1983) and Cocquyt & Vyverman (1994), among others have pointed out the need for more studies to increase knowledge on diatom taxonomy, distribution and ecology in the East African region and relationships between diatoms and critical environmental factors.

1.3. OBJECTIVES

Lake Victoria, inflowing rivers and other associated bodies of water in the basin are facing more ecological and environmental problems than ever before. This is because of a large human population, rapidly increasing urban and industrial settings, intensified agricultural cultivation and other developmental activities. These factors contribute discharges that greatly impact on watercourses and the lake. Most of the aquatic ecosystems are exhibiting symptoms of eutrophication, siltation and decreasing transparency, increasing algal biomass, changes in composition of biological communities and loss of biodiversity. As a result, the management and public attention has focussed on a number of issues. They include the quality of the water, domestic and recreational use of the water, use of the water for transportation, sustainability of the fishery and general degradation of the environment.

At a time when conservation measures and pollution control strategies are being implemented in the Lake Victoria basin, it is becoming increasingly important to evaluate the possibility of applying biological methods for assessment of ecological status to complement the routine physical and chemical methods. In principal, good and reliable techniques to monitor and predict water quality should indicate both recent and long term effects of changes at a certain locality or area. Diatom assemblages, particularly attached ones are more or less permanent residents in rivers and since they are in close contact with the water, they integrate both physical and chemical information over a period of time. The sensitivity of diatoms to changes in the environment in addition to many qualities they possess and advantages that they can offer makes them good candidates for biological monitoring in the Lake Victoria basin.

Biological assessment methods especially integrating diatoms as part of routine water quality monitoring are becoming popular especially in Europe and many temperate countries. Such kinds of systems are rare in the tropics and lacking in Lake Victoria basin. This study attempts to identify relationships between diatom assemblages and environmental conditions in three rivers draining into Lake Victoria and the lake itself, and to test the suitability of diatoms as bio-indicators of water quality.

The main objectives of this study are to:

1. Describe diatom community composition and diversity in rivers Nyando, Kibos and Kisat in the catchments of Lake Victoria.
2. Identify distribution patterns of diatom populations and communities and determine contribution of physical and chemical environment, space and time in defining the species distributions.
3. Asses the suitability of using diatom ecological indicator values in determining the ecological status and water quality in rivers Nyando, Kibos and Kisat, and in supporting management decisions and conservation efforts.
4. Describe diatom community composition and diversity in Lake Victoria and determine their distribution patterns in relation to environmental variables, and as indicators of water quality.

These objectives are treated and discussed in the forthcoming chapters.

The aim of the study was first, to determine the available diversity and ecology of the diatoms in Lake Victoria and its catchments and, secondly, to asses the potential use of the diatoms as tools for monitoring "ecological" water quality for management purposes and in formulation of strategies for conservation of the biodiversity.

Chapter 2

Materials and methods

2.1. GENERAL DESCRIPTION OF THE STUDY AREA

The study broadly covers two areas:

1. The catchments of rivers Nyando, Kibos and Kisat.
2. Lake Victoria (Kenya part).

2.1. The catchments of rivers Nyando, Kibos and Kisat

Lake Victoria basin in Kenya covers an area of about 47,709 km^2 (Republic of Kenya, 1986) in the western part of the country (Figure 2.1). The first study area which comprises Rivers Nyando, Kibos and Kisat is centrally located in the lake's basin within latitudes 0°18′ S to 0°04′ N and longitudes 34°43′ E to 35°30′ E. All the three rivers rise in catchments in the east and drain into Lake Victoria in the southwest. A large proportion of the rivers occur in Kisumu District (Kibos and Kisat) and Nyando District (Nyando) in Nyanza Province.

Nyando, the largest of the three rivers, has a catchment area of about 2,650 km^2 and an annual discharge of about 247 million m^3 (Burgis *et al.*, 1987). Its two major tributaries are Nyando (Masaita) and Mbogo. Nyando (Masaita) drains in a westward direction from its source in Tinderet Forest on the Nandi Escarpment (altitude 2590 m a.s.l.) and South-western Mau Forest on West Mau Escarpment (2438 m a.s.l.). Mbogo drains southwards from the eastern part of the Tinderet Forest

Nyando (Masaita) and Mbogo flow down the slopes of the West Mau Escarpment to pass through upper Kano plains (1300-1800 m a.s.l.) and confluent at a point 2.5 km above Ogilo Bridge. After the confluent, the Nyando flows southwest to pass through lower Kano plains and discharge into Nyakach Bay of Lake Victoria, through the extensive papyrus and reed dominated Miruka swamp.

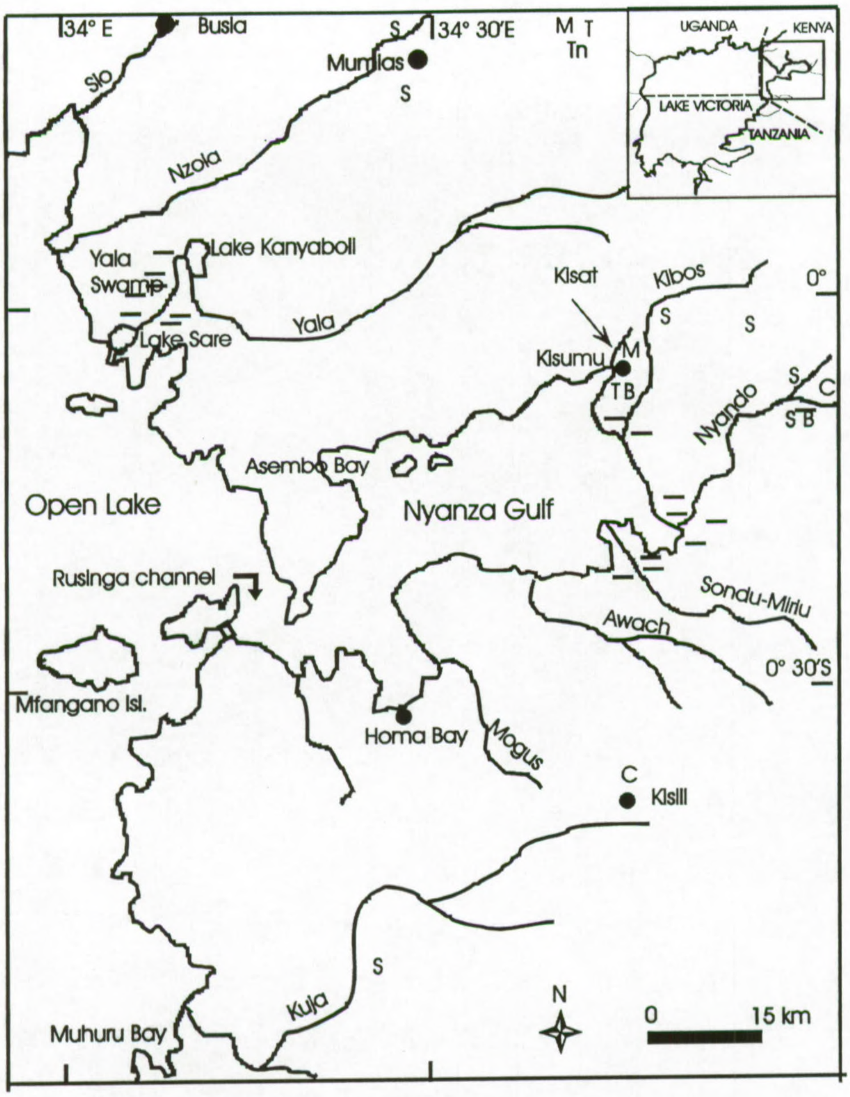

Figure 2.1. Map showing drainage in the Lake Victoria basin in Kenya and positions of Rivers Nyando, Kibos and Kisat. Main industries are shown (S= sugar, T = textile, B = brewery/distillery, Tn = tannery, C = coffee, M = miscellaneous).

The basin of Kibos is located on the eastern part of Kisumu District and covers an area of 490 km^2 (Burgis *et al.*, 1987). The annual discharge is about 68 million m^3. The river flows southwards from its source in South Nandi Forest located on the Nandi Escarpment (1981 m a.s.l.). It flows down the Nandi escarpment to confluent with its other major tributary, Awach, at the foot of the escarpment (1200 m a.s.l.). The Awach rises from the western part of the Nandi Escarpment. After the confluent, the Kibos (now also known as Nyamasaria), flows on the eastern outskirts of Kisumu town and enters the Nyakach Bay through a papyrus-dominated swamp.

The basin of Kisat, the smallest of the three rivers, is barely 10 km^2 and it is located within the northern sector of Kisumu municipality. The river rises from a small swamp (1177 m a.s.l.) near Migosi, a suburb of Kisumu town and flows eastwards through slums at Obunga then through Kisumu industrial area and discharges into Kisumu Bay of the Nyanza Gulf.

2.1.2. Geology and soil characteristics

The Lake Victoria basin in Kenya is underlain by the "Basement complex" of Aechean and Precambian, igneous and metamorphic rocks (Burgis *et al.*, 1987). The area occupied by the Nyanza Gulf has Tertiary and recent alkali volcanic and sedimentary rocks (Johnson *et al.*, 2000). The highland areas especially around Nandi Hills contain Precambrian intrusives composed mainly of granite rocks that include tiff, agglomerate and phonolite lava (Republic of Kenya, 1992). The phenolite lava of Pliocene age is found in the east of Nyando Division and around Kisumu town. Sediments of Pleistocene age mainly composed of lacustrine and fluviate deposits are generally distributed. Talus screes, colluvium and alluvium form recent systems and they are composed of silt, clays, sands, gravel and lateritic iron stones. Tallus screes are found along the foot of the escarpment, colluvium occurs from hill or wash accumulation and alluvium is formed by silt and sand carried by river flow. Reddish brown lateritic ironstones develop on the bed of phonolite lava.

Red clay-loam soils are found in the highland areas. Black cotton soil, sandy red soil and lateritic soil are predominant in the plains. The black cotton soil is composed of clay minerals and is widely spread. The sandy red soil consisting of quartz grains is distributed at foot of slopes and piedmont plains along the escarpment of granite rocks. Lateritic soils are formed from non-rich soils by weathering and decomposition of rocks by rain.

2.1.3. Climate

The climate is characterised by two main rainy seasons: the long and heavy rains occur from March to May and the short rains from October to November (Burgis, *et al.*, 1987). Relatively dry seasons occur in-between the two rainy seasons. The annual mean rainfall in the area of study varies between 1250 mm and 1550 mm (Burgis *et al.*, 1987). However heavier rainfall up to 1,600 mm is common in the highland areas of Kericho and Nandi (Republic of Kenya, 1992). Variations from normal climatic and rainfall patterns are increasingly observed in recent times. This was clearly evident during the El Nino phenomenon in late 1997 to 1998, resulting in a prolonged period of heavy rainfall (Figure 2.2).

Mean monthly air temperature range from 21.9 to 24.3 °C (Burgis, *et al.*, 1987). The highest temperatures are recorded in February and March and the lowest in December and January. The relative humidity ranges from 55% in the dry season to 75% in the rainy season (Republic of Kenya, 1992). The peak relative humidity occurs between May and July, during and after the long rains. The lowest relative humidity occurs in January.

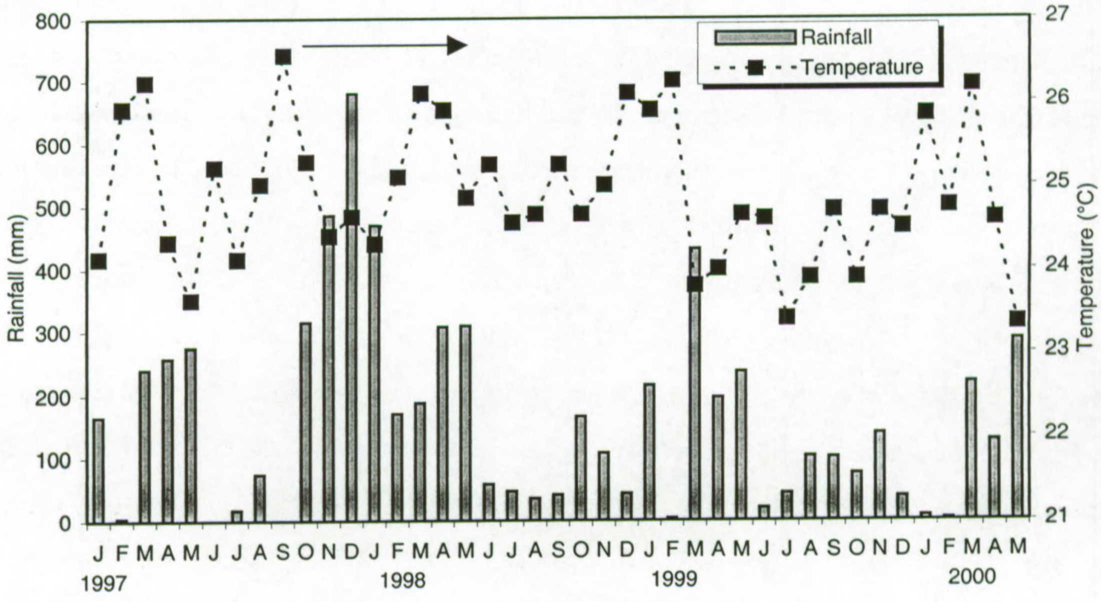

Figure 2.2. Monthly total rainfall and mean air temperature at Kisumu from January 1997 to May 2000 (arrow indicates period of El Nino phenomenon).

2.1.4. Population and land use

In 1999, Nyando District had an estimated population of 299,930 and Kisumu District 504,359 persons (Republic of Kenya, 1999). The population density was 349 persons km^{-2} but is higher in urban areas of Kisumu.

The major land use in the source of the Nyando is natural and plantation forests of Tinderet and the South-western Mau. These forests are under disturbance due to over-harvesting of forest products and human encroachment for agricultural cultivation and settlement. Human populations are low in areas below the forest and the principal land use includes tea and coffee plantations, livestock keeping especially cattle and smallholder subsistence farming of maize and vegetables. A limestone mine is located at Homa lime near Koru at the foot of the Nyando Escarpment.

In the middle basin, the Nyando traverses through the gently rolling Kano plains with extensive sugar cane plantations. Defuse pollution loads are mainly due to application of fertilizers in the sugar cane farms. Currently, major sources of wastewater discharge into the river are two large-scale sugar factories located at Muhoroni and Chemilil and an agro-chemical factory (distillery) that is mainly based on by-products of sugar refining also located at Muhoroni. Chemelil is located on River Mbogo, a major tributary of the Nyando. A third sugar factory is located further west at Miwani and although it does not discharge its effluents directly into the Nyando, runoff from its large tracts of sugar cane farms enter this river. Large human populations of mainly farm and factory workers and their dependants are found in settlements in the sugarcane zone. These factories and related activities discharge their waste effluents into the Nyando.

The mid Kano plains below the sugar cane zone supports high human population densities on small holder agricultural farms. The area is cultivated with maize, sorghum, pulses, and cotton. Some land is used for grazing of livestock, mainly cattle and goats. Ahero rice irrigation scheme is located on lower parts of the gently rolling plains and the water for irrigation is obtained from the Nyando. Application of fertilizers, herbicides and pesticides is done in the paddy fields.

The lower parts of the Kano plains are liable to flooding during heavy rains mainly due to the extremely gentle gradient of the river-beds, siltation in river channels and incidental rise in the Lake water level. Dykes have been constructed in several places to control floods and prevent destruction of villages and other property. Some of areas are left uncultivated and are used as pasture land. In final lower reaches, Nyando ends as a vast swamp. The swamp provides natural purification processes and it is an important habitat for avifauna and fish. Besides, the swamp provides social and economic services to the local population. However, overexploitation of the inherent resources, mainly harvesting of papyrus and other reeds may have reduced the filtering capacity of the swamp and discharge by the Nyando is regarded as one of the major sources of pollution in the Nyanza Gulf of Lake Victoria.

Along the course of the Nyando, there is incidental use of the water for laundry and open bathing by humans and watering of livestock, mainly cattle. Eutrophication, dead organic matter and sediment loading, and faecal bacteria contaminations are increasingly becoming major water quality concerns on this river.

The source of Kibos is in Nandi Forest on the Nandi escarpment. A tea plantation is located at the edge of the forest followed by a sparsely populated area with medium-scale farms of maize and dairy cattle. The slope of the land is steep and the river evolves into fast currents over a series of rapids with pebbles and boulders on the Nandi escarpment. An intake point for drinking water supply to part of Kisumu town is located at the foot of the escarpment near Kajulu village. A few sugarcane plantation and a small sugar factory are located immediately after the water intake point and before the Kibos confluents with Awach, its major tributary. The Awach originates from the relatively more populated Maragoli area in Vihiga District. Its catchments has a few small holdings agricultural farms with maize and vegetables as the main crops. Sand is excavated from the beds of the Awach and Kibos in this area and as a result bank collapse is evident in many places.

After the confluent of the Kibos and Awach, the river (now also known as Nyamasaria) passes through the westernmost part of the Kano plains. This area is characterised by small holdings agricultural farms of maize, sorghum and vegetables as main crops. Livestock, mainly cattle are also reared and a prison farm is located at Kibos village. The middle reaches of Kibos passes on the eastern outskirts of Kisumu town, which is increasingly becoming urban due to construction of residential houses and a few industries. This stretch has several sand mining sites. The lower reaches after Nyamasaria village is a floodplain area that is sparsely populated and primarily used as pastureland. A papyrus-dominated swamp connects the Kibos to Nyakach Bay of Lake Victoria. Like the Nyando, the course of the Kibos is used for drawing water for domestic purposes, laundry and open bathing by humans and watering of livestock. In general, Kibos especially the upstream is not influenced by industry or municipal sewage but mainly by runoff from forest and agricultural land.

The source of River Kisat is a small swamp on the eastern suburbs of Kisumu town. Draining and subsequent cultivation of the land has accelerated the drying up of a seemingly once vast swamp, leaving the river to a trickle. Some parts of the swamp has been converted into a few paddy fields, two fishponds and a seedbed for trees and flowers. Grazing fields for livestock mainly cattle, small farms of maize and vegetables and a few paddy fields are in the immediate vicinity. All these activities have modified most of the area that is also being converted for residential houses.

The middle reach of Kisat passes through an area with small farms of maize, sorghum, vegetables and cultivation is done up to the river banks. The Kisat passes through the densely populated slums of Obunga which lack sanitation facilities and streams of household sewage and residues from makeshift distilleries of 'changaa' an illicit local whisky, enter the river at various points. After the slums, the river flows through the Kisumu industrial area and the main industries include a brewery, textile mill, soap, confectionery, and fish processing factories, salt works, motor garages and stores for various items. The factories have no facilities for treating effluents and are connected to the sewage drainage system or discharge their waste effluents directly into the river. A municipal sewage treatment plant is located at the lower part of the industrial area. However, the sewage plant has not functioned for several years and during the whole period of this study, untreated sewage was continuously discharged directly into the river. A golf field is located just before the mouth of the Kisat in Kisumu Bay of Lake Victoria.

Kisat is greatly influenced right from the source by inputs of sediments from agricultural cultivation in the upstream, discharge of raw domestic sewage from Obunga slums, urban runoff, effluents from industries and raw municipal sewage.

2.1.5. Location and characteristics of the sampling stations on the rivers

The three rivers Nyando, Kibos and Kisat were selected on the basis of differing hydrology, habitat conditions and levels of pollution. These rivers when combined, may contain almost all the different levels of water quality present in many rivers in Kenya and the Lake Victoria catchments today. In addition, the three rivers are in close proximity to the Kenya Marine and Fisheries Research Institute (KMFRI), Kisumu Centre where the chemical and some of the biological analyses were done.

Sampling stations were selected to represent different ecological conditions and obvious environmental variations within each river, in order to understand the influence of natural as well as human activities on physical, chemical and biological components of the water body.

Natural conditions, land characteristics, upstream basin (e.g., type of land use, urban and industrial effluents, etc.) that may influence water quality were considered. For purpose of accessibility, most of the sampling sites were primarily located below bridge crossings. The location and general characteristic features of the twelve stations four on each river are given in Table 2.1 and Figure 2.3.

2.1.6. Sampling programme

The investigation was composed of both field and laboratory work. The twelve stations established on the three rivers are K1-K4 for Kibos, N1-N4 for Nyando and C1-C4 for Kisat (Figure 2.3, Table 2.1). Sampling was done during seven occasions: May, August, September and December 1998; February 1999; March 2000 and March 2001. In all cases, samples were collected on two consecutive days and sequentially from the uppermost to downstream stations.

2.1.7. Environmental measurements

Geographical position and altitude of each station was determined using a GARMIN GPS II PLUS global positioning system. The width of the stream channel was determined using a tape measure. Average depth was estimated from a series of depth measurements made at equal intervals across the stream channel by wading or using a sounding rope. Velocity of surface currents was estimated from time taken by a neutral buoyant object to travel over a pre-determined length of the river. Actual values of velocity were used to estimate the volume of discharge as a function of the mean velocity and the estimated cross-section of the stream (Wetzel & Likens, 2000).

In situ measurements were taken for water temperature and dissolved oxygen using a WTW Microprocessor Oximeter Oxi 320, pH with a WTW Microprocessor pH-meter H 320, conductivity with a WTW Microprocessor conductivity meter LF 96 and turbidity with a Hach 2100P Turbidimeter. All the meters were calibrated appropriately before each sampling trip. Hardness was determined by EDTA titrimetric method (American Public Health Association (APHA) 1995)) immediately on site at time of collection. Total alkalinity was also determined immediately by titration with 0.02 N HCl with mixed bromocresol green-

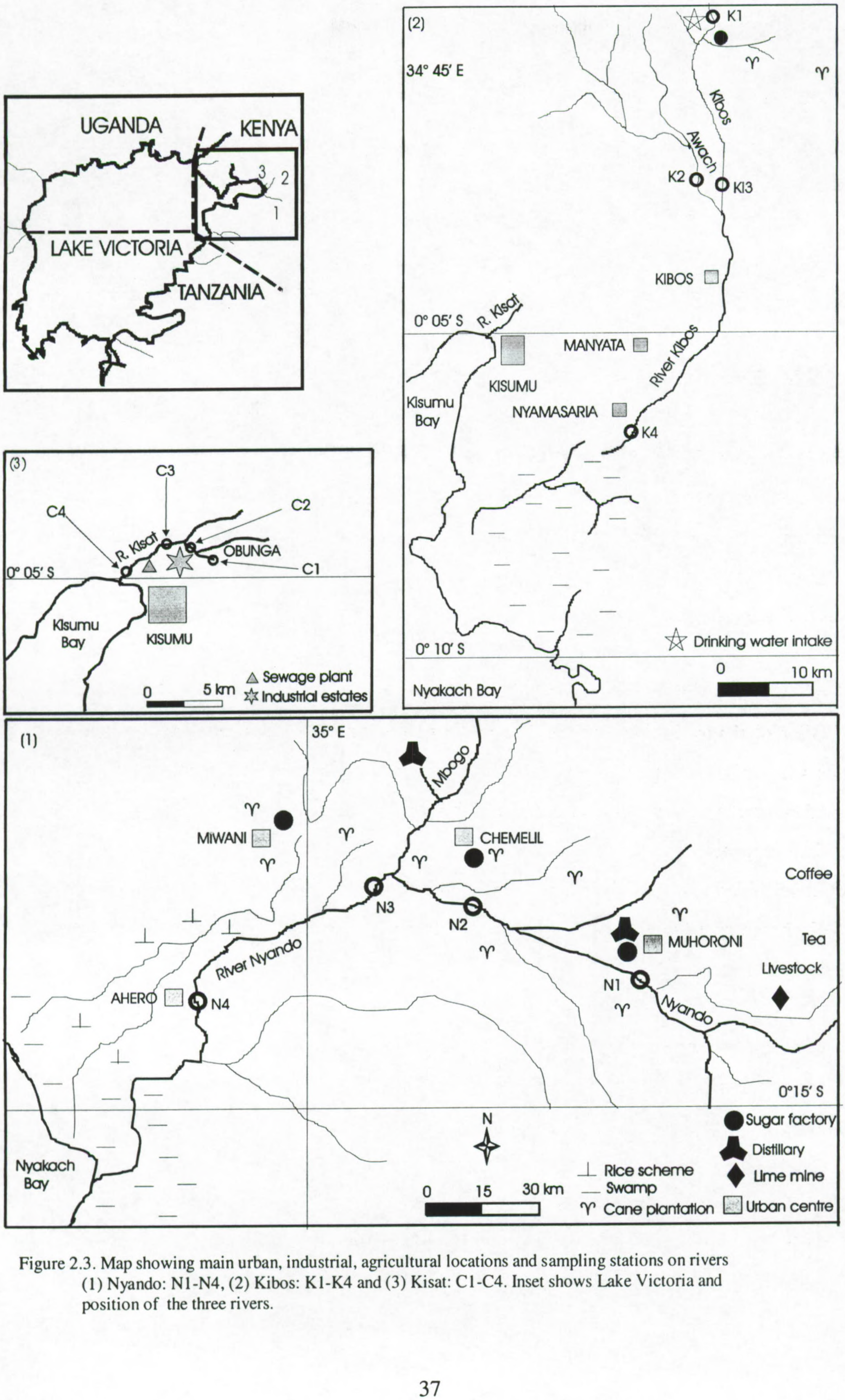

Figure 2.3. Map showing main urban, industrial, agricultural locations and sampling stations on rivers (1) Nyando: N1-N4, (2) Kibos: K1-K4 and (3) Kisat: C1-C4. Inset shows Lake Victoria and position of the three rivers.

Table 2.1. Description of the 12 sampling stations on rivers Kibos (K1-K4), Nyando (N1-N4) and Kisat (C1-C4).

Code	Station name	Coordinates	Altitude (m a.s.l.)	Source (km)	Characteristics of catchments and sampling station	Nature of water and utilization
K1	Kajulu	00°00′12′′ S 034°48′37′′E	1248	37	Forest, limited agricultural activities. Station at foot of escarpment. Steep gradient with rapids, high velocity. Substrate of boulders.	Clear water. Drinking water intake for Kisumu municipality, local domestic use, bathing and watering livestock.
K2	Riverside	00°01′59′′ S 034°47′36′′ E	1213	20	Several small holder agricultural farms. Steep gradient with rapids. High velocity. Substrate of small to big stones. Sand extraction from river bed. Bank collapse downstream.	Turbid. Used for drinking, domestic purposes, bathing and livestock.
K3	Wathorego	00°02′40′′ S 034°48′49′′ E	1202	41	Small sugar factory, cane farms, small holder farms, sand extraction. Sandy substratum with big stones. Fairly high velocity. Banks covered with reeds. Bank collapse evident in some places.	Turbid. Used for drinking, domestic purposes, bathing and for livestock.
K4	Nyamasaria	00°06′55′′ S 034°47′18′′ E	1170	50	Small holder farms, sand extraction. Sandy substratum with big stones, low velocity.	Turbid. Used for drinking, domestic purposes and for livestock.
N1	Muhoroni	00°09′48′′ S 035°11′01′′ E	1287	130	Forest, tea, coffee and cane farms, small holder farms, lime mine. Substrate with small to big stones. High velocity.	Turbid. Supply to sugar industry, drinking, domestic purposes, bathing and for livestock.
N2	Awasi-Chemelil bridge	00°07′20′′ S 035°05′51′′ E	1231	155	Sugar factory, distillery, cane farms, urban settlement. Substrate of alluvial bed, gravel, few big stones. Low velocity.	Murky water with boluses of black suspended material. Strong odour of molasses. Limited use for bathing and livestock.
N3	Ogilo bridge	00°07′21′′ S 035°00′02′′ E	1182	165	Sugar factories, cane farms, small holder farms. Below confluent of Nyando and Mbogo. Substrate of alluvial bed, soft rock and few boulders. Low velocity.	Turbid. Possible dilution by Mbogo tributary. Limited use for bathing and livestock. Abstraction to paddy fields.
N4	Ahero	00°03′48′′ S 034°56′42′′ E	1176	177	Cane farms, sugar factories, paddy fields, small holder farms. Low velocity.	Very turbid. Limited use for bathing and livestock.

Table 2.1. (continued).

Code	Station name	Coordinates	Altitude (m a.s.l.)	Source (km)	Characteristics of catchments and sampling station	Nature of water and utilization
C1	Kenya Breweries	00°04′42′′ S 034°45′44′′ E	1171	0.5	Brewery and slums. Immediately below the spring source for this tributary of Kisat. Substrate of concrete slab and stones. Low velocity.	Clear water. Used for domestic purposes and cleaning fish carcases.
C2	Obunga-Mbuta	00°04′42′′ S 034°45′38′′ E	1165	1.5	Brewery, slums and local open market for frying fish. Low velocity.	Slightly turbid, oily with soot and remnants of fish offal. Odour of rotting fish. Not used for any purpose.
C3	Kudho-kotur	00°04′46′′ S 034°45′17′′ E	1164	9	Industrial area and urban storm drains. Substratum of soft mud and small to big stones. Slimy moulds visible on submerged stones. Low velocity.	Murky water with boluses of black suspended material. Odour of raw sewage. Not used for any purpose.
C4	Golf course	00°04′50′′ S 034°44′55′′ E	1159	11	Industrial area, municipal sewage plant and urban storm drains. Substrate of soft black mud with few stones. Low velocity.	Murky water with boluses of black suspended material. Strong odour of raw sewage. Not used for any purpose.

methly red as indicator (Wetzel & Likens, 2000) and after checking for phenolphthalein alkalinity.

Water samples for analysis of nutrients were collected just below the surface, preserved with 0.2 ml mercuric chloride and kept on ice in a cooler box. The samples were taken to the laboratory and analyzed, using spectrophotometric methods as described by Wetzel & Likens (2000): for nitrate-nitrogen (cadmium reduction), phosphate-phosphorus (SRP, ascorbic acid) and dissolved silica SiO_2 (molybdosilicate). Prior to determination, water samples were brought to room temperature and filtered through cellulose-acetate membrane (pore size 0.45 µm). Total suspended solids (TSS) were determined on unpreserved samples by measuring residue retained by fiber-glass filters (Whatman GF/C) dried to a constant weight at 103 to 105 °C in an oven (APHA, 2000).

All the environmental variables were measured during all the seven sampling occasions except ammonia-nitrogen, total dissolved solids and biochemical oxygen demand. Ammonia-nitrogen was determined during 5 occasions (May 1998 to February 1999) by manual phenate method, and biochemical demand was determined by the 5-Day BOD test (incubation at 20 °C) only for samples of March 2001 according to APHA (1995). Total dissolved solids were estimated *in situ* with an ATI ORION model 105 and 115 conductivity meter only for samples of December 1998.

2.1.8. Biological measurements

Epilithic diatoms were collected at each station from at least 5 randomly selected submerged or semi-submerged stones, mainly cobbles free of filamentous algae or silt and with an obvious diatom film. The stones were obtained from different positions within a 5 m reach. The attached diatoms were gently removed from the upper surfaces of the stones, calculated to cover approximately 100 cm^2 using a clean soft tooth brush and repeated rinsing with distilled water. The collected composite material was preserved in 5 % formalin solution and transported to the laboratory.

The samples were let to sediment for 48 hours or more, supernatant decanted and the residue concentrated to a final volume of 10 to 20 ml. The samples (residue) were oxidised with strong acids. Concentrated sulphuric acid of an equal volume was added to the samples and the contents heated and boiled on a hot plate under a fume cupboard for 20 minutes or more (until the colour of the contents became black). The contents were let to cool and enough (5 to 10 ml) concentrated nitric acid was added. The contents were heated and boiled again until the colour cleared. They were cooled and left standing for several hours.

The residue, white in colour, containing diatom frustules was centrifuged and washed with distilled water at least 5 times (until acid-free). A sub-sample of clean frustules was transferred to a slide cover slip and dried gently. The dry cover slip was turned over onto a drop of Styrax® (Gum storax) mounting medium on a warm microscope slide. The Styrax spread under the cover glass and the cover glass was left to settle gently in place. The slide was removed from the hotplate and let to cool in a horizontal position. The cooling partially sealed the cover glass to the slide. Permanent preparations were ringed with nail polish, labelled with details including station number and date of sampling and stored in a slide box in a horizontal position.

The prepared slides were examined under a Leitz Dialux 20 EB light microscope at 1000 x magnification using immersion oil. A number of transects across the slide were examined, diatom taxa identified and relative abundance of individual taxa determined by counting a minimum of 300 frustules. Taxonomic identification mainly followed Krammer and Lange-Bertalot (1986-1991) and guidelines given in Barber & Haworth (1981). For identification of some species, other taxonomic literatures including Hustedt (1949), Huber-Pestalozzi (1962), Germain (1981), Gasse (1986), Vyverman (1991) and Cocquyt (1998) were also consulted.

2.1.9. Image capture and digitization

Digital images of specimens of diatoms were obtained with a JVC TK-C1381EG color video camera attached to a Leica DMLB binocular microscope, and Image Compact® image processing kit. For most specimens 1000 x magnification with immersion oil was used (400 x magnification for large specimens) The images were displayed, captured, digitised and processed. Characteristics of the specimens were recorded including length, width, numbers of striae, fibulae and other distinguishing features. The image processing kit reads and writes TIF format files. The TIF format files were compressed using JPEG technique to an average of 20 kilo bytes. The original images are retained in an archive. The JPEG images can be viewed on a computer monitor and are made available via Photo editor.

2.1.10. Data analysis

Results of the data from environmental and biological measurements on the rivers were used for subsequent analyses and are reported in Chapters 3 to 5 and the respective Annexes.

2.2 Lake Victoria (Kenya part)

The Kenya waters of Lake Victoria comprise the north-eastern part of the main open lake and the Nyanza Gulf (Figure 2.4). Burgis *et al.* (1987), Mavuti & Litterick (1991) and Crul (1995) give detailed description of this part of the lake. The Nyanza Gulf, a greatly indented and semi-enclosed shallow bay is thought to have originated separately from the main lake and the two became connected in Pleistocene. The gulf is joined to the main lake via Rusinga channel. A second channel, the Mbita channel, was closed by construction of a causeway linking the Rusinga Island to the mainland. Previously, strong currents through the latter channel helped in mixing of the waters in the gulf and exchanges with the main lake. (See also Chapter 1 Table 1.2 for morphometric and hydrological data of the lake).

Lake Victoria is situated at about 1134 m a.s.l. Its basin overlies Precambrian rocks and Quaternary sediments accumulated in several places including east of the Nyanza Gulf. The climate is typically equatorial with mean monthly air temperature range from 21.9 to 24.3 °C (mean maximum 28 °C - 31 °C). There are two main rainy seasons: The long rains from March to May and the short rains from October to November. The most important river catchments include those of Sio, Nzoia, Nyando, Sondu (Miriu) and Kuja. Rainfall directly onto the lake's surface contributes more than 80% of the total water budget (Johnson *et al.*, 2000).

The soils of the catchments are mainly red loams in the highland areas and dark clays in the lowlands and floodplains. Large forests exist in the highland areas of Kericho, Nandi, Kakamega and Mt. Elgon. Most of the rest of the land is under various types of agriculture and livestock rising. The main industries include sugar factories, paper mill, cotton and textile mills coffee and tea processing and various food industries.

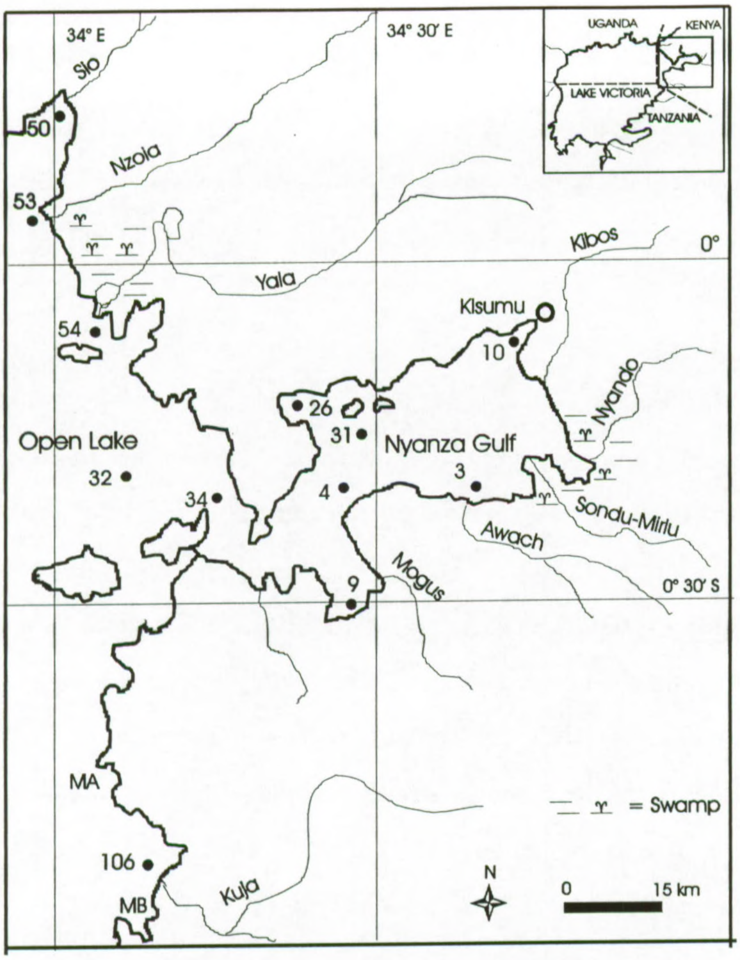

Figure 2.4. Map of Lake Victoria (Kenya) showing location of the sampling stations (3 – 106, MA, MB).

The Lake Victoria basin in Kenya is one of the most densely populated areas in the country. Densities over 300 inhabitants km^2 are common. The total population in the basin was estimated as 8.9 million in 1988 (Republic of Kenya, 1992). Small to medium size towns are scattered in the catchments areas. Kisumu, the largest town, has an expanding industrial activity and is a major port on Lake Victoria. Other major towns include Kakamega, Kisii, Kericho, Bungoma and Homa Bay. Fishing villages with sizeable populations are found along the shores and on the islands in the lake. There is considerable fishing activity by both artisan fishermen with small boats and industrial and commercial ones with trawlers.

Runoff from agricultural land and urban centres and effluents from industrial establishments provide a variety of inputs into watercourses, and in addition to an increasingly variable climate influence the physics, chemistry and biology of Lake Victoria. Current environmental issues are concerned with increasing eutrophication and deterioration of water quality, loss of biodiversity, declining fish catch, algal blooms and proliferation of the water hyacinth *Eicchornia crassipes*.

2.2.1. Locations and characteristics of sampling stations on Lake Victoria

Investigations were carried out at 14 sampling stations in November and December 1999 and January 2000. The stations were selected from among established and routine limnological stations of Kenya Marine and Fisheries Research Institute, and on the basis of proximity to points of pollution discharges, off-shore or in-shore (Fig. 2.4 and Table 2.2). Some stations were located in the Nyanza Gulf and others in the main lake.

Table 2.2. Location and characteristics of the 14 stations sampled in Lake Victoria (Kenya part).

Code	Station name	Position	Description and mean depth
10	Kisumu Bay	00° 06′ 18″ S 34° 44′ 64″ E	Nyanza Gulf, inshore shallow with urban influence. 3 m.
3	Mouth of River Awach	00° 16′ 15″ S 34° 41′ 15″ E	Nyanza Gulf, inshore shallow with river influence. 4 m
31	Ndere Island	00° 11′ 15″ S 34° 31′ 15″ E	Nyanza Gulf, off-shore shallow water. 6m.
26	Asembo Bay	00° 18′ 43″ S 34° 31′ 16″ E	Nyanza Gulf, inshore shallow with some urban influence. 5 m.
4	Gingra Rock	00° 21′ 15″ S 34° 26′ 15″ E	Nyanza Gulf, off-shore deep water. 11 m.
9	Homa Bay	00° 31′ 05″ S 34° 27′ 76″ E	Nyanza Gulf, inshore shallow with urban influence. 4 m.
34	Rusinga Channel	00° 21′ 32″ S 34° 26′ 56″ E	Confluent of Nyanza Gulf and open lake, off-shore, deep water. 47 m.
32	Bridge Island	00° 03′ 74″ S 34° 56′ 99″ E	Open lake, off-shore, deep water. 42 m.
54	Mouth of River Yala	00° 03′ 41″ S 34° 00′ 53″ E	Open lake, shallow with river influence, extensive swamp at river mouth. 4 m
53	Mouth of River Nzoia	00° 03′ 74″ N 34° 06′ 36″ E	Open lake, shallow with river influence. 6 m.
50	Mouth of River Sio	00° 13′ 27″ N 34° 00′ 08″ E	Open lake, shallow with river influence, small swamp at river mouth. 4 m.
MA	Matara Bay	00° 45′ 01″ S 34° 03′ 32″ E	Open lake, deep water. 17m
MB	Muhuru Bay	00° 57′ 49″ S 34° 06′ 08″ E	Open lake, deep water. 19 m.
106	Mouth of River Kuja	00° 54′ 48″ S 34° 07′ 52″ E	Open lake, fairly deep water with river influence. 9 m.

2.2.2. Determination of environmental variables on Lake Victoria

Geographical position of each station was determined using a GARMIN GPS II PLUS global positioning system. Lake depth was determined from the depth finder of the research vessel (RV Utafiti). A Hydrolab Surveyor II Multi-parameter Water Quality Monitoring System was used for *in situ* measurements of water temperature, dissolved oxygen, pH, and conductivity. Turbidity was measured with a 2100 P Hach Turbidimeter.

Water samples were collected with a Van Dorn sampler at 0.5 m below the surface. The sample was divided into aliquots for several analyses. Alkalinity was determined by titration with HCl and hardness were determined by EDTA titrimetric methods, immediately on site at time of collection. 500 ml of water for determination of nutrients was placed in a polyethylene bottle, preserved with 0.2 ml mercuric chloride, stored in ice and transferred to the laboratory. The samples were filtered (cellulose-acetate membrane, pore size 0.45μm). The filtrate was saved and analyzed for dissolved nutrient species following spectrophotmetric methods: nitrate-nitrogen (cadmium reduction), phosphate-phosphorus (SRP, ascorbic acid), silicate dissolved SiO_2 (molybdosilicate). Prior to determination, water samples were brought to room temperature and filtered through cellulose-acetate membrane (pore size 0.45 μm). All determinations unless otherwise stated followed suitable standard methods selected from APHA (1995) and Wetzel & Likens (2000) as described for the river samples.

100-500 ml water sample was filtered over Whatman GF/C glass fiber filters, for chlorophyll *a* analysis. The pigment was extracted in cold (refrigeration) 90% acetone in the dark for 18 to 24 hours. Chlorophyll *a* was determined by spectrophotometric analysis and calculated according to Strickland and Parsons (1968).

2.2.3. Collection and preparation of diatom samples from lake waters

Water for determination of diatoms was taken from the same sample used to subsample for chemical analyses. 500 ml of water was taken in a polyethylene bottle and preserved with Lugol's solution. The samples were let to settle for 48 hours or more and concentrated to a final volume of 10-20 ml.

Processing, and identification of the diatoms followed the same methods as described for epilithic diatoms from the rivers (Section 2.1.8). The samples were oxidised with concentrated sulphuric and nitric acids, cleaned frustules mounted in Stryrax® (Gum Storax) on slides and enumerated. Diatoms were examined under a Leitz Dialux 20 EB light microscope at 1000 x magnification using immersion oil. Taxonomic literature were mainly based on Krammer & Lange-Bertalot (1986-1991). In addition, guidelines given in Barber & Haworth (1981) were followed. For identification of some species, other taxonomic literatures including Hustedt (1949), Huber-Pestalozzi (1962), Germain (1981), Gasse (1986), Vyverman (1991) and Cocquyt (1998). At least 300 frustules were identified and counted for each sample. Species identifications were also cross-checked with a checklist of algal flora for the East African great lakes (Cocquyt *et al.*, 1993).

Data treatment and results are described in chapter 6 with additional information in Annex 6.

Chapter 3

Diatom species diversity and relationships to environmental variables in rivers Nyando, Kibos and Kisat of Lake Victoria catchments, Kenya

3.1. ABSTRACT

Species composition, richness and diversity of epilithic diatoms were investigated in relation to environmental variables in rivers Kibos, Nyando, and Kisat of Lake Victoria catchments in Kenya. Samples were collected on seven occasions between May 1998 and March 2001. 224 diatom taxa (218 species) belonging to 32 genera were recorded from the three rivers. *Navicula* and *Nitzschia* were the most represented genera. Temporal and spatial variations were indicated by both environmental data and species diversity measures. Species richness varied between 14 and 56 in Kibos, between 18 and 51 in Nyando and between 11 and 40 in Kisat. Maximum species diversity was recorded in Kibos (range 1.3 – 3.4) that is less influenced by human activities followed by Nyando (1.6 – 2.9), and Kisat the most polluted had the lowest values (0.4 – 2.5). Significant correlations were observed between the measures of diversity and altitude, width, depth, current velocity, volume of discharge and oxygen. Increase in ionic content, trophic state and organic loading reduced diversity downstream where a few species tolerant to pollution, such as *Nitzschia palea* dominated the community especially in Kisat. Our results are consistent with other studies and reaffirm the importance of diatom species diversity in indicating changes in diatom assemblages in response to changes in water quality.

3.2. INTRODUCTION

The Lake Victoria Basin is endowed with numerous rivers and streams many traversing large areas of land subjecting them to various human activities. Destruction of catchments through deforestation, human settlement, and agriculture coupled with effluents from industrial establishments and urban centres contribute inputs directly or indirectly into the rivers. Consequently, river habitats are increasingly altered and are faced with problems of changes in water quality and loss of biodiversity. Yet, little is known of many biological communities especially microscopic algae and their role in the ecosystem.

Investigations on rivers in Lake Victoria basin has mainly focused on fishes (Whitehead, 1959; Cadwalladr, 1965a, b; Balirwa & Bugenyi, 1980, 1988; Ochumba & Manyala, 1992; Lung'ayia, 1994) macrophytes (Gichuki *et al.*, 2001), chemical and physical environment (Mwashote & Shimbira, 1994) and hydrology (Burgis *et al.,* 1987). Recent studies on dynamics of water quality on the rivers in Lake Victoria basin in general and on rivers Nyando, Kibos and Kisat in particular are lacking. Furthermore, knowledge on factors that determine biodiversity especially of microscopic algae including diatoms in the rivers and streams in the region is poorly known. The only recent information on diatoms of East Africa from lotic environments seems to be the one of Pentecoste *et al.* (1997) from Ruwenzori Mountains in Uganda. However, several studies provide information on the diatom flora of Lake Victoria. They include those based on fossils (Richardson, 1964; Kendall, 1969; Stager, 1984), surface sediments (Richardson, 1968) water column and bottom mud (Gasse *et al.*, 1983; Gasse, 1986) and phytoplankton (Talling, 1966a, b, 1987; Cocquyt & Vyverman, 1993; Lung'ayia *et al.* 2000; Kling *et al.*, 2001).

Diatoms are an ecologically important group of algae (Mann & Droop, 1996) mainly as primary producers and contributors to the general biodiversity. They are sensitive to environmental changes and they have been employed to assess the state of aquatic ecosystems and responses to perturbations, and their recovery. The stability and resilience of biological ecosystems including consequences due to inter-specific interactions and impacts of human activities can be revealed through studies on biodiversity allowing for distinction and comparisons of the communities in time and space (Leitner and Turner, 2001). Measures of diversity can help to summarise abundance and distribution of species into a single value that characterises the state of the ecosystem, useful for management purposes (Kempton 1979; Van Dam, 1982).

One of the objectives of this study was to understand the diatom community composition and diversity in three rivers: Nyando, Kibos and Kisat with obvious environmental differences. All the three rivers drain into the Nyanza Gulf of Lake Victoria. Species richness, Shannon and Weaver (1963) diversity index and Simpson's (1949) index of dominance are the most commonly used measures of diversity (Lande, 1996) and were employed in this study to describe the diatom community patterns.

The basic water quality of the three rivers is also described in attempts to highlight the factors that influence or predict the diatom diversity. The effect of changes in water quality on other aquatic organisms including fish is briefly discussed. The results can act as baseline data with which changes in future can be compared. In addition, they can be used to determine the suitability of the rivers for aquatic life and for various utilities.

3.3. MATERIALS AND METHODS

3.3.1. Study area

The study area comprises of rivers Nyando, Kibos and Kisat largely located in Kisumu and Nyando districts in the Nyanza Province of Kenya and all draining into the eastern part of the Nyanza Gulf of Lake Victoria. The general area is within latitudes 0° 18´ S to 0° 04´ N and longitudes 34° 43´ E to 35° 30´ E (Figure 3.1, see also Chapter 2 Figure 2.1).

The climate has a bimodal pattern of rainfall with two main rainy seasons interspaced with two relatively dry seasons. The long and heavy rains occur between March and May and the short rains occur between October and November (Burgis, *et al.*, 1987). The mean annual rainfall varies between 1250 mm and 1550 mm. Mean monthly air temperature range from 21.9 to 24.3 °C. The area overlies the Kavirondo and Nyanzian Basement systems with Precambrian intrusive of granite and tertiary volcanic rocks (Burgis *et al.* 1987; Republic of Kenya, 1992).

River Nyando is the largest of the three rivers and rises from the western slopes of the Mau Escarpment and Tinderet forest. It has sub-basins in Kericho and Nandi Districts and flows through Nyando District. Forests, tea and coffee plantations subsistence farming and limestone mining are found in the upper reaches of the river. The river passes through an area with extensive sugar cane plantations and three major sugar refineries (Muhoroni, Chemelil and Miwani), and a distillery (Muhoroni) is located in the general area of the river. An irrigation scheme for paddy is located on the lower stream near Ahero. The catchment of the Nyando has a high human population density mainly on smallholder farms. The river discharges, via a papyrus dominated swamp, into the Nyakach Bay in the Nyanza Gulf of Lake Victoria.

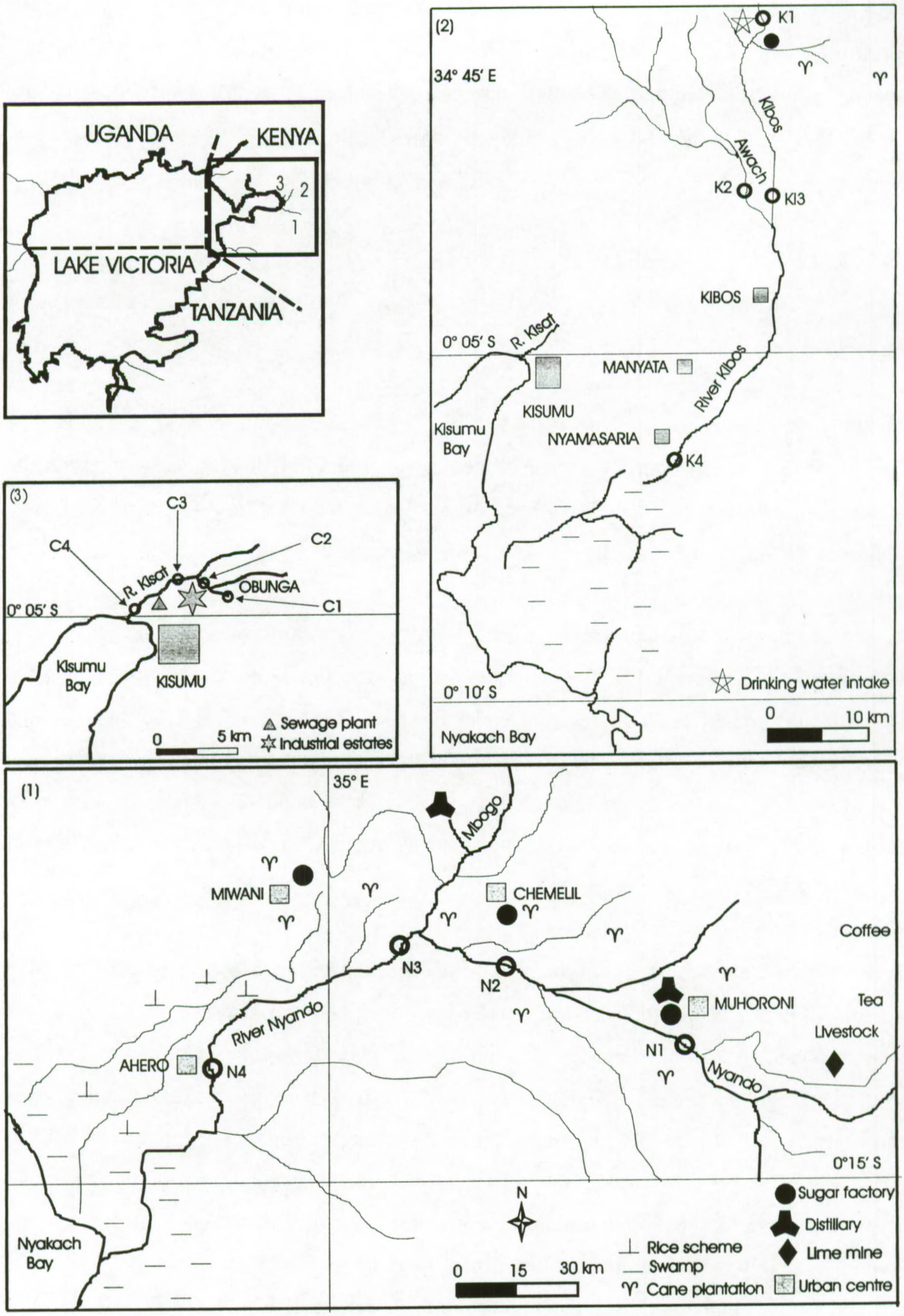

Figure 3.1. Map showing main urban, industrial, agricultural locations and sampling stations on rivers (1) Nyando: N1-N4, (2) Kibos: K1-K4 and (3) Kisat: C1-C4. Inset shows Lake Victoria and position of the three rivers.

River Kibos is located on the Northeastern part of Kisumu District. It originates from the western ridge of the Mau and Nyando Escarpment. The predominant type of land use in the river's basin is forestry, subsistence farming in the upstream. A few sugar cane farms are located in the middle reaches. Downstream, the river passes through the eastern outskirts of Kisumu town and enters the Nyakach Bay through a papyrus swamp.

Kisat is a small river and rises on the northern outskirts of Kisumu town. Subsistence farming is practised on the upper reaches, which is also increasingly becoming urban. The river passes through densely populated slums at Obunga and through an industrial estate in the lower reaches. A municipal sewage treatment plant is located in the final part of the river before it discharges into Kisumu Bay of the Nyanza Gulf.

12 stations were sampled, four on each river (Figure 3.1, Table 3.1), on seven occasions: May, August, September and December 1998; February 1999; March 2000 and March 2001. The ecological conditions of each river, and below and above each station were carefully considered. They include land characteristics, upstream basin (for example type of land use, river water use, urban and industrial effluents, etc.) and natural conditions influencing water quality. The location and general characteristic features of the three rivers, stations and sampling methods are described in detail elsewhere (see Chapter 2).

Table 3.1 Description of the 12 sampling stations on rivers Kibos (K1-K4), Nyando (N1-N4) and Kisat (C1-C4).

Code	Station name	Altitude (m a.s.l.)	Distance from source (km)	Characteristics of catchments and possible pollution sources
K1	Kajulu	1248	37	Limited agricultural activities (water is abstracted above this station for Kisumu town).
K2	Riverside	1213	20	Small agricultural holdings.
K3	Wathorego	1202	41	Small sugar factory, cane farms and sand extraction.
K4	Nyamasaria	1170	50	Domestic waste, sand extraction.
N1	Muhoroni	1287	130	Small agricultural holdings, lime mines, urban settlement.
N2	Awasi-Chemelil bridge	1231	155	Sugar factory, distillery, cane farms, urban settlement.
N3	Ogilo bridge	1182	165	Sugar factories, cane farms (dilution by a large tributary)
N4	Ahero	1176	177	Sugar factories, cane farms, paddy fields.
C1	Kenya Breweries	1171	0.5	Brewery.
C2	Obunga-mbuta	1165	1.5	Domestic sewage from slums, local breweries, open fish frying activities.
C3	Kudho-kotur	1164	9	Industrial area, urban runoff.
C4	Golf course	1159	11	Industrial area, sewage treatment plant.

3.3.2. Environmental variables

Data on the environmental conditions in the rivers included position and altitude of each station (GPS - global positioning system). Width and depth of the stream channel, current velocity and volume of discharge were measured according to methods described by Wetzel & Likens (2000). Others included water temperature, dissolved oxygen, pH, conductivity, total dissolved solids and turbidity (portable meters). Total dissolved solids was determined with a portable meter only once for samples of December 1998.

Water samples were taken and the following analysed according to Wetzel & Likens (2000): total alkalinity (titration with HCl), nitrate-nitrogen (cadmium reduction), ammonia-nitrogen (manual phenate), phosphate-phosphorus (SRP, ascorbic acid) and dissolved silica SiO_2 (molybdosilicate). Total suspended solids were estimated from residue filtered on GF/C filter and dried at 103 to 105 °C and hardness was determined by EDTA titrimetric method as described by APHA (1995). Biochemical oxygen demand was measured by 5-Day BOD test following APHA (1995) only for samples of March 2001.

3.3.3. Biological measurements

Diatom samples were taken from at least 5 stones at each station within a reach of 5 m. Diatom frustules were cleaned with sulphuric and nitric acids and mounted on glass slides in Styrax ® (Gum Storax). They were examined under a Leitz Dialux 20 EB light microscope at 1000 x magnification using immersion oil. At least 300 frustules were inspected in a number of transects across the slide and taxa represented identified and recorded. Taxonomic identification followed mainly Krammer & Lange-Bertalot (1986-1991) and guidelines given in Barber & Haworth (1981). Other taxonomic literatures that were also consulted include Hustedt (1949), Huber-Pestalozzi (1962), Germain (1981), Gasse (1986), Vyverman (1991) and Cocquyt (1998).

Digital image analysis system (JVC TK-C1381EG colour video camera and Image Compact® image processing kit), mounted on a Leica DMLB binocular microscope, was used to characterise dimensions and capture images of the most common taxa occurring in the samples.

3.3.4. Data analysis

Species richness S was calculated as the total number of species identified in a sample (population) (Lande, 1996; Hillebrand & Sommer, 2000).

S = total number of species or (variety) in a population.

Species diversity is a function of the number of species present and evenness with which individuals are distributed among these species (Hurlbert, 1971). The most commonly used measure of diversity is the Shannon and Weaver (1963) due to simple data collection, input and analysis (Lande, 1996). This index is independent of sample size and can reflect changes in the community due to perturbations and stress.

The Shannon and Weaver (1963) index H´, was calculated as:

$H' = - \Sigma\, pi \cdot \ln pi$

Where

pi = proportional abundance of i th species in a population (sample).

p = total number of individuals in a population.

Species evenness J´ or equitability index (Pielou, 1975) was determined by the equation:

$J' = H' / H'\max$

where

H´ = Shannon and Weaver (1963) index.

H´ max = theoretical maximum diversity in a population; $H' \max = \log_2 S$.

S = total number of species or (variety) in a population (sample).

J´ shows the evenness with which individuals are distributed among the species.

Simpson's index was calculated as index of dominance (Simpson, 1949):

$D = \Sigma\, pi^2$

Simpson's index is dependent on more abundant species and it works on the probability that two individuals randomly and independently chosen from a community will belong to the same species (Simpson 1949; Lande, 1996).

All the environmental variables used in the subsequent analysis, except pH and temperature, had skewed distributions (Kolmogorov-Smirnov and Liliefors test for normality) and were log transformed prior to analysis to give approximately normal distributions. Altitude is constant and was not log transformed. The data were compared among the three rivers and along each river by analysis of variance (ANOVA). The existence of temporal and spatial differences of species number, diversity, richness, evenness and dominance of the diatoms was also determined by ANOVA. Relationships among environmental variables, diversity indices, and between them were assessed by correlation analysis.

3.4. RESULTS

3.4.1. Environmental variables

A summary of the mean values and standard deviation of the environmental variables measured in the 12 sampling stations in rivers Nyando (N1-N4), Kibos (K1-K4), and Kisat (C1-C2) is given in Table 3.2. Most of the environmental variables measured showed high variations. The trends in the stations sampled along the three rivers are illustrated in Figures 3.2 a-c. The bar graphs represent absolute values of variables measured in a single analysis (altitude, TDS and BOD) while data from various sampling times are combined to construct the box plots.

The three rivers are arranged in a sequence starting with Kibos, followed by Nyando and finally Kisat, and starting with the upstream station in each river (Table 3.2. and Figures 3.2 a-c). This arrangement follows general gradients observed in values of the measured environmental variables and allows for descriptions of the patterns with ease. This arrangement will be maintained in subsequent mentions.

The stations in Kibos and Nyando had similar elevations, which are both higher especially upstream, than the ones in Kisat (Figure 3.2 a). The elevation of stations in Kibos ranged from 1170 to 1284 m a.s.l, in Nyando, they ranged from 1176 to 1287 m a.s.l and in Kisat, and they ranged from 1159 to 1171 m a.s.l. (Table 3.2). The highest elevation among the stations was at Muhoroni (C1) on the Nyando and the lowest was at Kodhu-kotur (C3) on the Kisat. The lower reaches of all the three rivers are located in low-lying plains with gentle slopes near the shores of Lake Victoria.

Table 3.2. Mean (M) and standard deviation (SD) of environmental variables measured in sampling stations on rivers Kibos (K1-K4), Nyando (N1-N4) and Kisat (C1-C4).

Station	K1		K2		K3		K4		N1		N2		N3		N4		C1		C2		C3		C4	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Altitude	1284		1213		1202		1170		1287		1231		1182		1176		1171		1165		1164		1159	
Width	5.9	2.0	4.1	0.9	7.0	3.6	8.9	4.3	11.9	4.0	13.6	4.1	15.9	5.1	18.4	6.6	0.6	0.1	0.6	0.3	2.1	0.3	4.3	1.1
Depth	0.6	0.3	0.5	0.4	0.9	0.4	0.9	0.4	0.6	0.3	1.4	0.6	1.6	0.8	1.4	0.7	0.3	0.1	0.2	0..2	0.4	0.2	0.4	0.2
Velocity	0.7	0.05	0.5	0.04	0.4	0.03	0.5	0.04	0.9	0.09	0.5	0.05	0.6	0.02	0.5	0.05	0.04	0.00	0.2	0.02	0.2	0.01	0.3	0.02
Discharge	2.4	2.1	1.4	1.6	2.7	2.0	5.3	3.4	10.6	12.7	14.5	15.0	19.9	16.9	18.6	19.0	0.01	0.0	0.02	0.0	0.2	0.2	0.4	0.3
Temperature	19.5	2.3	23.0	2.8	21.0	2.9	22.5	2.3	22.1	1.8	23.6	2.5	24.4	2.0	25.5	2.8	26.0	3.5	27.8	5.8	25.1	1.9	26.8	1.4
Oxygen	7.7	1.8	7.6	1.9	7,3	1.6	7.1	1.3	7.9	2.6	6.5	2.1	7.3	1.5	7.1	1.5	8.3	2.0	1.4	1.2	2.0	1.1	0.9	0.9
pH	7.7	0.6	7.6	0.9	7.7	0.6	7.7	0.8	7.4	0.6	7.6	0.5	7.6	0.8	7.9	0.6	7.2	0.7	6.8	0.5	6.8	0.3	7.0	0.6
Alkalinity	43	14	62	22	57	24	65	31	141	57	206	107	182	57	176	76	111	43	281	165	255	159	357	178
Hardness	39	15	42	14	44	12	45	22	107	44	149	55	125	31	131	31	161	77	205	103	298	234	207	151
Conductivity	83	17	108	37	106	36	117	45	270	119	354	176	293	85	294	92	537	103	1004	576	661	188	850	136
TDS	35		52		46		52		118		164		143		138		243		589		411		446	
Turbidity	61	45	87	54	106	100	285	283	194	205	230	191	295	245	423	411	27	26	249	333	100	82	226	130
TSS	68	42	82	53	144	108	304	269	272	202	350	241	405	265	517	390	242	334	385	471	242	198	357	189
Phosphate-P	82	116	69	118	76	98	70	98	71	84	275	462	131	135	118	114	233	392	439	528	204	210	683	867
Nitrate-N	292	281	311	257	342	374	297	276	309	275	533	814	298	271	272	246	556	478	849	1104	132	189	685	1560
Ammonia-N	77	59	66	35	64	63	59	31	76	66	70	83	84	96	53	45	102	75	282	223	2583	3401	2560	2325
Silicate	52	47	49	40	54	56	53	51	62	60	60	54	56	51	50	47	79	80	74	96	53	61	50	43
BOD	0.8		2.4		2.4		2.4		3.2		6.4		5.6		5.2		6.6		260		340		290	

Units : Altitude (m a.s.l.), width (m), depth (m) velocity (m s^{-1}), discharge (m^3 s^{-1}), temperature (°C), dissolved oxygen (mg O_2 l^{-1}), pH (pH units), total hardness (mg l^{-1} as CaCo$_3$), total alkalinity (mg l^{-1} as CaCo$_3$), conductivity (µS cm^{-1}), total dissolved solids TDS (mg l^{-1}), turbidity (NTU = Nephelometric turbidity units), total suspended solids TSS (mg l^{-1}), phosphate-phosphorus (µg l^{-1}), nitrate-nitrogen (µg l^{-1}), ammonia-nitrogen (µg l^{-1}), silicate SiO_2 (mg l^{-1}), BOD_5 (mg O_2 l^{-1}).

Table 3.5. Spearman rank correlation coefficient matrix for environmental variables (significant correlations are shown as *p<0.05; **p<0.01; ***p<0.001; for units see Table 3.2).

	Altitude	Width	Depth	Velocity	Discharge	Temp	Oxygen	pH	Hardness	Alkalinity	Cond	TDS	Turbidity
Altitude	1												
Width	0.47***	1											
Depth	0.32**	0.75***	1										
Velocity	0.50***	0.62***	0.51***	1									
Discharge	0.49***	0.91***	0.85***	0.81***	1								
Temp	-0.52***	-0.30**	-0.30**	-0.61***	-0.48***	1							
Oxygen	0.55***	0.33**	0.28*	0.30**	0.38***	-0.39***	1						
pH	0.34	0.30**	0.22*	0.08	0.24*	-0.16	0.45***	1					
Hardness	-0.43***	-0.25*	-0.24*	-0.34**	-0.34**	0.51***	-0.54***	-0.40***	1				
Alkalintiy	-0.42***	-0.12	-0.17	-0.23*	-0.23*	0.47***	-0.59***	-0.22*	0.86***	1			
Cond	-0.63***	-0.42***	-0.43***	-0.57***	-0.56***	0.64***	-0.59***	-0.32**	0.86***	0.83***	1		
TDS	-0.68*	-0.36	0.14	-0.75**	-0.37	0.62*	-0.95***	-0.80*	0.84***	0.91***	1***	1	
Turbidity	-0.16	0.43***	0.42***	0.48***	0.51***	0.05	-0.14	-0.29**	-0.02	0.04*	-0.07	0.68*	1
TSS	-0.21	0.29*	0.27*	0.17	0.26*	0.25*	-0.18	-0.40***	0.28**	0.18	0.16	0.69*	0.70***
Phophate-p	-0.29**	-0.15	-0.17	-0.43***	-0.31**	0.58***	-0.53***	-0.30**	0.44***	0.47***	0.44***	0.25	-0.001***
Nitrate-N	0.12	-0.08	-0.03	0.12	-0.001	-0.14	0.06	0.08	0.03	0.03	-0.13	-0.14	-0.02
Ammonia-N	-0.45***	-0.41**	-0.46***	-0.51***	-0.53***	0.31*	-0.59***	-0.19	0.44***	0.47***	0.57***	0.58*	-0.21
Silicate	0.07	0.06	0.02	0.24*	0.15	-0.29*	-0.01	-0.16	0.04	-0.02	-0.09	0.05	0.13
BOD_5	-0.69*	-0.53	-0.17	-0.62*	-0.44	0.80**	-0.59*	-0.75**	0.96***	0.90***	0.94***		0.14*

Table 3.5. (continued).

	TSS	Phosphate-P	Nitrate-N	Ammonia-N	Silicate	BOD_5
TSS	1					
Phosphate-P	0.35**	1				
Nitrate-N	-0.01	-0.05	1			
Ammonia-N	-0.16	0.40**	-0.35**	1		
Silicate	-0.02	-0.27*	0.60***	-0.13	1	
BOD_5	0.90***	0.82**	-0.21		-0.10	1

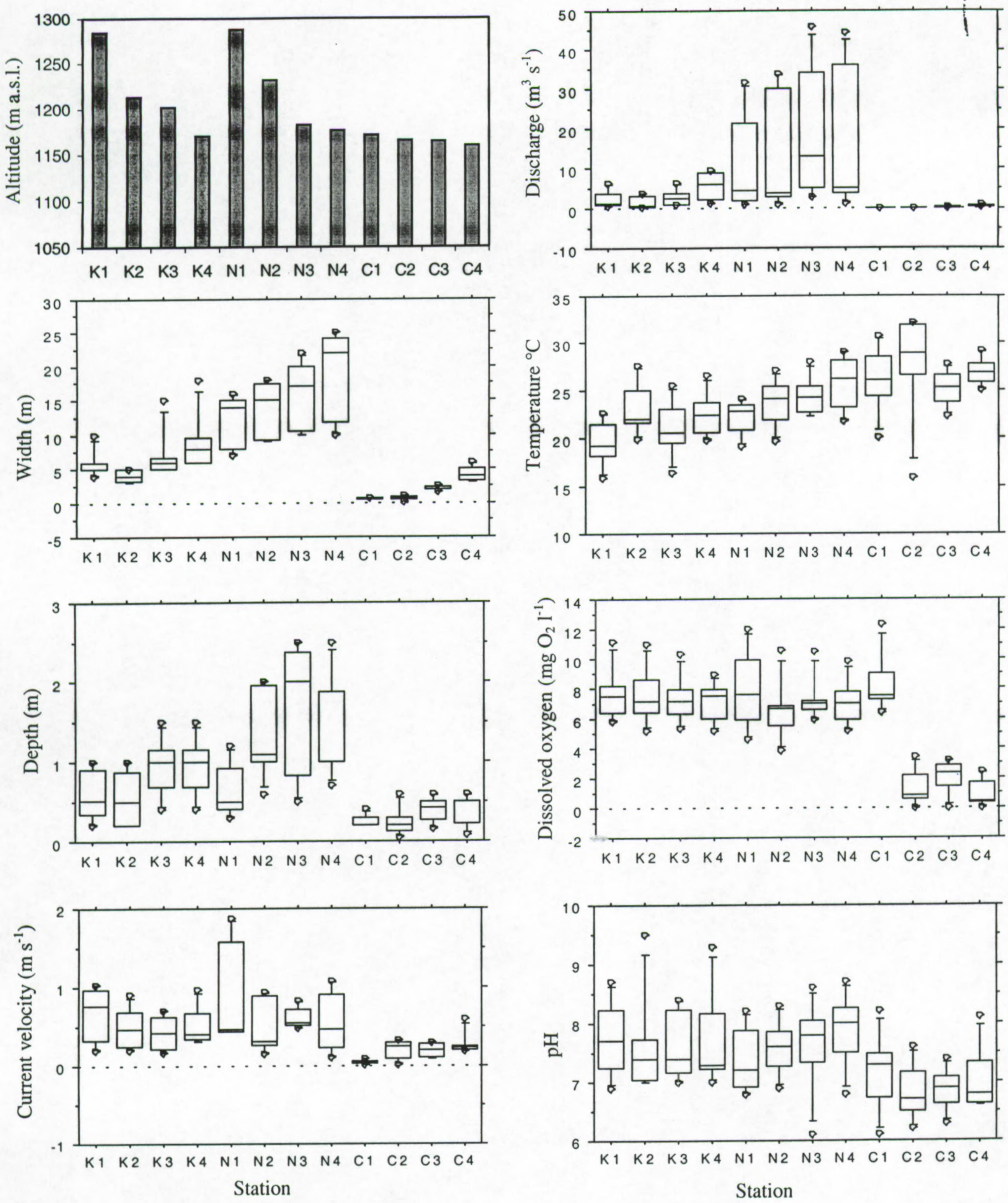

Figure 3.2 a. Bar graph for altitude and box plots for river channel width, depth, velocity, discharge, temperature, dissolved oxygen and pH in stations on rivers Kibos (K1-K4), Nyando (N1-N4) and Kisat (C1-C4). In the box plots, the medians, percentiles (25th and 75th), 1.5 interquartile range and outliers are included.

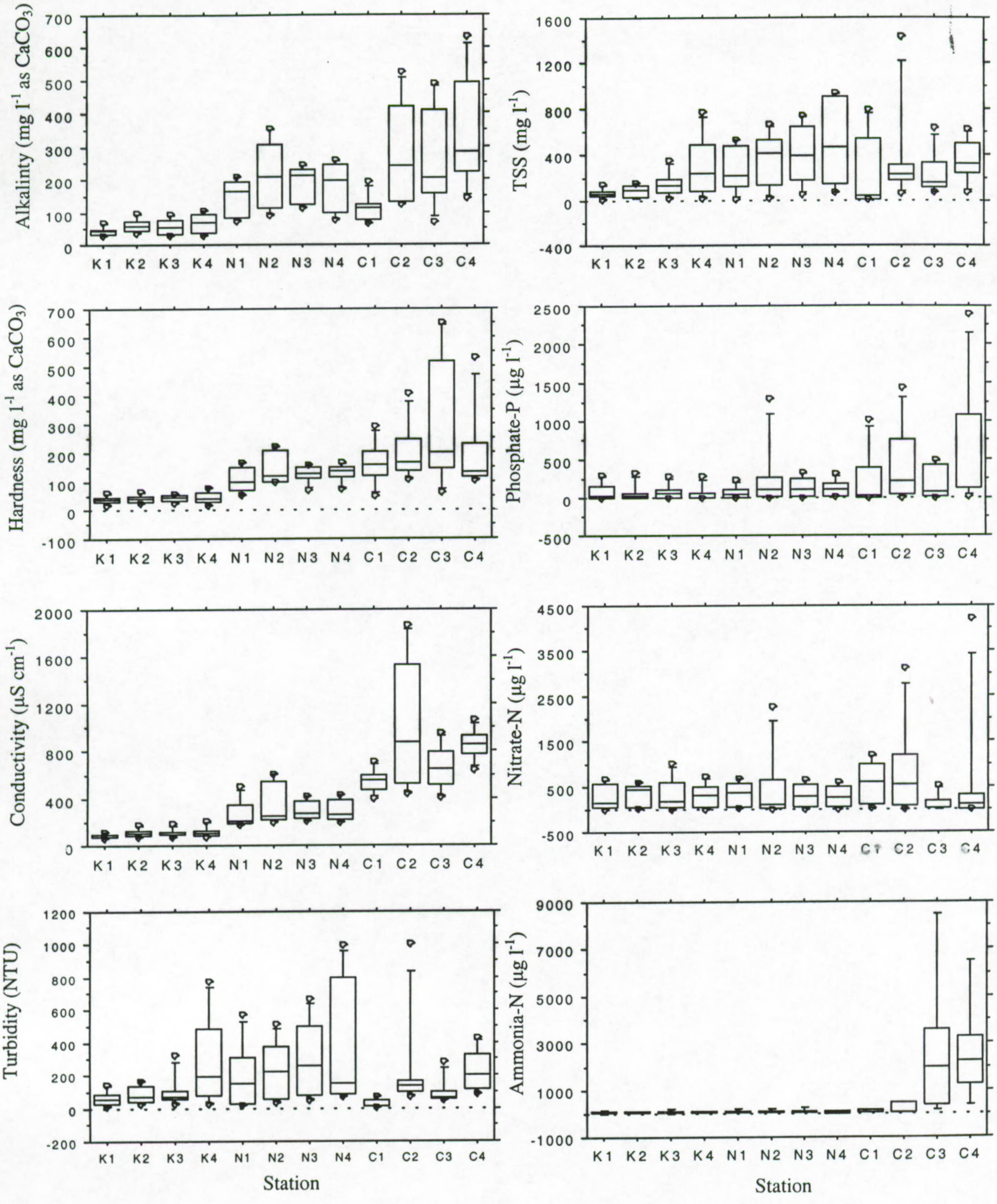

Figure 3.2 b. Box plots for alkalinity, hardness, conductivity, turbidity, total suspended solids TSS, phosphate-phosphorus, nitrate-nitrogen, and ammonia-nitrogen in rivers Kibos (K1-K4), Nyando (N1-N4) and Kisat (C1-C4). The median, percentiles (25th and 75th), 1.5 interquartile range and outliers are indicated.

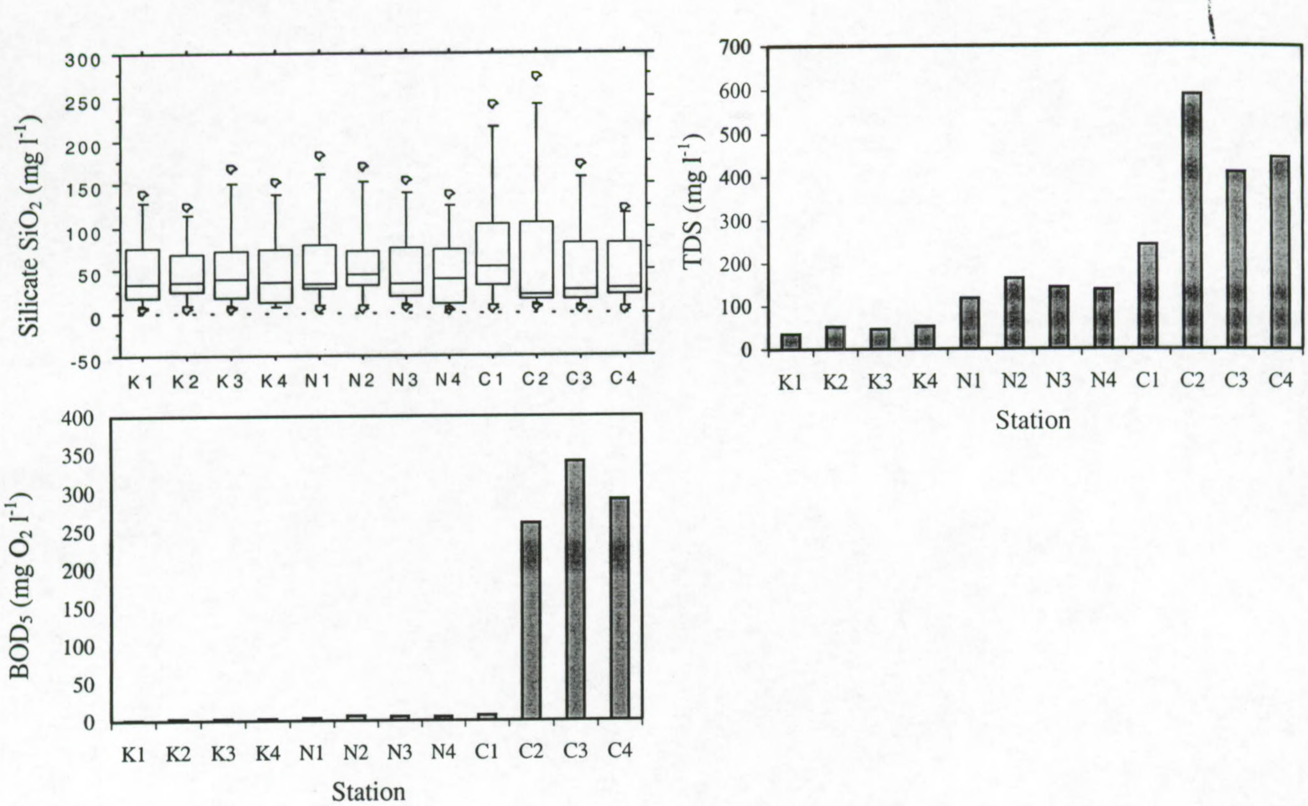

Figure 3.2 c. Box plots for silicate and bar graphs for total dissolved solids TDS and biochemical oxygen demand BOD_5 in rivers Kibos (K1-K4), Nyando (N1-N4) and Kisat (C1-C4). In the box plot, the median, percentiles (25th and 75th), 1.5 interquartile range and outliers are indicated.

Nyando is the largest of the three rivers in terms of width, depth and volume of discharge, followed by Kibos and Kisat is the smallest (Figure 3.2 a). Width, depth and volume of discharge tended to increase downstream in each river. The maximum widths were observed in lower Nyando at Ahero (Station N4) where a mean width of 18.4 m was recorded (Table 3.2). Ogilo Bridge (C3) had the deepest waters and highest volume of discharge with mean values of 1.6 m and 19.9 $m^3 s^{-1}$ respectively. This station is located at a point where Mbogo, a major tributary enters the Nyando about 2 Km upstream. Kisat had the smallest width with a mean of 0.6 m at Kenya Breweries (C1) and Obunga-Mbuta (C2). The smallest depths with a mean value of 0.2 m and the smallest volume of discharge with a mean of 0.01 $m^3 s^{-1}$ were also recorded in Kisat at Obunga-Mbuta (C1) and Kenya Breweries (C1) respectively.

Higher current velocities were recorded in Kibos than in Nyando, although Muhoroni (N1) on the latter river had slightly higher values with greater spread (Figure 3.2 a). Kisat had the lowest current velocities. Current velocity tended to reduce downstream in Kibos and Nyando while in Kisat; it increased in the same direction. The highest mean current velocity, 0.9 $m s^{-1}$ was observed at Muhoroni (N1) on the Nyando and the lowest mean current velocity was 0.04 $m s^{-1}$ at Kenya Breweries (C1) on Kisat (Table 3.2).

Water temperature was generally lower in Kibos than in Nyando and Kisat. Lower temperatures were recorded upstream in the former two rivers and they increased gradually downstream (Figure 3.2 a). Overall, the lowest temperatures for all the three rivers were recorded at on Kibos with a mean value of 19.5 °C at Kajulu (K1; Table 3.2). Temperature had inconsistent patterns from upstream to downstream in Kisat. Mean temperature value increased from 26.0 °C at Kenya Breweries (C1) to the maximum 27.8 °C at Obunga-Mbuta (C2). An open market for frying fish is located between these two stations. Temperature decreased to a mean value of 25.1 °C at Kodhu-kotur (C3), and increased again to 26.8°C at Golf Bridge (C4) which receives discharges from the municipal sewage treatment plant.

Dissolved oxygen was generally higher in Kibos and Nyando than in Kisat (Figure 3.2 a). Kibos had almost constant levels of dissolved oxygen in all its stations, while in Nyando and Kisat, the levels decreased downstream. The upstream stations in Kibos and Nyando had mean dissolved oxygen values of more than 7.5 mg $O_2 l^{-1}$ (Table 3.2). However, the highest values of dissolved oxygen were recorded in upstream Kisat with a mean of 8.3 mg $O_2 l^{-1}$ at

Kenya Breweries (C1) but decreased sharply to 1.4 mg O_2 l^{-1} at Obunga-Mbuta (C2) and to very low levels of oxygen or even anoxic conditions further downstream.

pH in Kibos and Nyando was slightly alkaline although the range was narrow and very close to neutral (Figure 3.2 a). In Kisat pH was slightly lower, mainly between pH 6 and 7. The highest mean pH was 7.7 measured on Kibos at Kajulu (K1), Wathorego (K3) and Nyamasaria (K4), while the lowest mean pH, 6.8 was observed at Obunga-mbuta (C2) and Kodhu-kotur on Kisat.

Total alkalinity, total hardness, conductivity and total dissolved solids were lower in Kibos particularly upstream when compared to Nyando, while Kisat had the highest values (Figure 3.2 b, c). These environmental variables increased gradually downstream in each river. The lowest values occurred on River Kibos at Kajulu (K1) with a mean of 43 mg l^{-1} for total alkalinity, 39 mg l^{-1} for total hardness, 83 μS cm^{-1} for conductivity and an absolute value of 35 mg l^{-1} for TDS. The highest values for these four environmental variables were recorded on Kisat: 357 mg l^{-1} for alkalinity at Golf bridge (C4), 298 mg l^{-1} for hardness at Kodhu-kotur, 1004 μS cm^{-1} for conductivity at Obunga-Mbuta and an absolute value 589 mg l^{-1} for TDS was also recorded at Obunga-Mbuta (C2).

Turbidity was higher in Nyando than in Kibos and Kisat and it increased gradually downstream in all the three rivers (Figure 3.2 b). A remarkably low mean value of 27 NTU for turbidity was recorded at Kenya Breweries (C1) on Kisat (Table 3.2) increasing sharply to 249 NTU at Obunga-Mbuta (C2). The highest mean value for turbidity, 423 NTU, was recorded at Ahero (N4) on the Nyando (Table 3.2).

Total suspended solids (TSS) followed almost similar patterns as for turbidity: low values upstream increasing gradually downstream in each river and higher values were observed in Nyando when compared to the other two rivers (Figure 3.2 b). However, the lowest mean value, 68 mg l^{-1} was recorded in upstream of Kibos at Kajulu (K1) as opposed to the lowest value of turbidity observed at Kenya Breweries (C1) on Kisat (Table 2.1). The highest mean TSS 517 mg l^{-1} was recorded at Ahero (C4) on the Nyando.

Higher concentrations of phosphate (PO_4-P) also showing greater variations were recorded in Kisat and Nyando than in Kibos (Figure 3.2 b). The highest mean phosphate value, 867 μg l^{-1}

was recorded at Golf course (C4) on Kisat and the lowest mean value 69 μg l^{-1} was recorded at Wathorego (K3) on Kibos (Table 3.2).

The concentrations of nitrate (NO_3-N) varied little in Kibos and Nyando (Figure 3.2 b). Higher concentrations of nitrate were found in upstream of Kisat at Kenya Breweries (C1) and Obunga-Mbuta where mean values of 556 μg l^{-1} and 849 μg l^{-1} were recorded respectively. The levels of nitrates reduced downstream and high variations occurred at Golf course (C4) (Table 3.2).

The concentrations of ammonia (NH_4-N) varied little in Kibos and Nyando (Figure 3.2 b) where mean concentrations varied between 53 and 84 μg l^{-1} (Table 3.2). The upper stations in Kisat also had low concentrations of ammonia, which increased tremendously downstream at Kodhu-kotur (C3) and Golf course (C4). A maximum mean value of 2560 μg l^{-1} for ammonia was recorded at Golf course. The increase in ammonia seems to accompany the decrease in nitrate.

Silicate (SiO_2) occurred in appreciable concentrations in all the three rivers and it showed no particular trends (Figure 3.2 c). The mean values of silicate ranged from 49 mg l^{-1} at Riverside (K2) in Kibos to 79 mg l^{-1} at Kenya Breweries (C1) in Kisat.

Biochemical oxygen demand (BOD_5) remained low in Kibos and Nyando but the values were higher in Kisat (Figure 3.2 c). In Kibos and Nyando, absolute values ranged between 0.8 mg O_2 l^{-1} (Kajulu, K1) to 6.4 mg O_2 l^{-1} (Awasi-Chemelil bridge, N2). In Kisat, BOD_5 values increased tremendously from a mean of 6.6 mg O_2 l^{-1} at Kenya Breweries (C1) upstream to between 260 and 340 mg O_2 l^{-1} downstream (Table 3.2). A dilution factor of between 80 and 200 of the original samples was found appropriate in obtaining the rather high BOD_5 values in lower Kisat.

Most of the environmental variables showed significant differences between the three rivers (Table 3.3) and between stations in each river (Table 3.4). Fewer variables differed significantly between Kibos and Nyando than between either of the two Kisat. The most number of variables with significant differences occurred between Kibos and Kisat, whereas, Kisat had the highest number of variables with significant differences between the stations.

Table 3.3 . Analysis of variance (ANOVA) for some environmental variables in rivers Kibos, Nyando and Kisat. (significant differences are shown as ANOVA *p<0.05; **p<0.01; ***p<0.001; for units see Table 3.2)

Environmental variable	Kibos vs. Nyando	Kibos vs. Kisat	Nyando vs. Kisat
Altitude		***	***
Width	***	***	***
Depth	**	***	***
Current velocity		***	***
Volume of discharge	***	***	**
Temperature	**	***	**
Dissolved oxygen		***	***
pH		***	***
Hardness	***	***	**
Alkalinity	***	***	
Conductivity	***	***	***
Turbidity	*		*
Total suspended solids	**		
Nitrate-nitrogen			
Ammonia-nitrogen		*	*
Phosphate-phosphorus		**	
Silicate			

Table 3.4 . Analysis of variance (ANOVA) for some environmental variables in stations in rivers Kibos, Nyando and Kisat. (significant differences shown as ANOVA *p<0.05; **p<0.01; ***p<0.001, for units see Table 3.2).

Kibos	K2	K3	K4
K1	Altitude*** temp* width*	Width** depth* discharge*	Altitude*** temperature* Turbidity*
K2		Altitude*** width* depth *	Altitude*** width*** depth* discharge*
K3			
Nyando	N2	N3	N4
N1	Altitude*** depth*	Depth* temperature*	Altitude*** depth** temperature*
N2			
N3			Altitude**
Kisat	C2	C3	C4
C1	Altitude*** oxygen*** alkalinity*	Altitude*** oxygen*** discharge*** velocity** turbidity**	Altitude*** width*** oxygen*** conductivity*** velocity*** discharge*** turbidity*** alkalinity* ammonia*
C2		Width** discharge*	Altitude***, width***, discharge***
C3			Width*** oxygen* conductivity* turbidity*

Table 3.5 gives the correlation matrix of the environmental variables. There were strong correlations between width, depth, volume of discharge and current velocity (r = 0.51 to 0.91), which are variables that partly determine river hydrology. Altitude was positively

correlated with current velocity (r = 0.50) and dissolved oxygen (r = 0.55) but negatively with most other variables. Volume of discharge was negatively correlated with most variables but it was positively correlated with turbidity. Turbidity, TSS and TDS were strongly correlated (r = 0.68 to 0.70). Variables that are mainly associated with mineralisation: hardness, alkalinity, conductivity, TDS were highly correlated (r = 0.83 to 1). The highest correlation, r = 1 (r = 0.998) or close to unity was found for conductivity and TDS.

Phosphate was significantly correlated with temperature and BOD_5 and negatively with oxygen. Whereas, nitrate showed no significant correlations with the other variables except with silicate and weakly with ammonia. Silicate also showed weak or no correlations with most other variables except with nitrate.

BOD_5 was negatively correlated with variables associated with hydrology (altitude, width, depth, velocity, discharge), oxygen and pH. However, BOD_5 was correlated positively with temperature, variables associated with mineralisation (hardness, alkalinity, conductivity, TDS), TSS and phosphate. In contrast, dissolved oxygen was negatively correlated with hardness, alkalinity, conductivity, TDS, phosphate and ammonia. Ammonia was positively correlated to conductivity and TDS but showed a weak negative but significant correlation with nitrate.

3.4.2. Diatom species composition

A total of 224 diatom taxa (218 species) belonging to 32 genera were recorded from the three rivers (Table 3.6). 155 taxa occurred in Kibos, 150 in Nyando and 123 in Kisat. 74 taxa were common to all the three rivers, 37 were exclusive to Kibos, 29 to Nyando and 24 to Kisat. In the species list, we maintain the name *Synedra cunningtonii* G.S. West (Huber-Pestalozzi, 1962; Gasse, 1986) since there are no descriptions (e.g., in Krammer & Lange-Bertalot, 1991) on change of this name to "*Fragilaria*" species.

Among the genera, *Navicula* had the highest numbers of taxa (46) followed by *Nitzschia* (40), *Pinnularia* (18) and *Cymbella* (17). *Achnanthes*, *Fragilaria* and *Eunotia* were represented by 11 taxa each while *Gomphonema* had 10 taxa. The rest of the genera had less than 10 taxa. Several taxa could not be identified properly either due to very small size of the frustules and

Table 3.6. List of diatom taxa in rivers Kibos, Nyando and Kisat (+ indicates present).

Taxon name	Kibos	Nyando	Kisat
Achnanthes bioretii Germain	+	+	+
Achnanthes daonensis Lange-Bertalot	+		
Achnanthes delicatula (Kützing) Grunow			+
Achnanthes exigua Grunow	+	+	+
Achnanthes flexella (Kützing) Brun	+	+	+
Achnanthes inflata (Kützing) Grunow	+		
Achnanthes cf. *lanceolata* (Brébisson) Grunow	+	+	+
Achnanthes cf. *minutissima* Kützing	+	+	+
Achnanthes oblongella Oestrup		+	
Achnanthes ploenensis Hustedt	+	+	
Achnanthes trinodis (W. Smith) Grunow	+	+	
Amphipleura pellucida (Kützing) Kützing	+		
Amphora coffeaeformis (Agardh) Kützing	+	+	+
Amphora commutata Grunow	+	+	+
Amphora holsatica Hustedt	+	+	
Amphora montana Krasske	+	+	+
Amphora ovalis (Kützing) Kützing	+	+	
Amphora veneta Kützing	+	+	
Aulacoseira ambigua (Grunow) Simonsen	+	+	+
Aulacoseira granulata (Ehrenberg) Simonsen	+	+	+
Caloneis bacillum (Grunow) Cleve	+	+	+
Caloneis leptosoma (Grunow) Krammer		+	
Caloneis molaris (Grunow) Krammer	+	+	+
Caloneis pulchra Messikommer		+	
Capartograma crucicula (Grunow ex Cleve) Ross			+
Cocconeis placentula var. *lineata* (Ehrenberg) Van Heurck	+	+	+
Cyclotella meneghiniana Kützing	+	+	+
Cyclotella ocellata Pantocsek	+	+	+
Cyclotella stelligera Cleve & Grunow			+
Cymatopleura solea (Brébisson) W. Smith		+	
Cymbella affinis Kützing	+	+	+
Cymbella alpina Grunow			+
Cymbella amphicephala Naegeli	+		
Cymbella cesatii (Rabenhorst) Grunow	+		+
Cymbella delicatula Kützing	+	+	
Cymbella descripta (Hustedt) Krammer & Lange-Bertalot			+
Cymbella elginensis Krammer	+		
Cymbella falaisensis (Grunow) Krammer & Lange-Bertalot	+	+	+
Cymbella gracilis (Ehrenberg) Kützing		+	
Cymbella mesiana Cholnoky	+		
Cymbella microcephala Grunow			+
Cymbella naviculliformis (Auerswald) Cleve	+		
Cymbella prostrata (Berkeley) Cleve	+		
Cymbella silesiaca Bleisch	+	+	+
Cymbella similis Krasske		+	
Cymbella tumidula Grunow	+	+	+
Cymbella turgidula (Brébisson) Van Heurck		+	
Diploneis alpina Meister	+		
Diploneis elliptica (Kützing) Cleve	+	+	+
Diploneis ovalis (Hilse) Cleve	+		+
Epithemia adnata (Kützing) Brébisson		+	+
Epithemia argus (Ehrenberg) Kützing		+	+
Epithemia sorex Kützing		+	+
Eunotia bilunaris (Ehrenberg) Mills	+	+	
Eunotia crista-galli Cleve	+		
Eunotia didyma Grunow			+
Eunotia exigua (Brébisson) Rabenhorst			+
Eunotia faba Ehrenberg	+		+
Eunotia glacialis Meister			+
Eunotia intermedia (Krasske) Nörpel & Lange-Bertalot			+
Eunotia minor (Kützing) Grunow	+	+	+
Eunotia pectinalis (Dillwyn) Rabenhorst	+	+	+

Table 3.6. (continued).

Taxon name	Kibos	Nyando	Kisat
Eunotia praerupta Ehrenberg	+		
Eunotia soleirolii (Kützing) Rabenhorst	+		+
Fragilaria bidens Heiberg	+		
Fragilaria capucina var. *vaucheriae* (Kützing) Lange-Bertalot	+	+	+
Fragilaria construens (Ehrenberg) Grunow	+	+	+
Fragilaria construens f. *subsalina* (Hustedt) Hustedt	+	+	+
Fragilaria construens f. *venter* Ehrenberg		+	+
Fragilaria exigua Grunow	+		
Fragilaria parasitica (W. Smith) Grunow			+
Fragilaria pinnata Ehrenberg	+	+	+
Fragilaria pulchella (Ralfs) Lange-Bertalot		+	+
Fragilaria tenera (W. Smith) Lange-Bertalot		+	+
Fragilaria ulna (Nitzsch) Lange-Bertalot	+	+	+
Frustulia rhomboides (Ehrenberg) De Toni	+	+	+
Frustulia rhomboides var. *viridula* (Brébisson) Cleve	+		
Frustulia vulgaris Thwaites) De Toni	+	+	
Gomphocymbella beccari (Grunow) Forti	+		
Gomphonema affine Kützing	+	+	
Gomphonema angustatum (Kützing) Rabenhorst	+	+	
Gomphonema cf. *angustum* Agardh	+	+	+
Gomphonema augur Ehrenberg	+		+
Gomphonema clavatum Ehrenberg		+	
Gomphonema clevei Fricke	+		
Gomphonema gracile Ehrenberg	+	+	+
Gomphonema insigne Gregory		+	
Gomphonema olivaceum (Hornemann) Brébisson	+	+	+
Gomphonema parvulum (Kützing) Kützing	+	+	+
Gyrosigma acuminatum (Kützing) Rabenhorst	+	+	
Gyrosigma scalproides (Rabenhorst) Cleve	+	+	
Hantzschia amphioxys (Ehrenberg) Grunow	+	+	+
Hantzschia elongata (Hantzsch) Grunow		+	
Melosira cf. *moniliformis* (O.F. Müller) Agardh			+
Navicula accomoda Hustedt		+	
Navicula agrestis Hustedt	+	+	
Navicula cf. *atomus* (Kützing) Grunow	+		
Navicula brekkaensis Petersen	+	+	
Navicula capitata Ehrenberg	+		
Navicula capitata var. *hungarica* (Grunow) Ross	+		
Navicula capitatoradiata Germain	+	+	+
Navicula cari Ehrenberg	+		
Navicula cinta (Ehrenberg) Ralfs	+		
Navicula cohnii (Hilse) Lange-Bertalot	+	+	
Navicula cf. *confervacea* (Kützing) Grunow	+	+	+
Navicula contenta Grunow	+	+	+
Navicula cryptocephala Kützing	+	+	+
Navicula cryptotenella Lange-Bertalot	+	+	+
Navicula cuspidata (Kützing) Kützing	+	+	+
Navicula elginensis (Gregory) Ralfs	+	+	
Navicula erifuga Lange-Bertalot		+	
Navicula exigua (Gregory) Grunow	+	+	
Navicula gallica (W. Smith) Lagerstedt			+
Navicula gastrum (Ehrenberg) Kützing	+	+	+
Navicula cf. *goeppertiana* (Bleisch) H. L. Smith	+	+	+
Navicula cf. *heimansioides* Lange-Bertalot	+	+	+
Navicula heufleriana (Grunow) Cleve	+		
Navicula cf. *impexa* Hustedt	+	+	+
Navicula insociabilis Krasske	+		+
Navicula jaagii Meister	+		
Navicula cf. *kotschyi* Grunow		+	
Navicula laevissima Kützing	+		
Navicula lapidosa Krasske		+	
Navicula cf. *minima* Grunow	+	+	
Navicula cf. *minuscula* Grunow			+

Table 3.6. (continued).

Taxon name	Kibos	Nyando	Kisat
Navicula monoculata **Hustedt**	+	+	
Navicula mutica Kützing	+	+	+
Navicula muticopsis Van Heurck		+	
Navicula oblonga **Kützing**		+	
Navicula cf. *perlatoides* (O. Müller) Hustedt	+		+
Navicula pseudanglica Lange-Bertalot	+	+	
Navicula pseudotuscula Hustedt		+	
Navicula pupula Kützing	+	+	+
Navicula pygmaea Kützing	+	+	+
Navicula saxophila Bock		+	
Navicula schroeteri Meister	+	+	+
Navicula seminulum **Grunow**	+		+
Navicula spinifera **Bock**		+	
Navicula cf. *subminuscula* Manguin	+	+	+
Navicula viridula (Kützing) Ehrenberg	+	+	+
Neidium affine (Ehrenberg) Pfitzer	+	+	+
Neidium ampliatum (Ehrenberg) Krammer	+		
Neidium densestriatum (østrup) Krammer			+
Neidium ladogensis (Cleve) Foged		+	
Neidium productum (W. Smith) Cleve	+		
Nitzschia acicularioides **Hustedt**	+	+	
Nitzschia acicularis (Kützing) W. Smith	+	+	+
Nitzschia acuminata (W. Smith) Grunow		1	
Nitzschia amphibia Grunow	+	+	+
Nitzschia angustata Grunow			+
Nitzschia brevissima Grunow		+	
Nitzschia calida Grunow		+	+
Nitzschia capitellata Hustedt	+		
Nitzschia clausii Hantzsch	+	+	+
Nitzschia dissipata (Kützing) Grunow	+	+	+
Nitzschia filiformis (W. Smith) Van Heurck		+	+
Nitzschia cf. *flexa* Schumann	+	+	+
Nitzschia fonticola Grunow	+	+	+
Nitzschia frustulum (Kützing) Grunow	+	+	+
Nitzschia fruticosa Hustedt		+	+
Nitzschia cf. *gracilis* Hantzch	+	+	+
Nitzschia hantzschiana Rabenhorst		+	
Nitzschia inconspicua Grunow	+	+	+
Nitzschia intermedia Hantzsch	+	+	+
Nitzschia lanceolata W. Smith		+	
Nitzschia levidensis (W. Smith) Grunow	+	+	
Nitzschia linearis (Agardh) W. Smith	+	+	+
Nitzschia linearis var. *tenuis* (W. Smith) Grunow	+		
Nitzschia nana Grunow			+
Nitzschia nyassensis O. Müller	+		
Nitzschia obtusa **W. Smith**			+
Nitzschia palea (Kützing) W. Smith	+	+	+
Nitzschia perminuta **(Grunow) M. Paragallo**	+	+	+
Nitzschia prolongata Hustedt	+		
Nitzschia recta Hantzsch	+	+	+
Nitzschia reversa Hantzsch			+
Nitzschia scalaris (Ehrenberg) W. Smith	+		
Nitzschia scalpelliformis Grunow			+
Nitzschia sigma (Kützing) W. Smith		+	+
Nitzschia sigmoidea (Nitzsch) W. Smith	+	+	+
Nitzschia speciosa Hustedt	+		
Nitzschia subacicularis Hustedt		+	
Nitzschia thermaloides Hustedt	+	+	+
Nitzschia tryblionella Hantzsch		+	+
Nitzschia umbonata (Ehrenberg) Lange-Bertalot		+	+
Orthoseira cf. *dendroteres* (Ehrenberg) Crawford	+	+	
Pinnularia acoricola Hustedt	+		
Pinnularia acrosphaeria Rabenhorst			+
Pinnularia borealis Ehrenberg	+	+	+

Table 3.6. (continued).

Taxon name	Kibos	Nyando	Kisat
Pinnularia braunii (Grunow) Cleve	+	+	+
Pinnularia divergens W. Smith	+	+	+
Pinnularia divergentissima (Grunow) Cleve	+		+
Pinnularia gibba Ehrenberg	+	+	
Pinnularia gibba var. *mesogongyla* (Ehrenberg) Hustedt		+	+
Pinnularia intermedia (Lagerstedt) Cleve	+		
Pinnularia lata (Brébisson) W. Smith	+		+
Pinnularia microstauron (Ehrenberg) Cleve	+	+	+
Pinnularia nobilis Ehrenberg			+
Pinnularia obscura Krasske	+		+
Pinnularia similis Hustedt		+	
Pinnularia subcapitata Gregory	+	+	
Pinnularia subrostrata (A. Cleve) Cleve-Euler	+	+	+
Pinnularia superdivergentissima Chaumont & Germain	+	+	
Pinnularia viridis (Nitzch) Ehrenberg	+		
Rhoicosphenia abbreviata (Agardh) Lange-Bertalot	+	+	
Rhopalodia brebisonii Krammer		+	
Rhopalodia gibba (Ehrenberg) O. Müller	+	+	+
Rhopalodia gibberula (Ehrenberg) O. Müller		+	
Rhopalodia hirundiniformis O. Müller			+
Rhopalodia rupestris (W. Smith) Krammer	+		
Stauroneis anceps Ehrenberg	+	+	
Stauroneis phoenicenteron (Nitzsch) Ehrenberg	+		
Stenopterobia curvula (W. Smith) Krammer	+		
Stenopterobia delicatissima (Lewis) Brébisson		+	
Stephanodiscus rotula (Kützing) Hendey	+	+	+
Surirella angusta Kützing	+	+	+
Surirella bifrons Ehrenberg		+	
Surirella biseriata Brébisson	+		
Surirella brebisonii Krammer & Lange-Bertalot		+	
Surirella cf. *capronii* Brébisson			+
Surirella linearis W. Smith	+	+	
Surirella ovalis Brébisson	+	+	
Surirella splendida (Ehrenberg) Kützing	+	+	
Synedra cunningtonii G.S. West		+	+

difficulties in determining very fine distinguishing features under the maximum resolution of the light microscope.

40 taxa accounted for 10% or more of the total abundance in at least one sample (Table 3.7). However, some of these species occurred in high abundance only once or in very few stations. Figure 3.3 illustrates trends in distribution of 15 species with consistently high abundance in at least 5 stations (list in Table 3.8).

Table 3.7. Diatom taxa with 10% or more relative abundance in a sample.

Taxon name	Taxon name
Achnanthes cf. *bioretii* Germain	*Navicula* cf.*atomus* (Kützing) Grunow
Achnanthes cf. *minutissima* Kützing	*Navicula contenta* Grunow
Achnanthes exigua Grunow	*Navicula cryptocephala* Kützing
Amphora montana Krasske	*Navicula cryptotenella* Lange-Bertalot
Aulacoseira granulata (Ehrenberg) Simonsen	*Navicula exigua* (Gregory) Grunow
Caloneis molaris (Grunow) Krammer	*Navicula* cf. *goeppertiana* (Bleisch) H. L. Smith
Cocconeis placentula var. *lineata* (Ehrenberg) Van Heurck	*Navicula insociabilis* Krasske
Cymbella delicatula Kützing	*Navicula mutica* Kützing
Epithemia adnata (Kützing) Brébisson	*Navicula schroeteri* Meister
Fragilaria construens (Ehrenberg) Grunow	*Navicula* cf. *subminuscula* Manguin
Fragilaria pinnata Ehrenberg	*Navicula viridula* (Kützing) Ehrenberg
Fragilaria ulna (Nitzsch) Lange-Bertalot	*Nitzschia amphibia* Grunow
Gomphonema angustum Agardh	*Nitzschia fruticosa* Hustedt
Gomphonema olivaceum (Hornemann) Brébisson	*Nitzschia palea* (Kützing) W. Smith
Gomphonema parvulum (Kützing) Kützing	*Nitzschia perminuta* (Grunow) M. Paragallo
Hantzschia amphioxys (Ehrenberg) Grunow	*Nitzschia scalpelliformis* Grunow
Navicula capitata Ehrenberg	*Nitzschia umbonata* (Ehrenberg) Lange-Bertalot
Navicula capitatoradiata Germain	*Pinnularia microstauron* (Ehrenberg) Cleve
Navicula cf. *heimansioides* Lange-Bertalot	*Stauroneis anceps* Ehrenberg
Navicula cf. *impexa* Hustedt	*Stephanodiscus rotula* (Kützing) Hendey

Nitzschia palea occurred in appreciable numbers in all the stations (Figure 3.3 a). However the numbers of this species were lower in Kibos, increased in Nyando and reached maximum in Kisat where a mean relative abundance of 57% was recorded at Kodhu-kotur (C3). The abundance of this species tended to increase downstream in each river. *Gomphonema angustum* was the second most consistent species occurring in high abundance and contributing up to 22% of the total frustule counts at Ogilo Bridge (N3). This species occurred in high percentages mainly in Kibos and Nyando, and reduced sharply in Kisat. *Navicula* cf. *goeppertiana*, another abundant species occurred in low percentages in Kibos and Nyando but

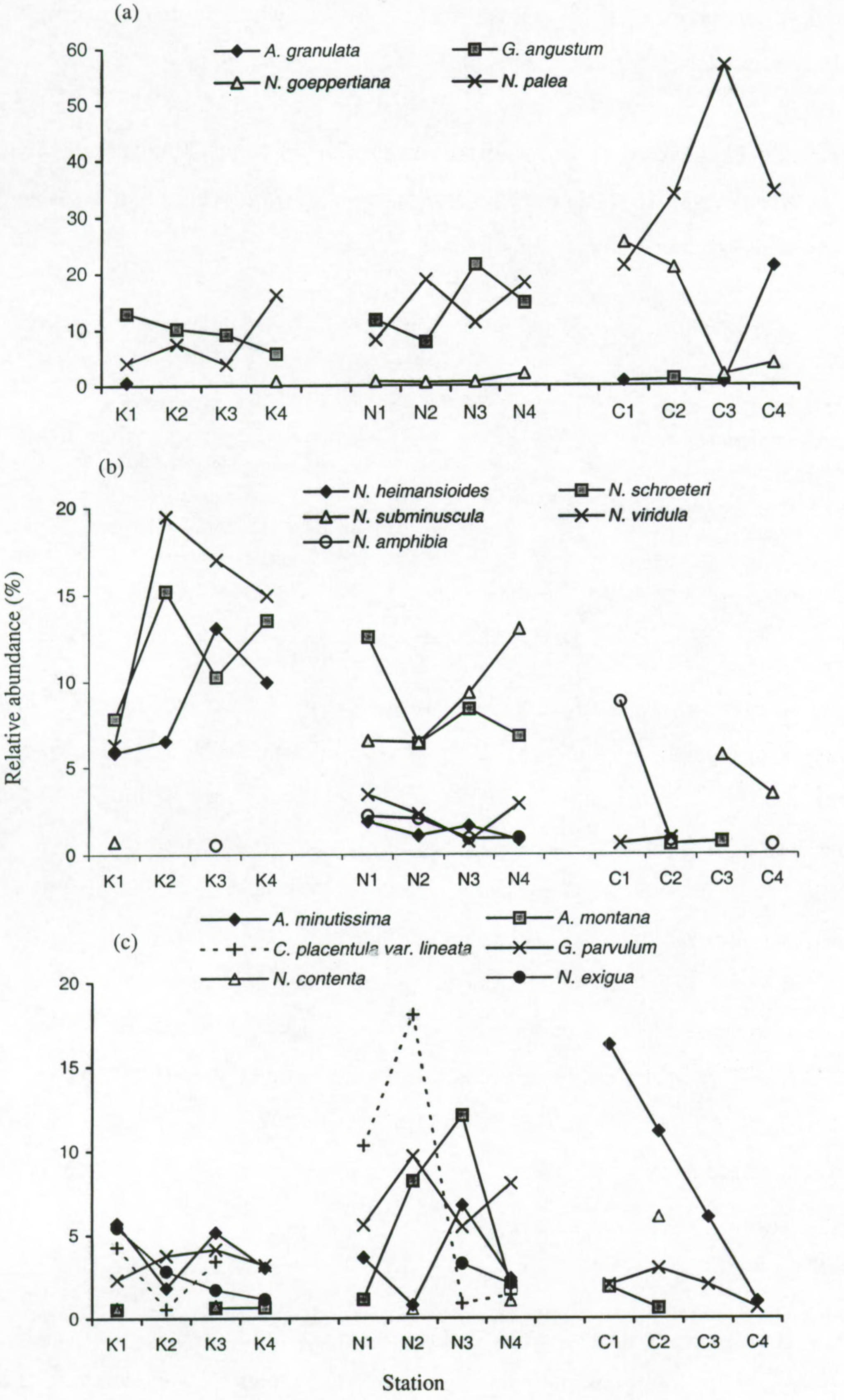

Figure 3.3. Trends in most important diatom taxa with mean relative abundance of 1% or more in at least 5 stations in rivers Kibos (K1-K4), Nyando (N1-N4) and Kisat (C1-C4).

occurred in high percentages in Kisat especially upstream where it contributed up to 25% at Kenya Breweries (C1). The percentages of *Aulacoseira granulata* were very low in upstream of Kisat and they increased markedly to 21% at Golf course (C4). *Navicula viridula, N. schroeteri* and *N. heimansioides* occurred consistently in high abundances in Kibos and reduced in Nyando and Kisat (Figure 3.3 b). *Nitzschia amphibia* occurred in low abundance in Nyando and increased in the upstream of Kisat.

Table 3.8. Most important diatom taxa with 1-5% or more mean relative abundance in at least 5 stations.

Taxon name	Taxon name
Achnanthes cf. *minutissima* Kützing	*Navicula exigua* (Gregory) Grunow
Amphora montana Krasske	*Navicula* cf. *goeppertiana* (Bleisch) H. L. Smith
Aulacoseira granulata (Ehrenberg) Simonsen	*Navicula schroeteri* Meister
Cocconeis placentula var. *lineata* (Ehrenberg) Van Heurck	*Navicula* cf. *subminuscula* Manguin
Gomphonema cf. *angustum* Agardh	*Navicula viridula* (Kützing) Ehrenberg
Gomphonema parvulum (Kützing) Kützing	*Nitzschia amphibia* Grunow
Navicula cf. *heimansioides* Lange-Bertalot	*Nitzschia palea* (Kützing) W. Smith
Navicula contenta Grunow	

Cocconeis placentula var. *lineata* and *Gomphonema parvulum* occurred in high abundance in the upstream of Nyando at Muhoroni (N1) and Awasi-Chemelil Bridge (N2; Figure 3.3 c). Whereas, *Amphora montana* and *Navicula* cf. *subminuscula* occurred in fairly high abundance in middle reaches of Nyando at Awasi-Chemelil bridge and Ogilo bridge (N3; Figure 3.3 b,c). Maximum abundance of *Navicula* cf. *subminuscula* were observed in downstream of Nyando at Ahero (C4) and was found in appreciable numbers in downstream Kisat at Kodhu-kotur (C3) and Golf course (C4). *Achnanthes* cf. *minutissima* occurred in low abundance in Kibos and Nyando, increased to its maximum in upstream of Kisat at Kenya Breweries (C1) and decreased sharply downstream (Figure 3.3 c). Most of the other abundant species occurred in higher percentages in Kibos and/ or Nyando although a few species such as *Hantzschia amphioxys* occurred mainly in Kisat.

3.4.3. Digital images of diatoms

More than 100 images of specimens of diatoms were captured, digitised and stored. Digital images of some of the most common diatom taxa in our samples are included in Annex 3. The illustrations will help in developing a library of microscopy digital images for future identification and reference purposes. All the illustrations are kept in an achieve and a complete account is still in preparation.

3.4.4. Diatom species diversity

The mean value and standard deviations of values for diatom species richness, diversity, evenness and dominance in the sampling stations are summarised in Table 3.9. Their distributions among the 12 stations and the 3 rivers are shown in Figure 3.4. All the measures of diversity showed variations between and within the rivers.

Table 3.9. Mean (M) and standard deviation (SD) of diatom diversity characteristics in the sampling stations.

Station	Species richness		Diversity		Evenness		Dominance	
	M	SD	M	SD	M	SD	M	SD
K1	32	10	2.3	0.7	0.46	0.12	0.22	0.20
K2	34	11	2.5	0.5	0.49	0.07	0.16	0.09
K3	38	10	2.3	0.7	0.44	0.11	0.23	0.17
K4	31	9	2.3	0.6	0.46	0.09	0.19	0.11
N1	34	12	2.6	0.4	0.51	0.04	0.13	0.05
N2	32	8	2.2	0.2	0.44	0.04	0.21	0.05
N3	29	4	2.2	0.3	0.46	0.06	0.19	0.08
N4	31	7	2.4	0.3	0.50	0.06	0.14	0.04
C1	26	5	1.9	0.3	0.41	0.06	0.25	0.09
C2	29	7	1.9	0,4	0.39	0.07	0.29	0.15
C3	19	6	1.3	0.6	0.31	0.15	0.46	0.26
C4	28	6	1.8	0.5	0.38	0.10	0.29	0.17

Higher species richness, with a large spread, were generally observed in Kibos and Nyando than in Kisat (Figure 3.4). Lower species numbers were observed in upstream of Kibos, they increased in middle reaches and reduced again downstream. Species richness showed a decrease downstream in Nyando and Kisat. However, in Kisat, a slight increase was observed at Golf course (C4). The highest mean value of species richness, 38, was found at Wathorego (K3) on Kibos and the lowest 19 were at Kodhu-kotur (C3) on Kisat (Table 3.9). The absolute range for species richness was 14 to 56 for Kibos, 18 to 51 for Nyando and 11 to 40 for Kisat. Higher species diversity was generally observed in Kibos and Nyando than Kisat (Figure 3.4). Patterns in species diversity were almost the same for all stations in Kibos. In Nyando, higher values of species diversity were observed upstream at Muhoroni (N1), reduced at Awasi-Chemelil Bridge (N2) and increased downstream. Similarly, in Kisat, higher species diversity occurred upstream at Kenya Breweries (C1) and Obunga-Mbuta (C2), decreased at Kodhu-kotur and increased again downstream. The highest mean species diversity was 2.6 recorded at Muhoroni (N1) on the Nyando and the lowest was 1.3 at Kodhu-kotur (C3) on Kisat (Table

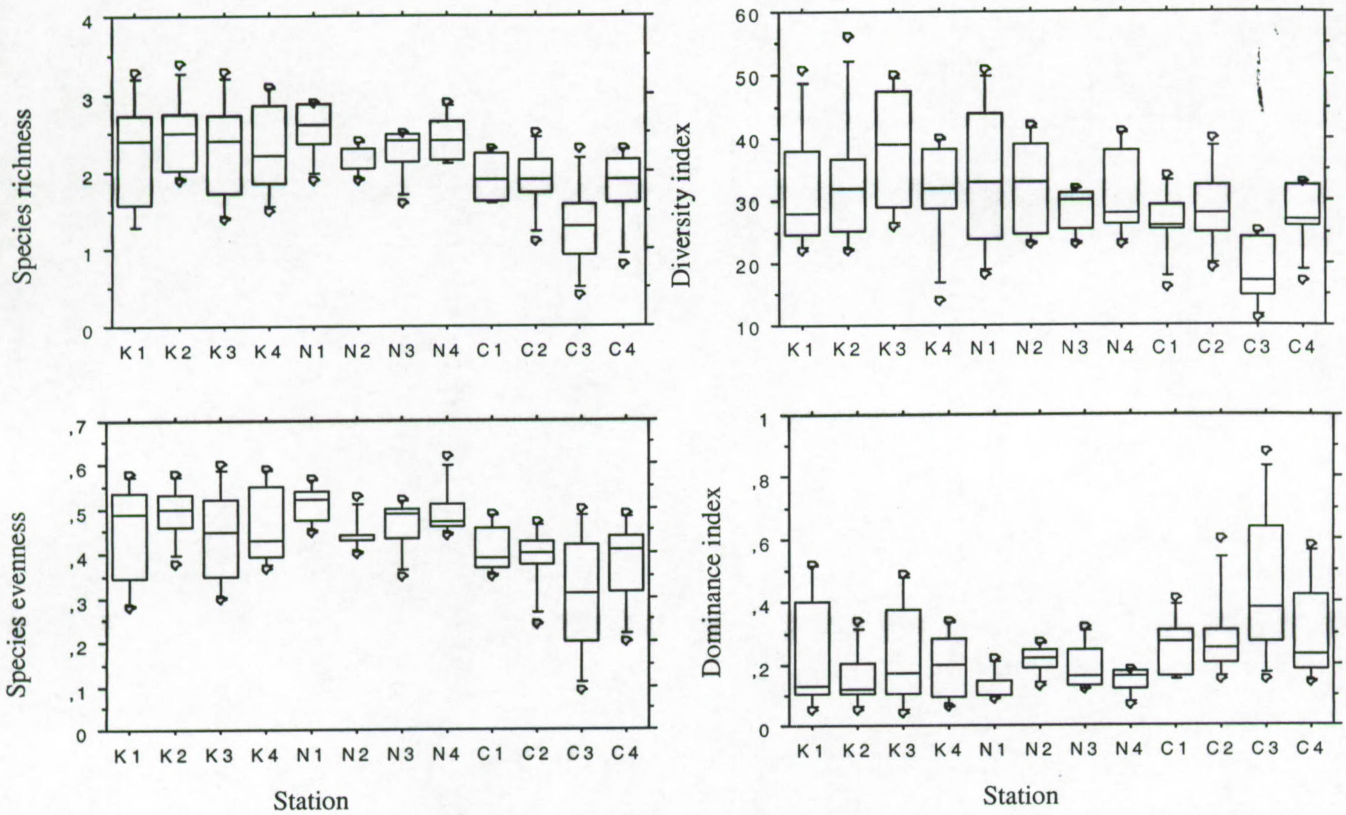

Figure 3.4. Box plots for species richness, diversity, evenness and dominance of diatoms in Kibos (K1-K4), Nyando (N1-N4) and Kisat (C1-C4). The median, percentiles (25th and 75th), 1.5 interquartile range and outliers are indicated.

3.9). The absolute values of species diversity ranged from 1.3 to 3.4 in Kibos, 1.6 to 2.9 in Nyando and 0.4 to 2.5 in Kisat.

Species evenness closely followed the trends in species diversity: higher values in Kibos and Nyando when compared to Kisat, and a general decrease downstream in all the three rivers (Figure 3.4). The highest mean value of species evenness 0.5 was observed at Muhoroni (N1) on Nyando and the lowest 0.31 occurred at Kodhu-kotur (C3) on Kisat (Table 3.9). Absolute values of evenness ranged between 0.3 and 0.6 in Kibos, 0.4 and 0.6 in Nyando and 0.1 and 0.5 in Kisat.

Kisat had higher values of dominance index and with higher spread, followed by Kibos (Figure 3.4) while Nyando had the lowest values. In Kibos, dominance index tended to increase downstream. J increased in middle reaches of Nyando and reduced downstream. In Kisat, the upstream station, Kenya Breweries (C1) had lower values, which increased downstream to reach maxima at Kodhu-kotur (C3), and reduced at Golf course (C4). The highest mean value of dominance index, 0.46, was recorded in Kisat at Kodhu-kotur (C3) and the lowest 0.13 was in Nyando at Muhoroni (N1; Table 3.9). Values of dominance index ranged from 0.04 to 0.52 in Kibos, 0.07 to 0.32 in Nyando and from 0.14 to 0.88 in Kisat.

There were no significant differences in species richness between Kibos and Nyando but both rivers differed significantly with Kisat (ANOVA $p<0.001$ and $p<0.01$ respectively, and for both indices). No significant differences in species richness were observed between stations in each river. However in Kisat, species richness showed significant differences between Kodhu-kotur (C3) and Kenya Breweries (C1, $p<0.05$), Obunga-mbuta (C3, $p<0.01$) and Golf course (C4, $p<0.05$).

No significant differences were observed in species diversity between Kibos and Nyando. However, both the two rivers had significantly different diversity from Kisat ($p<0.001$ and $p<0.01$ respectively). There were also no significant differences in evenness between Kibos and Nyando but both had significantly different values of evenness than Kisat ($p<0.01$ and $p<0.001$, respectively). There were no significant differences in evenness between stations in each river.

Significant differences were found for the dominance index between Kibos and Kisat and between Nyando and Kisat ($p<0.01$ and $p<0.001$ respectively). There were no significant differences in dominance index between stations in Kibos and Kisat. However, in Nyando, significant differences in dominance index occurred between Awasi-Chemelil bridge (N2) and Muhoroni (N1), and between Awasi-Chemelil bridge and Ahero (N4; $p<0.01$ and $p<0.05$ respectively).

Temporal significant differences were found for species richness and diversity ($p<0.001$, respectively) and evenness ($p<0.01$) but not for dominance. All the indices showed significant variations due to the river but not with the sampling station. Species richness, diversity and evenness were positively correlated significantly with each other but negatively with dominance index (Table 3.10).

Table 3.10. Spearman rank correlation coefficient matrix for indices of diatom species numbers, richness, diversity, evenness and dominance (n = 84, * for all values $p<0.001$).

	Species richness	Diversity	Evenness	Dominance
Species richness	1			
Diversity	0.70	1		
Evenness	0.47	0.95	1	
Dominance	-0.54	-0.96	-0.97	1

3.4.5. Relationships between diatom species diversity and environment

Significant correlations were found between the diversity measures (species richness, diversity and evenness) and altitude, width, depth, velocity and volume of discharge (Table 3.11). However, the measures of diversity were also significantly correlated negatively with most variables associated with pollution including temperature, hardness, alkalinity, conductivity, ammonia-nitrogen and phosphate-phosphorus. Species richness was positively correlated with nitrate-nitrogen, while species diversity was positively correlated significantly with dissolved oxygen.

Unlike the other measures of diversity, dominance index was significantly correlated negatively with variables associated with river hydrology (altitude, width, depth, velocity, discharge), dissolved oxygen, turbidity and ammonia-nitrogen. Positive significant correlations were also found between dominance index and temperature, hardness, alkalinity, conductivity and phosphate all of which tended to increase downstream.

Table 3.11. Correlation analysis (Spearman rank correlation coefficient) between species richness, diversity, evenness and dominance, and environmental variables (significant correlations are shown as **p*<0.05; ***p*<0.01; ****p*<0.001).

Environmental variable	Richness	Diversity	Evenness	Dominance
Altitude	0.28*	0.46***	0.45***	-0.41***
Width	0.24*	0.47***	0.49***	-0.43***
Depth	0.27*	0.39***	0.37***	-0.32**
Current velocity	0.25*	0.44***	0.44***	-0.39***
Volume of discharge	0.27*	0.48***	0.49***	-0.43***
Temperature	-0.24*	-0.35**	-0.35**	0.34**
Dissolved oxygen	0.10	0.38***	0.43***	-0.40***
Biochemical oxygen demand	-0.25	-0.59*	-0.59*	-0.55
pH	0.03	0.17	0.20	-0.16
Total hardness	-0.21	-0.41***	-0.43***	0.41***
Total alkalinity	-0.16	-0.37***	-0.39***	0.37***
Conductivity	-0.35**	-0.51***	-0.48***	0.45***
Total dissolved solids	0.47	0.16	0.15	-0.19
Turbidity	0.28**	0.34**	0.33**	-0.31**
Total suspended solids	0.23*	0.22*	0.17	0.17
Nitrate-nitrogen	0.44***	0.21	0.06	-0.11
Ammonia-nitrogen	-0.25	-0.42***	-0.40**	-0.35**
Phosphate-phosphorus	-0.01	-0.21	0.26***	0.23*
Silicate	0.17	0.04	-0.02	-0.02

3.5. DISCUSSION

3.5.1. Environmental variables

Among the three rivers studied, Nyando has larger catchments and many of its tributaries originate from highland areas with high rainfall. Our upstream stations on this river are located in a high order stream area with a wide and deep channel and large volume of discharge. Greater variability in width, depth, velocity and discharge especially on the Nyando may reflect seasonal rainfall patterns in the catchments. Changes in water level and discharge of the river: high flow during rainy seasons and low flow in dry season could affect the ecosystem by altering the quantity and quality of habitat for aquatic organisms including that for diatoms and even fish.

Inputs from tributaries contribute to the fluctuations in width, depth and volume of discharge downstream in all the three rivers although other sources including effluents from industries may play a big role in the hydrological features for example in the smaller River Kisat.

The general gradients in hydrological patterns and most environmental variables on the Nyando were interrupted at Ogilo Bridge (N3). This can be related to the diluting effect of Mbogo, a major tributary that confluents with Nyando upstream. As expected, current velocity decreased downstream in lower Nyando and Kibos due to less marked relief. Conversely, current velocity increased downstream in Kisat. Kisat is a small river and although its hydrological patterns may follow alternations between dry and rainy seasons, they are mainly subject to unprecedented discharges of effluents from industries and the sewage treatment plant in the immediate vicinity.

Lower water temperatures were recorded upstream in all the three rivers and the lowest occurred in Kibos. The headwaters of Kibos and Nyando are in cool and forested highland areas and in addition to higher velocity and turbulence makes their upstream to have lower temperatures. Temperature increases gradually downstream due to various factors including increase in the stream channel width, decrease in current velocity exposing large surfaces to heating by the sun, and input of effluents from industries such as the sugar factories on the Nyando. Water abstraction from Nyando for paddy irrigation near Ahero reduces the volume downstream and increases expose to the sun that may lead to higher water temperatures as observed at Ahero (N4). Kisat had the highest water temperature owing to its small size, shallow depth and low slope that exposes it more to direct heating by the sun. Domestic sewage from Obunga slums, effluents from industries and heat from kilns (for frying fish) that are constructed on the ground in the local open fish market at Obunga-mbuta, may increase the temperature of the river water. Temperature remained rather low in Kibos mainly because of less human activities in the catchments and vicinity of the river.

Dissolved oxygen was higher especially in upstream of Kibos than in Nyando and was generally low in Kisat. The dissolved oxygen in the first two rivers is more or less regulated by high flows, turbulence and low temperatures in the upstream. These factors and mixing in the upper reaches increases the potential of re-aeration and saturation of water with oxygen (Jeffries & Derek, 1990). Decrease in dissolved oxygen occurs downstream due to increase in temperature, reduction in current velocity and turbulence. Addition of effluents, eutrophication and inputs of dead organic matter as the river flows downstream reduces oxygen even to critical levels as observed in lower Kisat.

"Good" quality water especially in upstream of rivers Kibos and Nyando was indicated by low biochemical oxygen demand (BOD) values. Higher BOD values downstream, especially in Kisat, is due to "poor" water quality with higher organic pollution and trophic state. In the water with poor quality, oxygen is used up during the breakdown of the dead organic matter by bacteria and in addition, chemical oxidation of the organic matter increases the BOD (Jeffries & Derek, 1990). Higher BOD and probably chemical oxygen demand in Kisat could also be the reason why oxygen levels reduce drastically downstream. The high BOD in Kisat is due to discharges of effluents from factories directly into the river. In addition, the municipal sewage treatment plant located near the lower part of the Kisat, between Kodhu-kotur (Station C3) and Golf course (C4), was not functioning during the whole period of our study. Raw sewage was continually released into the river also contributing to the BOD. This section of the river usually characterised by murky waters with strong odour of raw sewage; largely appear polluted and may not be used for any meaningful purposes.

High BOD may have undesirable effects on many aquatic organisms (Jeffries & Derek, 1990). In Kisat where high BOD and very low oxygen levels occur, is devoid of fish except the occasional appearance of the lungfish *Protopterus aethiopicus* and the African catfish *Clarias gariepinus* that are caught in the lower reaches mainly during the rainy season when dilutions of the water occur (Personal observation). These two fish species are adapted to life in low oxygen conditions because of possession of breathing accessories that also enables them to uptake atmospheric oxygen (Greenwood, 1966).

During our sampling in December 1998, we observed many dead fish, mainly *Barbus* spp. and *Alestes* spp., floating on river Nyando at Awasi-Chemelil Bridge (station N2). This station is located downstream of the sugar factory and distillery at Muhoroni and probably, these industries occasionally release large amounts of effluents containing pollutants including high BOD. This section of the river was usually characterised by murky waters with lumps of black organic floating material and with strong odour of molasses. *Barbus* spp. and *Alestes* spp. are among fish species that are facing serious declined both in Lake Victoria and effluent rivers. Deterioration in environmental status of the inflowing rivers could be a contributing factor to their decline.

Heavy fish mortalities were already observed in the 1950s on River Kuja, in the southern part of Lake Victoria catchments, and they were blamed on pollution of waste products from copper mines in the proximity of the river (Whitehead, 1959). Other dangers to the sustainability of the river fisheries in the region then included over-fishing especially of breeding stocks and destruction of breeding grounds through irrigation projects, water control barrages and hydroelectric schemes (Whitehead, 1959). These activities were exasperated with increasing human population, changes in land use and establishment of industries. The resulting modifications in the river habitats and changes in water quality could have lead to the total collapse of the once prosperous river fishery (Cadwalladr, 1965a; Kibaara, 1981).

As with temperature, total alkalinity, total hardness, conductivity, total dissolved solids, ammonia (and BOD) were lower in Kibos particularly upstream when compared to Nyando and Kisat. These variables tended to increase downstream due to inputs of dissolved substances including ions and mineral salts from various sources such as dissolution from substratum rocks and soils in the catchments, sediments along the riverbed and organic matter from various sources. Discharges from tributaries, industry, agriculture and other human activities could also be important sources. Kisat had the highest values of these variables mainly due to effluents of domestic sewage and residues from distilleries of a local whisky in the slums at Obunga. Other sources include the open market for frying fish at Obunga where salt is used in appreciable quantities, effluents from industries and discharges from the sewage treatment plant.

The foothills of the escarpment along the course of the Nyando have limestone deposits. The limestone is excavated either from underground mines or from the land surface. As a result, one of the major concerns is land disturbance, contamination of waters with lime dust, salts and other operational wastes. This could contribute to the higher turbidity and total suspended solids (TSS) observed in the Nyando. In addition, release of limestone may partly explain the rather elevated levels of conductivity, hardness and alkalinity on this river, which in high amounts may affect aquatic organisms.

Two main water quality concerns related to agriculture especially on the Nyando, are soil and sediment erosion, and increased potential for nutrients, pesticides and herbicides to enter the water. Cultivation on relatively steep slopes, practice of tilling the land in dry season mainly to control weeds exposes soil to agents of erosion. These seem to contribute to the higher turbidity and total suspended solids (TSS) values in Nyando when compared to the other two rivers.

Clearing of forests and vegetation in the catchments of rivers and streams aggravates effects of soil erosion, increased sediment load and runoff. In addition, draining of associated swamps mainly for agriculture and human settlement, and cultivation close to the banks increases soil erosion. Sand harvesting from riverbeds is common, for example in lower Kibos, and this may increase the disturbance and movement of substratum particles increasing the turbidity. The long-term consequences of these activities may manifest in alterations of flow regimes and water quality of these rivers. Both turbidity and total suspended solids tended to increase downstream in each river due to inputs, especially of sediments from the catchments through tributaries and runoff from the riparian agricultural land.

pH was slightly alikaline in Kibos and Nyando and slightly acidic in Kisat. However, the mean pH range was rather consistent in the rivers and over the sampling time. It ranged 7.4 to 7.9 in Kibos and Nyando could be due to a flow regime regulated by heavy rainfall and underground springs. Although Nyando flows through an area with limestone, this seems to have little effect on the pH of the river and absolute values ranged 6.1 to 8.7. Most of the pH values in all the three rivers had a narrow range around neutral and values of less than pH 7 were very few.

Nyando and Kisat had higher concentrations of nutrients especially phosphate and ammonium than Kibos. Phosphorus tended to increase downstream in Nyando probably due to use of inorganic fertilizers in the agricultural areas. Runoff from agricultural land accompanied by erosion increases potential for soil and nutrients including phosphate (and leaking of herbicides and pesticides) into rivers. In Kisat, higher concentrations of phosphate are due to discharges of effluents from the industrial area and various forms of sewage.

Incidental bathing and laundry with detergents by the riparian population along most of the length of the river may be an additional source of nutrients on the Nyando. Large herds of livestock mainly cattle are watered directly in the river and in the process they disturb soil along their paths and sediments in the river releasing compounds trapped there. They also release faeces and other wastes rich in organic matter into the water.

From a study on the Njoro River in the Rift valley of Kenya, Mathoko (2001) documents some of the most common human activities that greatly impact on small rivers. They include washing of linen, water abstraction with all sorts of containers, bathing, swimming, watering of livestock, and washing of cars and sand harvesting. These activities are also common on rivers Nyando and lower sections of the Kibos and the associated physical disturbance and chemical inputs can cause long-term effects that may negatively impact on the river hydrology and biota.

Nitrate-nitrogen was also high in all the three rivers probably originating from agricultural land both in small holding and large farms where use of inorganic fertilizers is encouraged for maximum crop yields. A decrease in concentrations of nitrate but a tremendous increase in ammonium with a mean value of up to 2583 $\mu g\ l^{-1}$ was observed in lower Kisat. This was due to decomposition of organic matter, especially nitrogenous compounds from factory effluents and sewage discharges, associated with bacterial processes that can reduce nitrate to nitrite.

Concentration of silicate remained consistently high in all sections of the three rivers and it showed no particular trends. Silicate is derived from weathering processes and is mainly utilized by diatoms in the formation of their shells or frustules (Lampert & Sommer, 1997). A concentration of silicate less than 0.5 mg SiO_2 can limit diatom growth (Wetzel and Likens, 2000). The silicate values in this study had mean concentration ranging between 49 and 79 mg l^{-1}, which are high and therefore this nutrient is not limiting for diatoms in the three rivers that were investigated.

Some environmental variables that are highly correlated and that can be used to quantify same components included conductivity and total dissolved solids ($r = 0.998 \approx 1$) and alkalinity and hardness ($r = 0.86$). The former two are measures of overall quantity of dissolved substances and the latter two can measure total acid-compensating ability of waters (Wetzel & Likens 2000). Turbidity and total suspended solids (TSS) were also highly correlated. For future research, only one from each combination of the variables can be chosen to save on time, expenses and allow more samples to be taken.

Most of the values of environmental variables recorded in rivers Nyando, Kibos and Kisat by this study are comparable to the ones found elsewhere in Africa. However, Kisat seems to be an exception by having waters with very low values of dissolved oxygen (mean 0.9 to 1.4 mg $O_2\ l^{-1}$) and high BOD (260 to 340 mg $O_2\ l^{-1}$) downstream. The dissolved oxygen for Kisat is lower than the average values ranging 6.28 to 7.28 mg $O_2\ l^{-1}$ found in Cross River in Nigeria (Akpan & Offem, 1993), 4 to 15 mg $O_2\ l^{-1}$ in the River Nile near Cairo (Abdel-Hamid *et al.*, 1992) and 5.6 to 6.3 mg $O_2\ l^{-1}$ in River Jong in Sierra Leone (Wright, 1982). The BOD reported for Cross River had an absolute range from 0.2 to 3.8 mg $O_2\ l^{-1}$ (mean range 1.03 to 2.35).

The negative effect on water quality in Kisat due to industry is also seen for the Nile near Cairo where slightly high BOD ranging between 3.7 to 50.2 mg $O_2\ l^{-1}$ are reported (Abdel-Hamid *et al.*, 1992). However, unlike the Nile, Kisat is a very small river and has little self-purification resulting in high BOD and low dissolved oxygen downstream. The lower reaches of Kisat may have turned into more or less of a sewer.

3.5.2. Diatom species composition and diversity

Kibos, Nyando, and Kisat have diverse diatom communities. Although there were similarities in diatom assemblages in the three rivers, some differences occurred in the proportions of the species, including the dominant ones. The longitudinal succession of species composition was probably a result of changing environmental conditions from upstream to downstream and with time. Pollution sensitive species such as *Gomphonema* cf. *angustum*, *Navicula* cf. *heimansioides*, *N. viridula*, *N. schroeteri* and *N. cryptocephala* occurred in larger numbers in upstream stations of rivers Kibos and Nyando and they reduced downstream. Although *Nitzschia palea* occurred in all the stations in all the three rivers, low numbers of this species were observed in upper Kibos and it dominated downstream reaching a maximum mean relative abundance of 50% or more in Kisat.

Cocconeis placentula, *Amphora montana* and *Gomphonema parvulum* also co-dominated in Nyando especially upstream and their numbers were lower in Kibos and Kisat. *Navicula goeppertiana* was the most abundant species in upstream of Kisat and it was overtaken by *Nitzschia palea* at Station C2 and downstream. Other abundant species in Kisat included *Hantzschia amphioxys* and *Achnanthes* cf. *minutissima*. In studies of the diatoms of Papua New Guinea, Vyverman (1991) found *Hantzschia amphioxys* to occur in waters with medium to high conductivity and turbidity, as is the case in Kisat. *Achnanthes minutissima* occurs in clean sections of rivers in The Netherlands (Van Dam, 1982) and in Britain (Round, 1991b). However, this species is also widely distributed and it can have a complex of forms adapted to different conditions (Steinberg & Schiefele 1988; Cox, 1991). Sládeček (1973) also reports *A. minutissima* to occur in all the classes of saprobity except the extremely polluted waters and the sharp decline of this species downstream in Kisat is expected due to increase in pollution.

Preparation of illustrated accounts of species identified is an important requirement for standardisation in using diatoms for monitoring (Round, 1991 b). This is especially so in areas such as Lake Victoria where recent taxonomic keys for diatoms are lacking. In this study, illustrations, mainly of specimens of the dominant taxa were made and form invaluable baseline records that can be used for taxonomic and other purposes. They include future identification and confirmation of species, for long-term monitoring and as educational material. A complete account of all the digital images captured is still in preparation. In addition, permanent microscope slides are stored as part of the specimen material for future references.

All the measures of diversity reflected both latitudinal and environmental gradients. The differences in the diversity indices over the sampling period highlight temporal variability, while the differences between stations in each river and between the rivers indicated spatial variability. Species richness was generally higher in areas with moderate ionic content and nutrient enrichments in Kibos and Nyando, but decreased in polluted lower sections especially in Kisat. This is probably why, positive significant correlations were found between species richness and altitude, width, depth, current velocity, volume of discharge and nitrate-nitrogen but negatively to variables associated with mineralization, eutrophication and organic pollution. This shows the negative effects of pollution on species richness. Khan (1991) attributes decline in species richness to severe organic loading by rubber, which did not however affect species evenness in the Liggi River Basin in Malaysia. This latter relationship was not exhibited by our data and a decline in species richness was accompanied by a reduction in species evenness.

The mean values of species richness ranging from 19 to 38 and diversity from 1.3 to 2.6 found in this study are comparable to 8.27 to 21 and 1.38 to 2.86 respectively, reported by Khan (1991) for the Liggi River Basin in Malaysia. As for species richness, species diversity was higher in Kibos than Nyando and Kisat. The values of diversity indicate some influence of environmental factors on the diatom community and can distinguish between less polluted waters in Kibos and polluted waters in Kisat.

Many of the diatom species in Kibos and Nyando also occurred in fairly equitable proportions. This is probably why diversity was highly related to evenness (r = 0.95) than to richness (r = 0.70). Similar observations on relationships between diversity, richness and evenness are reported for micro-algae assemblages in nutrient enrichment experiments (Hillebrand & Sommer, 2000). Our data shows that species diversity and evenness were significantly correlated to altitude, depth and width of the river channel, current velocity and discharge, and oxygen. Negative correlations between species diversity and nutrient enrichments occurred with phosphate and ammonia. Nitrate seems to encourage species richness. In the nutrient enrichment experiments, Hillebrand & Sommer (2000) also found a decrease in diversity and evenness with increase in nitrate and phosphate but dominance by a few species.

Water temperature, ionic content, trophic state and organic loads that tend to increase downstream appear to have a strong effect on diatom community structure. Diversity and evenness of the diatoms reduced downstream also due to reductions in pollution sensitive species, resulting in dominance of a few species that are tolerant to pollution. This is why dominance index was negatively correlated with the other measures of diversity but positively with variables associated with pollution (except temperature and phosphate).

All the indices of diversity showed variation with time probably because of seasonal changes in weather conditions. Alterations between rainy season and dry season might influence the life cycles of diatoms and colonization. In addition, ecological factors including interactions and competition with other micro-algae, bacteria, protozoa and grazers (Elber & Schanz, 1990) may influence diatom abundance, species richness and diversity. Physical disturbance such as sand harvesting and trampling on the riverbed by humans and livestock, a common occurrence in this region, can cause physical disturbance that may also affect stability of diversity of diatoms and other benthic organisms. Mathoko (2001) for example, found such activities to affect the structure of macroinvertebrates on River Njoro in the Kenya Rift Valley.

Our study reaffirms that environmental variables have effects on the diatom community structure. Low but significant correlations were found between diatom diversity measures and environmental variables. This is also consistent with other studies and according to Hillebrand & Sommer (2000) and Khan (1991); diversity indices cannot directly be used to indicate water quality but rather changes in diatom assemblages in response to changes in water quality. Our findings can contribute to a better understanding of how temporal and spatial patterns of diversity is determined in stream and river diatom communities in the region.

3.6. CONCLUSIONS

The study gives baseline information on recent water quality of rivers Nyando, Kibos and Kisat. Nyando is a source of water for the rural population in its catchments, sugar industry and paddy irrigation. Kibos is an important source of water for the riparian population source and for Kisumu municipality. Kisat was a source of water for the surrounding population but its waters are of inferior quality and are of minimal use.

Kisat is the most influenced by human activities and is affected mainly by high amounts of ions, eutrophication and organic pollution to critical levels that impair the aquatic life. Effluents from human activities largely determine the volume of this river that was at one time regular like other small rivers in the region. Kisat has turned more or less into a sewer and its waters cannot also be used for any meaningful purposes. Nyando is faced with high sediment loads, eutrophication and organic pollution, whereas, Kibos is the least influenced by human activities.

Results of our study reveal temporal and spatial fluctuations in environmental variables, diatom species composition and diversity. Further, relationships between environmental variables and diatom diversity indices are demonstrated. High diatom diversity and evenness on the Kibos and upper Nyando is enhanced by good water quality. The location of the drinking water intake for part of Kisumu municipality on this river at Kajulu is therefore proper.

Kibos can be chosen as a reference river for this study, due to overall high species richness, higher diversity associated with lower ionic content, lower trophy and lower organic inputs when compared to Nyando and Kisat. A major goal for the future of Kibos should be to maintain and improve the prevailing water quality and available diversity through protection and conservation of the catchments from further degradation. The headwaters in particular and those of other rivers need maximum attention due to their high sensitivity and vulnerability to environmental changes. The aim should be to reduce human activities including encroachments and deforestation and to help facilitate proper management. Nyando requires measures for more protection whereas, Kisat may requires total rehabilitation.

The measures of diversity can be used to indicate both short and long-term changes in diatom assemblages in relation to environmental changes. However, single measurements may not be enough to conclusively explain dynamics in the environment and biological communities as indicated by presence of outliers in our data. Expansion of data collection to less disturbed upstream reaches, on other rivers and streams, and at more regular intervals could help increase information on potential diversity in the Lake Victoria catchments.

Diatoms and other microscopic algae play an important role as primary producers and therefore they are important components of the general biodiversity in aquatic ecosystems. Studies of these organisms should be incorporated in the context of environmental impact assessments and formulation of conservation strategies.

Chapter 4

Assessment of water quality in rivers Kibos, Nyando and Kisat in the catchments of Lake Victoria (Kenya) using diatom indicator values

4.1. ABSTRACT

The water quality of rivers Kibos, Nyando and Kisat in Lake Victoria basin were studied on seven occasions between May 1998 and March 2001 using seven known diatom ecological indicator values: Saprobity, Oxygen requirements, Trophic state, Nitrogen uptake metabolism, Moisture, pH and Salinity. Taxa with known ecological indicator values occurred consistently in high abundance in all stations and throughout the sampling period. Strong relationships were observed between the indicator values and between the indicator values and environmental variables. They satisfactorily predicted the ecological water quality of the rivers investigated. The indicator values were significantly correlated with the corresponding environmental variables. Most significant correlations occurred with Saprobity, Oxygen, Trophic state and Nitrogen uptake metabolism. Data from diatom pollution sensitivity index agree with the ones obtained from ecological indicator values and measured environmental variables. Among the three rivers, Kibos is less polluted while Kisat is the most polluted, and pollutants generally increase downstream in each river. The results show trends similar to other studies elsewhere under comparable environmental conditions and confirm the suitability of the diatom ecological indicator values for assessing water quality based on the diatom assemblages in the three rivers and can be extended to others in the region.

4.2. INTRODUCTION

Routine monitoring of water quality in the Lake Victoria region mainly employs physical and chemical methods. These methods allow for detection of levels of environmental parameters including nutrients and pollutants at snap sampling. They have limitations in detecting both short-term and long-term fluctuations in the levels of critical environmental variables that influence water quality and their effects on living organisms. Because of these limitations, other standard methods and techniques are explored to complement the existing methods. Biological methods use integrated information from organisms that are exposed for some time to water thereby allowing for the overall effect of the physical and chemical environment. Biological methods of assessing water quality have been developed and satisfactorily used elsewhere. They include those based on micro-organisms, benthic macro-invertebrates, benthic algae, diatoms, macrophytes, phytoplankton, fish and animals (Whitton, 1991; Kelly & Whitton, 1998; Dixit, *et al.*, 1999).

Diatoms have several advantages over other indicator organisms. They include wide geographical distributions, occurrence in large abundances, fast growth rates and high sensitivity to various physical, chemical and biological changes (Van Dam *et al.*, 1994; Stevenson & Pan, 1999). Sampling, processing and storage of diatoms is relatively simple and can be adapted readily (Whitton, 1991; Prygiel & Coste, 1993). Their taxonomy is well known when compared to other algae and other indicator organisms (Whitton, 1991). However, there have been some slight problems of identification of diatom species recently. The presence of a large collection of literature on the diatom community as indicators of water quality (Round, 1991a, b) makes it possible for development of reliable and practical indices using harmonised approaches. In addition, availability of computer software allows for rapid calculation of important diatom indices making their use more practical (Lecointe *et al.*, 1993).

Various diatom indices are in use in routine monitoring and management of water bodies in several countries, especially in Europe (Prygiel & Coste, 1993; Whitton & Kelly, 1995; Kelly & Whitton, 1998; Kelly, 1998; Kelly *et al.*, 1998). Many of the indices are based on data generated from autoecological information, saprobic system, community structure and ecological assemblages (Prygiel & Coste, 1993). The indices usually have good correlations with eutrophication, organic pollution and other water quality variables. Most of the indices are also strongly correlated with each other (Kelly *et al.*, 1995). Many diatoms are cosmopolitan and it becomes appropriate to develop indices based on existing ones with some modifications to suit a particular region.

Epilithic diatoms growing on hard surfaces and rocks are preferred for monitoring water quality especially in rivers although those those grow on other substrata including macrophytes sand and artificial substrates are used (Kelly *et al.* 1998). Hard substrates are usually found at all seasons along most of river courses from source to mouth (Round, 1991a, b) and collection of samples from such substrates is easily done using simple tools.

The objective of this study was to assess the practical application of various diatom ecological indicator values, obtained from epilithic diatom assemblages, in monitoring the ecological status and water quality in rivers Kibos, Nyando and Kisat in the Lake Victoria basin. The values compiled by Van Dam *et al.* (1994) were found suitable for our study. The rationale is that many taxa present in our samples also occur in their checklist. In addition, the indicator values give information on pollution as well as the ecological habitat. The "Indice de polluo-sensibilite", also named IPS or pollution sensitivity index (Coste 2001, unpublished) that is still under development primarily to assess pollution was also evaluated for its suitability for our samples.

4.3. MATERIALS AND METHODS

4.3.1. Study area

Rivers Kibos, Nyando, and Kisat are located at the easternmost tip of the Nyanza Gulf of Lake Victoria in Kenya, within latitudes 0°18′S to 0°04′N and longitudes 34°43′E to 35°30′E (Figure 4.1, also see Figure 2.1). This region has two main rainy seasons interspaced with two relatively dry seasons. The long and heavy rains occur between March and May and the short rains occur between October and November. The mean annual rainfall varies between 1250 mm and 1550 mm (Burgis, *et al.*, 1987). Excessive runoff during torrential heavy rainfall occasionally results in large volumes that flood the rivers, especially the Nyando also causing raises in the level of Lake Victoria. The region has warm to hot weather. Mean monthly air temperature range from 21.9 to 24.3 °C. The highest temperatures are recorded in February and March and the lowest in December and January.

The Lake Victoria catchments in Kenya overlie the Kavirondo and Nyanzian Basement systems with Precambrian intrusive of granite and tertiary volcanic rocks (Republic of Kenya, 1992). The region is one of the most densely populated areas in Kenya and river catchments are continuously deforested mainly for human settlement and agricultural development. Smallholdings of agricultural activities mainly on tea, coffee, subsistence crops and livestock in the highland areas and a mixture of small subsistence holdings and large-scale sugar-cane farms in the lowlands dominate the land use. Intensive cultivation and poor agricultural methods particularly in smallholdings often result in degeneration of the farmlands.

Urban settlements and industrial activities mainly based on sugar and food processing are expanding rapidly and many of them lack adequate waste treatment facilities. Soil erosion, agricultural runoff and discharge of incompletely treated and even raw sewage are major sources of effluents polluting the rivers. As a result, a number of environmental impacts are apparent, among them, heavy silt loads, eutrophication, loss of habitats for aquatic organisms including rare fish species, deterioration of water quality to levels unfit for human consumption and other meaningful purposes and increase in water-borne diseases.

Rivers Kibos, Nyando and Kisat differ in their hydrological regimes and pollution sources. Kibos drains an area of about 490 km^2 (Burgis *et al.*, 1987). The annual discharge is about 68 million m^3. This river has two major tributaries: the Awach draining an area with agricultural smallholdings and the Kibos draining an area with limited agricultural activities and sparse human population. Drinking water for part of Kisumu town is abstracted from the later tributary.

Nyando, the largest of the three rivers, has a catchment area of about 2,650 km^2 and an annual discharge of 247 million m^3 (Burgis *et al.*, 1987). It has several large tributaries and receives runoff from small-scale agricultural holdings (tea, livestock, and subsistence crops), large-scale agricultural land (tea, coffee, sugar cane plantations, paddy) and effluents from a lime factory, two major sugar factories and a distillery.

Kisat is a small river and drains an area of about 10 km^2. It receives runoff from agricultural smallholdings and Kisumu town, household wastes from a slum area, effluents from an industrial area and a municipal sewage treatment plant. Detailed descriptions of the rivers and the sampling stations are given elsewhere (see chapter 2).

4.3.2. Description of sampling stations

12 sampling stations were selected on the three rivers Nyando (N1-N4), Kibos (K1-K4) and Kisat (C1-C4). The location and brief description of the stations is given in Figure 4.1 and Table 4.1 respectively. The stations were selected to represent variations in environmental conditions in the three rivers and with respect to sources of pollution.. In addition to the possible pollution sources mentioned, open laundry, bathing by humans, and watering of livestock, mainly cattle, are common in Nyando and Kibos. Sampling was done on seven

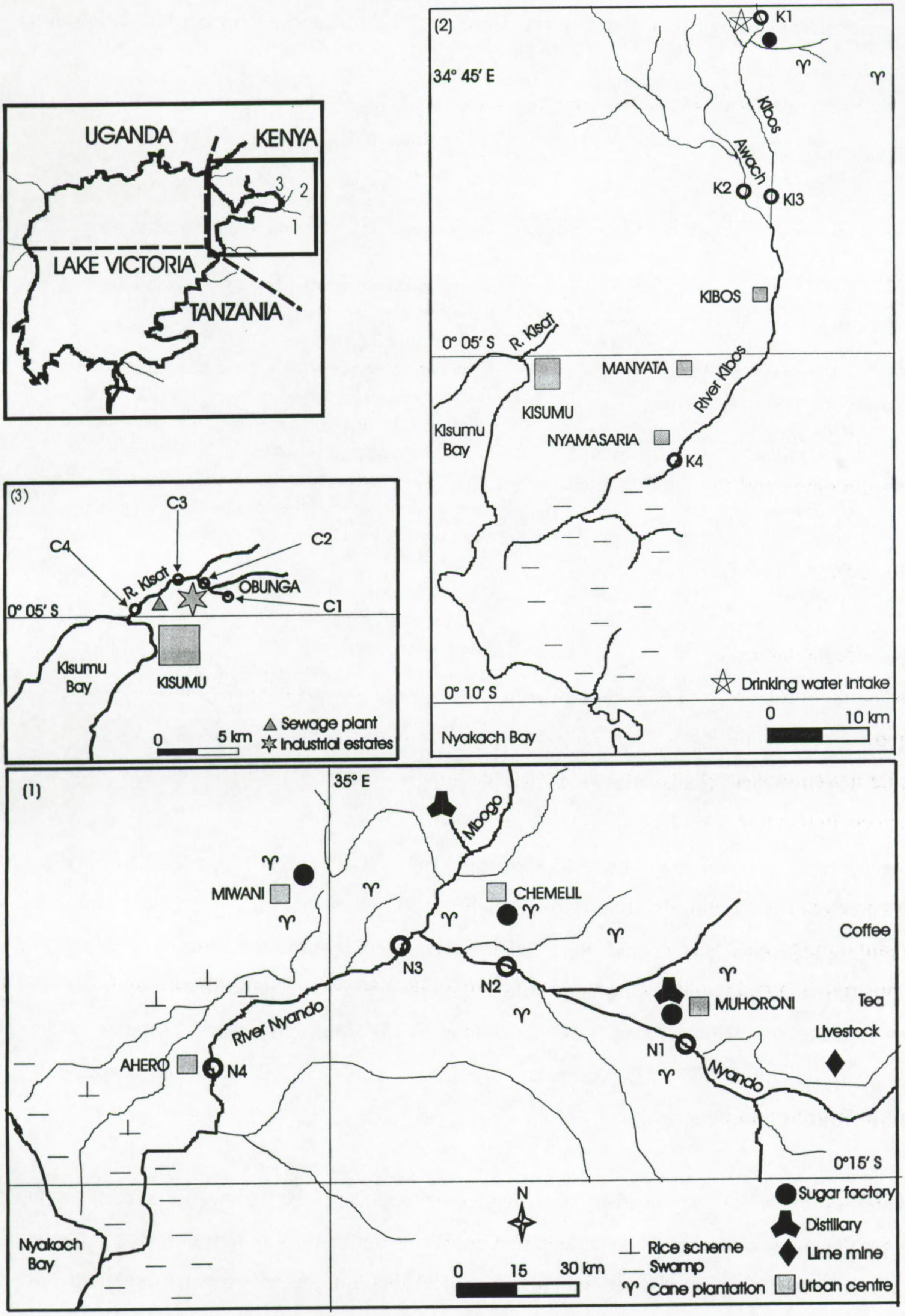

Figure 4.1. Map showing main urban, industrial, agricultural locations and sampling stations on rivers (1) Nyando: N1-N4, (2) Kibos: K1-K4 and (3) Kisat: C1-C4. Insert map shows Lake Victoria and position of the three rivers.

occasions: May, August, September and December 1998; February 1999; March 2000 and March 2001.

Table 4. 1. Description of the 12 sampling stations on rivers Kibos (K1-K4), Nyando (N1-N4) and Kisat (C1-C2).

Code	Station name	Altitude (m a.s.l.)	Distance from source (km)	Characteristics of catchments and possible pollution sources
K1	Kajulu	1248	37	Limited agricultural activities (water is abstracted above this station for Kisumu town).
K2	Riverside	1213	20	Small agricultural holdings.
K3	Wathorego	1202	41	Small sugar factory, cane farms and sand extraction.
K4	Nyamasaria	1170	50	Domestic waste, sand extraction.
N1	Muhoroni	1287	130	Small agricultural holdings, lime mines, urban settlement.
N2	Awasi-Chemelil bridge	1231	155	Sugar factory, distillery, cane farms, urban settlement.
N3	Ogilo bridge	1182	165	Sugar factories, cane farms (dilution by a large tributary)
N4	Ahero	1176	177	Sugar factories, cane farms, paddy fields.
C1	Kenya Breweries	1171	0.5	Brewery.
C2	Obunga-Mbuta	1165	1.5	Domestic sewage from slums, local breweries, open fish frying activities.
C3	Kudho kotur	1164	9	Industrial area, urban runoff.
C4	Golf course	1159	11	Industrial area, sewage treatment plant.

4.3.3. Environmental measurements

Geographical position and altitude of each station was determined using a GARMIN GPS II PLUS global positioning system during the first trip, which was also used in selecting the sampling stations. Data on environmental variables were taken at the same time as samples for diatoms. Water temperature and dissolved oxygen were measured *in situ* with a WTW Microprocessor Oximeter Oxi 320, pH with a WTW Microprocessor pH-meter H 320, conductivity with a WTW Microprocessor conductivity meter LF 96 and turbidity was with a Hach 2100P Turbidimeter.

Water samples, for various determinations, were collected just below the surface of the stream using acid-washed polyethylene bottles. Water for analysis of nutrients was preserved with 0.2 ml mercuric chloride and the samples kept on ice in a cooler box and later transferred to the laboratory refrigerator. Suitable standard methods were selected from those outlined by APHA (1995) and Wetzel and Likens (2000). Prior to determination, water samples were brought to room temperature and filtered through cellulose-acetate membrane (pore size 0.45 μm). Spectrophotometric methods were used to determine nitrate-nitrogen (cadmium reduction, diozoic complex), ammonia-nitrogen (manual phenate, indophenol-blue), phosphate-phosphorus (SRP, ascorbic acid), silicate dissolved SiO_2 (molybdosilicate, heteropoli blue).

Alkalinity and hardness were determined by titration with HCl and EDTA titrimetric methods respectively, in the field at the time of collection. Total suspended solids (TSS) were determined by measuring residue retained by fibre glass filters (Whatman GF/C) dried to a constant weight at 103 to 105 °C in an oven. Total dissolved solids (TDS) were measured only once in December 1998, with ATI ORION model 105 and 115-conductivity meter. Similarly, biochemical oxygen demand was determined only in March 2001, by the 5-Day BOD test.

4.3.4. Biological sample collection and processing

Epilithic diatoms were collected at each sampling station from at least 5 randomly selected submerged or semi-submerged stones, mainly cobbles free of filamentous algae or silt and with an obvious diatom film. The stones were obtained from different positions within a 5 m reach. The attached diatoms were gently removed from the upper surfaces of the stones, calculated to cover approximately 100 cm^2 using a clean soft tooth brush and repeated rinsing with distilled water. The collected composite material was preserved in 5 % formalin solution and transported to the laboratory.

The samples were oxidised with concentrated sulphuric and nitric acids by heating under a fume cupboard. A subsample of cleaned diatom frustules was mounted in Styrax ® (Gum Storax) on a glass slide and examined under a Leitz Dialux 20 EB light microscope at 1000 x magnification using immersion oil. At least 300 frustules were inspected in a number of transects across the slide and diatom taxa identified and recorded. Taxonomic identification mainly followed Krammer and Lange-Bertalot (1986-1991) and guidelines given in Barber & Haworth (1981). For identification of some species, other taxonomic literatures included Hustedt (1949), Huber-Pestalozzi (1962), Germain (1981), Gasse (1986), Vyverman (1991) and Cocquyt (1998).

Table 4.2. Classification of diatom ecological indicator values according to Van Dam *et al.* (1994).

(S) Saprobity

		Water quality class	Oxygen saturation(%)	BOD_5^{20} (mg l^{-1})
1	oligosaprobous	I, I - II	>85	<2
2	β-mesosaprobous	II	70 - 85	2 - 4
3	α-mesosaprobous	III	25 - 70	4 - 13
4	α-meso-/polysaprobous	III - IV	10 - 25	13 - 22
5	polysaprobous	IV	<10	>22

(O) Oxygen requirements

1 continuously high (about 100% saturation)
2 fairly high (above 75% saturation)
3 moderate (above 50% saturation)
4 low (above 30% saturation)
5 very low (about 10% saturation)

(T) Trophic state

1 oligotraphentic
2 oligomesotraphentic
3 mesotraphentic
4 meso-eutraphentic
5 eutraphentic
6 hypereutraphentic
7 oligo- to eutraphentic (hypereutraphentic)

(N) Nitrogen uptake metabolism

1 nitrogen-autotrophic taxa, tolerating very small concentrations of organically bound nitrogen
2 nitrogen-autotrophic taxa, tolerating elevated concentrations of organically bound nitrogen
3 facultative nitrogen-heterotrophic taxa, needing periodically elevated concentrations of organically bound nitrogen
4 obligately nitrogen-heterotrophic taxa, needing continuously elevated concentrations of organically bound nitrogen

(M) Moisture

1 never, or only rare, occurring outside water bodies
2 mainly occurring in water bodies, sometimes on wet places
3 mainly occurring in water bodies, also rather regularly on wet and moist places
4 mainly occurring on wet and moist or temporarily dry places
5 nearly exclusively occurring outside water bodies

(R) pH

1	acidobiontic	optimum occurrence at pH <5.5
2	acidophilous	mainly occurring at pH <7
3	circumneutral	mainly occurring at pH values of about 7
4	alkaliphilous	mainly occurring at pH >7
5	alkalibiontic	exclusively occurring at pH >7
6	indifferent	no apparent optimum

(H) Salinity

		Cl^- (mg l^{-1})	Salinity (‰)
1	fresh	<100	<0.2
2	fresh brackish	<500	<0.9
3	brackish fresh	500 - 1000	0.9 - 1.8
4	brackish	1000 - 5000	1.8 - 9.0

4.3.4. Data treatment

The diatom ecological indicator values of each station were obtained from scores of weighted averages of the diatom assemblages based on values compiled and refined by Van Dam *et al.* (1994). The indicator values included Saprobity (S), Oxygen requirements (O), Trophic state (T), Nitrogen uptake metabolism (N), Moisture (M), pH (R) and Salinity (H) (Table 4.2).

Relative abundance of taxa and frustules with each ecological indicator value (calculated as a percentage of total sample) were compared for significance between the three rivers and between stations in each river by Wilcoxon matched pairs test. Actual scores of the indicator values for the stations were assessed by Analysis of variance (ANOVA). Relationships between environmental variables and the ecological indicator values were calculated by correlation analysis. Skewed environmental variable distributions were log transformed prior to the analysis.

The "Indice de polluo-sensibilite", also named IPS or pollution sensitivity index (Coste 2001, unpublished) that is still under development, was calculated according to a formula similar to the one proposed by Zelinka & Marvan (1961):

$$\text{IPS (from 5 to 1)} = \Sigma A \, . \, SV \, . \, W \, / \, \Sigma A \, . \, W$$

Where A = mean relative abundance in percentage of a taxon.

SV = sensitivity value (5 = very sensitive, 1 = very resistant).

W = weight of the indicator (1 = bad indicator; 3 = good indicator).

The results were transformed to a scale of 20 to 1 (to allow comparison with another index on macroinvertebrates), using the formula:

$$\text{Q (from 20 to 1)} = (\text{IPS} \, . \, 4.75) - 3.75$$

Where Q = quality class ($Q \geq 17$ = non polluted, Q = 16 to 13 = weakly polluted, Q = 12 to 9 = moderately polluted, Q = 8 to 5 = heavily polluted and $Q \leq 4$ = very heavily polluted).

4.4. RESULTS

4.4.1. Environmental variables

Table 4.3 summarises the characteristics of the environmental variables measured. A detailed description on their trends is given elsewhere (see Chapter 2: Table 3.2). The stations in Kibos and Nyando had similar and higher elevations than the ones of Kisat. Nyando is the largest of the three and generally had the largest widths, depths and volume of discharge, followed by Kibos and Kisat in that order. These variables increased downstream in each river. Higher current velocities were recorded in Nyando and Kibos than in Kisat. Current velocity tended to reduce downstream in Nyando and Kibos but increased downstream in Kiast.

Kisat had the highest water temperature, alkalinity, hardness, conductivity, total dissolved solids, total suspended solids and biochemical oxygen demand (BOD) than Nyando. Kibos that is less influenced by human activities, had the lowest values of these variables. These variables generally increased downstream in each river and very markedly in Kisat. Kisat receives effluents from various activities including domestic sewage from slums of Obunga, an open market that specialises in frying fish, effluents from factories and a municipal sewage treatment plant. The sewage treatment plant was not functioning during the whole period of this study.

Nyando and Kisat had higher concentrations of plant nutrients especially phosphate and ammonium than Kibos. Nyando has a large catchments area with various agricultural activities that may contribute high levels of nutrients. Incidental bathing, laundry by riparian population may also contribute to high phosphates in the river. In Kisat, effluents from industries and various sewage discharges are main sources of nutrients.

Higher turbidity and nitrate-nitrogen in Nyando are mainly due to runoff from agricultural activities. Kibos that is less influenced by human activities has higher levels of dissolved oxygen than Nyando and Kisat. Dissolved oxygen concentration decreased downstream in each river particularly in Kisat where anoxic conditions were recorded downstream.

Table. 4.3. Mean values for environmental variables in the sampling stations on rivers Kibos (K1-K4), Nyando (N1-N4) and Kisat (C1-C4).

Station	Altit.	Width	Depth	Veloc.	Disch.	Temp.	DO	BOD	pH	Alk.	Hard.	Cond.	TDS	Turb.	TSS	PO_4-P	NO3-N	NH_4-N	SiO_2
K1	1284	5.9	0.6	0.66	2.38	19.5	7.7	0.8	7.7	43	39	83	35	61	68	82	292	77	52
K2	1213	4.1	0.5	0.50	1.43	23.0	7.6	2.4	7.6	62	42	108	52	87	82	69	311	66	49
K3	1202	7.0	0.9	0.42	2.70	21.0	7.3	2.4	7.7	57	44	106	46	106	144	76	342	64	54
K4	1170	8.9	0.9	0.52	5.29	22.5	7.1	2.4	7.7	65	45	117	52	285	304	70	297	59	53
N1	1287	11.9	0.6	0.93	10.62	22.1	7,9	3.2	7.4	141	107	270	118	194	272	71	309	76	62
N2	1231	13.6	1.4	0.53	14.46	23.6	6.5	6.4	7.6	206	149	354	164	230	350	275	533	70	60
N3	1182	15.9	1.6	0.62	19.90	24.4	7.3	5.6	7.6	182	125	293	143	295	405	131	298	84	56
N4	1176	18.4	1.4	0.54	18.61	25.5	7.1	5.2	7.9	176	131	294	138	423	517	118	272	53	50
C1	1171	0.6	0.3	0.04	0.01	26.0	8.3	6.6	7.2	111	161	537	243	27	242	233	556	102	79
C2	1165	0.6	0.2	0.20	0.02	27.8	1.4	260.0	6.8	281	205	1004	589	249	385	439	849	282	74
C3	1164	2.1	0.4	0.20	0.19	25.1	2.0	340.0	6.8	255	298	661	411	100	242	204	132	2583	53
C4	1159	4.3	0.4	0.27	0.40	26.8	0.9	290.0	7.0	357	207	850	446	226	357	683	685	2560	50

Units : Altitude (m a.s.l.), width (m), depth (m) velocity (m s^{-1}), discharge (m^3 s^{-1}), temperature (°C), dissolved oxygen, DO (mg O_2 l^{-1}), pH (pH units), total hardness (mg l^{-1} as $CaCo_3$), total alkalinity (mg l^{-1} as $CaCo_3$), conductivity (µS cm^{-1}), total dissolved solids, TDS (mg l^{-1}), turbidity (NTU = Nephelometric turbidity units), total suspended solids, TSS (mg l^{-1}), phosphate-phosphorus (µg l^{-1}), nitrate-nitrogen (µg l^{-1}), ammonia-nitrogen (µg l^{-1}), silicate SiO_2 (mg l^{-1}), BOD_5 (mg O_2 l^{-1}).

Table 4.4. Mean percentage taxa (T) and frustules (F) with diatom indicator values in the sampling stations (percentage of total taxa in a sample).

Station	Saprobity		Oxgen requirement		Trophic state		Nitrogen uptake		Moisture		PH		Salinity	
	T	F	T	F	T	F	T	F	T	F	T	F	T	F
K1	92	97	79	87	91	97	80	85	81	76	93	97	94	97
K2	91	95	79	87	92	96	76	74	83	77	94	96	94	96
K3	91	98	79	92	92	98	78	84	83	74	92	98	94	98
K4	91	98	79	93	90	98	77	80	82	81	92	99	93	99
N1	92	99	83	94	91	98	79	81	85	83	93	99	95	99
N2	92	99	84	95	92	98	79	89	85	89	93	99	94	99
N3	93	99	82	92	93	99	80	86	87	75	95	99	96	99
N4	90	98	79	92	91	98	76	87	84	80	92	98	93	98
C1	89	97	82	96	90	97	77	95	85	97	92	98	94	99
C2	89	98	80	95	89	98	77	94	83	96	90	98	92	98
C3	89	94	82	91	91	95	77	88	87	95	91	96	94	96
C4	86	90	77	88	85	89	74	87	79	88	87	90	88	90

4.4.2. Numbers of taxa and frustule counts with diatom indicator values

224 taxa of diatoms were examined and the full list is included elsewhere (see Chapter 3, Table 3.6). 192 taxa, representing 83.5% of all the taxa identified had at least one of the known ecological indicator values examined in this study. The mean percentage taxa and frustules with known diatom ecological indicator values per sample were higher than 50% except for Nitrogen uptake metabolism (N) and Moisture (M) (Table 4.4, Figures 4.2 a, b, c). Frustules with N and M with percentage as low as 48% and 21%, respectively, were observed in a few samples.

4.4.3. Numbers of taxa and frustule counts with Saprobity indicator values

The percentage numbers of taxa with known Saprobity (S) indicator values per sample were similar in Kibos and Nyando (Table 4.4, Figure 4.2 a) and they were both significantly higher than the ones of Kisat ($p<0.05$). There were no significant differences in percentage taxa with S-values between stations in Kibos and Nyando. However, in Kisat, Kenya Breweries (Station C1) had higher percentage taxa with S-values than Golf course (C4; $p<0.05$).

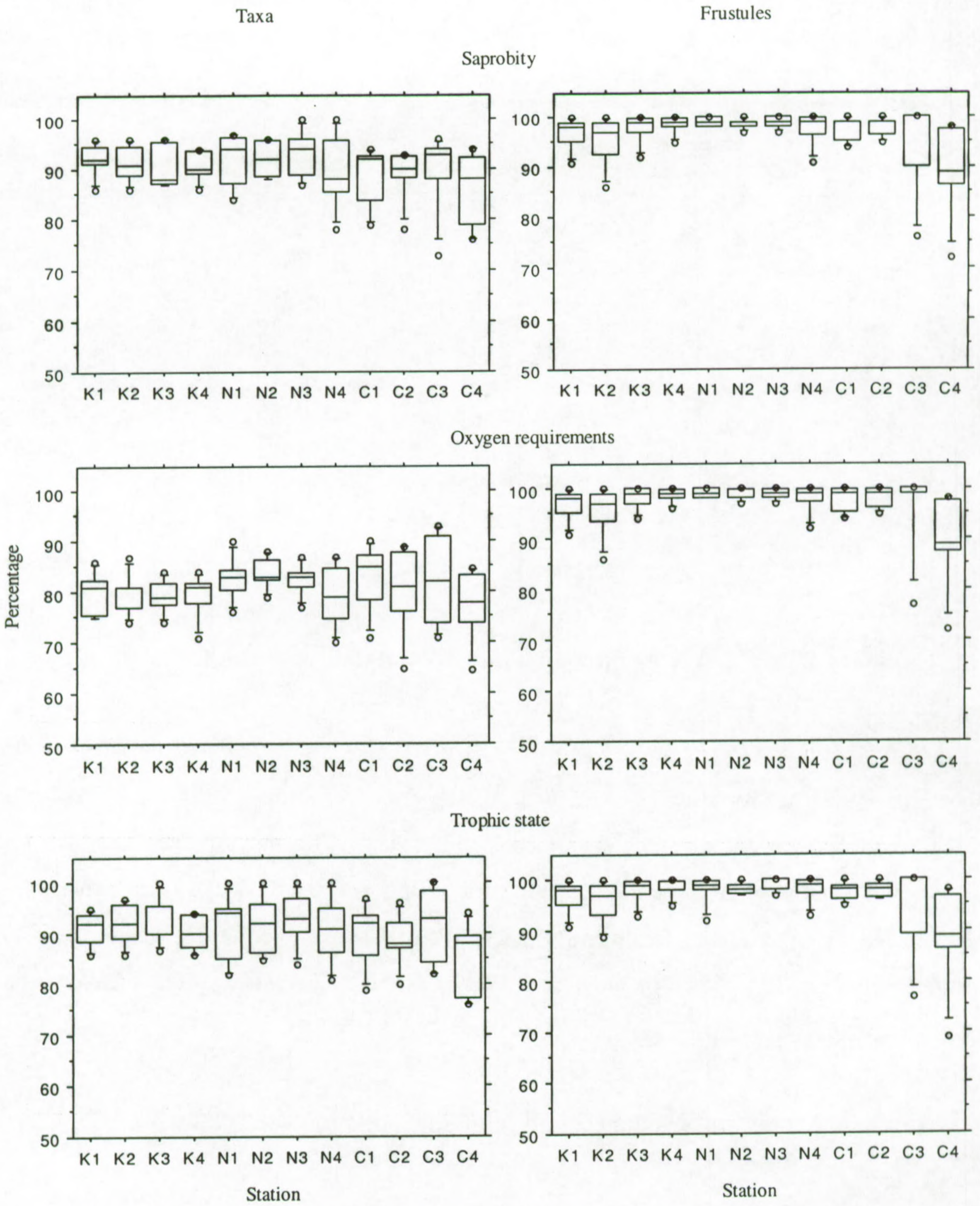

Figure 4.2 (a). Medians, quartiles, 10th and 90th percentiles and outlier values for diatom taxa and frustule counts with indicator values for Saprobity, Oxygen requirements and Trophic state at the sampling stations. (percentage of total sample).

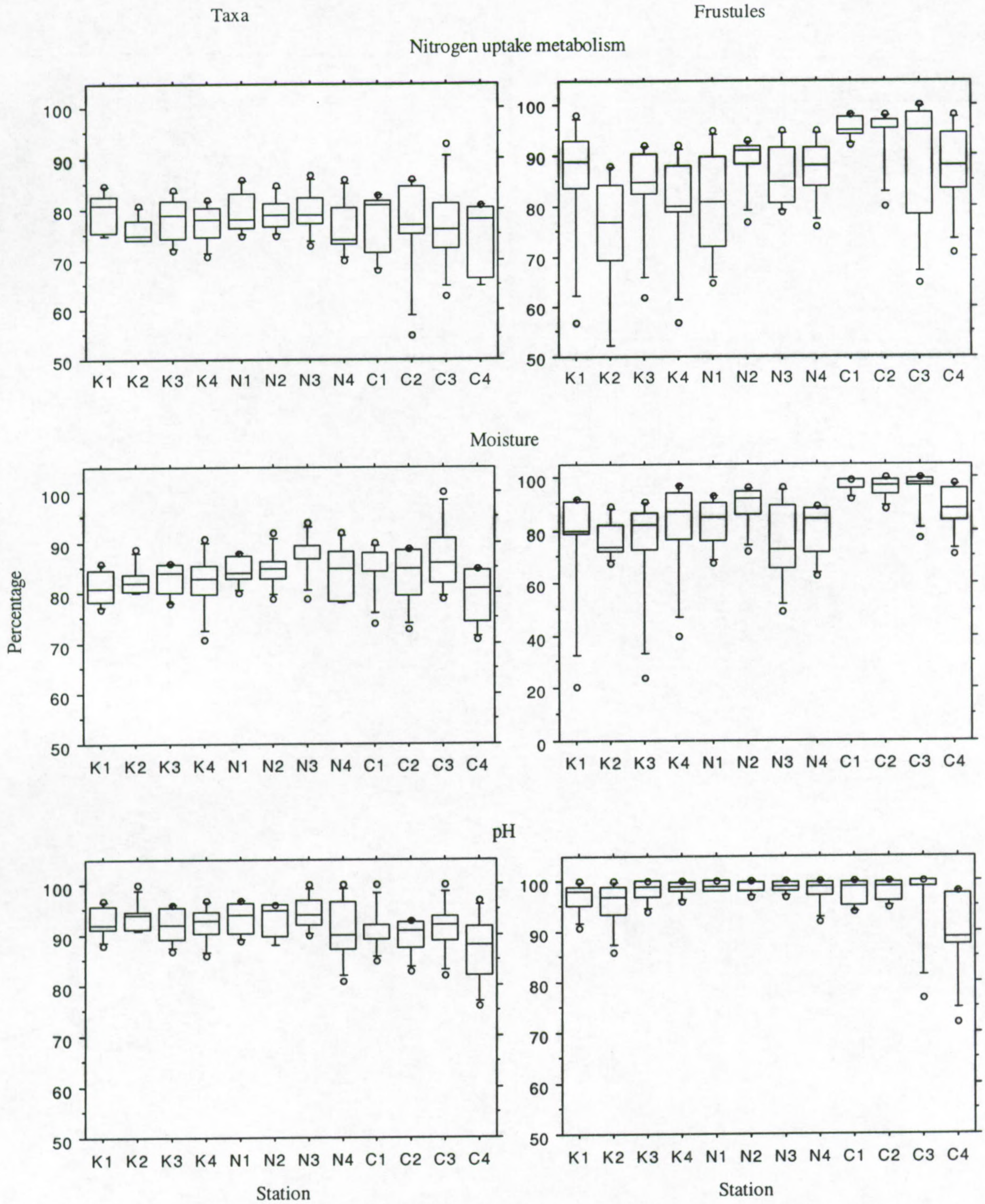

Figure 4.2 (b). Medians, quartiles, 10th and 90th percentiles and outlier values of diatom taxa and frustule counts with indicator values for Nitrogen uptake metabolism, Moisture and pH (percentage of total sample).

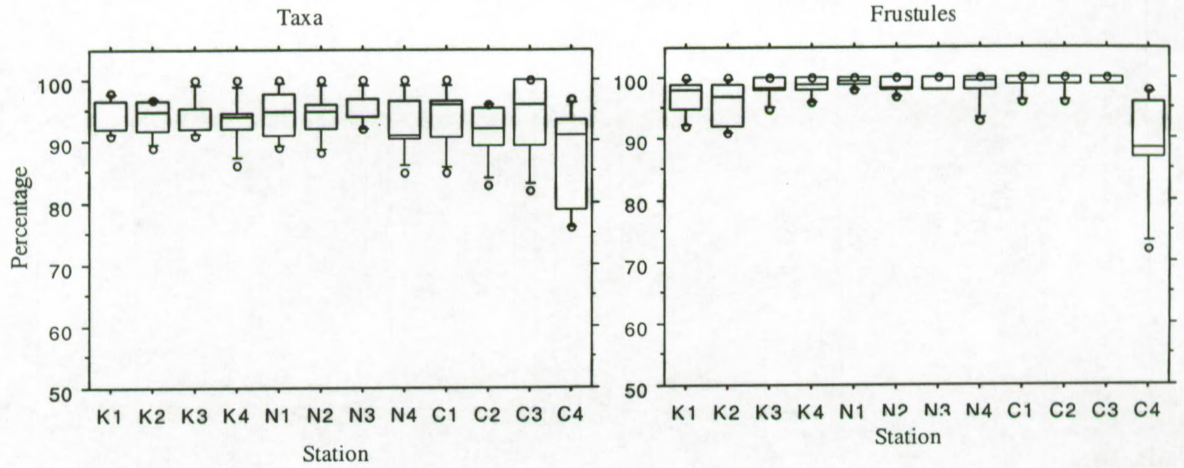

Figure 4.2 c). Medians, quartiles, 10^{th} and 90^{th} percentiles, and outliers for diatom taxa and frustule counts with indicator values for Salinity. (percentage of total sample).

Nyando had higher percentage frustules with S-values per sample than Kibos and Kisat respectively ($p<0.05$). There were no significant differences in percentage frustules with S-values between stations in Kibos and Nyando. In Kisat, Obunga-Mbuta (C2) had higher percentage taxa with known S-values than Golf course (C4).

4.4.4. Numbers of taxa and frustule counts with Oxygen requirements indicator values

Nyando had higher percentage taxa with known Oxygen requirements (O) indicator values per sample (Table 4.4, Figure 4.2 a) than Kibos ($p<0.05$) and both were not significantly different from Kisat. There were no significant differences between stations in the all the three rivers, in percentage taxa and percentage frustules with O-values per sample. In Kibos, Wathorego (K3) had higher percentage frustules with O-values than Riverside (K2, $p<0.05$) which also showed more variations. In Kisat, Kenya Breweries (C1) had higher percentage frustules with O-values than Golf course (C4, $p<0.05$). There were no significant differences in percentage frustules with known O-values between stations in Nyando.

4.4.5. Numbers of taxa and frustule counts with Trophic state indicator values

The percentage taxa with known Trophic state (T) indicator values were similar in Kibos and Nyando (Table 4.4, Figure 4.2 a) and both were significantly higher than in Kisat ($p<0.05$). There were no significant differences in percentages taxa with T-values between sampling stations in Kibos and Nyando. In Kisat, Kenya Breweries (C1) and Kudho-kotur (C3) had higher percentage taxa with T-values than Golf course (C4, $p<0.05$), respectively.

Kibos and Nyando had similar percentages of frustules with known T-values per sample. However, the percentage frustules with T-values in Nyando were significantly higher than in Kisat ($p<0.05$). There were no significant differences in the frustules with known T-values between stations in Kibos and Nyando but within Kisat, Obunga-Mbuta (C2) had higher percentages than Golf course (C4, $p<0.05$).

4.4.6. Numbers of taxa and frustule counts with Nitrogen uptake metabolism indicator values

There were no significant differences in percentage taxa with known Nitrogen uptake metabolism (N) indicator values between the three rivers and between the stations within each river (Table 4.4, Figure 4.2 b). However, the percentage frustules with N-values were higher in Kisat and Nyando than in Kibos ($p<0.05$) respectively. No significant differences in percentage frustules with known N-values were observed between stations in Nyando. Within Kibos, Kajulu (K1) had higher percentage frustules with known N-values than Riverside (K2, $p<0.05$), which also showed more variations between samples. In Kisat, Kenya Breweries (C1) had higher percentage frustules with N-values than Golf-course (C4, $p<0.05$).

4.4.7. Numbers of taxa and frustule counts with Moisture indicator values

Percentage taxa with known Moisture (M) indicator values per sample were higher in Nyando (Table 4.4, Figure 4.2 b) than in Kibos ($p<0.05$) but both were not significantly different from Kisat. There were no significant differences in percentage taxa with M-values between stations in Kibos and Nyando. In Kisat, Kenya Breweries (C1) and Kodhu-kotur (C3) had higher percentage taxa with M-values than Golf course (C4, $p<0.05$) respectively.

Higher percentage frustules with M-values occurred in Kisat than in Nyando and Kibos ($p<0.05$) respectively (Table 4.4, Figure 4.2 b). Within Kibos, Kenya Breweries (C1) had higher percentage frustules with M-values than Golf course (C4, $p<0.05$).

4.4.8. Numbers of taxa and frustule counts with pH indicator values

Kibos and Nyando had higher percentage taxa with known pH (R) indicator values than Kisat ($p<0.05$) (Table 4.4, Figure 4.2 b). There were no significant differences in percentage taxa with R-values between stations in all the three rivers. Although the mean percentage frustules with R-values in Kibos were similar to the one of Nyando, the two rivers were significantly different ($p<0.05$). The differences could be due to more fluctuations in Kibos, especially at Riverside (K2) and Kajulu (K1). Nyando had significantly higher percentage frustules with R-values than Kisat ($p<0.05$). There was no significant difference in percentage frustules with R-values between stations within Kibos and Nyando. In Kisat, Kenya Breweries (C1) and Obunga-Mbuta (C2) had higher percentage frustules with R-values than Golf course (C4, $p<0.05$).

4.4.9. Numbers of taxa and frustule counts with Salinity indicator values

There were no significant differences in percentage taxa with known Salinity (H) indicator values between Kibos, Nyando and Kisat. Within Kisat, Kenya Breweries (C1) and Kodhu-kotur (C3) had higher percentage taxa with H-values than Golf course (C4, $p<0.05$).

Nyando and Kisat had similar percentage frustules with H-values. However, Nyando, had significantly higher percentage frustules with H-values than Kibos ($p<0.05$). Within Kisat, Kenya Breweries (C1) and Obunga-mbuta (C2) had similar percentage frustules with H-values and were both significantly higher than at Golf course (C4, $p<0.05$).

4.4.10. Distribution of the taxa and frustule counts with Saprobity indicator values

Saprobity (S) indicator values are classified into a scale ranging from 1 to 5 (Table 4.2). The lowest, S-value 1 represents oligosaprobous taxa that prefer very low organic pollution and the highest, S-value 5 are polysaprobous taxa that can tolerate very high organic pollution.

The mean percentage taxa and frustules with S-values are shown in Figures 4.3 a, b respectively. There were minor differences in the percentage taxa of each S-value in all the stations. Taxa with S-value = 2 had the highest percentage contributing between 35% and 42% of total in numbers of taxa with indicator values per sample. Taxa with S-value 1 contributed between 13 and 23%, those with S-value 3 between 12% and 22% and with S-value 4 between 9% and 19%. Taxa with S-value 5 remained very low at less than 10%.

The highest percentage frustules with S-value 1, (43%) occurred at Kajulu (K1) in upstream of Kibos and they decreased gradually downstream. In Nyando, frustules with S-value 1 contributed up to 16% at Muhoroni (N1). They showed a decrease at Awasi-Chemelil Bridge (N2), increased at Ogilo Bridge (N3) and reduced again downstream. The percentage frustules with S-value 1 remained low at less than 5% at all stations in Kisat. Frustules of taxa in this class that also occurred in high percentages included *Gomphonema angustum*, *G. gracile*, *Navicula* cf. *heimansioides*, *N. insociabilis*, *Frustulia rhomboides*, *Fragilaria construens* f. *subsalina*, *Nitzschia perminuta* and *Cymbella falaisensis*.

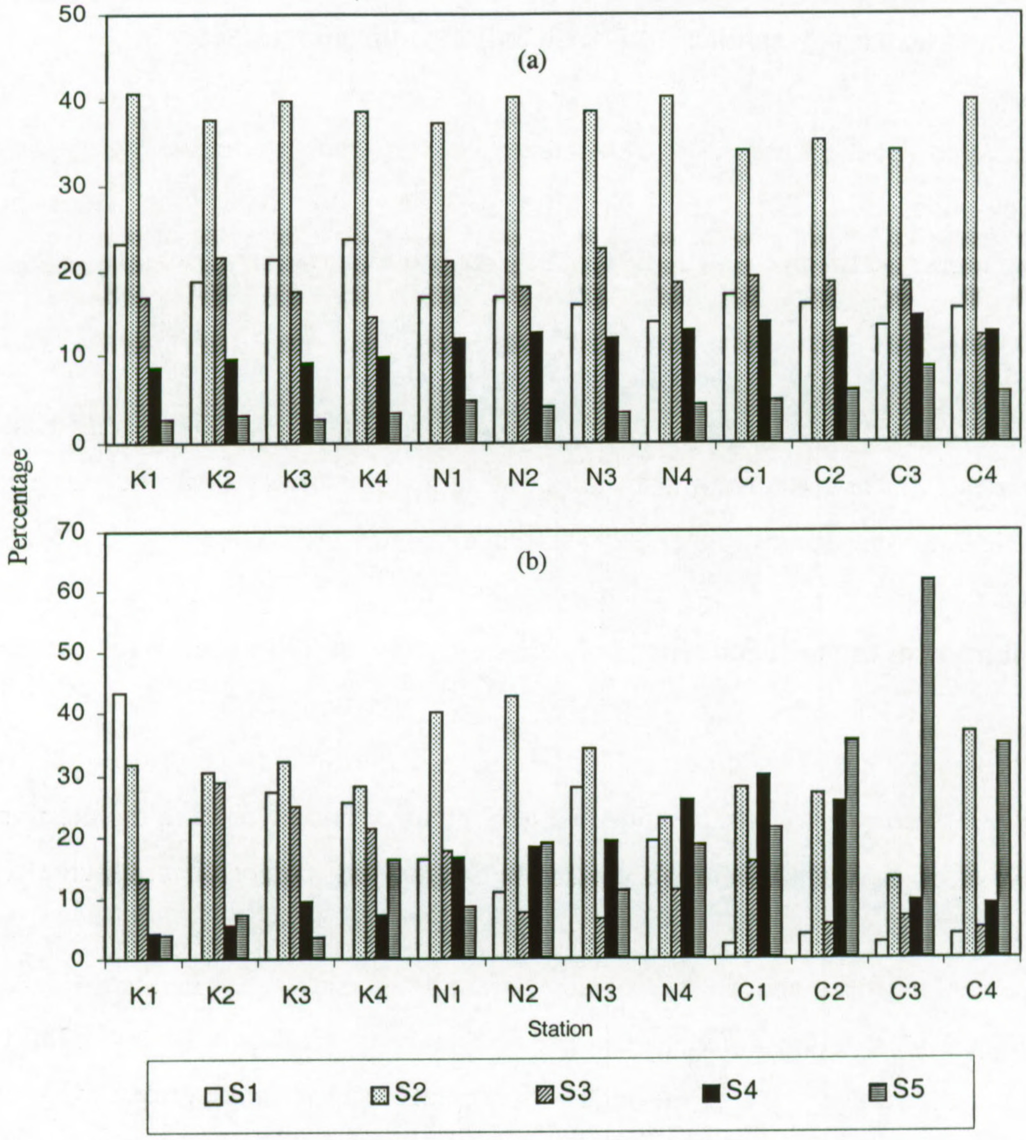

Figure 4.3. Mean (a) taxa and (b) frustule counts in each class of Saprobity indicator values per station (percentage of total sample).

The numbers of frustules with S-value 2 showed little variations in Kibos and ranged between 20% and 32%. The frustules with S-value 2 were higher in upstream of Nyando at Muhoroni (N1) and Awasi-Chemelil Bridge (N2) and they decreased gradually downstream. Similarly, higher percentages were occurred in upstream of Kisat, decreased in midstream and increased sharply downstream at Golf course (C4). Frustules of taxa with S-value 2 that occurred in high percentages include *Navicula schroeteri*, *N. cryptotenella*, *N. contenta*, *Achnanthes exigua*, *Achnanthes* cf. *minutissima*, *Cocconeis placentula* var. *lineata*, *Fragilaria capucina* var. *vaucheriae*, *Amphora montana*, *Aulacoseira granulata*, *Gomphonema olivaceum*, *Surirella angusta*, *Nitzschia sigmoidea*, *N. dissipata*, *N. frustulum* and *N. intermedia*.

Lower percentage frustules with S-value 3, 13%, were observed in upstream of Kibos at Kajulu (K1) and showed a general increase downstream. The distribution of frustules with S3 was irregular in Nyando and in Kisat where they occurred in higher percentages upstream and decreased downstream. Frustules of taxa in this class with higher percentages include *Navicula cryptocephala*, *N. viridula*, *N. mutica*, *N. capitata*, *N. capitatoradiata*, *Nitzschia amphibia*, *Cymbella silesiaca*, *Hantzschia amphioxys* and *Achnanthes* cf. *lanceolata*.

Frustules with S-value 4 occurred in low numbers in Kibos and they showed a gradual increase downstream. Higher percentages of these frustules, up to 26% were observed in Nyando. In Kisat, the highest percentage of frustules with S4, 30%, was recorded at Kenya Breweries (C1) and they decreased downstream. Frustules of taxa with S-value 4 that occurred in high percentages included *Fragilaria ulna*, *Gomphonema parvulum*, *Navicula subminuscula*, *N. goeppertiana*, *N. pupula* and *Cyclotella meneghiniana*.

The percentage frustules of S-value 5 generally increased downstream in all the three rivers and from Kibos, Nyando to Kisat respectively. Although the taxa with S-value 5 were very few they occurred in high abundance especially in Kisat where the highest percentage, 62% was observed at Kudho-kotur (C3). The taxa included *Nitzschia palea* and *Nitzschia umbonata*. Another taxa, *Stephanodiscus rotula*, that is not included in the list of Van Dam *et al.* (1994) occurred in high percentages in lower Kisat and it may prefer the same environmental conditions like the former two taxa.

4.4.11. Distribution of the taxa and frustule counts with Oxygen requirements indicator values

Oxygen requirements indicator (O) values have a scale ranging from 1 to 5 (Table 4.2). The lowest value represents taxa that continuously require high oxygen saturation (about 100%) taxa and the highest value 5, represent taxa that can tolerate very low oxygen saturation.

The highest percentage taxa with O-values at all stations, except at Ogilo bridge (N3) on the Nyando, belonged to O-value 1 contributing up to 35% (Figure 4.4 a, b). The highest percentage frustules in this class occurred in Kibos, with 50% at Kajulu (K1), followed by Nyando and Kisat. The percentages of frustules in this class were generally higher upstream and they reduced downstream in all the three rivers except in Nyando where there was a steep increase from 28% at Muhoroni (N1) to 52% at Ogilo Bridge (N3). Frustules of taxa with O-value 1 that occurred in high percentages included *Gomphonema angustum*, *Achnanthes* cf. *minutissima*, *Amphora montana*, *Navicula schroeteri*, *N. mutica*, *N. heimansioides*, *N. contenta*, *Gomphonema gracile*, *Nitzschia perminuta* and *Fragilaria construens* f. *subsalina*. The steep increase in percentage frustules with O-value 1 at Ogilo Bidge was mainly due to large numbers of *Gomphonema angustum*.

Taxa with O-value 2 contributed between 12% and 21%. Percentages frustules with this class value the second most highest in Kibos contributing up to 25% at Riverside (K2) and they reduced downstream. Frustules with O-value 2 occurred in very low numbers in both Nyando and Kisat. *Hantzschia amphioxys*, *Stauroneis anceps*, *Navicula viridula*, *Gomphonema olivaceum*, *Surirella angusta*, *Caloneis bacillum*, *Nitzschia linearis* and *N. dissipata* are taxa in this class that had high numbers of frustules.

Taxa with O-value 3 had the second highest percentage contributing up to 29%. Percentages of frustules with O-value 3 were very low in Kibos but increased in Nyando contributing 30% at Muhoroni (N1) and 27% at Awasi-Chemelil Bridge (N3). Their percentages were low in Kisat except at Golf Course (C4) where they contributed 24%. Frustules of taxa in this group that occurred in high numbers included *Cocconeis placentula* var. *lineata*, *Navicula cryptocephala*, *N. capitatoradiata*, *Fragilaria ulna*, *Nitzschia amphibia*, *N. sigmoidea*, *Cymbella silesiaca*, *Gyrosigma attenuatum* and *Aulacoseira granulata*.

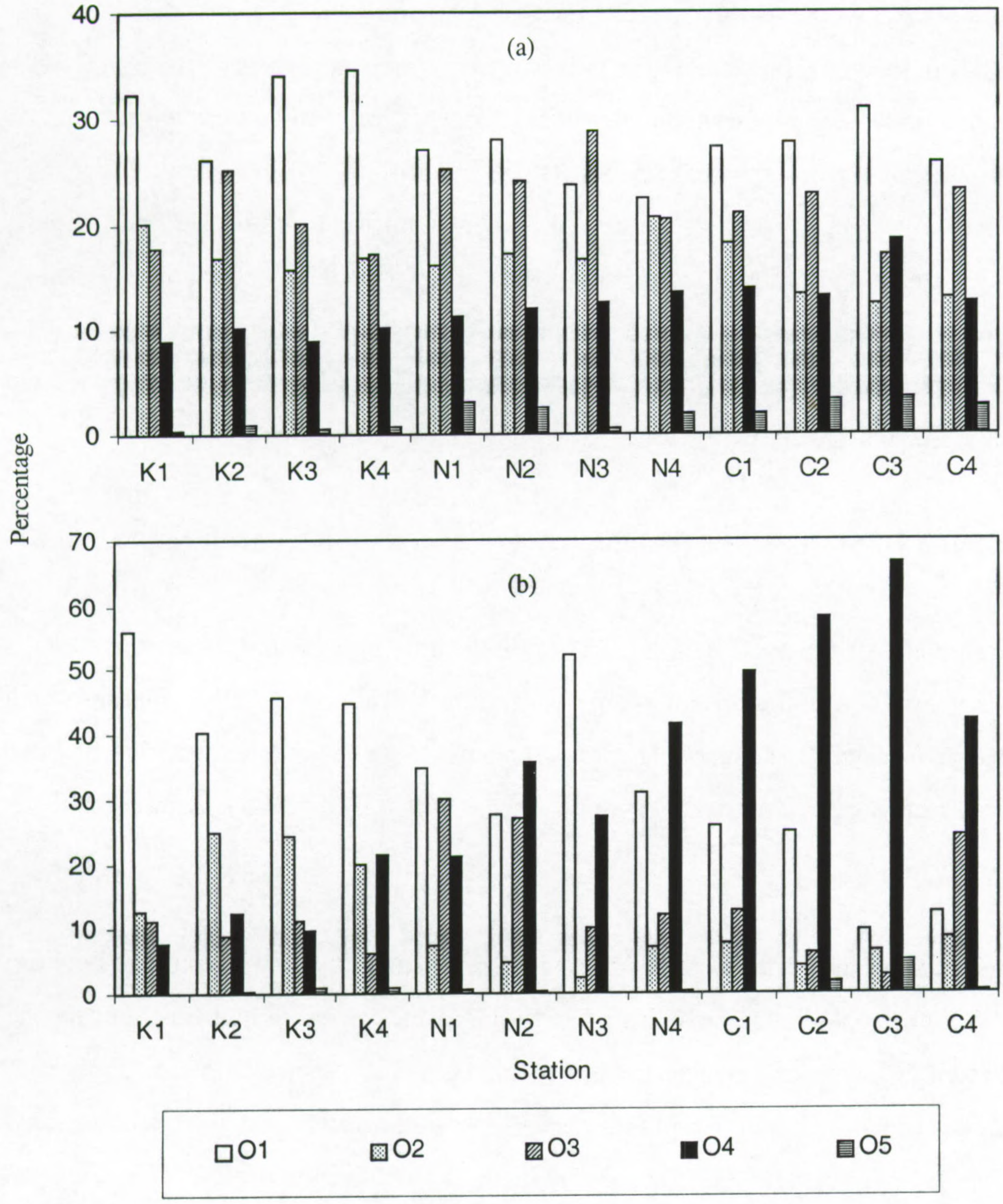

Figure 4.4. Mean (a) taxa and (b) frustule counts in each class of Oxygen requirements indicator values per station (percentage of total sample).

Taxa with class O-value 4 generally increased downstream in all the three rivers. They were lower in Kibos and increased in Nyando and Kisat. In Kisat, class O-value 4 contributed up to 10% at Riverside (K2) and in Nyando up to 14% at Ahero (N4). They occurred with a relatively high percentage, 18%, at Kudho-kotur (C3) in Kisat. The percentages frustules with O-value 4 increased gradually from Kibos to Nyando and to Kisat and from upstream to downstream in all the three rivers respectively. In Kibos, percentage frustules with O-value 4 were low at Kajulu (K1; 8%) and they increased to 21% at Nyamasaria (K4). In Nyando, they increased from 21% at Muhoroni to 42% at Ahero. Whereas, in Kisat frustles with O-value 4 increased from 50% at Kenya Breweries (C1) to 67% at Kodhu-kotur (C3) and then decreased to 42% at Golf course (C4). Frustules in this class that occurred in high percentages included *Nitzschia palea*, *Gomphonema parvulum*, *Navicula* cf. *goeppertiana* and *N. subminuscula*.

The percentage taxa with O-value 5 were very low in Kibos at less than 1% and slightly increased downstream in Nyando and Kisat. Frustules of this class occurred in very low percentages in all the three rivers and their highest, 5%, occurred at Kodhu-kotur (C3) in Kisat. Only two taxa of this class, *Nitzschia umbonata* and *Cyclotella meneghiniana* occurred in appreciable numbers especially in Kisat.

4.4.12. Distribution of the taxa and frustule counts with Trophic state indicator values

The lowest value, 1, for the scale of Trophic state indicators represents oligotraphentic taxa that prefer very low concentrations of inorganic nutrients (Table 4.2). The highest, which should ideally be T-value 6, represents hypereutraphentic taxa that prefer waters with very high enrichments of inorganic nutrients. T-value 7 represents taxa that are indifferent and can occur in all trophic states.

The highest percentage taxa with T-values belonged to T-value 5, which contributed between 33% and 46% (Figure 4.5 a). Similarly, frustules with T-value 5 had the highest abundance at all stations except in lower Kisat where frustules with T-value 6 superseded them (Figure 4.5 b). Frustules of taxa with T-value 5 and that occurred in high percentages included *Navicula schroeteri*, *N. mutica*, *N. viridula*, *N. subminuscula*, *N. goeppertiana*, *Gomphonema parvulum*, *G. olivaceum*, *Cocconeis placentula* var *lineata*, *Amphora montana*, *Achnanthes* cf. *lanceolata*, *Nitzschia sigmoidea*, *N. amphibia*, *N. frustulum*, *N. intermedia*, *Achnanthes lanceolata* and *Aulacoseira granulata*.

The percentage taxa with T-value 6 were low at all stations. However, although the percentage frustules in this class were low in Kibos, they increased in Nyando and became the most abundant downstream in Kisat. Frustules of taxa of T-value 6 that occurred in high percentages included *Nitzschia palea* and *N. umbonata*.

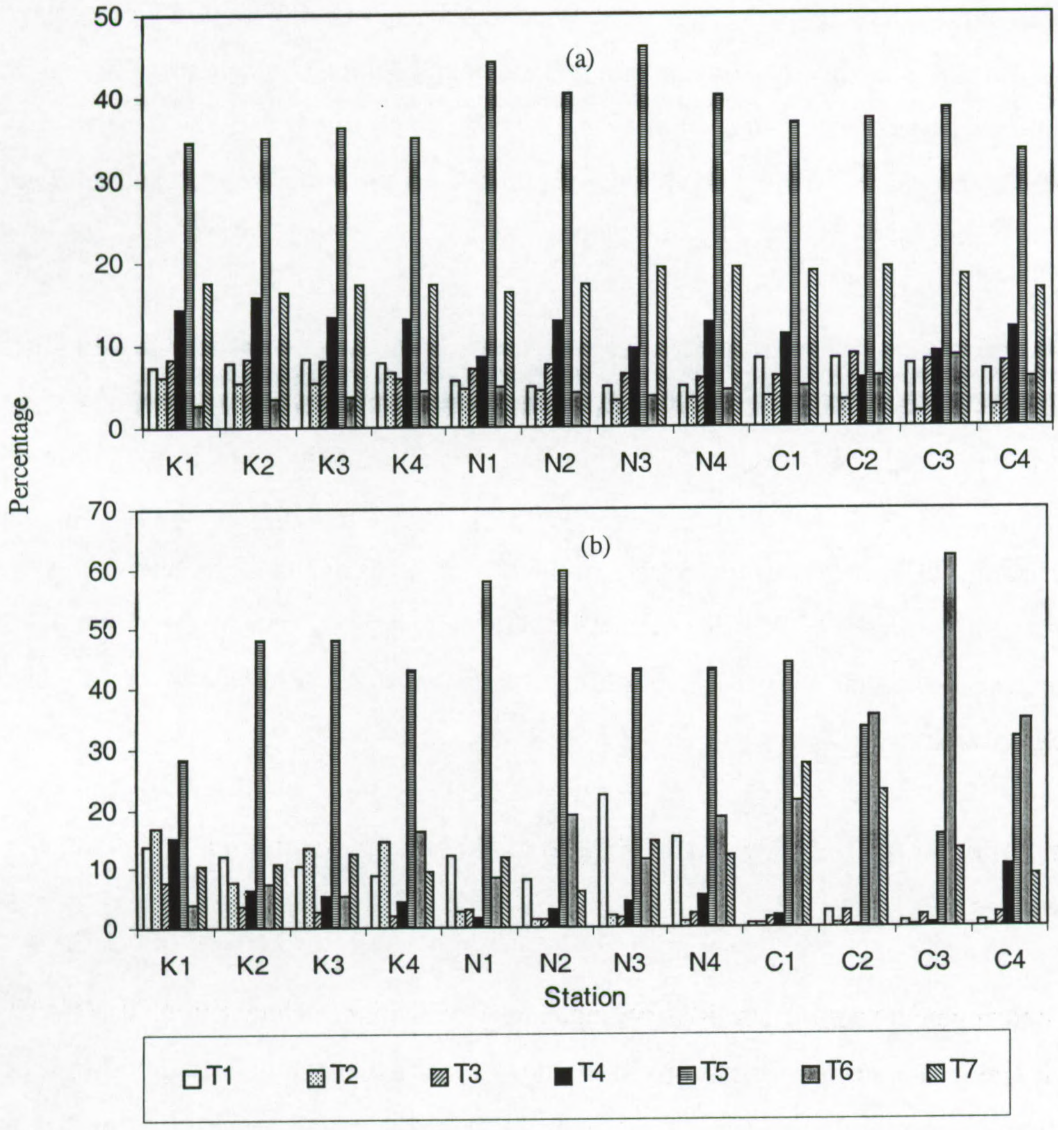

Figure 4.5. Mean (a) taxa and (b) frustule counts in each class of Trophic state indicator value per station (percentage of total sample).

Taxa with T-value 7 had the second highest percentages at all stations after those with T-value 5, contributing up to 19%. The percentages frustules in this class remained low in Kibos and Nyando (up to 14%). They occurred in high percentages, 27%, at Kenya Breweries (C1) in Kisat and reduced gradually downstream.. Taxa in this class that occurred with high numbers of frustules included *Achnanthes* cf. *minutissima*, *A. exigua*, *Navicula cryptocephala*, *N. cryptotenella*, *N. contenta*, *Cymbela silesiaca* and *Hantzschia amphioxys*.

Taxa with T-values 1, 2 and 3 occurred in low percentages and with little variations in all the stations. The numbers of frustules of taxa with these values occurred in low percentages in Kisat and were slightly higher in the upstream of Kibos and Nyando. They decreased downstream in both the later two rivers. The most important taxa with high percentage frustules with T-value 1 included *Gomphonema angustum* and *Pinnularia braunii*. Those with T-value 2 included *Navicula* cf. *heimansioides* and *Nitzschia perminuta* and the ones with T-value 3 included *Fragilaria capucina* var. *vaucheriae*, *Gomphonema gracile* and *Eunotia pectinalis*.

Although the percentages of taxa with T-value 4 were distributed in all stations, slightly higher percentage frustules (15%) with this value occurred in upstream of Kibos at Kajulu (K1) and they decreased gradually downstream. They became much lower in Nyando and Kisat. The most important taxa in this class included *Navicula decussis*, *N. pupula*, *N. capitata*, *Nitzschia dissipata*, *Fragilaria construens* f. *subsalina* and *Stauroneis anceps*. Slightly elevated percentages of frustules with T4 at Golf course in Kisata was mainly due to higher percentages of taxa with T-value 4: *Cyclotella ocellata*, *Epithemia adnata* and *Fragilaria construens*.

4.4.13. Distribution of the taxa and frustule counts with Nitrogen uptake metabolism indicator values

The scale for Nitrogen uptake metabolism (N) indicator values ranges from 1 to 4 (Table 4.2). Taxa with N-value 1 nitrogen-autotrophs and they tolerate very low concentrations of organically bound nitrogen, whereas, taxa with N-value 4 are obligatory nitrogen heterotrophs.

The highest percentage taxa with Nitrogen uptake metabolism at all sampling stations belonged to class N-value 2 contributing between 30% and 47% (Figure 4.7 a). Frustules with N-value 2 also occurred in high percentages in all the three rivers (Figure4.7 b), especially in Kibos and upper Nyando. The most abundant taxa with this N-value included *Amphora montana*, *Cocconeis placentula* var *lineata*, *Achnanthes lanceolata*, *A. minutissima*, *Navicula viridula*, *N. mutica*, *N. contenta*, *N. cryptocephala N. pupula*, *Hantzschia amphioxys*, *Fragilaria ulna*, *Nitzschia sigmoidea*, *N. dissipata*, *Cymbella silesiaca*, *Gomphonema olivaceum* and *Aulacoseira granulata*.

Taxa with N-value 1 had the second highest percentages and they occurred at all the sites. The highest percentage frustules with this value were recorded at Kajulu (K1) in the upstream of

Kibos where they contributed 41% and they reduced gradually downstream. In Nyando, lower percentages of frustules with N-value 1 occurred at the upstream Muhoroni (N1) and Awasi-Chemelil Bridge (N2), increased to 28% at Ogilo Bridge (N3) and reduced again downstream. In Kisat, frustules with N-value 1 contributed little, up to 4% in upstream sites in Kisat and were lacking downstream at Golf course (C4). The most important taxa included *Gomphonema angustum*, *Navicula* cf. *heimansioides*, *N. exigua*, *Nitzschia perminuta* and *Gomphonema gracile*.

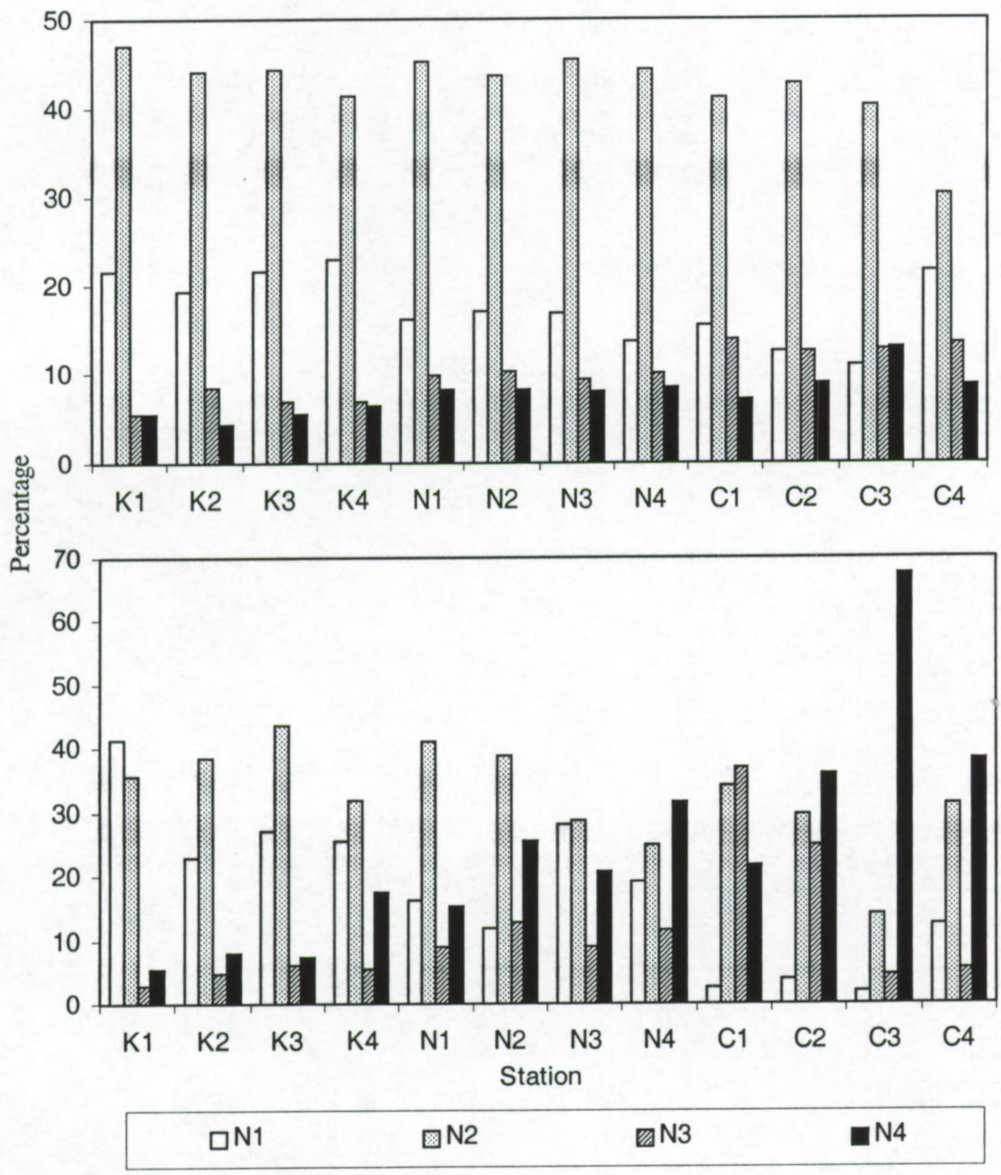

Figure 4. 7. Mean (a) taxa and (b) frustule counts in each class of Nitrogen uptake metabolism indicator value per station (percentage of total sample).

Lower percentages of frustules with N-value 3 occurred in upstream of Kibos and they increased gradually downstream. This pattern also occurred in Nyando although their percentages were higher than in Kibos. The most abundant frustules with N-value 3 included *Gomphonema parvulum*, *Navicula goeppertiana*, and *Nitzschia amphibia*.

Both taxa and frustules with N-value 4 occurred in lower percentages in upstream of Kibos and they increased gradually downstream. Similarly, frustules with N-value 4 increased downstream in Nyando, contributing up to 32% at Ahero (N4). The percentage frustules with N4 were high in Kisat, becoming the highest at Obunga-Mbuta (36%) and they increased steeply to 68% at Kodhu-kotur and 38% at Golf course (C4). The most abundant taxa with N-value 4 included *Nitzschia palea*, *N. umbonata* and *Navicula subminuscula*.

4.4.14. Distribution of the taxa and frustule counts with Moisture indicator values

The scale for Moisture indicator (M) values ranges between 1 and 5 (Table 4.2). The lowest value, 1, represents taxa that always occur in water bodies and the highest value, 5, represents taxa that mainly occur outside water bodies.

M-value 3 had the highest percentage taxa and frustules at all stations in the three rivers (Figure 4.8 a and b). Taxa with this value contributed between 32% to 47% to the total taxa and the frustules between 30% and 84%. The percentages of both taxa and frustules were lower and similar in Kibos and Nyando but higher in Kisat ($p<0.05$). Taxa in this class with high percentage frustules included *Navicula decussis*, *N. subminuscula*, *N. goeppertiana*, *N. schroeteri*, *Nitzschia perminuta*, *N. amphibia*, *N. palea*, *Achnanthes* cf. *minutissima*, *A. exigua* and *Amphora commutata*.

Taxa with M-value 2 had the second highest percentages at most stations (up to 24%). Their percentages were higher in Kibos and Nyando than in Kisat. Frustules of this M-value occurred in low percentages in Kisat where they also generally decreased downstream. Slightly higher percentages of frustules with M-value 2 occurred in Nyando at Muhoroni (N1) and Awasi-chemelil Bridge (N2). Important taxa with this class included *Cocconeis placentula*, *Navicula cryptotenella*, *N. cryptocephala*, *N. pupula*, *Nitzschia sigmoidea*, *Fragilaria ulna* , *Cyclotella meneghiniana* and *Stauroneis anceps*.

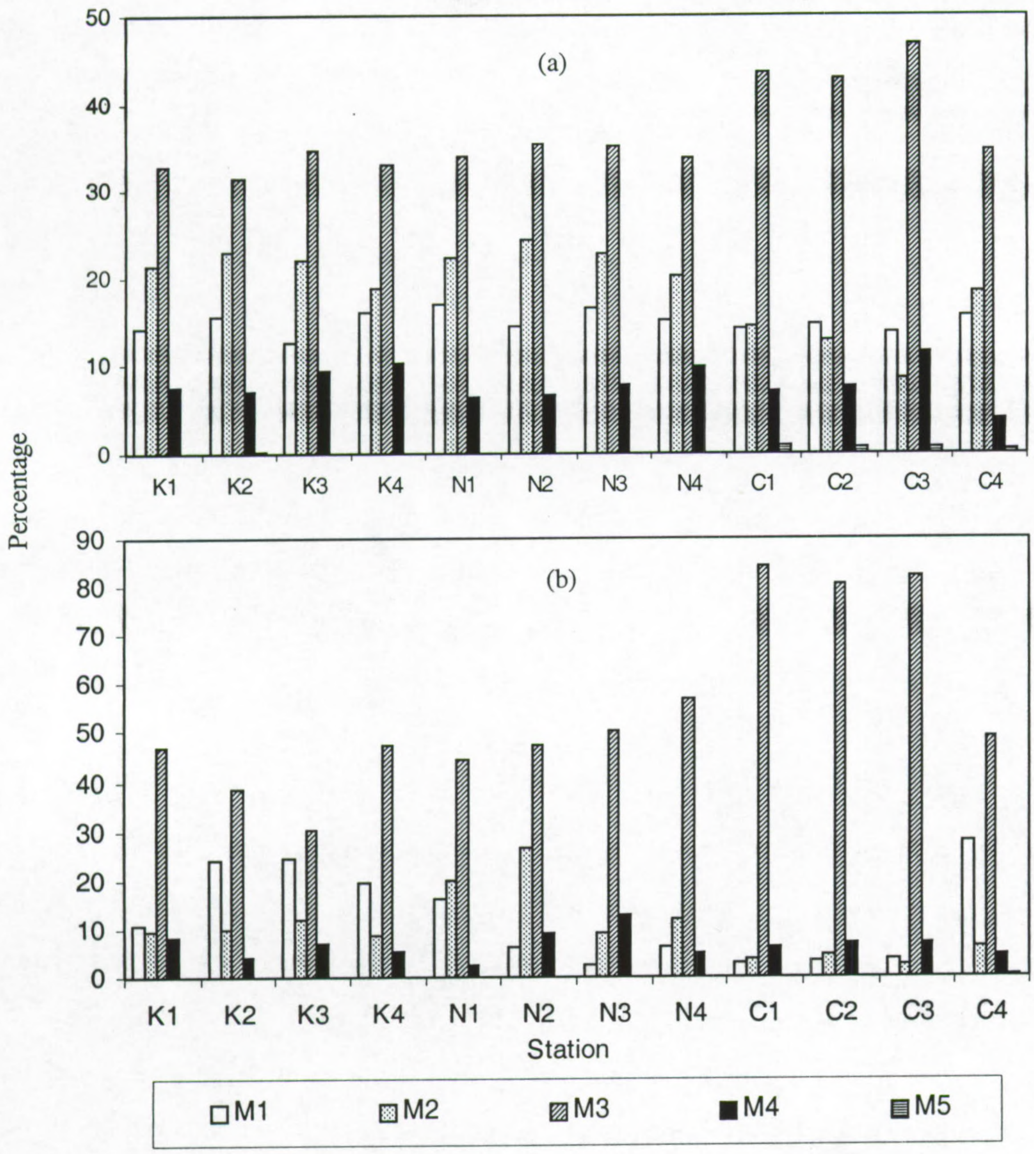

Figure 4.8. Mean (a) taxa and (b) frustule counts in each class of Moisture indicator values per station (percentage of total sample).

Taxa with M-value 1 occurred in low percentages (up to 17%) in all stations. The percentage frustules were also low and the highest 25% occurred in Kibos at Wathorego (K3). M1 taxa were generally higher upstream and decreased downstream in Kibos and Nyando. In Kisat, percentage frustules with M1 were very low except at Golf course (C4) where a maximum percentage of 28% was observed. The most important taxa in this class included *Navicula viridula*, *N. capitatoradiata*, *Aulacoseira granulata*, *Gomphonema olivaceum*, *Cymbella silesiaca*, *Gyrosigma attenuatum* and *Fragilaria construens* f. *subsalina*. A high percentage occurrence of frustules with M-value 1 at Golf course was due partly to large numbers of *Aulacoseira granulata*.

Taxa with M-value 4 occurred in low percentages (up to 11%) in all stations. The percentage frustules with this M-value were also low. *Amphora montana*, *Hantzschia amphioxys*, *Navicula mutica*, *N. insociabilis*, *N. contenta* and *Caloneis molaris* were the most important taxa with M-value 4. Percentage of both taxa and frustules with M-value 5 were negligible at all stations and they were represented by *Cymbella alpina*, *Pinnularia lata* and *Navicula gallica*.

4.4.15. Distribution of the taxa and frustule counts with pH indicator values

pH indicator (R) indicator values have a scale ranging from 1 to 6 (Table 4.2). R-value 1 stands for acidobiontic taxa that have their optimal occurrence at pH of less than 5.5 whereas, R-value 6 represents taxa that have no apparent optimum. pH-value 5 represents alkalibiontic taxa that always occur at pH greater than 7.

R-value 4 had the highest percentage taxa at all the stations in all the three rivers and they ranged between 46% and 61% (Figure 4.9 a and b). The highest percentage, 61%, was recorded at Awasi-Chemelil in Nyando. Similarly, frustules with R-value 4 had the highest percentages at all stations except at Obunga-Mbuta (C2) and downstream of Kisat where frustules with R-values 3 became more abundant. The percentage frustules with R-value 4 tended to decreased downstream in all the three rivers. Taxa of this class that had high percentage frustules especially in Kibos and Nyando included *Gomphonema angustum*, *Navicula decussis*, *Amphora montana*, *Cocconeis placentula* var. *lineata*, *Navicula cryptocephala*, *N. cryptotenella*, *N. subminuscula*, *N. schroeteri*, *N. viridula*, *N. contenta*, *Nitzschia amphibia*, *N. sigmoidea*, *N. perminuta*, *Fragilaria ulna* and *F. construens* f. *subsalina*. In Kisat, R-value 4 was represented mainly by *Nitzschia clausii* and *Aulacoseira granulata*.

Taxa with R-value 3 had the second highest percentage at most stations after the ones with R4. Frustules with R-value 3 superseded the ones of R4 in lower Kisat. Frustules with R-value 3 and that occurred in high percentages included *Achnanthes* cf. *minutissima*, *Fragilaria capucina* var. *vaucheriae*, *Hantzschia amphioxys*, *Navicula mutica*, *N. cryptocephala*, *N. pupula*, *Gomphonema parvulum*, *G. gracile*, *Nitzschia palea*, *N. intermedia* and *N. umbonata*. Others are *Stauroneis anceps*, *Cymbella silesiaca* and *Caloneis molaris*.

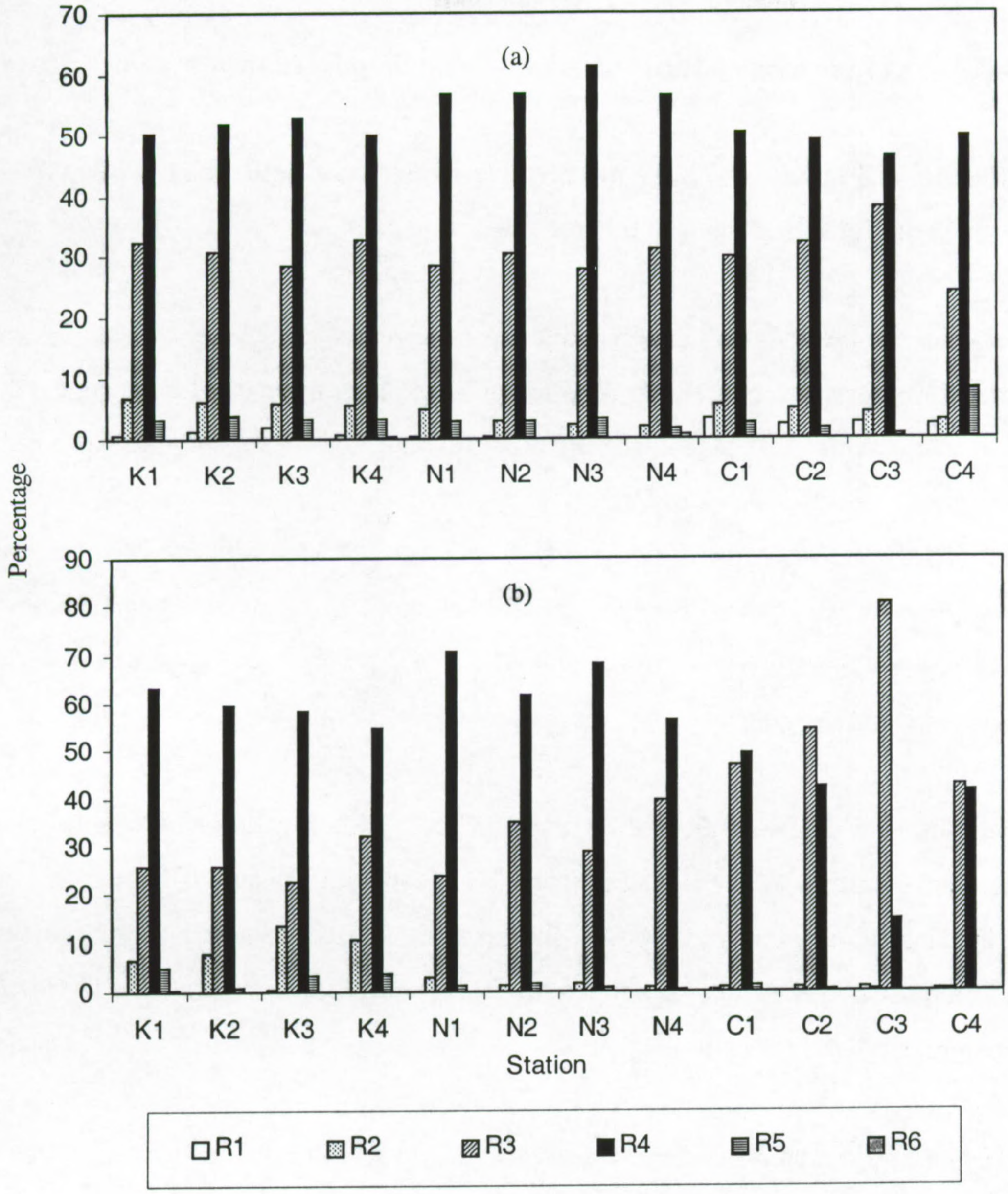

Figure 4.9. Mean (a) taxa and (b) frustule counts in each class of pH indicator values per station (percentage of total sample).

Taxa with R-value 2 occurred at very low percentages at all stations and the highest 7% was recorded at Kajulu in Kibos. The frustules of R2 also occurred in low percentages in all the three rivers and the highest 13% was recorded at Wathorego (K3) in Kibos. The most important taxa with this value included *Navicula* cf. *heimansioides*, *Frustulia rhomboides* and *Eunotia pectinalis*. Taxa and frustules with R-value 1 and R-value 5 occurred in very low percentages at all stations whereas taxa with R6 were negligible.

4.4.16. Distribution of the taxa and frustule counts with Salinity indicator values

The lowest Salinity (H) indicator value 1 has taxa that prefer very fresh water, while class 4, the highest value represents taxa that can tolerate brackish water (Table 4.2).

The highest percentage taxa and frustules belonged to S-value 2 at all the stations contributing up to 78% and 92% respectively (Figures 4.10 a and b). A large number of taxa occurred in this class and those with high percentage frustules included *Gomphonema angustum*, *G. parvulum*, *G. olivaceum*, *Navicula decussis*, *N. cryptocephala*, *N. cryptotenella*, *N. viridula*, *N. contenta*, *N. viridula*, *N. goeppertiana*, *N. subminuscula*, *Cocconeis placentula* var *lineata*, *Fragilaria capucina* var *vaucheriae*, *F. ulna*, *Achnanthes* cf. *minutissima*, *A. exigua*, *Amphora Montana*, *Hantzschia amphioxys*, *Caloneis bacillum*, *Nitzschia palea*, *N. amphibia*, *N. sigmoidea*, *N. perminuta*, *N. intermedia*, *N. dissipata* and *Gyrosigma attenuatum*.

Taxa and frustules with other H-values (1, 3 and 4) occurred in very low percentages at all stations. Taxa and frustules with H-value 3 contributed up to 10% and 18% respectively. Slightly elevated percentage frustules of this class occurred in Kibos and Nyando and was mostly made represented by taxa such as *Navicula schroeteri*, *N. mutica*, *Cyclotella meneghiniana* and *Nitzschia frustulum*.

Taxa with H1 had low percentages of up to 17% with slightly higher percentages of frustules in Kibos. The most important taxa included *Navicula* cf. *heimansioides*, *Cyclotella ocellata*, *Navicula insociabilis*, *Eunotia pectinalis*, *Cymbella falaisensis* and *Pinnularia braunii*. Taxa and frustules with H-value 4 were present in very low percentages at most stations.

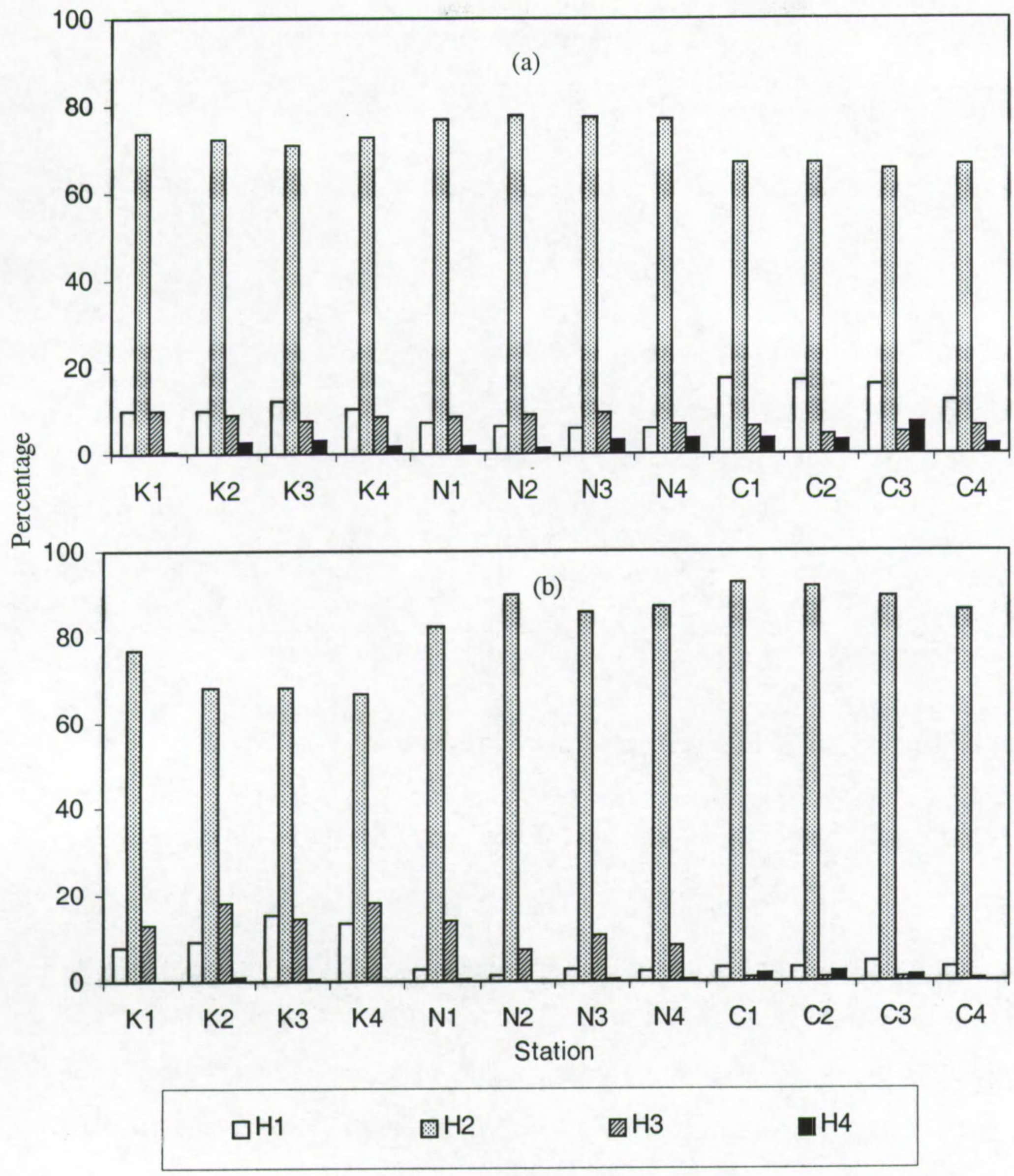

Figure 4.10. Mean (a) taxa and (b) frustule counts in each class of Salinity indicator values per station (percentage of total sample).

4.4.17. Distribution of the diatom indicator values

Table 4.5 summarises the mean value and standard deviation of the 7 diatom ecological indicator values calculated for the sampling stations on the three rivers. Figure 4.11 shows the distribution of the indicator values among the stations.

Table 4.5. Mean (M) and standard deviation (SD) of the seven diatom indicator values in the sampling stations.

Station	Saprobity		Oxgen requirement		Trophic State		Nitrogen uptake		Moisture		pH		Salinity	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
K1	1.5	0.3	1.7	0.4	3.9	1.1	1.7	0.4	2.7	0.4	3.6	0.2	2.1	0.1
K2	1.8	0.3	1.9	0.2	4.4	0.4	2.0	0.2	2.3	0.5	3.6	0.2	2.1	0.2
K3	1.8	0.5	1.9	0.5	4.4	0.7	1.9	0.3	2.3	0.5	3.5	0.4	2.0	0.3
K4	2.0	0.4	2.1	0.4	4.5	0.6	2.2	0.4	2.5	0.3	3.5	0.4	2.0	0.2
N1	2.3	0.4	2.4	0.3	4.7	0.4	2.3	0.3	2.4	0.3	3.7	0.1	2.1	0.1
N2	2.7	0.6	2.8	0.6	4.9	0.5	2.6	0.5	2.7	0.4	3.6	0.3	2.1	0.1
N3	2.0	0.4	2.1	0.5	4.4	1.0	2.2	0.3	3.0	0.2	3.7	0.2	2.1	0.1
N4	2.6	0.6	2.7	0.6	4.7	0.7	2.6	0.5	2.8	0.2	3.6	0.2	2.1	0.1
C1	2.9	0.5	2.9	0.5	5.7	0.3	2.8	0.4	3.0	0.1	3.5	0.2	2.0	0.0
C2	3.0	0.6	3.1	0.5	5.6	0.2	3.0	0.4	3.0	0.2	3.4	0.3	2.0	0.1
C3	3.4	0.6	3.5	0.5	5.8	0.1	3.5	0.4	3.0	0.2	3.1	0.2	2.0	0.0
C4	3.0	0.6	3.1	0.6	5.3	0.4	2.8	0.8	2.3	0.6	3.6	0.3	2.0	0.0

Saprobity (S) indicator values were generally lower in Kibos than in Nyando, while Kisat had the highest values. S-values increased downstream in each river. However, in Nyando, this general trend was interrupted at Ogilo Bridge (N3) where a mean S-value of 2.0 was recorded, which is a decrease from the 2.7 recorded at Awasi-Chemelil Bridge (N2) upstream. S-values increased again downstream to a mean of 2.6 at Ahero (N4). Similarly, S-values increased downstream to a maximum mean of 3.4 at Kodhu-kotur (C3) and then decreased to a mean value of 3.0 at Golf course. Overall, the lowest mean S-value was 1.5 recorded at Kajulu on Kibos. Absolute S-values ranged from 1.1 to 2.4 in Kibos, 1.5 to 3.4 in Nyando and 2.2 to 4.1 in Kisat.

Oxygen metabolism indicator (O) values followed similar trends to the ones of Saprobity. Lower O-values were recorded in Kibos, they increased in Nyando and Kisat (Figure 4.11). As for Saprobity, the general increase of O-values downstream was interrupted by lower values at Ogilo Bridge (N3) on the Nyando and at Golf course (C4) on the Kisat. The lowest mean O-value, 1.7, was recorded at Kajulu (K1) on Kibos and the highest 3.5 were recorded at Kodhu-kotur on the Kisat. Absolute values varied from 1.1 to 2.8 in Kibos, 1.6 to 3.4 in Nyando and 2.2 to 4.3 in Kisat.

Trophic state (T) indicator values showed a slight general increase from Kibos to Nyando to Kisat (Figure 4.11). The T-values varied little in Kibos, tended to increase slightly

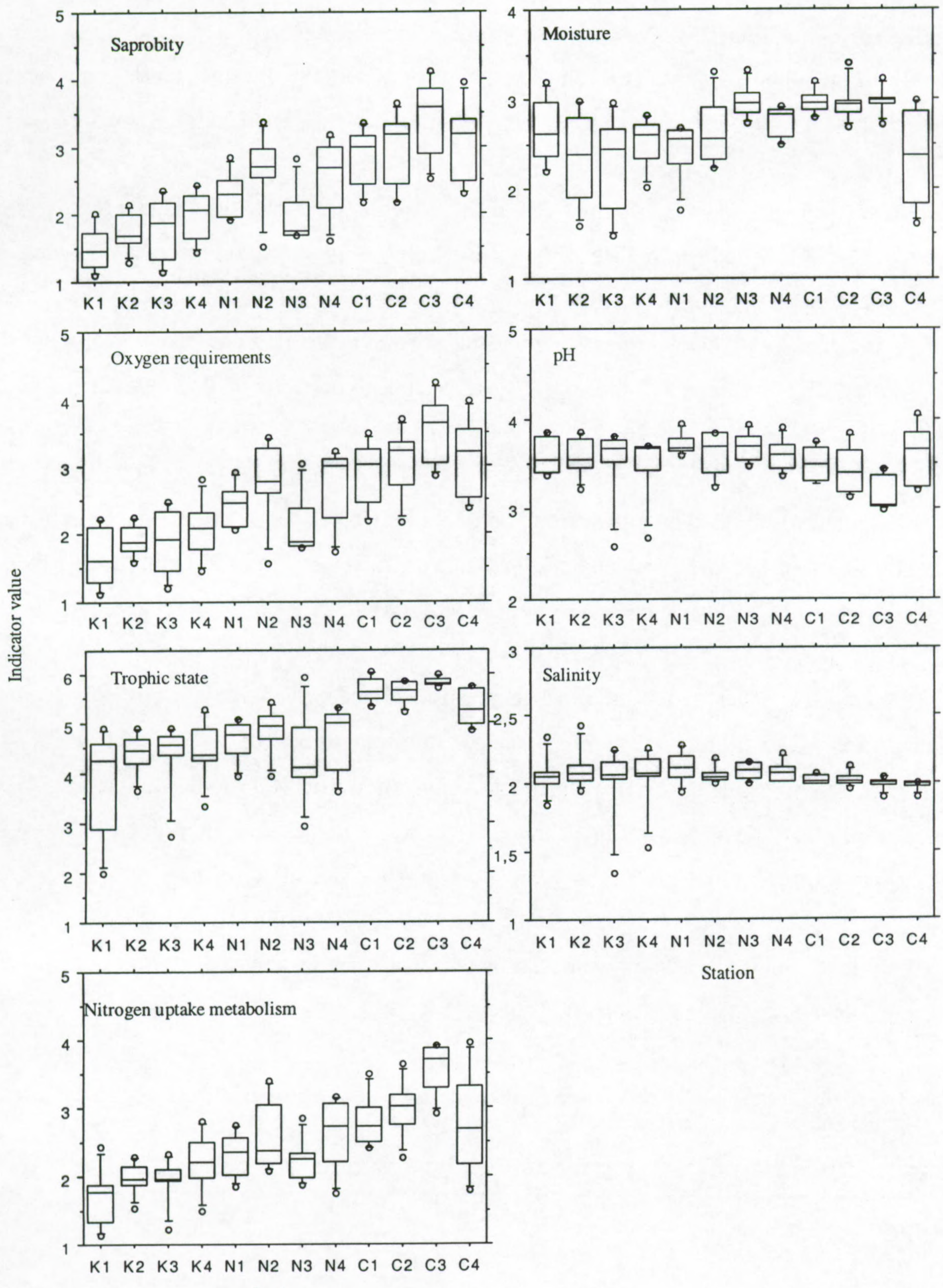

Figure 4.11. Medians, quartiles, 10th and 90th percentiles and outlier values of diatom ecological indicator values at the sampling stations

downstream in Nyando and Kisat, and with less pronounced interruptions at Ogilo Bridge (N3) and Kodhu-kotur (C3). The lowest mean T-value was 3.9 recorded at Kajulu (K1) on Kibos and the highest 5.8 was at Kodhu-kotur (C4) on Kisat. The T-values ranged between 2 and 5.3 on Kibos, between 2.9 and 5.7 on Nyando and between 4.9 and 6.1 on Kisat.

Lower Nitrogen uptake metabolism (N) indicator values were observed in Kibos than in Nyando, and Kisat had the highest (Figure 4.11). N-values showed a generally increased downstream in Kibos. Slight variations of N-values occurred in Nyando while in Kisat, the general increase of N-values downstream was interrupted by a sharp decrease at Golf course (C4). Kajulu (K1) on Kisat recorded the lowest mean N-value, 1.7 and Kodhu-kotur (C3) on Kisat the highest (3.5).

Moisture indicator (M) values varied from 1.5 to 3.2 in Kibos, from 1.8 to 3.3 in Nyando and from 1.6 to 3.4 in Kisat. The highest mean M-value, 3.4, was recorded at Ogilo Bridge (N3) on the Nyando and the lowest mean M-value 3.0 was at Golf course (C4) on the Kisat.

pH (R) indicator values varied little in Kibos and in Nyando where they varied from 2.6 to 2.9 and from 3.2 to 4.0 respectively. In Kisat, R-values ranged between 3.0 and 4.1, and they showed a slight decrease from the upstream Kenya Breweries (C1) to Kodhu-kotur (C3). There were also little variations in Salinity (H) indicator values in all the three rivers. H-values varied from 1.3 to 2.4 in Kibos, 1.9 to 2.3 in Nyando and 1.9 to 2.1 in Kisat.

The diatom ecological indicator values showed significant differences between the three rivers (Table 4.6) and within each river (Table 4.7).

Table 4.6. Analysis of variance (ANOVA) for the diatom indicator values in rivers Kibos, Nyando and Kisat. (significant differences are shown as ANOVA $*p<0.05$; $**p<0.01$; $***p<0.001$).

Indicator value	Kibos vs Nyando	Kibos vs Kisat	Nyando vs Kisat
Saprobity	***	***	***
Oxygen requirements	***	***	***
Trophic state		***	***
Nitrogen uptake metabolism	***	***	***
Moisture	*	**	
pH			***
Salinity			***

Table 4.7. Analysis of variance (ANOVA) for the diatom indicator values in the stations in rivers Kibos, Nyando and Kisat. (significant differences shown as ANOVA $*p<0.05$; $**p<0.01$).

Kibos	K2	K3	K4
K1			Saprobity*
K2			
K3			
Nyando	N2	N3	N4
N1		Moisture**	Moisture*
N2		Saprobity**	
N3			Moisture*
Kisat	C2	C3	C4
C1		Nitrogen uptake* Oxygen requirement* pH**	Moisture* Salinity*
C2		Nitrogen uptake*	Moisture*
C3			Trophic state** Nitrogen uptake* pH*

Temporal significant differences were found for Trophic state ($p<0.001$); Oxygen requirements and moisture ($p<0.01$) and for Saprobity and Nitrogen uptake metabolism ($p<0.05$) but not for pH and alkalinity. Significant variations due to the river were observed for all the indicator values: $p<0.001$ for Saprobity, Trophic state, Nitrogen uptake metabolism and Oxygen requirements; $p<0.01$ for pH and Moisture and $p<0.05$ for salinity.

4.4.18. Interrelationships between diatom indicator values

Various levels of relationships were observed between the diatom indicator values (Table 4.8). The strongest correlation occurred between Saprobity and Oxygen requirements indicator values ($r=0.98$; $p<0.001$). Saprobity was also highly correlated with Nitrogen uptake metabolism and Trophic state indicator values. High correlations were also observed between Oxygen requirements and Nitrogen uptake metabolism and between Oxygen requirements and Trophic state indicator values. Significant negative correlations occurred between some indicator values, for example between Saprobity and pH and between Saprobity and Salinity.

Table 4.8. Correlation analysis (Spearman's rank correlation coefficient) between diatom indicator values. (significant correlations are shown as $^{**}p<0.01$; $^{***}p<0.001$).

	Saprobity	Oxygen requirements	Trophic state	Nitrogen uptake	Moisture	pH	Salinity
Saprobity	1						
Oxygen requirements	0.98***	1					
Trophic state	0.73***	0.74***	1				
Nitrogen uptake	0.89***	0.90***	0.82***	1			
Moisture	0.14	0.13	0.37***	0.37***	1		
pH	- 0.42***	- 0.44***	-0.47***	- 0.55***	-0.32**	1	
Salinity	- 0.42***	- 0.40***	- 0.28	-0.28**	-0.03	0.46***	1

4.4.19. Relationships between diatom indicator values and environmental variables

Significant correlations were observed between the diatom indicator values and various environmental variables (Table 4.9). Saprobity, Oxygen requirements, Trophic state and Nitrogen uptake metabolism indicator values were the most correlated with the environmental variables. Saprobity was strongly correlated with BOD, TDS, conductivity, temperature, hardness, alkalinity and ammonia negatively with current velocity and altitude. Oxygen requirements indicator values were highly correlated with BOD, TDS, conductivity, temperature and hardness, and negatively with velocity and altitude.

High correlations were observed between Trophic state indicator values and TDS, conductivity, BOD, temperature and hardness and negatively with current velocity, volume of discharge, altitude and width. Whereas, Nitrogen uptake metabolism indicator values were highly correlated with BOD, conductivity, TDS, hardness, temperature, velocity and altitude. Moisture indicator values showed low but significant relationships with hardness and conductivity and negatively with altitude and pH. Salinity and pH indicator values also showed low but significant correlations with mainly physical variables including altitude, width, depth, current velocity, volume of discharge and temperature.

4.4.20. Pollution sensitivity index

200 taxa or 89% of all taxa identified in this study had known pollution sensitivity values and were used in the calculation of the pollution sensitivity index (IPS). None of the rivers or

stations sampled had non-polluted waters (Table 4.10). The quality classes resulting from the IPS index are shown on the map in Figure 4.12.

Table 4.9. Correlation analysis (Spearman's rank correlation coefficient) between diatom indicator values and environmental variables (significant correlations are shown as **p*<0.5; ***p*<0.01; ****p*<0.001).

Variable	Saprobity	Oxygen	Trophic state	Nitrogen uptake	Moisture	pH (R)	Salinity
Altitude	-0.52***	-0.50***	-0.56***	-0.51***	-0.25*	0.32**	0.39***
Width	-0.36***	-0.36***	-0.50***	-0.35**	0.19	0.33**	0.47***
Depth	-0.34**	-0.33**	-0.36***	-0.28*	-0.06	0.27*	0.46***
Velocity	-0.58***	-0.59***	-0.62***	-0.55	-0.07	0.37***	0.44***
Discharge	-0.48***	-0.49***	-0.57***	-0.45***	-0.12	0.36***	0.53***
Temperature	0.62***	0.64***	0.53***	0.60***	0.13	-0.25*	-0.42***
Dissolved oxygen	-0.43***	-0.42***	-0.29**	-0.31**	-0.04	0.14	0.36***
BOD_5	0.89***	0.82***	0.63*	0.89***	0.46	-0.20	-0.50
pH	-0.22*	-0.19	-0.32**	-0.21	-0.24*	0.07	0.12
Hardness	0.67***	0.64***	0.51***	0.59***	0.31**	-0.13	-0.35***
Alkalinity	0.59***	0.56***	0.37***	0.49***	0.20	-0.08	-0.33**
Conductivity	0.79***	0.77***	0.68***	0.70***	0.27*	-0.23*	-0.49***
TDS	0.80**	0.78**	0.78**	0.62*	0.33	0.07	0.03
Turbidity NTU	-0.09	-0.09	-0.09	-0.10	0.05	0.15	0.26*
TSS	0.16	0.17	0.13	0.17	0.16	0.06	0.08
Nitrate-N	-0.23*	-0.31**	-0.17	-0.22*	-0.001	0.16	0.10
Ammonia-N	0.50***	0.49***	0.30*	0.37**	-0.09	-0.24	-0.43***
Phosphate-P	0.43***	0.44***	0.26*	-0.33**	-0.11	-0.16	-0.32**
Silicate	-0.24*	-0.27*	-0.20	-0.26*	0.14	0.16	0.06

Table 4.10. Water quality classes of rivers Kibos (K1-K4), Nyando (N1-N4) and Kisat (C1-C4), derived based on pollution sensitivity index (IPS) values

Station	IPS	Quality class (Q)
K1	3.54	13
K2	2.90	10
K3	3.19	11
K4	2.65	9
N1	2.92	10
N2	2.25	7
N3	2.70	9
N4	2.36	7
C1	2.21	7
C2	2.03	6
C3	1.35	3
C4	1.85	5

($Q \geq 17$ = non polluted, Q = 16 to 13 = weakly polluted, Q = 12 to 9 = moderately polluted, Q = 8 to 5 = heavily polluted and $Q \leq 4$ = very heavily polluted).

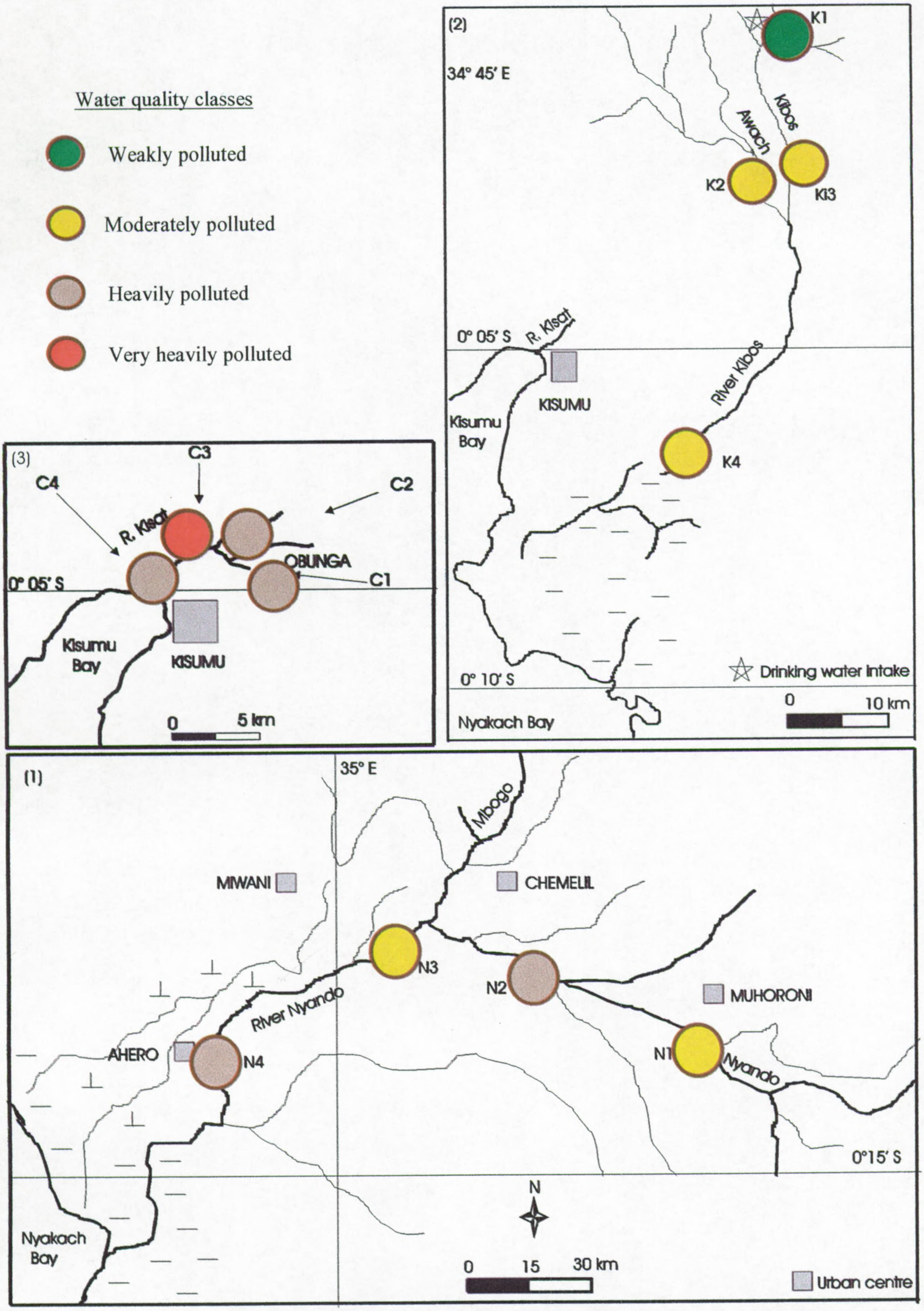

Figure 4.12. Map showing water quality classes based on diatom pollution sensitivity index at sampling stations on rivers (1) Nyando: N1-N4, (2) Kibos: K1-K4 and (3) Kisat: C1-C4.

Overall, the least polluted waters among the three rivers were observed on River Kibos and the "cleanest water" which is weakly polluted, occurred upstream at Kajulu (K1). The other three stations of Kibos had moderately polluted water and the quality tended to decrease downstream. Moderately polluted waters were also observed in the upstream of Nyando at Muhoroni (N1) but declined to heavy pollution at Awasi-Chemelil Bridge (N2). The water quality improved to moderate pollution at Ogilo Bridge (N3) and declined again to heavy pollution at Ahero (N4). Kisat was heavily polluted right from the upstream stations at Kenya Breweries (C1) and Obunga-mbuta (C2) and became very heavily polluted at Kodhu-kotur (C3). There was a slight improvement in water quality downstream at Golf course but the waters were still heavily polluted.

4.5. DISCUSSION

Most of the diatom taxa recorded in rivers Kibos, Nyando and Kisat are of cosmopolitan distribution. This is indicated by the high percentages of both taxa and frustules (Figures 4.2a-c) with ecological indicator values also appearing in the checklist of Van Dam *et al*. (1994). Consistently high percentage of taxa with the ecological indicator values were recorded suggesting that the diatom-based indicator methods can be applied in all the rivers at all times. Fluctuations in abundance and composition of the assemblages are probably a reflection of prevailing environmental conditions in the different regimes of each river. However, all the indicator values showed more or less stable patterns across the seasons. Significant correlations were observed between the diatom indicator values examined in this study and between the indicator values and the environmental variables that are among the ones routinely used for water quality monitoring in the Lake Victoria basin.

The different levels of Saprobity were recognised by typical diatom communities. The diatom community of River Kibos was dominated by oligosaprobous and β-mesosaprobous taxa suggesting that the river has little organic pollution and has high levels of oxygen saturation especially upstream. The water quality in Kibos can be considered as class I-II according to the classification of Van Dam *et al* (1994).

Nyando was dominated by β-mesosaprobous and α-mesosaprobous taxa, indicating water quality of class II-III. These taxa can tolerate increasing levels of organic pollution and reducing levels of oxygen saturation. Nyando is draining a large area and is already facing organic pollution in our upstream station at Muhoroni (N1). The organic pollution seems to increase downstream at Awasi-Chemelil Bridge (N2) probably due to additional discharges of effluents from the sugar factory and a distillery at Muhoroni. A diluting effect by River Mbogo, a major tributary that joins Nyando before Ogilo Bridge (N3) could encourage the growth of the taxa with lower Saprobity. High Saprobity downstream at Ahero could be due to the additional inputs of organic matter from a high rural population and the rice irrigation scheme.

Kisat fluctuated largely between β-mesosaprobous upstream to α-meso-/polysaprobous, water quality class III-IV. The river was dominated by taxa that are tolerant to heavy organic loads and low oxygen saturation especially downstream.

The environmental data (Table 4.3) shows that Kibos had lower BOD than Nyando whereas Kisat had the highest values among the three rivers. This indicates generally that the levels of organic pollution are lower in Kibos, followed by Nyando, and Kisat had the highest. Organic pollution tended to increase downstream in each river and this pattern was also seen in the data of the Saprobity indicator values. Saprobity indicator values showed strong and significant correlations with BOD_5 (r=0.89, p<0.001) and negatively with dissolved oxygen (r=-0.43, p<0.001). Our results are in agreement with the ones of Lobo *et al*. (1995) who also reports significant relationships between Saprobic index (SI) and BOD in selected rivers in Tokyo, Japan.

Patterns in distribution of taxa with different oxygen requirements closely followed the ones of Saprobity. Kibos was dominated by high oxygen saturation indicators especially upstream. Nyando had a mixture of moderate to low oxygen indicators. The moderate oxygen indicators occurred upstream of Nyando. Kisat had higher abundances of taxa that prefer low oxygen saturation especially downstream. Although oxygen saturation was not measured in this study, the levels of dissolved oxygen were higher in Kibos and Nyando especially upstream, than in Kisat. Oxygen indicator values were significantly correlated with dissolved oxygen (r=-0.42, p<0.001). Such distributions of diatom assemblages reflecting different oxygen saturation levels have been used to distinguish oxygen rich waters that were also poor in nitrogenous compounds in rivers in South Africa (Schoeman, 1976).

The data from analysis of diatoms shows that the three rivers have substantial concentrations of inorganic nutrients and that Kibos has moderate levels, Nyando has elevated levels, while Kisat has higher concentrations. On average, Kibos was meso-eutraphentic (Trophic state value 3) although it varied from oligo-mesotraphentic (T-value 2) upstream to eutraphentic (T-value 5) downstream at Nyamasaria (K4). Nyando tended towards eutraphentic although a lowering to meso-eutraphentic diatom assemblage occurred at Ogilo Bridge (N3) due to presence of high abundance of meso-eutraphentic taxa. Kisat was eutraphentic upstream and increasingly became hypereutraphentic downstream.

Higher trophic levels in Nyando and Kisat are confirmed by higher concentrations of phosphate-phosphorus and nitrate-nitrogen and ammonia than in Kibos (Table 4.3) whereas concentrations of silicates are almost similar in the three rivers. Dissolved ions (conductivity) are also higher in Nyando and Kisat than in Kibos. Trophic state indicator values were highly correlated with biochemical oxygen demand and ionic content. Trophic state indicator values also showed low but significant correlations with phosphate (r=0.26, p<0.05) and ammonia (r= 0.30, p<0.05) but not with nitrate-nitrogen suggesting that the latter is subject to more fluctuations.

Although strong correlations usually occur between trophic indices and inorganic nutrients, the concentration of these nutrients especially phosphorus, may be correlated with other variables associated with organic pollution (Kelly & Whitton, 1995, 1998). To overcome this, indices specialised for monitoring nutrients separating their effects from organic pollution have been developed. Such indices include the Trophic diatom index (TDI) that has two versions: the TDI-P for phosphorus and TDI-NP for phosphorus and nitrogen (Kelly *et al.*, 1995, 1996).

Strong relationships between Saprobity and Oxygen requirements, Nitrogen uptake metabolism and Trophic state indicator observed in our study are expected as these values are already highly correlated in the list of Van Dam *et al.* (1994). Similarly high correlations are reported for Specific pollution sensitivity index (SPI), Generic diatom index (GDI) and the two versions of the Trophic diatom index (TDI) (Kelly *et al.*, 1995). The Saprobity and Oxygen requirements indicator values used in our study may help us to identify pollution due to organic loads whereas, Trophic state indicator values and partly Nitrogen uptake metabolism could reflect inorganic nutrient enrichments. Although these indicator values can be used alone, they can explain better the ecological status in the rivers when used in combination.

Kibos was dominated by nitrogen autotrophic taxa especially upstream. These taxa prefer small concentrations of organically bound nitrogen. The Nyando had increasingly high abundances of facultative nitrogen heterotrophic taxa upstream and obligately nitrogen heterotrophs downstream. Kisat had high percentages of obligately nitrogen heterotrophs especially downstream although also nitrogen autotrophs were present. This suggests that Kibos has low nitrogen concentrations, Nyando has increasingly high levels of nitrogen that are also subject to fluctuations and Kisat has higher enrichments of nitrogen than the former two rivers.

Examination of environmental data (Table 4.3) confirms that Kibos had lower concentrations of both nitrate-nitrogen and ammonia-nitrogen than Nyando. However, in Kisat, the levels of ammonia-nitrogen increased tremendously while nitrate-nitrogen declined especially downstream, because of decomposition processes of nitrogenous compounds by bacteria, also accompanied by lower oxygen levels. Nitrogen uptake metabolism indicator values were significantly correlated with both nitrate-nitrogen (r=-0.22, p<0.05) and ammonia (r=0.37, p<0.01). Schoeman (1976) reported similar observations when comparing less polluted and polluted waters in the Jukskei-crocodile river system in South Africa where the abundance of nitrogen heterotrophic taxa correlated with high concentrations of nitrogenous compounds.

The diatom communities in the three rivers mainly dwell within the river waters although a few occur on regularly wet and moist places. This confirms that the rivers have permanent flow regimes. Higher M values at Ogilo Bridge (N3) on the Nyando could be explained by the confluent upstream with Mbogo, a major tributary. These two tributaries drain different sub-basins and consequently, irregular water discharges and levels may encourage taxa that can grow on exposed wet surfaces. Such taxa grow on rocks and other hard substrates that are semi-submerged in water or are adjacent to riverbanks usually covered by a film of water or in the drawdown area. They may also occur outside the river zone mainly during floods that commonly occur in rainy seasons when seepage of water from exposed soil provide microenvironments on rocks and stones.

Alkaliphilous taxa dominated the diatom communities in Kibos and Nyando although circumneutral taxa also occurred in high percentages. Circumneutral taxa dominated in Kisat especially downstream. This suggests that the waters of Kibos and Nyando are mainly above pH 7 and the ones of Kisat are mainly having a pH of about 7. The analysis of the diatom data is clearly confirmed by the environmental data. On average, Kibos had pH 7.7, Nyando 7.6 and Kisat 7. However, the pH indicator values were not significantly correlated with the measured pH. This may indicate that the effects of pH on diatoms are not very clear and it is likely to be overshadowed by other environmental variables. Moreover, the pH range was rather narrow and the lower pH-values (e.g., pH<7) are generally lacking in this study.

Although chloride concentrations were not measured in this study, the Salinity indicator values from diatom analysis suggests that all the three rivers: Kibos, Nyando and Kisat are mainly freshwater systems. are mainly freshwater systems. The diatom communities were composed mainly of taxa that prefer fresh water (up to the limit of fresh to brackish water). Brackish water taxa were also present but in very low numbers. Salinity may not be a major factor in the distribution of the diatoms and therefore not very relevant in our study of the rivers in Lake Victoria region where salt springs or large-scale uses of salt are lacking. This could be why there were little variations in Salinity indicator values. However, Salinity indicator values were significantly correlated with several environmental variables (Table 4.9). Van Dam *et al.* (1994) compiled the salinity indicator values since they also considered coastal but inland brackish water systems.

There were clear ecological differences between the three rivers (Table 4.6) and between stations in each river (Table 4.7). Kibos was the least polluted river and on average, the "cleanest water" was found at Kajulu (K1) on the Kibos. The waters at this station had low ionic content, low trophy and low saprobity. The environmental variables are used in estimation of these conditions include conductivity (83 $\mu S\ cm^{-1}$), total alkalinity (43 mg l^{-1}), hardness (39 mg l^{-1}); phosphate-phosphorus (82 $\mu g\ l^{-1}$) and ammonia-nitrogen (2.58 mg l^{-1}), and dissolved oxygen (7.7 mg $O_2\ l^{-1}$) and BOD (0.8 mg $O_2\ l^{-1}$), respectively. These relatively clean waters were characterised by low values of Saprobity, Oxygen requirements, Trophic state and Nitrogen uptake metabolism. The associated taxa and that occurred in high percentages included the ones known to prefer "clean waters" such as *Gomphonema angustum*, *Navicula* cf. *heimansioides*, *N. exigua*, *N. schroeteri*, *N. insociabilis*, *Frustulia rhomboides*, *Fragilaria construens* f. *subsalina* and *Nitzschia perminuta*.

Although Kibos especially upstream provides a good reference point for our study with regard to "clean water", the upstream already having some levels of pollution. Kajulu, with the "cleanest water" was classified by the pollution sensitivity index (IPS) as "weekly polluted" while the downstream was classified as moderately polluted.

Nyando tended to have waters with intermediate ecological conditions between the ones of Kibos and Kisat. The upstream of Nyando had moderately polluted waters at Muhoroni (N1). However, the downstream of this river had more or less similar characteristics with upper and middle Kisat and they both showed increasing levels of pollution especially downstream.

In all the rivers, pollutants tended to increase downstream as indicated by increase in the same direction of the ecological indicator values for Saprobity, Oxygen requirements, Trophic state and Nitrogen uptake metabolism and IPS. These trends were also observed in the data on environmental variables (Chapter 3, this study). This is due to gradual enrichment of the water with pollutants as river travels downstream through areas with more influence of human activities. However, this general trend may be altered along the way depending on other factors. For example, great fluctuations in most environmental variables and ecological diatom indicator values were observed at Ogilo Bridge on the Nyando where a large tributary confluent with the main river upstream. Similarly, the IPS showed the river improved from heavily polluted at Awasi-Chemelil Bridge to moderately polluted waters at Ogilo Bridge. This is due to dilution by River Mbogo, a major tributary that joins the Nyando upstream of this station. Our observations agree with the ones of Round (1991 b) who reports similar patterns with fluctuations of physical, chemical and biological parameters downstream of stream confluents in rivers in the United Kingdom and he relates this to dilution effects.

The most polluted waters in our study occurred in downstream of Kisat. The river receives effluents from various activities including domestic sewage from the slums at Obunga, open fish frying activities, effluents from factories and a municipal sewage treatment plant that was non-functional during the whole period of this study. The IPS showed that the most polluted section of the Kisat was at Kodhu-kotur which had "heavily polluted" waters. This station is located immediately below Kisumu industrial area and recorded high conductivity (mean 661 $\mu S\ cm^{-1}$), total alkalinity (255 $mg\ l^{-1}$), hardness (234 $mg\ l^{-1}$); phosphate-phosphorus (204 $\mu g\ l^{-1}$) and ammonia-nitrogen (2.58 $mg\ l^{-1}$), dissolved oxygen (2 $mg\ O_2\ l^{-1}$) and BOD (340 $mg\ O_2\ l^{-1}$).

Higher levels of pollution on the Kisat encourage growth of pollution tolerant diatom taxa resulting in high Saprobity, Oxygen requirements, Trophic state and Nitrogen uptake metabolism indicator values especially in the downstream stations of Kodhu-kotur (C3) and Golf club (C4). The most abundant taxa in this part of the river included *Nitschia palea*, *N. umbonata*, *Gomphonema parvulum* and *Navicula goeppertiana* and *Stephanodiscus rotula*. The latter species (S. *rotula*) is absent in the list of Van Dam *et al.* (1994) and was therefore not included in calculations of diatom indicator values. According to Krammer & Lange-Bertalot (1991), *S. rotula* occurs in brackish or marine waters. The high ionic content (high conductivity and hardness) could be the reason why this species is able to grow in high abundance in lower Kisat.

It is interesting that some of the taxa that we found both in clean and polluted waters are also encountered in similar environments elsewhere. Schoeman (1976) reports high abundances of *Achnanthes minutissima*, *Fragilaria capucina* (var. *vaucheriae* ?) and *Navicula schroeteri* in clean waters with high oxygen and poor nitrogen in the Jukskei-crocodile river system in South Africa, while *Nitzschia palea* occurred in heavily polluted and nitrogen enriched waters. Our data also agrees with most of the ecological descriptions of diatoms in Papua New Guinea (Vyverman, 1991) and other parts of East Africa (Gasse *et al.*, 1983; Gasse, 1986).

4.6 CONCLUSIONS

Rivers Kibos, Nyando and Kisat have consistently high abundances of diatoms, in both space and time, many of them with known ecological indicator values. Although the diatoms occur throughout the rivers, their proportions reflect changes in the water quality. The diatom data indicate that Kisat is the most polluted among the three rivers; Nyando has intermediate pollution levels while Kibos is close to reference but is influenced downstream. The significant correlations between the diatom indicator values and between the diatom indicator values and environmental variables confirm that the diatom assemblages can be employed successfully in assessing water quality of the three rivers in this study.

The results provide baseline information and reliable methods to use diatom indicator values to asses possible future changes and for management purposes. Future assessments to monitor water quality using diatoms should also test other diatom indices, be extended upstream, to sites with relatively low pollution and with less human interference. This would lead to further refinements and improve the knowledge on ecological responses of the diatom taxa. **This work should be extended to other rivers of the Lake Victoria catchments or similar rivers in the east African region. Further, the use of other diatom-based indices should be tested.**

Chapter 5

Diatom assemblages and their relationship to environmental variables in rivers Nyando, Kibos and Kisat of Lake Victoria catchments, Kenya

5.1. ABSTRACT

Spatial and temporal distribution patterns of epilithic diatoms and their relationship to environmental variables were investigated in rivers Nyando, Kibos and Kisat draining into Lake Victoria. Samples were collected from 12 sampling stations, 4 on each river on 7 occasions between May 1998 and March 2001. A total 224 diatom taxa were collected and 19 environmental variables measured. Data were processed by multivariate analysis. Cluster analysis by Two-Way INdicator SPecies Analysis (TWINSPAN) revealed two major species groups. The first group comprises samples of "clean water" rivers Nyando and Kibos together, with *Navicula exigua, N. schroeteri* and *Gyrosigma scalproides* as indicator species. The second group is composed of samples from the more polluted Kisat. Further separations resulted in 14 final groups reflecting water types irrespective of the position of sampling station. Ordination by Canonical Correspondence Analysis (CCA) revealed that the distribution of the diatoms was significantly influenced by environmental variables. Conductivity, alkalinity, turbidity, dissolved oxygen, and silicate were identified as the most important variables in species dispersion. Altitude was also found to be important in species distribution through its influence on the upstream-downstream gradients in other environmental variables. Species including *Nitzschia palea, N. clausii, N. scalpeliformis, Epithemia adnata* and *Navicula* cf. *goeppertiana* were associated with waters of high ionic content and high trophy, while *Navicula* cf. *heimansioides, Nitzschia perminuta, Navicula mutica* and *Gyrosigma scalproides* showed preference for waters with low ionic content and low trophic state. The results of this study confirm that diatoms are suitable indicators of water quality in the three rivers investigated and offer opportunity for their use in monitoring studies and for management purposes in the Lake Victoria basin.

5.2. INTRODUCTION

Rivers in the catchments of Lake Victoria play an important role in the biogeochemical cycle by transporting water from runoff and aquifers to the lake. They traverse through large land surfaces, may therefore be regarded as the main conduits of material and transformers of particulate, and dissolved forms en route from land to the lake. Rivers play an important ecological role of providing habitats for aquatic organisms including potamodromous fish that breed upstream, as well as other wildlife.

Like in many parts of the world, rivers in the Lake Victoria region provide various services to the riparian populations. The bulk of drinking water and water for domestic purposes especially in the rural areas is obtained directly from rivers and streams. Other benefits to the society include provision of fish food, water for agriculture, industry, municipalities and recreation. However, the river ecosystems are increasingly threatened by degradation of the catchments through deforestation and clearing of vegetation, large human populations, intensified agricultural activities and industrial establishments. These activities and components discharge various forms of products and waste most of which end up in the rivers. In this way, rivers are often turned into sinks for direct waste disposal (Akpan & Offem, 1993). Environmental impacts of these largely anthropogenic influences in Lake Victoria region include large sediment loads and siltation of river channels downstream as well as the lake itself, eutrophication and anoxia (this study, chapter 3). Other deleterious effects include interference with life cycles of aquatic organisms including fish and loss of biodiversity, increased occurrence of water borne diseases and drying up of some streams.

In contrast to the attention given to Lake Victoria, the impacts of these external influences on the stream ecology are largely not described, yet the area also provide opportunity to asses ecological character of tropical rivers very close to the equator. Most of the rivers have a variety of habitats within a short area including recent geological formations, altitudinal trends in slope, shifts from cool mountains to hot climate in the lowlands, subject to changes in land use and human populations.

General lack of baseline information on river hydrobiology has lead to ineffective management. As demands for good quality water for human consumption and aquatic life increases, its future availability will increase need for protection and rational management. To achieve this goal, realistic ecological tools concerned with biological quality of the water, will be required in addition to existing physical and chemical based monitoring systems.

Diatoms offer good prospects as biological indicator organisms in the region. They are generally considered to have high relations with prevailing environmental conditions and have successfully been used as bio-monitoring organisms in rivers and lakes elsewhere. Diatoms reflect gradients in saprobity (Sládeček, 1973; Van Dam *et al.*,1994), trophic state (Christie & Smol, 1993; Kelly &

Whitton, 1995; Kelly, 1998), alkalinity and pH (Ter Braak & Van Dam, 1989; ten Cate *et al.*, 1993; Davis *et al.*, 1994). The general state and changes of the aquatic environment (Round, 1991a, Battarbee *et al.*, 1997; Dixit *et al.*, 1999; Kelly *et al.*, 1998) and geographical factors (Lobo *et al.*, 1995; Moser *et al.*, 1996) can be indicated by diatom distributions. Diatoms are also important primary producers and form major part of diet for some fishes including *Barbus* spp. (Pentecost *et al.*, 1997). Most of these findings except the latter, mainly describe situations in temperate countries.

The environmental variables, composition of the epilithic diatoms and the use of ecological indicator values to assess water quality of rivers Nyando, Kibos and Kisat are described in separate papers (see chapter 3 and 4, this study). In this paper, these previous studies are expanded by describing the spatial and temporal distributions of the diatoms community and their relationships with environmental variables in the three rivers located on the equator.

5.3. MATERIALS AND METHODS

5.3.1. Study area

The studies were carried out on rivers Nyando, Kibos and Kisat located in the central part of Lake Victoria basin in Kenya (Figure 5.1). All the three rivers rise in their catchments in the east and drain into the Nyanza Gulf of Lake Victoria. The area is underlain by the "Basement complex" of Aechean and Precambian, igneous and metamorphic rocks with sediments of Pliocene, Pleistocene age and recent systems (Burgis *et al.*, 1987). The climate is conventionally described as equatorial with two main rainy seasons occurring between March and May and October and November. The mean annual rainfall varies between 1250 mm and 1550 mm. Mean monthly air temperature range from 21.9 to 24.3 °C.

The catchments of the Nyando are more than 2,650 km^2 in area. The river has an annual discharge of 247 million m^3 (Burgis *et al.*, 1987). It has several large tributaries and receives runoff from small-scale agricultural holdings (tea, livestock, and subsistence crops), large-scale agricultural land (tea, coffee, sugar cane plantations, paddy) and effluents from a lime factory, two major sugar factories and a distillery.

Kibos drains an area of about 490 km^2 and the annual discharge is about 68 million m^3 (Burgis *et al.*, 1987). The river has two major tributaries: the Awach drains an area with few agricultural

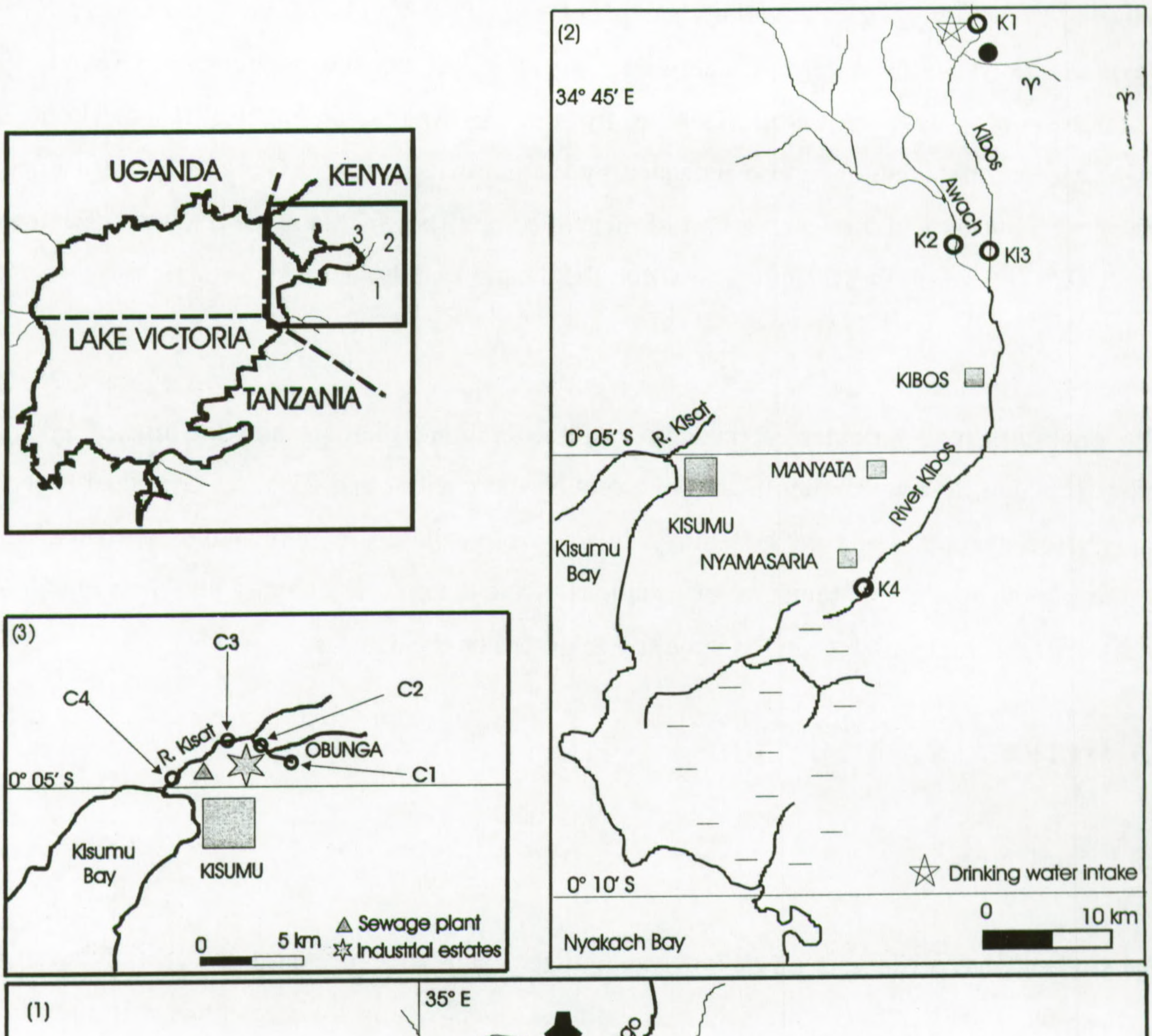

Figure 5.1. Map showing main urban, industrial, agricultural locations and sampling stations on rivers (1) Nyando: N1-N4, (2) Kibos: K1-K4 and (3) Kisat: C1-C4. Inset shows Lake Victoria and position of the three rivers.

smallholdings and the Kibos drains an area with limited agricultural activities and sparse human population. Drinking water for part of Kisumu town is abstracted from the later tributary.

Kisat is a small river and drains an area of about 10 km^2. It receives runoff from agricultural smallholdings, household wastes from a slum area, effluents from an industrial area and a municipal sewage treatment plant.

Quantitative sampling of epilithic diatom flora was done at 12 stations, 4 stations on each river: on seven occasions: May, August, September and December 1998; February 1999; March 2000 and March 2001. Table 5.1 summarizes the characteristics of the sampling stations also shown in Figure 5.1.

Table 5.1. Description of the 12 sampling stations on rivers Kibos (K1-K4), Nyando (N1-N4) and Kisat (C1-C4).

Code	Station name	Altitude (m a.s.l.)	Distance from source (km)	Characteristics of catchments and possible pollution sources
K1	Kajulu	1248	37	Limited agricultural activities (water is abstracted above this station for Kisumu town).
K2	Riverside	1213	20	Small agricultural holdings.
K3	Wathorego	1202	41	Small sugar factory, cane farms and sand extraction.
K4	Nyamasaria	1170	50	Domestic waste, sand extraction.
N1	Muhoroni	1287	130	Small agricultural holdings, lime mines, urban settlement.
N2	Awasi-Chemelil bridge	1231	155	Sugar factory, distillery, cane farms, urban settlement.
N3	Ogilo bridge	1182	165	Sugar factories, cane farms (dilution by a large tributary)
N4	Ahero	1176	177	Sugar factories, cane farms, paddy fields.
C1	Kenya Breweries	1171	0.5	Brewery.
C2	Obunga-mbuta	1165	1.5	Domestic sewage from slums, local breweries, open fish frying activities.
C3	Kudho-kotur	1164	9	Industrial area, urban runoff.
C4	Golf course	1159	11	Industrial area, sewage treatment plant.

5.3.2. Environmental variables

The following environmental variables were measured in the field: altitude (GPS - global positioning system) width and depth of the stream channel (measuring tapes, graduated poles, sounding rope), current velocity, volume of discharge (buoyant object, channel cross-section); water temperature, dissolved oxygen, pH, conductivity and turbidity (portable meters). Water samples for chemical analysis were taken and analyzed for total suspended solids (GF/C filters, 103 to 105 °C), and alkalinity and hardness (EDTA titration). Spectrophotometric methods were used to determine nitrate-nitrogen (cadmium reduction, diozoic complex), phosphate-phosphorus (SRP, ascorbic acid), silicate dissolved SiO_2 (molybdosilicate, heteropoli blue). Total dissolved solids (portable meter) and biochemical oxygen demand (O_2: azide-permanganate combined method, 5 days incubation at 20 °C) were determined on a few occasions and the results are reported elsewhere (see chapter 3). Stream characteristics were measured according to Wetzel & Likens (2000) and chemical analysis were carried out using suitable methods selected from APHA (1995) and Wetzel & Likens (2000).

5.3.3. Biological determinations

At least five submerged stones or rocks at each station were scrapped for diatoms and the composite material preserved in 5% formalin. Diatom frustules were cleaned with sulphuric and nitric acids and mounted on glass slides in Styrax ® (Gum Storax). They were examined under a Leitz Dialux 20 EB light microscope at 1000 x magnification using immersion oil. At least 300 frustules were inspected in a number of transects across the slide and taxa represented identified and recorded. Taxonomic identification followed mainly Krammer & Lange-Bertalot (1986-1991) and guidelines given in Barber & Haworth (1981). For identification of some species, other taxonomic literatures included Hustedt (1949), Huber-Pestalozzi (1962), Germain (1981), Gasse (1986), Vyverman (1991) and Cocquyt (1998).

(See Chapter 2, this study, for more details on sampling stations, methods used and enumeration of diatoms).

5.3.4. Data analysis

Data analysis was performed by employing multivariate statistics with the aim to determine patterns of similarities and differences and relationships between taxa and the environmental variables. Classification of the diatom samples was performed using TWINSPAN (Two-Way INdicator SPecies Analysis (Hill 1979, 1994), contained in the PC-ORD software package (McCune & Mefford, 1999). TWINSPAN is a divisive technique that divides an initial population into smaller groups of closely similar community compositions. It defines qualitative pseudo-species that can either be present or absent, but that are based on species abundance. The output gives a species by site table and indicator species with their cut levels at each division. Preferential species that occur more often in one group than in another are also given. TWINSPAN was constrained to operate on five cut levels (0, 5, 25, 50 and 75% abundance).

Variations in the data were explored further by ordination using the computer program CANOCO version 4.0 (Ter Braak & Smilauer, 1998). First, Detrended Correpondence Analysis (DCA) determined the maximum variation in diatom species data. DCA is an ordination, which is constrained by external variables and is a direct comparison of species distribution. Canonical Correspondence Analysis (CCA) was used to analyze the importance of the measured environmental variables in explaining distribution of diatom species. CCA is an ordination technique for direct gradient analysis in which the axes are constrained to be linear combinations of the measured environmental variables. The significance of the relationship between the species and the environmental variables was determined using the Monte Carlo permutation test. Constrained CCAs were run for each environmental variable to test their individual exploratory strengths.

Out of the 19 environmental variables measured, 16 were used in the initial CCA, whereas three variables (TDS, BOD and ammonia) had incomplete data sets. All the environmental variables used in the subsequent analysis, except pH and temperature, had skewed distributions (Kolmogorov-Smirnov and Liliefors test for normality) and were log transformed prior to the analysis. Altitude was not log transformed.

In both TWINSPAN and CCA analysis, the samples were abbreviated to give the river (K: Kibos, N: Nyando, C: Kisat) station number (1, 2, 3, 4) the month of sampling (My: May, Au: August, Se: September, De: December, Fe: February, Mr: March) and the year (98: 1998, 99:1999, 00: 2000, 01: 2001). For example, K1My98 refers to a sample of station number 1 on River Kibos in May 1998.

5.4. RESULTS

5.4.1. Environmental variables

Table 5.2. gives a summary of the environmental variables measured in this study. Detailed descriptions of the environmental variables are given elsewhere (see Chapter 3, this study). The samples covered several types of river habitats ranging from areas of relatively high relief to lowlands and with varying human activities. The higher upstream areas have small channels with lower ionic content, low trophic state, low temperature and low volume of discharge but higher dissolved oxygen when compared to waters in the lowlands near the mouths of the rivers. Various human activities seem to interfere and modify these general trends, especially in River Kisat.

Table. 5.2. Mean values for environmental variables in the sampling stations on rivers Kibos (K1-K4), Nyando (N1-N4) and Kisat (C1-C4).

Station	Alt.	Width	Depth	Veloc.	Disch.	Temp.	DO	BOD	pH	Alk.	Hard.	Cond.	TDS	Turb.	TSS	PO_4-P	NO3-N	NH_4-N	SiO_2
K1	1284	5.9	0.6	0.66	2.38	19.5	7.7	0.8	7.7	43	39	83	**35**	61	68	82	292	77	52
K2	1213	4.1	0.5	0.50	1.43	23.0	7.6	2.4	7.6	62	42	108	**52**	87	82	69	311	66	49
K3	1202	7.0	0.9	0.42	2.70	21.0	7.3	2.4	7.7	57	44	106	**46**	106	144	76	342	64	54
K4	1170	8.9	0.9	0.52	5.29	22.5	7.1	2.4	7.7	65	45	117	**52**	285	304	70	297	59	53
N1	1287	11.9	0.6	0.93	10.62	22.1	7,9	3.2	7.4	141	107	270	**118**	194	272	71	309	76	62
N2	1231	13.6	1.4	0.53	14.46	23.6	6.5	6.4	7.6	206	149	354	**164**	230	350	275	533	70	60
N3	1182	15.9	1.6	0.62	19.90	24.4	7.3	5.6	7.6	182	125	293	**143**	295	405	131	298	84	56
N4	1176	18.4	1.4	0.54	18.61	25.5	7.1	5.2	7.9	176	131	294	**138**	423	517	118	272	53	50
C1	1171	0.6	0.3	0.04	0.01	26.0	8.3	6.6	7.2	111	161	537	**243**	27	242	233	556	102	79
C2	1165	0.6	0.2	0.20	0.02	27.8	1.4	260.0	6.8	281	205	1004	**589**	249	385	439	849	282	74
C3	1164	2.1	0.4	0.20	0.19	25.1	2.0	340.0	6.8	255	298	661	**411**	100	242	204	132	2583	53
C4	1159	4.3	0.4	0.27	0.40	26.8	0.9	290.0	7.0	357	207	850	**446**	226	357	683	685	2560	50

Units : Altitude (m a.s.l.), width (m), depth (m) velocity (m s^{-1}), discharge (m^3 s^{-1}), temperature (°C), dissolved oxygen, DO (mg O_2 l^{-1}), pH (pH units), total hardness (mg l^{-1} as $CaCo_3$), total alkalinity (mg l^{-1} as $CaCo_3$), conductivity (µS cm^{-1}), total dissolved solids, TDS (mg l^{-1}), turbidity (NTU = Nephelometric turbidity units), total suspended solids, TSS (mg l^{-1}), phosphate-phosphorus (µg l^{-1}), nitrate-nitrogen (µg l^{-1}), ammonia-nitrogen (µg l^{-1}), silicate SiO_2 (mg l^{-1}), BOD_5 (mg O_2 l^{-1}).

5.4.2. Classification of diatoms

224 diatom taxa were identified for all the three rivers and their relative abundances recorded. The full list of species and their codes are included in Annex 5. All the 224 taxa from 84 samples were used in the TWINSPAN analysis. The TWINSPAN divided all the samples into two major groups, namely those of Nyando and Kibos together (left arm of the dendrogram) separately from the ones of Kisat (right arm) (Figure 5.2). The indicator species for the first major group comprising samples from Nyando and Kibos are *Navicula exigua, N. schroeteri* and *Gyrosigma scalproides.* The most preferential species included *Stauroneis anceps, Gomphonema gracile,* and *Navicula mutica*. There were no indicator species for the second major group (Kisat) and preferential species included *Eunotia pectinalis, Nitzschia palea, Pinnularia braunii* and *Navicula* cf. *goeppertiana*. The most preferential species were determined by calculating the ratio of the weight of occurrence of the preferential species in a group (for example in the positive group) to the weight of occurrence of the same species in the other group (for example in the negative group), expressed as a percentage. The species with the highest contribution factor was regarded as the most preferential.

A further division resulted into two groups in each major group and subsequently into final 14 groups. Table 5.3 gives the indicator species at different splitting levels, while Table 5.3 summarises data on environmental characteristics of the assemblages of each TWINSPAN group. A description of each final group follows.

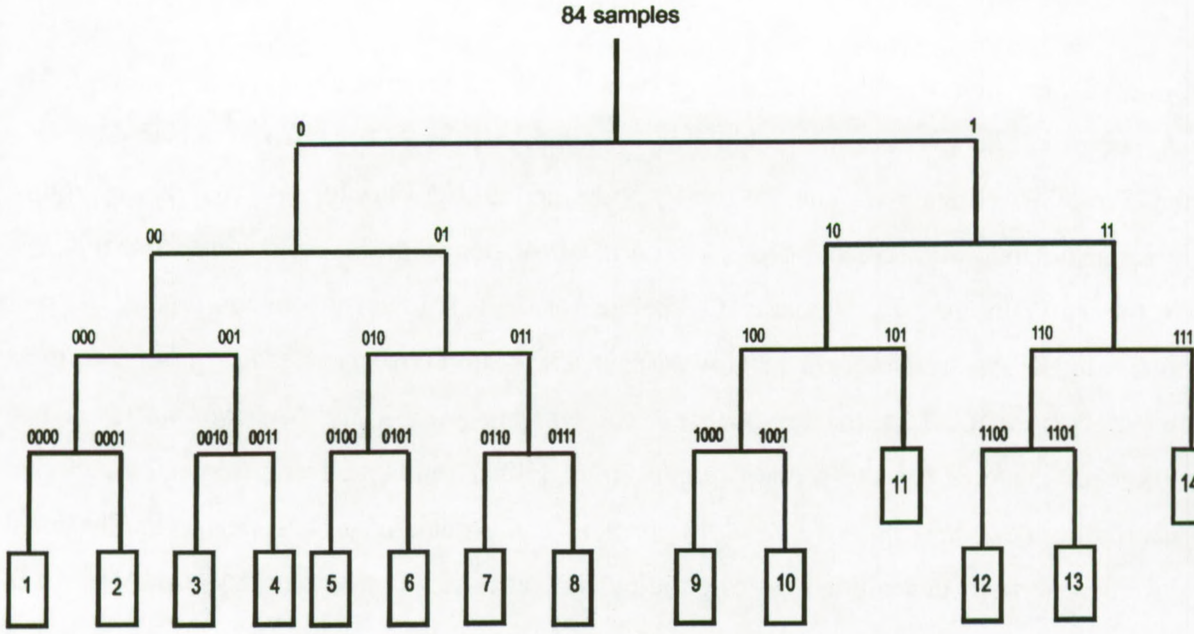

Figure 5.2. TWINSPAN classification of samples based on relative abundance of diatoms of 84 samples from rivers Kibos, Nyando and Kisat. Subsequent splitting levels are shown and their indicator species are given in Table 5.3. TWINPAN groups are indicated (1 to 14).

Table 5.3. Indicator species for various splitting levels of the TWINSPAN analysis.

Splitting level	Number of samples	Indicator species
0	56	*Navicula exigua, N. schroeteri, Gyrosigma scalproides*
000	13	*Nitzschia perminuta*
0000	6	*Gomphonema olivaceum*
001	23	*Nitzschia amphibia, Gomphonema parvulum, Cymbella silesiaca, Navicula capitatoradiata*
0001	7	*Navicula viridula, Fragilaria ulna*
0010	3	*Navicula mutica, Pinnularia braunii*
01	20	*Navicula contenta, N. mutica, Amphora commutata, Gomphonema gracile*
010	11	*Frustulia rhomboides*
0101	4	*Cymbella silesiaca*
011	9	*Nitzschia recta, Amphora montana*
0111	4	*Gomphonema olivaceum*
101	1	*Pinnularia divergentissima*
1001	8	*Nitzschia palea*
11	6	*Aulacoseira granulata*
111	1	*Achnanthes* cf. *lanceolata*
1100	4	*Achnanthes* cf. *minutissima*

Table 5.4. Mean values of environmental variables for the TWINSPAN groups.

TWINSPAN group	Altitude (m a.s.l.)	Width (m)	Depth (m)	Veloc. ($m\ s^{-1}$)	Disch. ($m^3\ s^{-1}$)	Temp. (°C)	DO ($mg\ l^{-1}$)	PH	Alkalinity ($mg\ l^{-1}$)	Hardn. ($mg\ l^{-1}$)	Conduct. ($\mu S\ cm^{-1}$)	Turbid. (NTU)	TSS ($mg\ l^{-1}$)	PO_4-P ($\mu g\ l^{-1}$)	NO_3-N ($\mu g\ l^{-1}$)	SiO_2 ($mg\ l^{-1}$)
1 (n=6)	1234	7.0	0.6	0.6	3.5	21.0	7.3	8.4	77	52	126	46	39	16	257	59
1 (n=7)	1230	7.7	0.8	0.3	2.0	21.5	6.5	7.6	69	48	138	163	80	118	99	16
3 (n=3)	1195	6.0	0.7	0.3	1.0	26.6	6.8	7.8	69	47	125	86	140	296	52	33
4 (n=20)	1222	12.6	0.9	0.5	7.6	24.5	7.3	7.9	171	121	323	145	258	190	288	36
5 (n=7)	1222	9.4	0.8	0.8	9.2	20.5	7.1	7.2	69	73	124	312	342	14	681	146
6 (n=4)	1217	6.3	1.3	0.7	5.9	19.0	10.4	7.6	34	39	73	349	353	4	67	15
7 (n=5)	1191	20.6	2.3	0.7	34.3	22.9	9.7	7.2	156	103	213	590	668	48	383	73
8 (n=4)	1220	11.5	1.3	1.1	19.6	21.6	5.7	6.9	138	94	140	342	383	82	558	77
9 (n=13)	1168	0.9	0.3	0.1	0.1	26.1	4.6	7.0	229	188	786	160	231	272	726	93
10 (n=8)	1165	1.4	0.3	0.2	0.1	27.0	2.5	6.9	252	232	678	67	372	407	166	28
11 (n=1)	1164	2.0	0.2	0.1	0.03	26.4	2.3	6.6	204	610	679	86	630	480	5	26
12 (n=4)	1159	4.8	0.3	0.3	0.4	26.4	0.9	7.1	345	221	835	218	275	663	1147	28
13 (n=1)	1159	3.0	0.5	0.3	0.4	26.9	0.3	6.6	636	234	767	289	309	862	114	87
14 (n=1)	1159	5.0	0.5	0.2	0.6	25.8	0.3	7.4	200	120	940	339	465	127	86	122

5.4.3. TWINSPAN groups

TWINSPAN group 1 (level 000) n = 6)).
Samples K1Au98, K1De98, K3De98, K4De98, N3De98, K1Mr01.

This group comprises samples of mainly stations in upstream of River Kibos in August and December 1998 although also stations of lower Kibos are included. One sample of Nyando also appear in this group but seem to be misplaced. The indicator species was *Gomphonema olivaceum*. Preferential species included *Achnanthes flexella, Frustulia rhomboides, Gomphonema affine, G. angustum, Nitzschia perminuta, Navicula insociabilis* and *Rhoicosphenia abbreviata*. The samples are from on average clean waters with low temperature, low ionic content, low turbidity, low trophic state, moderately high dissolved oxygen, slightly enriched with nitrate (NO_3-N) and mainly from higher elevations (Table 5.4). This group had more or less alkaline water with the highest pH (8.4) when compared to all the other groups. All the samples except the one from Ogilo Bridge (N3Dec98) are from Kibos, a river with less disturbed catchments.

TWINSPAN group 2 (level 0001) n = 7))
Samples K1Fb99, K2Fb99, K3Fb99, K4Fb99, K1Mr00, K2Mr01, K4 Mr01.

Comprise samples from stations of River Kibos mainly collected in February 1999 and March 2001. The indicator species were *Navicula viridula* and *Fragilaria ulna*. The most preferential species included *Navicula pupula, Surirella splendida, Achnanthes* cf. *lanceolata, Navicula capitata,* and *Nitzschia intermedia*. The samples are from relatively "clean water" of Kibos but they are slightly more turbid and slightly enriched with phosphate (PO_4-P) than the ones of TWINSPAN group 1 (Table 5.4).

TWINSPAN group 3 (level 0010) n = 3))
Samples K2Mr00, K3Mr00, K4Mr00.

Consists of samples from both upstream and downstream of River Kibos in March 2000. The indicator species are *Navicula mutica* and *Pinnularia braunii*. Preferential species include *Navicula capitata, N. atomus, N. insociabilis, Achnanthes inflata, Eunotia pectinalis, Gomphonema augur, Pinnularia gibba* and *P. obscura*. The samples are from clean water as in TWINSPAN group 1 and 2 but with higher temperature and more enriched with phosphate (Table 5.4).

TWINSPAN group 4 (level 0011) n = 23))

Samples N1My98, N2My98, N4Se98, K2De98, N1De98, N2De98, N4De98, N1Fe99, N2Fe99, N3Fe99, N4Fe99, N1Mr00, N2Mr00, N3Mr00, N4Mr00, K3Mr01, N1Mr01, N2Mr01, N3Mr01, N4Mr01.

Comprises a large group of samples from all stations of River Nyando during all the sampling times except August 1998. This group also contains samples from Riverside (station K2) and Nyamasaria (K3) of River Kibos in December 1998 and March 2001 respectively. The preferential species of this group included *Nitzschia amphibia, Gomphonema parvulum, Navicula capitatoradiata, Navicula* cf. *subminuscula, Nitzschia linearis, Cyclotella meneghiniana, Cymbella tumidula,* and *Navicula* cf. *impexa.* The samples are from waters with elevated electrolyte content, high turbidity, high suspended solids and high trophic state (Table 5.4). Stations from which these samples were collected, especially the ones of River Nyando receive runoff from agricultural areas and effluents from sugar factories. Two samples of Kibos from Riverside (K2) and Nyamasaria (K3) are included in this group.

TWINSPAN group 5 (level 0100) n = 7))

Samples K4Au98, K1Se98, K2Se98, K3Se98, K4Se98, N1Se98, N2Se98.

Contains mainly samples from stations of Kibos in September 1998. This group also includes one sample from Nyamasaria (K4) collected in August 1998 and two samples from stations of Nyando, N1 and N2 both of September 1998. Preferential species included *Nitzschia flexa, N. perminuta, Cymbella cesatii, Navicula agrestis, Fragilaria construens, Cocconeis placentula* var. *lineata,* and *Navicula* cf. *heimansioides*. On average, the samples had lower water temperature when compared to the first 4 TWINSPAN groups. The samples of group 5 had higher turbidity, suspended solids, nitrate and silicate but lower phosphate.

TWINSPAN group 6 (level 0101) n = 4))

K1My98, K2My98, K3My98, K4My98.

Contains all stations of Kibos in May 1998. The indicator species was *Cymbella silesiaca*. Preferential species included *Pinnularia subcapitata, Diploneis elliptica, Stenopterobia curvula, Cyclotella meneghiniana, Fragilaria capucina* var. *vaucheriae* and *Gyrosigma scalproides.* This group had on average high dissolved oxygen content (mean of 10.4 mg O_2 l^{-1}) and the lowest values of temperature (19 °C), total alkalinity, 34 (mg l^{-1}), total hardness 39 (mg l^{-1}), conductivity (73 µS

cm^{-1}) phosphate (4 $\mu g\ l^{-1}$) and silicate 15 mg l^{-1}) when compared to all other TWINSPAN groups (Table 5.4). Turbidity and suspended solids appear to be incidentally high probably due to trampling by livestock that are commonly watered directly in the river and sand extraction from the river bed mainly at Wathorego (K3) and Nyamasaria (K4).

TWINSPAN group 7 (level 0110) n = 5)).
N3My98, N4My98, N2Au98, N3Au98, N3Se98

Contains samples from stations of middle and downstream River Nyando collected in May, August and September 1998. Preferential species included *Amphora Montana, Caloneis bacillum, C. molaris, Cyclotella ocellata, Navicula* cf. *impexa, Nitzschia clausii* and *N. sigma*. The samples are from stations, which on average had the highest volume of discharge (34.3 $m^3\ s^{-1}$) mainly contributed by Station N3 (Ogilo Bridge). The samples are from waters with high levels of dissolved oxygen, neutral pH, elevated ions, high nitrate and very high turbidity and suspended solids. The high values of turbidity and total suspended solids are due to inputs from agricultural runoff and effluents from sugar industries.

TWINSPAN group 8 (level 0111) n = 4))
K2Au98, K3Au98, N1Au98, N4Au98.

Comprise stations of middle stream Kibos in August 1998 and two stations of Nyando, one from upstream (Muhoroni, N1) and the other one from downstream (Ahero, N4) of August 1998. The indicator species was *Gomphonema olivaceum*. Preferential species included *Pinnularia braunii, Achnanthes inflata, Amphipleura pellucida, Frustulia rhomboides* var. *viridula, Gomphonema angustatum, Stauroneis anceps,* and *Surirella ovalis*. The samples are also from stations with high volume of discharge, high turbidity, high levels of suspended solids and high concentration of nitrates but low levels of dissolved oxygen (mean 5.8 mg $O_2\ l^{-1}$) (Table 5.4).

TWINSPAN group 9 (level 1000) n = 13))
C1My98, C3My98, C1Au98, C2Au98, C1Se98, C2Se98, C3Se98, C1De98, C2De98, C2Fe99, C1Mr00, C2Mr00, C1Mr01.

Consists of mainly samples from Kenya Breweries (C1) in upstream of Kisat. Samples from Obunga-mbuta (C2) and Kodhu kotur (C3) are also included in this group. Preferential species included *Gomphonema angustum, Caloneis molaris, Navicula* cf. *goeppertiana, Synedra* *cunningtonii, Cymbella tumidula, Eunotia didyma, Achnanthes* cf. *minutissima* and *Surirella angusta*. River Kisat has low volume of discharge, current velocity and dissolved oxygen. The waters of this group had high temperature, neutral pH, high alkalinity, hardness, conductivity and concentrations of nutrients (phosphates and nitrates). Although Kenya Breweries (C1) is located near a spring source, it probably receives effluents from the brewery, whereas Obunga-mbuta evidently receives discharges from the brewery, slums and open-air local market for frying fish.

TWINSPAN group 10 (level 1001) n = 8))
C2My98, C3Au98, C3De98, C1Fe99, C3Fe99, C3Mr00,C2Mr01, C4Mr01.

The samples are mainly from Kodhu-kotur (C3) of River Kisat but also include samples from all the other stations of this river. The indicator species was *Nitzschia palea* and the preferential species were *Amphora commutata, Cymbella cesatii, Navicula cuspidata* and *Navicula* cf. *impexa*. This group has the highest mean temperature (27 °C) when compared to other groups, high ion content, enriched with nutrients (phosphate and nitrate) and low dissolved oxygen with a mean value of 2.5 mg O_2 l^{-1} (Table 5.4). Although the waters seem to have low turbidity, they have large amounts of total suspended solids. The indicator species for this group is *Nitzschia palea* that is tolerant to polluted waters. Group 10 represents all stations on River Kisat which receives all types of discharges, ranging from domestic sewage from slums, a local open market for frying fish in the upstream, industrial area and cultivated fields in the in middle stream, and the municipal sewage treatment plant downstream.

TWINSPAN group 11 (level 101) n = 1)).
C3Mr01

Only one sample from Kodhu kotur (C3) on River Kisat collected in March 2001 represents this gorup. Indicator species was *Pinnularia divergentissima*. Preferential species included *Navicula subminuscula, Navicula* cf. *impexa* and *Nitzschia filiformis*. The water quality characteristics are almost similar to the ones of TWINSPAN group 10, with low dissolved oxygen. However, ionic content and total suspended solids are much higher probably due to discharges from the industries. pH was slightly acidic (pH 6.6) whereas, the lowest concentration of nitrate (5 µg l^{-1}) was recorded in this sample when compared to the previous group as well as all other groups (Table 5.4).

TWINSPAN group 12 (level 1100) n = 4)).

C4My98, C4De98, C4Fe99, C4Mr00.

Consisting only of samples from Golf course (C4) on River Kisat. Indicator species is *Achnanthes* cf. *minutissima*. Preferential species included *Stephanodiscus rotula, Gomphonema angustum, Nitzschia inconspicua, Rhopalodia gibba,* and *Aulacoseira granulata*. Others are *Caloneis bacillum, Cymbella cesatii*. Golf course (C4) is located at the lowest elevation among all stations sampled. It receives a mixture of discharges including domestic wastes from slums, cultivated fields, open fish frying market, industries, municipal sewage treatment plant and urban runoff. The waters had high temperature, high electrolyte content, high levels of eutrophication (with the highest concentration of nitrate, 1147 $\mu g\ l^{-1}$) and anoxic (Table 5.4). Although *Achnanthes* cf. *minutissima* appears as the indicator species for this group, it is normally associated with clean water and its presence here seems to be misplaced.

TWINSPAN group 13 (level 1101) n = 1))

C4Au98

This group is made up of only one sample from Golf course (C4) on Kisat collected in August 1998. Preferential species included *Nitzschia palea, N. sigmoidea, N. fonticola, Navicula cuspidata, N. pupula,* and *Pinnularia microstauron.* These species normally grow in eutrophic waters. Although the sample of this group is from Golf course (C4) the same station as the ones of TWINSPAN group 12, the two groups have different water quality characteristics. Water of TWINSPAN group 13 is more anoxic, has lower pH tending towards acidic, while alkalinity, hardness and turbidity, total suspended solids and phosphate (highest value for all groups: 862 $\mu g\ l^{-1}$) are higher than in group 12.

TWINSPAN group 14 (level 111) n = 1))

C4Se98

This group is also made up of one sample collected at Golf course (C4) on Kisat in September 1998. Indicator species was *Achnanthes* cf. *lanceolata*. Preferential species included *Amphora cofeaeformis, Diploneis ovalis, Navicula insociabilis, Nitzschia acicularis, Nitzschia sigmoidea, Pinnularia borealis, Hantzschia amphioxys*. The waters of this sample differ to some extent from other samples of the same station (TWINSPAN groups 12 and 13). TWINSPAN group 14 has higher pH, alkalinity, conductivity (the highest value for all group, 940 $\mu S\ cm^{-1}$), turbidity, total suspended solids and silicate.

5.4.4. Ordination of the diatoms

Detrended Correpondence Analysis (DCA) analysis of the diatom data revealed a total variance of 19.8 % in the species dispersion (Table 5.5). The first axis and second axis of the DCA accounted for 8.1% and 12.9% of all the variance in the species data respectively. The eigenvalue, a measure of importance of each axis, was high for the first axis (0.613). The lengths of gradient for the first axis was also high (4.9 standard deviations) revealing that the variation covered by the data sets were large and therefore with good structure. This allowed the option of using the more robust Canonical Correspondence Analysis (CCA).

Table 5.5. Results of ordination by Detrended Correpondence Analysis (DCA) of data on diatoms in rivers Kibos, Nyando and Kisat.

Axes	1	2	3	4	Total inertia
Eigenvalues	0.613	0.362	0.302	0.215	7.543
Lengths of gradient	4.933	2.844	3.230	2.254	
Cumulative % variance of species data	8.1	12.9	16.9	19.8	
Sum of all unconstrained eigenvalues					7.543

The initial Canonical Correspondence Analysis (CCA) was performed using 16 environmental variables with complete data sets, 84 samples and all 225 species. Unrestricted Monte Carlo Permutation test was significant for both the first canonical axis as well as all canonical axes (p<0.05). This indicated that there was a strong relationship between diatom species distribution and the measured environmental variables, also confirmed further by the preceding results.

Environmental variables associated with stream hydrology: channel width, depth, current velocity and volume of discharge, were highly correlated (Table 5.6). They also showed high variance inflation factors (78, 37, 67, 391 respectively) of species-environment correlations. Variables with variance inflation factors of more than 20 are almost perfectly correlated with other variables or redundant with one another and are omitted from further analysis (Ter Braak & Smilauer, 1998). Therefore width, depth, current velocity and volume of discharge were not included in the second CCA.

Only species with relative abundance 1% or more in at least one sample were also included in the second CCA. The second data set comprised 12 variables, 143 species and all the 84 samples. The eigenvalue for CCA axis 1 was 0.49 (Table 5.7). This is a high eigenvalue indicating that axis 1 represented a strong gradient. The axis 2 and 3 were slightly lower and indicated weaker gradients

Table 5.6. CCA weighted correlation matrix for the 16 environmental variables used in the CCA analysis.

	Altit.	Width	Depth	Veloc.	Disch.	Temp.	Oxyg.	pH	Hard.	Alk.	Cond.	Turb.	NO_3-N	PO_4-P	SiO_2	TSS
Altit.	1.0000															
Width	0.3677	1.0000														
Depth	0.1560	**0.6983**	1.0000													
Veloc.	0.4256	**0.6739**	0.4571	1.0000												
Disch.	0.3830	**0.9280**	**0.7998**	**0.8441**	1.0000											
Temp.	-0.5005	-0.3897	-0.3051	**-0.5823**	**-0.5083**	1.0000										
Oxyg.	0.4491	0.3909	0.4141	0.1703	0.3746	-0.3482	1.0000									
pH	0.2112	0.3005	0.1979	0.1281	0.2481	-0.1740	0.4248	1.0000								
Hard.	0.3799	-0.3032	-0.2455	-0.3022	-0.3404	0.4742	**-0.5146**	-0.4127	1.0000							
Alk.	-0.3746	-0.1839	-0.2270	-0.1678	0.2268	0.4606	**-0.5852**	-0.2300	**0.8491**	1.0000						
Cond.	-0.5060	-0.4789	-0.4574	-0.4682	**-0.5496**	**0.5789**	**-0.6649**	-0.3533	**0.8395**	**0.8371**	1.0000					
Turb.	-0.1595	0.4198	0.3642	0.4446	0.4811	-0.0430	-0.1674	-0.2563	0.0135	0.0490	-0.0509	1.0000				
NO_3-N	0.0824	-0.0739	0.0737	0.0372	0.0095	0.1443	0.1510	0.0807	-0.0019	0.0379	-0.1395	-0.1190	1.0000			
PO_4-P	-0.2221	-0.1538	-0.2102	-0.3577	-0.2844	**0.5608**	-0.3559	-0.3354	0.4219	0.4604	0.4229	-0.0134	-0.1003	1.0000		
SiO_2	0.0351	0.0210	0.0727	0.1623	0.1010	-0.2308	-0.0645	-0.1240	0.0122	-0.702	-0.1089	0.1071	**0.5290**	-0.2849	1.0000	
TSS	-0.2023	0.2068	0.2473	0.0686	0.1988	0.2441	-0.1778	-0.4036	0.2395	0.1457	0.1366	**0.7348**	-0.1299	0.3871	-0.0521	1.0000

than the first axis. An overall variance in the species dispersion of 7.971 and the total species-environment correlations of 62.7% show the importance of the environmental variables in the species dispersion. The first axis explained 6.2% of the total variation in the species data. Species-environment correlations were high for the first as well as the next three axes.

Table 5.7. Results of the second ordination by CCA of data on diatoms in rivers Kibos, Nyando and Kisat.

Axes	1	2	3	4	Total inertia
Eigenvalues	0.490	0.263	0.208	0.173	7.971
Species-environment correlations	0.926	0.796	0.742	0.786	
Cumulative % variance of species data	6.2	9.5	12.1	14.2	
Cumulative % variance of species-environment relation	27.1	41.7	53.2	62.7	
Sum of all unconstrained eigenvalues					7.971
Sum of all canonical eigenvalues					1.807

Tests of significance using the Monte Carlo Permutation Tests revealed that of the 12 environmental variables, conductivity, alkalinity, dissolved oxygen, turbidity and silicate ($p<0.01$), and altitude ($p<0.05$) were significant in explaining the variance in the species data.

A final CCA was performed using only all the six significant environmental variables to determine the strength of each one of them in the species dispersion and if they are the only ones that explain the dispersion. All the six variables were still significant in the final CCA ($p<0.05$, Table 5.8). The species-environment relation when only these six significant environmental variables are considered is higher (82.3%) than when all the twelve variables are present (62.7%) (Tables 5.7 and 5.9). The six significant variables are therefore the main environmental variables that strongly explain the distribution of the diatom species in rivers Kibos, Nyando and Kisat, in space and time. This was also confirmed by the significance of all canonical axes ($p<0.01$). However, the remaining part of the variation cannot be explained by our data and may be due to other variables not included in the analysis or measured in this study.

Table 5.8. Weighted correlation matrix in the final showing the relationship between species axis and the 6 significant environmental variables in the final CCA. The significance values are also given.

Environmental variable	Axis 1	Axis 2	Axis 3	Axis 4	*P*-value
Conductivity	0 .8690	0.0853	-0.1145	0 .1789	0.005
Total alkalinity	0.6251	-0.0326	-0.4058	0.2487	0.005
Dissolved oxygen	-0.6921	0.3231	0.1631	0.0729	0.005
Altitude	-0.6206	0.1432	0.0278	0.3743	0.005
Silicate	-0.0644	0.2862	0.0166	-0.3030	0.010
Turbidity	-0.0174	0.1542	-0.5161	-0.3805	0.025

Table 5.9. Results of the final ordination by CCA of data on diatoms in rivers Kibos, Nyando and Kisat, with only the six significant variables.

Axes	1	2	3	4	Total inertia
Eigenvalues	0.480	0.235	0.197	0.131	7.971
Species-environment correlations	0.919	0.772	0.731	0.702	
Cumulative % variance of species data	6.0	9.0	11.4	13.1	
Cumulative % variance of species-environment relation	37.9	56.4	72	82.3	
Sum of all unconstrained eigenvalues					7.971
Sum of all canonical eigenvalues					1.268

A forward selection of the significant environmental variables showed that conductivity explained 25% of the variation in species composition due to the measured environmental variables. Alkalinity and dissolved oxygen were the next most important variables and each explained 10% of the total variation in species composition. Turbidity explained 9% whereas altitude and silicate explained 8% of the variation each.

CCA axis 1 was strongly correlated with conductivity and alkalinity and to a lesser degree temperature, hardness and phosphate (Table 5.10, Figure 5.3). Axis 1 therefore reflects warm waters rich in ionic content and trophic state, related to discharges of wastes from Obunga slums, effluents from industries and raw sewage from the municipal sewage "treatment plant". The high values of these variables in the Kisat can be associated with pollution. The waters reflected by axis 1 also occur in low lands and have low dissolved oxygen.

Table 5.10. Weighted correlation matrix showing the relationship between species axis and the 12 environmental variables used in the initial CCA.

	Axis 1	Axis 2	Axis 3	Axis 4
Altitude	**-0.6192**	0.1519	0.0985	-0.2502
Temperature	**0.5633**	0.0396	0.0280	-0.2307
Dissolved oxygen	**-0.6791**	0.3218	0.2185	0.0448
pH	-0.4345	-0.2090	0.1081	-0.0918
Total hardness	**0.6745**	0.1907	-0.1602	-0.3329
Total alkalinity	**0.6219**	-0.0107	-0.3087	-0.3764
Conductivity	**0.8647**	0.0334	-0.0242	-0.2248
Turbidity	0.0048	0.2387	0.1419	0.0052
Nitrate-nitrogen	-0.1058	0.1843	-0.1205	0.2944
Phosphate-phosphorus	0.3195	-0.1223	0.0004	-0.3825
Silicate	-0.0465	0.2843	-0.0176	0.2583
Total suspended solids	0.1856	0.3117	-0.2888	-0.645

CCA axis 2 represents a gradient of turbidity and silicate (Table 5.10, Figure 5.3). Axis 2 reflects highly turbid waters enriched with silicate and nitrate, and can be related to agricultural activities, runoff and weathering of rocks. Oxygen and altitude were highly correlated negatively to the first

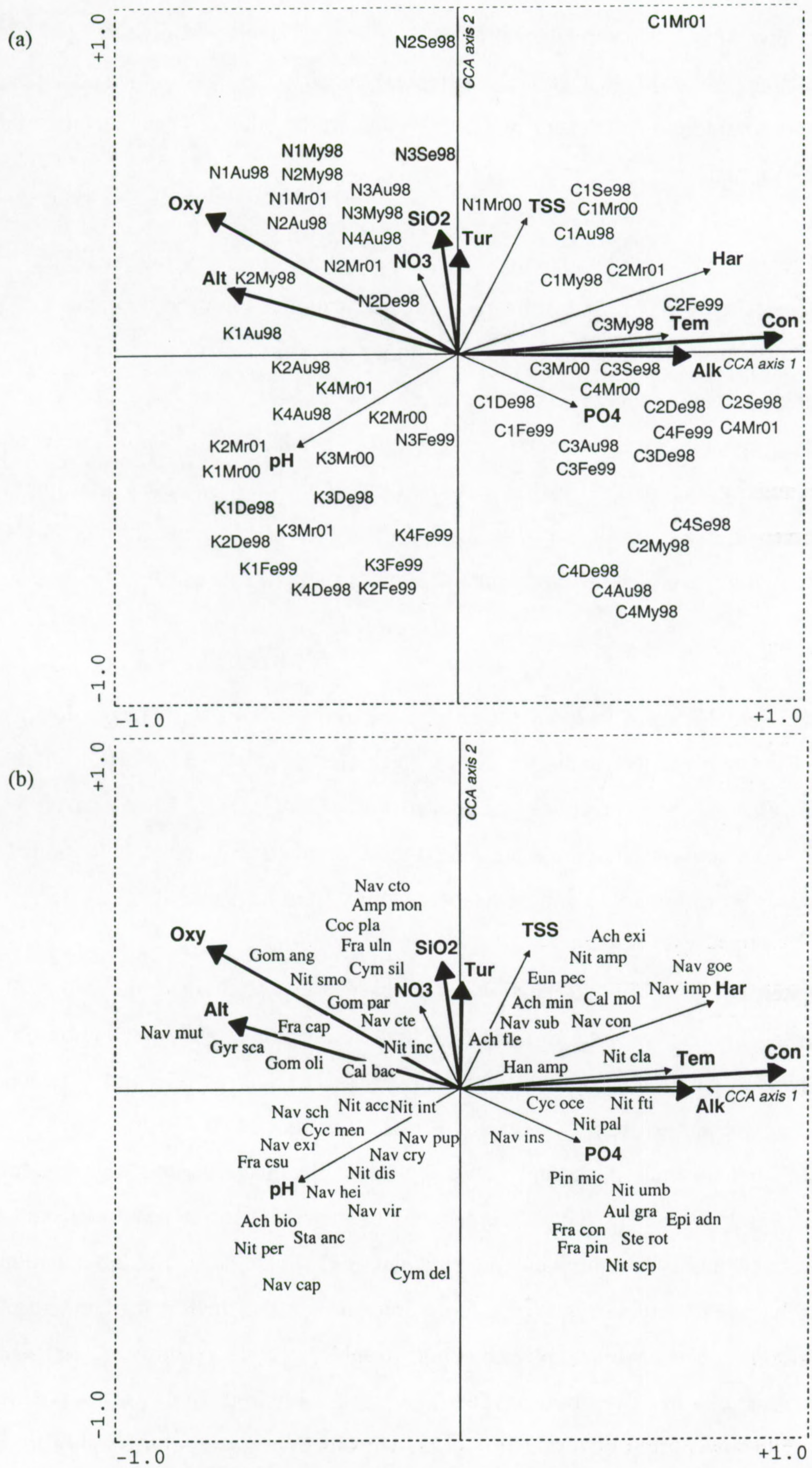

Figure 5.3. Biplot of scores of environmental variables and sample scores (b), and species scores (b) of the **canonical correspondence analysis (CCA) with 84 samples and 12 environmental variables (solid arrows).** Significant environmental variables in bold. For taxon names see Table 5.11.

axis. Altitude is also related to distance from source and ideally, waters in the upstream are expected to have very low ionic concentration, low trophic levels and high oxygen content as was observed in River Kibos. pH is negatively correlated to both CCA axis 1 and axis 2. pH is also more closely related to gradients of altitude and oxygen than to the other environmental variables (Tables 5.9, 5.9 and Figure 5.3).

In the final ordination diagrams for samples and species, the option "visual visibility" in Canodraw was set at level 1 to display only few most common distributions in order to increase clarity (Figure 5.3 a, b). The main patterns of community variation with respect to environmental variation are shown in the ordination diagram. Species (and sample) scores are weighted averages of each species with respect to environmental variables (Ter Braak, 1986), while the arrows represent direction of maximum variation of the measured environmental variables. The importance of an environmental variable is proportional to the length of the environmental vector in the biplot, and the smaller the angle between the environmental vector and axis, the greater the linear association.

The distribution of the samples by the CCA closely conformed to the patterns given by TWINSPAN. Samples from River Kisat occupy the right side of the CCA ordination, generally separated from samples of Nyando and Kibos on the left (Figure 5.3 a). High ionic content and trophic state clusters were positively associated with CCA axis 1. This axis represents strong gradients for conductivity; alkalinity and temperature, hardness and phosphate indicating polluted waters. Samples scoring highly on this axis were mainly from River Kisat.

A broad cluster that is highly correlated with CCA axis 1 can be divided into two groups. The first group has high conductivity, high alkalinity, high temperature and high hardness (upper right quadrant), mainly comprising samples from upper Kisat (Stations C1 and C2). These stations receive various discharges from Obunga slums and effluents from a few industries, and the waters are warm and rich in ions. A second group (bottom right quadrant) has high conductivity, high alkalinity and high phosphate. These are samples mainly from lower Kisat at Kodhu-kotur (C3), which receives effluents from the industrial area and Golf course (C4). The latter station in addition receives discharges of raw sewage from the municipal sewage treatment plant. The waters have both high amounts of ion, high alkalinity, high trophic state in relation to phosphate and high saprobity indicated by low dissolved oxygen (and presumably high BOD as observed in Chapter 4, this study). The lower right quadrant in the CCA ordination correspond roughly to TWINSPAN groups 12 to 14 whereas the ones on the upper right corresponds to TWINSPAN groups 9 to 11.

Table 5.11. List of species codes in Figure 5.3 b and their full species names.

Code	Species name
Ach bio	*Achnanthes bioretii* Germain
Ach min	*Achnanthes* cf. *minutissima* Kützing
Ach exi	*Achnanthes exigua* Grunow
Ach fle	*Achnanthes flexella* (Kützing) Brun
Amp mon	*Amphora montana* Krasske
Aul gra	*Aulacoseira granulata* (Ehrenberg) Simonsen
Cal bac	*Caloneis bacillum* (Grunow) Cleve
Cal mol	*Caloneis molaris* (Grunow) Krammer
Coc pla	*Cocconeis placentula* var. *lineata* (Ehrenberg) Van Heurck
Cyc men	*Cyclotella meneghiniana* Kützing
Cyc oce	*Cyclotella ocellata* Pantocsek
Cym del	*Cymbella delicatula* Kützing
Cym sil	*Cymbella silesiaca* Bleisch
Epi adn	*Epithemia adnata* (Kützing) Brébisson
Eun pec	*Eunotia pectinalis* (Dillwyn) Rabenhorst
Fra cap	*Fragilaria capucina* var. *vaucheriae* (Kützing) Lange-Bertalot
Fra con	*Fragilaria construens* (Ehrenberg) Grunow
Fra csu	*Fragilaria construens* f. *subsalina* (Hustedt) Hustedt
Fra pin	*Fragilaria pinnata* Ehrenberg
Fra uln	*Fragilaria ulna* (Nitzsch) Lange-Bertalot
Gom ang	*Gomphonema angustum* Agardh
Gom oli	*Gomphonema olivaceum* (Hornemann) Brébisson
Gom par	*Gomphonema parvulum* (Kützing) Kützing
Gyr sca	*Gyrosigma scalproides* (Rabenhorst) Cleve
Han amp	*Hantzschia amphioxys* (Ehrenberg) Grunow
Nav cap	*Navicula capitata* Ehrenberg
Nav cto	*Navicula capitatoradiata* Germain
Nav hei	*Navicula* cf. *heimansioides* Lange-Bertalot
Nav imp	*Navicula* cf. *impexa* Hustedt
Nav con	*Navicula contenta* Grunow
Nav cry	*Navicula cryptocephala* Kützing
Nav cte	*Navicula cryptotenella* Lange-Bertalot
Nav exi	*Navicula exigua* (Gregory) Grunow
Nav goe	*Navicula* cf. *goeppertiana* (Bleisch) H. L. Smith
Nav ins	*Navicula insociabilis* Krasske
Nav mut	*Navicula mutica* Kützing
Nav pup	*Navicula pupula* Kützing
Nav sch	*Navicula schroeteri* Meister
Nav vir	*Navicula viridula* (Kützing) Ehrenberg
Nit aci	*Nitzschia acicularioides* Hustedt
Nit amp	*Nitzschia amphibia* Grunow
Nit cla	*Nitzschia clausii* Hantzsch
Nit dis	*Nitzschia dissipata* (Kützing) Grunow
Nit fti	*Nitzschia fruticosa* Hustedt
Nit inc	*Nitzschia inconspicua* Grunow
Nit int	*Nitzschia intermedia* Hantzsch
Nit pal	*Nitzschia palea* (Kützing) W. Smith
Nit per	*Nitzschia perminuta* (Grunow) M. Paragallo
Nit scp	*Nitzschia scalpelliformis* Grunow
Nit smo	*Nitzschia sigmoidea* (Nitzsch) W. Smith
Nit umb	*Nitzschia umbonata* (Ehrenberg) Lange-Bertalot
Pin mic	*Pinnularia microstauron* (Ehrenberg) Cleve
Sta anc	*Stauroneis anceps* Ehrenberg

Samples with intermediate scores between CCA axis 1 and axis 2 were associated with waters with high total suspended solids mainly from upper Kisat.

Samples with mesotrophic to eutrophic waters were negatively correlated to CCA axis 1 but were closer to CCA axis 2 (upper left quadrant). CCA axis 2 represents mainly gradients in turbidity, silicate and nitrate that are variables associated with agricultural activities and weathering processes. Most of the samples in this cluster belong to River Nyando. The samples, which are in the upper left quarter and very close to axis 2, are also represented in TWINSPAN groups 6 to 8 and the ones in the remaining quarter correspond to TWINSPAN groups 3 to 5.

Samples from low trophic waters also with high pH had negative scores on both CCA axis 1 and CCA2. They included samples of upper Kibos such as K2My98 and K1Au98, found in relatively high elevations and with high concentration of oxygen. The samples are mainly from all stations of Kibos with high pH (lower left quadrant). This cluster of samples in the CCA ordination corresponds roughly to TWINSPAN groups 1 and 2.

In the species plot (Figure 5.3 b, Table 5.11 for full species names), a cluster of pollution tolerant species is strongly correlated with CCA axis 1 (right hand side of ordination diagram). They include the ones that tolerate high conductivity, high alkalinity and high temperatures such as *Nitzschia clausii*, *N. fruticosa* and *Cyclotella ocellata*; while those with a high phosphate optima occur in the bottom right quadrant including *Nitzschia palea, Cyclotella ocellata, Pinnularia microstauron, Epithemia adnata, Nitzschia umbonata* and *Stephanodicus rotula*. Species, which tolerate high ionic content associated with total hardness, include *Navicula* cf. *goeppertiana* and *N. impexa*.

Achnanthes exigua, *Nitzschia amphibia* and *Eunotia pectinalis* are among species with intermediate scores between CCA axis 1 and axis 2, which indicate their occurrence in waters with high turbidity and rich in ions and minerals. *Navicula capitatoradiata, Amphora montana, Cocconeis placentula* var. *lineata, Fragilaria ulna* and *Cymbella silesiaca* have a high score on CCA axis 2 which indicates their optimum occurrence in highly turbid waters rich in silicate and nitrate.

Oxygen and altitude are highly correlated negatively with the first axis. Species such as *Gomphonema angustum, Nitzschia sigmoidea, Navicula mutica, Gyrosigma scalproides* and *Fragilaria capucina* are found in areas with high altitude also associated with high concentrations of dissolved oxygen. Species from waters with increasing levels of pH and which had negative scores on both CCA axis 1 and axis 2 were found mainly in Kibos. This river especially upstream has low ionic content, low trophic state and low turbidity. Characteristic species included *Navicula capitata, Navicula* cf. ***heimansioides, Nitzschia perminuta, Achnanthes bioretii,*** and *Fragilaria construens* f. *subsalina* (Figure 5.3 bottom left quandrant). Others are *Navicula schroeteri*, *N. exigua, N. viridula* and *Cyclotella meneghiniana.*

5.6. DISCUSSION

Waters with high ionic content (conductivity, alkalinity, hardness), temperature and nutrients especially phosphate were found in River Kisat that drains an industrial area and receives various forms of wastes and sewage inputs. It appears that the levels of these environmental variables that contribute to pollution also seem to be related to the size of the river. Kisat is a small river and it is possible that direct discharges of the raw effluents and sewage exceed the natural water greatly modifying its quality. This is more acute in the lower sections of this river, which has characteristics of a sewer, and microbial transformations of large quantities of dead organic matter result in anoxic conditions.

Higher turbidity, larger amount of suspended solids and nitrates are mainly found in River Nyando and can be related to agricultural activities that may also be associated with deforestation in the catchments. Discharge of effluents from the sugar factories could be additional sources of suspended solids, ions, trophy and organic matter. However, the effects of these pollutants may be less obvious due to the relatively large size and flushing rates of the Nyando. High dissolved oxygen and relatively high pH, low ionic content and low trophic state are found in River Kibos. This is because the river drains an area with less human activity (see also Chapter 3, this study for more detailed discussions on environmental variables measured).

The diatom community structure was well defined by our data based on species composition. The TWINSPAN analysis classified the diatom communities into 14 groupings of samples. The first division resulted into two major groups. The left arm represents samples from relatively "clean waters" of Rivers Kibos and Nyando (Figure 5.3, left arm) with *Navicula exigua, N. schroeteri* and *Gyrosigma scalproides* as indicator species. Absence of these indicator species in Kisat (right arm) differentiated the "dirty water" in this river from the "clean" water in the first two rivers. The first major group was finally split into eight assemblages (TWINSPAN groups 1 to 8) and the second group into six assemblages (TWINSPAN groups 9 to 14).

The separations into distinct assemblages with their indicator species irrespective of the sampling station and time of collection indicate response of the diatom assemblages to environmental factors. Within the groups, samples from different collection times from the same station seemed generally to be closely related to one another. Samples from different stations of the same river were also closely related. The final assemblages had average values of environmental variables different from each other but following some gradients.

While the other indicator species and preferential species seem to reflect well with the average environmental conditions of each assemblage and according to known ecological preferences (e.g., Van Dam *et al.* 1994; Chapter 4 this study), appearance of *Achnanthes* cf. *minutissima*, a clean water species, as an indicator for the TWINSPAN group 12 seems unusual. However, Steinberg & Schiefele (1988) report different varieties of this species to occur in waters with varying quality in Germany. *A. minutissima* var. *saxophila* for example occurred in heavily polluted waters; *A. minutissima* var. *minutissima* occurred in waters with no pollution, whereas, *A. minutissima* var. *jackii* occurred in less polluted waters rich in dissolved oxygen. In the present study, all varieties of *Achnanthes* cf. *minutissima* were considered together as one species and the varieties occurring in lower Kisat could be tolerant to pollution.

TWINSPAN has been recognized as a good technique for identifying structure in field data (Cao *et al.*, 1997) and this was seen for our data. However, this technique is more sensitive to very small differences and analyses that are more robust are required to explain the variations in species distribution to finer details.

Further support of the patterns shown by the TWINSPAN came from the results explained by the ordination of the samples. Indirect ordination by detrended correspondence analysis (DCA) of all the 84 samples, 230 species from all the three rivers (Nyando, Kibos and Kisat) gave a high length of gradient and eigen value for the first axis (4.93 and 0.613 respectively). This indicated a strong predetermined discrimination of the samples and the presence of a structure in the data.

Canonical correspondence analysis (CCA) revealed that six major environmental gradients control the diatom species composition in the three rivers. These are functions of conductivity, alkalinity, turbidity, silicate, dissolved oxygen and altitude. The first CCA axis 1 represented a conductivity and alkalinity gradient, and to lesser extends temperature, hardness and phosphate. Conductivity and alkalinity reflect impacts of ions (Pan & Stevenson, 1996). Although the normal sources for ions are in the bedrock in the catchments, higher ion content in River Kisat for example, is due to inputs from industrial effluents and large amounts of dead organic matter.

The importance of conductivity and alkalinity in influencing diatom species distributions in several biotopes in East Africa is also reported by Gasse *et al.* (1983). Similarly, Vyverman (1992) found conductivity to strongly influence distribution of diatoms in Papua New Guinea. In the present study, conductivity and alkalinity differentiated mainly polluted waters occurring in River Kisat (Figure 5.3, right side of the CCA biplot) from the less polluted Kibos and Nyando. Diatoms known to be tolerant to pollution were also strongly correlated with these environmental variables.

The broad group of diatoms that can tolerate pollution and occurring in River Kisat can be split roughly into two clusters. First, species that seem to prefer elevated levels of phosphates and occur mainly in stations of lower Kisat (Figure 5.3 a, b, lower right quadrant). This section of the river receives discharges from the sewage treatment plant in addition to the ones from industries. Microbial transformations of the large amounts of dead organic matter also result in anoxic conditions. Most of the species present in high abundances are also mentioned in literature to be tolerant to high eutrophic conditions elsewhere including The Netherlands (ten Cate *et. al.* 1993) and Papua New Guienea (Vyverman, 1991). The species include *Nitzschia palea, N. umbonata, N. fruticosa, Navicula* cf. *subminuscula, Pinnularia microstauron, Cyclotella ocellata* and *Fragillaria pinnata. Stephanodiscus rotula,* a species that could be expected to reflect lake conditions was present in high abundance in this group. These pollution tolerant species were usually few in a sample but they occurred in high abundances.

The second type of pollution indicator species are those which in addition to the variables mentioned previously (conductivity, alkalinity, temperature and phosphate) can tolerate high levels of water hardness (upper right quadrant of Figure 5.3). These waters occur in upper Kisat that also receives all sorts of waste discharges from Obunga slums and possibly effluents from the Kenya Breweries factory located in this area. Obunga slums lack proper sanitation facilities and piped water supply. Litter and trash from households, detergents from laundry and residues from distillation of "changa", an illicit local whisky, are disposed off in dumpsites and open drains that eventually connect to the river. Soot, salt wastes, burnt cooking oil and fish offals from the open air fish frying concern at lower Obunga are also washed into the Kisat. The waters in this section of the river are characterised by species that can tolerate high electrolyte content. They include *Navicula* cf. *goeppertiana, N. impexa, Caloneis molaris, Achnanthes exigua* and *Nitzschia amphibia.*

Many of the species shown in the CCA to occur in the polluted waters of the Kisat (Figure 5.3) are also contributing to high weighted values of saprobity in this river (Chapter 4, this study). They include *Nitzschia palea, N. umbonata, N. amphibia, Navicula* cf. *goeppertiana, Navicula* cf. *subminuscula* and *Hantzschia amphioxys*. Some of these species including *Navicula* cf. *goeppertiana* and *Nitzschia palea* also appear in the list of Lange-Bertalot (1979) as among the most tolerant to pollution. Similarly, the latter two species have been found in heavily polluted waters in Germany (Steinberg & Schiefele, 988). Lange-Bertalot (1979) suggests the use of such tolerant species for water quality estimation in moderate to extremely polluted conditions.

CCA axis 2 represents the gradient of turbidity and silicate and to a lesser extends nitrate and suspended solids. High turbidity can be associated with soil erosion from agricultural activities while silicate could be associated with drainage in rather sandy soils and weathering processes in the catchments and mainly on River Nyando. Similarly, high levels of nitrates and suspended solids (also reflected by turbidity) are due to agricultural activities and release of large amounts of sediments into the river. Other contributions of these variables come from effluents of sugar factories. The diatoms found here include *Cymbella silesiaca, Amphora montana, Navicula capitatoradiata, Fragilaria ulna* and *Cocconeis placentula* var. *lineata*. A closely related group of species that prefer waters with less turbidity, high dissolved oxygen and occur in slightly higher altitudes (Figure 5.3, close to arrows for gradients of dissolved oxygen and altitude) includes *Gomphonema angustum, G. parvulum and Nitzschia sigmoidea* and *Fragilaria capucina.*

Oxygen and altitude are negatively correlated to CCA axis 1 and may be interpreted as gradients of CCA axis 2. Although altitude appears to be significant in explaining diatom species distributions, it is ecologically relevant in indirectly providing gradients for the main environmental variables. Water temperature, ionic content, nutrients and turbidity were for example lower in higher elevations in rivers Kibos and Nyando than in the lowlands downstream where the waters were more enriched and turbid. The higher elevations are also closely related to upstream sections of the rivers closer to the source and as expected, with more smaller stream channel, high current velocity and high dissolved oxygen. Waters representing the characteristics of higher elevations are found mainly in stations of upper Kibos at Riverside (K2My98) and Kajulu (K1Aug) (Figure 5.3, upper left quadrant). The most common species in these waters included *Navicula mutica, Gyrosigma scalproides,* and *Gomphonema olivaceum.*

Stream channel characteristics including width, depth, current velocity and volume of discharge had high strongly correlated and showed high inflation factors in the CCA. Such highly correlated variables, which can also provide more or less the same information, are referred to as "redundant" with each other. According to Ter Braak & Smilauer (1998), a variable with large variable inflation factor of 20 or more is almost perfectly correlated with other variables and does not provide any new information to the regression equation. Its canonical coefficient is unstable, cannot be interpreted meaningfully and therefore the variable is removed from further analysis. Altitude therefore may be considered a proxy for the stream channel characteristics since it is most likely to be having an indirect effect them.

Altitude has been found to be among important variables that influence the distribution of diatoms in other rivers. (Chessman (1986), for example reports patterns in distribution of diatoms in La Trobe system in Australia to be primarily in response to environmental gradients from cool, chemically dilute upland streams to warm enriched lowland streams. Chessman (1986) attributes this to natural responses as well as artificial influences from agricultural, urban and industrial developments in the region.

Pentecoste *et al.* (1997) found high relations between composition and distribution of diatoms and altitude in Bujuku-Mubuku river system on the Ruwenzori mountains in Uganda (Pentecoste *et al.*, 1997), conforming to the results of this study. Among the species found in large numbers by Pentecoste *et al.* (1997) in higher altitudes and that also occurred in our samples include *Gomphonema angustum*, *Cocconeis placentula*, *Fragilaria capucina* var *vaucheriae* and *Cymbella silesiaca*. Similarly, Ormerod *et al.* (1994) reports pronounced altitudinal changes in composition of diatoms in a river system in Nepal.

Most of the samples from Kibos are close to the vector for pH (Figure 5.3, upper left quadrant) that is negatively correlated with both CCA axes 1 and 2. Kibos has the least developed catchments when compared to Nyando and Kisat, and therefore receives fewer inputs from human activities. The diatom community comprises species that are sensitive to eutrophication, high ion content and turbidity. They included *Navicula decussis*, *Navicula* cf. *heimansioides*, *N. capitata*, *Fragilaria construens* f. *subsalina* and *Nitzschia perminuta*. The taxa that mostly indicated clean water were generally lacking in the highly polluted waters of Kisat. Similarly, diatoms indicating clean water have also been found lacking in polluted waters in the Netherlands (ten Cate *et al.*, 1993).

Although pH is known to be a major environmental variable determining diatom distributions, especially in temperate countries (Van Dam & Mertens, 1995) and also in some water bodies mainly in saline lakes in East Africa (Gasse *et al.*, 1983), its effects in this study seem to be minimal. Recent alkali volcanic and sedimentary rocks underlie the Nyanza Gulf area (Johnson *et al.*, 2000) where the rivers investigated are located. Basic bedrock also indicated by limestone mines in the upstream of Nyando could be the reason for the slightly higher pH in the Kibos and Nyando.

The classification of rivers Kibos, Nyando and Kisat based on diatom composition and measured environmental variables clearly shows differences between "clean" water and polluted waters. Clean waters are found in areas with medium to low human activity (River Kibos) in relatively elevated areas. "Medium quality" waters may be found in areas with high agricultural activities in medium altitudes (River Nyando) whereas, polluted waters mainly due to industrial effluents and municipal sewage discharges are observed in the lowlands (River Kisat). Vyverman (1992) reports similar findings for diatoms in Papua New Guinea also a tropical region. However, Vyverman's (1992) samples were classified into two broad categories: highland samples with low electrolyte content and lowland samples with high electrolyte samples.

Many of the species that are reported in our study have almost habitat characteristics similar to that described for the same species by Vyverman (1991) including mention on trophic status, and the ones described by Gasse (1986) for lakes in East and Central Africa. The present study covered a wide range of river habitats most likely to be found in many rivers in the Lake Victoria region. The results contribute knowledge to our understanding of the present flora of diatoms, their ecology and responses to different environmental conditions and perturbations.

5.7. CONCLUSIONS

Rivers Kibos, Nyando and Kisat have a wide range of water quality conditions resulting in major differences in the composition and distribution of epilithic diatoms, revealing the existence of several assemblages, each with specific habitat preferences. Classification and ordination clearly separated the samples into two broad groups reflecting differences in their geographic, physical and chemical structure. The first group comprised less polluted waters of Kibos and Nyando together and the second group was the more polluted Kisat.

At the first level of TWINSPAN separation, the first group had *Navicula exigua, N. schroeteri* and *Gyrosigma scalproides* as the indicator species, which differentiates this group from the second group (Kisat) that largely lacks them. There were also notable differences in the diatom flora between the two major groups. The first group was separated further into two sub-groups, one with samples from Kibos and the second with samples from Nyando. Within these subgroups were samples which reflected high altitude and high dissolved oxygen. The group of Kisat had upstream and downstream sub-groups. These major separations were associated with obvious differences in diatom species composition.

CCA analysis clearly showed that the observed variation in diatom community structure among the rivers and sites were strongly explained by gradients of six environmental variables: conductivity, alkalinity, turbidity, silicate, dissolved oxygen and altitude. Major differences between the two main groups, Nyando and Kibos versus Kisat were thereby explained by differences in the environmental variables and differences in pollution levels.

Waters with low ionic content, low trophic state, low turbidity, low temperature, high oxygen content and occurring mainly in high altitudes had pollution sensitive species and were mainly present in Kibos. This river has catchments with less human activity.

Highly turbid waters with relatively high trophic state mainly due to nitrate and silicate, in addition to large amounts of suspended matter had species that tolerate high turbidity and trophy. These were mainly waters from the Nyando. Deforestation associated with human settlement and agricultural activities results in high soil erosion and subsequently high turbidity, sediment loading and nutrients.

Waters with high ionic content (conductivity and alkalinity) mainly had pollution tolerant diatom species. They can be separated into two. There are those that can tolerate higher hardness (calcium and magnesium ions) and occurred in upper Kisat that largely receives domestic sewage from slums and possibly Kenya Breweries. Then there are those that prefer high phosphates and mainly occurred in downstream Kisat that receives effluents from industrial area and the municipal sewage plant.

This study shows that most of good quality waters are found in Kibos. Nyando has fair quality while Kisat has the greatest proportion of low-grade water. Data on the environmental conditions and indicator diatom assemblages, for example on the Kibos, can be used to track developments on this river and to monitor improvements on the other rivers in the face of any rehabilitation programs. Pollution abatement and prevention could include improvement of the sanitation infrastructure, especially in the slum areas and treatment of industrial effluents and sewage. A further interest of this study could be to see whether better water quality would be realized in the small Kisat that is also vulnerable to pollution and other rivers thereafter by observations on diatoms.

High correlations and levels of significance of species to environmental variables exhibited by the multivariate analyses clearly demonstrated that epilithic diatoms can provide complementary information on water quality and ecological conditions in rivers Kibos, Nyando and Kisat and can therefore be used for monitoring purposes of these and other rivers in the region.

Although we collected our samples rather irregularly, the general structure of the diatom community appears to remain the same. Some slight changes occurred and they were more or less confined to the particular site. This can explain why samples from the same stations obtained during different times remain close to each other both in cluster and ordination analysis. However, our analysis did not include effects of season. The importance of seasonality in influencing the diatom distributions can be revealed through more regular sampling, which is a more practical way for further research.

Chapter 6

Diatom assemblages and their relationship to environmental Variables in Lake Victoria (Kenya part)

6.1. ABSTRACT

Diatom assemblages and environmental variables were analyzed from 14 stations in the Kenya part of Lake Victoria during three trips in November and December 1999 and January 2000. 101 taxa belonging to 29 genera were identified and 13 environmental variables measured. Species diversity ranged from 0.1 to 2.5 in the Nyanza Gulf and from 0.1 to 1.7 in the open lake. Species richness, diversity and evenness were highly correlated with conductivity and silicate. Two-way indicator species analysis separated the diatom community into two main groups comprising assemblages of the Nyanza Gulf and the ones from the open lake, reflecting environmental gradients. The open lake was generally associated with higher abundance of *Nitzschia acicularis* that was also the indicator species for this group. *Aulacoseira agassizii, Cyclotella meneghiniana, Nitzschia fonticola and Cyclostephanos dubius* were indicator species for the Nyanza Gulf group. Canonical correspondence analysis identified conductivity, alkalinity, dissolved oxygen and lake depth as the environmental variables that significantly explain variations in the diatom assemblages. The results provide evidence that diatoms can be useful indicators of water quality in Lake Victoria.

6.2. INTRODUCTION

Rapid changes in the environment and ecology of Lake Victoria in the last few decades are of great concern to managers, riparian population and the scientific community. Introduction of alien fish species in the 1950s and 1960s in addition to increased fishing activities has seen the decimation of a once highly diverse fish community (Ogutu-Ohwayo, 1990; Witte *et al.*, 1992). The fishery is now dominated by three species: the introduced Nile perch (*Lates niloticus*) a voracious piscivore and Nile tilapia (*Oreochromis niloticus*), and an indigenous cyprinid *Rastrineobola argentea*.

The waters of lake have indicated eutrophication mainly associated with high human population, deforestation and agricultural activities in the catchments. Increased inputs of nutrients have enhanced algal biomass and domination of the phytoplankton by cyanobactria especially in shallow waters (Ochumba & Kibaara, 1989; Hecky 1993; Lung'ayia *et al.*, 2000, Lung'ayia *et al.*, 2001). A persistent stratification has caused incomplete mixing of the water column and the bottom waters of the deeper parts of the lake are increasingly becoming anoxic (Hecky *et al.* 1994). Bottom-dwelling fish species have been displaced and the bottom waters now harbour large populations of a freshwater prawn *Caradina nilotica* (Muli, 1996). In addition, the anoxic layer is moving to shallower depths due to accumulation of large amounts of dead algae and other plant material (Ochumba & Kibaara, 1989; Hecky & Bugenyi, 1992, Mugidde 1993; Lung'ayia *et al.* 2000, 2001).

Incomplete mixing of the water column has led to less re-circulation of silicon, lost to the hypolimnion through dead sinking diatoms. The reduction in the concentration of silicon in the epilimnion (Kilham & Kilham, 1990; Verschuren *et al.*, 1998), an important component in the formation of frustules of diatoms can be associated with reduction in biomass and increased photosynthetic rates of the diatoms (Hecky, 1993; Kling *et al.*, 2001). The composition of the diatom community also seem to have changed and recent studies indicate that *Aulacoseira* spp. are overtaken by *Nitzschia acicularis* as the most abundant diatoms (Kling *et al.* 2001; Lung'ayia (in press, LV 2000 conference proceedings).

An important recent addition to ecological problems facing Lake Victoria is the invasion by the water hyacinth, a problematic aquatic weed, since late 1980s. Extensive cover of water surfaces by mats of the weed is known to degrade the water quality. Low oxygen levels, for example, are now found even in inshore shallow waters (Lung'ayia *et al.*, 2001), a condition that previously occurred only in the deeper parts of the lake (Talling 1966b; Hecky, 1993). Further, the effects of shredding of the plant as one of the control methods and dumping the residue into the lake are not known. The re-occurrence of the weed in areas where it has been removed and its effects on the water quality and ecology are social, economic and public concerns.

In this paper, patterns in distribution of diatoms in the surface waters of Lake Victoria are described in relation to environmental characteristics. References are made to diatom assemblages reported previously to gain an insight into the continuously changing environment of the lake.

6.3. MATERIALS AND METHODS

6.3.1. Study area

The Kenya part of Lake Victoria is situated in the Northeastern part of the Lake. It comprises the Nyanza Gulf (also known as Kavirondo Gulf or Winam Gulf) and part of the main Lake (Fig. 6.1) contributing about 6% of the total area of the lake. The Nyanza Gulf is joined to the main lake via Rusinga channel. A causeway linking Rusinga Island to the mainland blocks Mbita Channel, a second channel between the two water masses. Fast water currents that previously passed through this second channel were curtailed reducing water exchange between the gulf and the open lake and causing negative effects on the fishery (Burgis *et al.*, 1987) and probably on the limnology of the area.

Lake Victoria is situated at an elevation of 1134 m a.s.l. And straddles across the equator. Its basin overlies Precambrian rocks and Quaternary sediments accumulated in several places including east of the Nyanza Gulf (Kendall, 1969, Burgis *et al.*, 1987). The climate is typically equatorial with monthly mean air temperature ranging 21.9 to 24.3 °C. There are two main rainy seasons: The long rains from March to May and the short rains from November to December.

The catchments area of Lake Victoria in Kenya is about 47,709 km^2 (Republic of Kenya, 1986). Drainage is by several rivers and streams that flow through some of the most densely populated areas in the country. Agricultural land, urban centers and industrial activities are sources of inputs into the lake. In addition, a flourishing fishery and lake transportation have attracted a number of settlements and activities along the shores and in the islands.

14 routine stations (Figure 6.1) were investigated during November and December 1999 and January 2000. The stations are among the ones used for limnological monitoring of Lake Victoria by Kenya Marine and Fisheries Research Institute (KMFRI). They include a range of depths from shallow inshore to deep offshore both in the Nyanza Gulf and in open lake,

and are under various environmental influences. (see Chapter 2 for more details on sampling stations).

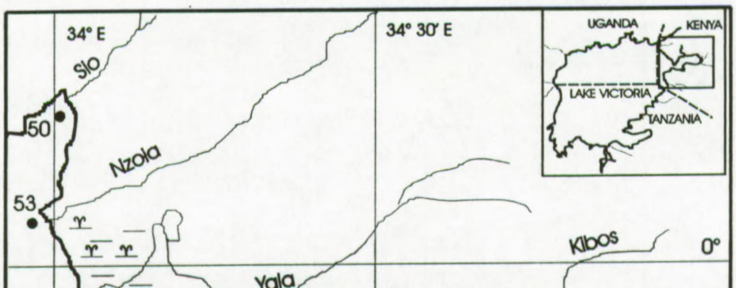

Figure 6.1. Map of Lake Victoria (Kenya) showing location of the sampling stations (3 – 106, MA, MB).

6.3.2. Environmental variables

In situ measurements of water temperature, dissolved oxygen, pH, and conductivity were taken with a Hydrolab Surveyor II Multi-parameter Water Quality Monitoring System. Secchi depth was estimated with a 20 cm diameter black-white Secchi disc. Turbidity was measured with a 2100 P Hach Turbidimeter. Lake depth was determined by an echo sounder on board the research vessel, and confirmed by readings from the Hydrolab.

Water samples were collected from 0.5 m below the surface. Total alkalinity was determined by titration with HCl and total hardness was determined by EDTA titration immediately on collection. Water samples for analysis of nutrients were collected in 500 ml polyethylene bottle, preserved with 0.2 ml mercury (11) chloride, stored in ice and transferred to the laboratory. The samples were filtered (cellulose-acetate membrane, pore size 0.45µm). Spectrophotometric methods were used to determine nitrate-nitrogen (cadmium reduction), phosphate-phosphorus (SRP, ascorbic acid), silicate dissolved SiO_2 (molybdosilicate), using suitable methods selected from APHA (1995) and Wetzel & Likens (2000). Chlorophyll *a* was determined by spectrophotometric analysis according to Strickland and Parsons (1968) after cold (refrigeration) extraction of the pigment in 90% acetone for 18 to 24 hours.

6.3.3. Diatoms

500 ml of sub-sample of water for other analyses was fixed with Lugol's solution. The samples were concentrated by settling for several days to a final volume of 20-30 ml. Diatoms were cleaned with sulphuric and nitric acids and mounted in Styrax® (Gum storax) for microscopic examination at magnification 1000 x under oil immersion. At least 300 frustules from each sample were counted and identified according to Krammer & Lange-Bertalot (1986-1991) and guidelines given in Barber & Haworth (1981). Other taxonomic literatures included Huber-Pestalozzi (1962), Germain (1981), Gasse (1986) Vyverman (1991) and Cocquyt (1998). Cross-checking of species identification was done with the checklist of Cocyut *et al.*, (1993) for East African great lakes.

6.3.4. Data analysis

The diatom data were used to calculate species richness (S) (Lande, 1996; Hillebrand & Sommer, 2000), Shannon & Weaver (1963) diversity index, species evenness or equitability index (Pielou, 1975) and index of dominance (Simpson, 1949). Correlation analysis was used to determine relations between the diversity measures and between diversity measures and environmental variables.

The diatom data were classified by TWINSPAN (Two-Way INdicator SPecies Analysis (Hill 1979, 1994), contained in the PC-ORD software package (McCune & Mefford, 1999). Pseudospecies cut levels were set at percent abundance of 0, 5, 25, 50 and 75%.

The computer program CANOCO version 4.0 (Ter Braak & Smilauer, 1998) was used for ordination of the diatom data. First detrended correspondence analysis (DCA) was used to determine variations in species data and patterns in structure of the assemblages. Canonical correspondence analysis (CCA), a direct gradient method was used to explore relations between diatom distributions and measured environmental variables. Prior to CCA analysis, environmental variables with skewed distributions were log transformed (except pH, dissolved oxygen and phosphate-phosphorus).

For both TWINSPAN and CCA analysis, the samples were abbreviated to give the station code (3 – 105, MA, MB), the month of sampling (No: November, De: December, Ja: January) and year of sampling (99: 1999, 00: 2000). For example, 9Ja00 refers to a sample of station 9 in January 2000.

6.4. RESULTS

6.4.1. Environmental variables

Mean values of environmental variables of the surface waters of the 14 stations of Lake Victoria during this study are given in Table 6.1. There were some considerable variations in some of the environmental variables. Lake depth generally increased from near-shore to offshore and from Nyanza Gulf to open lake. Secchi-depth followed a similar pattern: low values in near shore waters and increasing offshore and in the open lake. pH ranged from 6.7 to 9.6 but showed no particular trends. Concentration of dissolved oxygen varied from 4.0 to 8.5. Temperature also varied little although a slightly higher mean value (27.8 °C) was recorded at station 10. Actual values of temperature ranged between 25.1 and 28.1 °C.

Conductivity, total alkalinity, total hardness, turbidity, silicate (SiO_2) and nitrate (NO_3-N) were higher in the shallow near shore waters in the Nyanza Gulf and decreased offshore and in the open lake. However, in the open lake, slightly elevated levels of these environmental variables were recorded in the southern stations (106 and MB) when compared to the northern stations.

Actual values for the area of study varied from 104 to 208 $\mu S\ cm^{-1}$ for conductivity, 32 to 100 mg l^{-1} as $CaCo_3$ for total alkalinity, 12 to 72 mg l^{-1} for total hardness, 4.8 to 57 NTU for turbidity, 0.2 to 27.5 mg l^{-1} for silicate and 6 to 169 $\mu g\ l^{-1}$ for nitrate. Conversely, phosphate (PO_4-P) tended to increase from near shore to offshore and higher values were recorded offshore in the open lake. The actual values varied from 3 to 98 μg l^{-1}. Patterns in chlorophyll *a* were rather irregular both in the Nyanza Gulf and in the main lake, although higher values were recorded at the mouths of rivers Sio and (Station 50) and Nzoia (53).

Table. 6.1. Mean values for environmental variables in the sampling stations in Lake Victoria.

Station	10	31	26	3	4	9	34	32	54	53	50	MA	106	MB
Depth	3	6	5	4	11	4	47	42	4	6	4	17	9	19
Secc.	0.6	0.8	0.9	0.6	1.0	0.9	1.6	1.7	1.3	0.8	0.8	1.7	0.8	1.3
Turb.	26	17	25	31	9	24	9	7	12	26	24	7	27	12
Temp.	27.8	26.3	25.9	26.2	26.1	25.8	25.9	26.1	26.2	26.2	26.2	26.1	26.5	25.5
Oxyg.	6.1	6.2	6.8	5.8	6.0	5.5	6.3	6.7	6.3	6.2	6.4	7.6	7.3	6.5
pH	7.9	7.5	7.6	8.1	8.1	8.3	8.2	8.8	7.8	7.8	7.9	8.5	7.8	7.6
Alka.	69	69	67	65	60	48	47	46	42	44	47	43	42	41
Hard.	46	43	52	48	40	49	50	26	31	32	29	37	34	35
Cond	178	174	176	175	167	169	127	119	114	116	118	115	111	110
PO_4-P	25	31	25	54	31	22	47	46	38	46	36	59	66	55
NO_3-N	91	51	29	54	21	37	45	29	40	60	21	24	72	64
SiO_2	19	18	17	16	14	10	5	2	4	4	3	3	7	2
Chl *a*	17	15	13	15	22	12	19	18	14	23	39	8	14	9

Units : Lake depth (m), Secchi depth (m), turbidity (NTU = Nephelometric turbidity units), temperature (°C), dissolved oxygen, (mg O_2 l^{-1}), pH (pH units), total alkalinity (mg l^{-1} as $CaCo_3$), total hardness (mg l^{-1} as $CaCo_3$), conductivity (μS cm^{-1}), phosphate-phosphorus (μg l^{-1}), nitrate-nitrogen (μg l^{-1}), silicate SiO_2 (mg l^{-1}), chlorophyll *a* (μg l^{-1}).

6.4.2. Diatom species richness and diversity

101 diatom taxa belonging to 29 genera were identified (Table 6.2) and their relative abundances recorded. *Navicula* was the most represented genus with 22 taxa followed by *Nitzschia* with 14 taxa. *Fragilaria* was represented by 9 taxa, *Gomphonema* by 8 and *Amphora* 6 while the rest of the genera had less than 6 taxa.

Table 6.2. List of diatom taxa recorded in Lake Victoria (Kenya part) and their codes used in TWINPAN and CCA.

Code	Taxon	Code	Taxon
Ach min	*Achnanthes* cf. *minutissima* Kützing	Mas smi	*Mastogloia smithii* Twaites
Ach cle	*Achnanthes clevei* Grunow	Nav bac	*Navicula bacillum* Ehrenberg
Ach hun	*Achnanthes hungarica* (Grunow)	Nav bre	*Navicula brekkaensis* Petersen
Ach plo	*Achnanthes ploenensis* Hustedt	Nav cte	*Navicula cryptotenella* Lange-Bertalot
Amp ped	*Amphora pediculus* (Kützing) Grunow	Nav cto	*Navicula capitatoradiata* Germain
Amp cof	*Amphora coffeaeformis* (Agardh) Kützing	Nav cry	*Navicula cryptocephala* Kützing
Amp com	*Amphora commutata* Grunow	Nav cus	*Navicula cuspidata* (Kützing) Kützing
Amp mon	*Amphora montana* Krasske	Nav dec	*Navicula decussis* Østrup
Amp ova	*Amphora ovalis* (Kützing) Kützing	Nav dig	*Navicula digitoradiata* (Gregory) Ralfs
Amp ven	*Amphora veneta* Kützing	Nav gas	*Navicula gastrum* (Ehrenberg) Kützing
Ano fol	*Anomoeneis follis* (Ehrenberg) Cleve	Nav gre	*Navicula* cf. *gregaria* Donkin
Ast for	*Asterionella formosa* Hassal	Nav nya	*Navicula nyassensis* O. Müller
Aul aga	*Aulacoseira agassizii* (Ostenfeld) Simonsen	Nav obl	*Navicula oblonga* Kützing
Aul amb	*Aulacoseira ambigua* (Grunow) Simonsen	Nav pal	*Navicula* cf. *palatoides* (O. Müller) Hustedt
Aul nya	*Aulacoseira nyassensis* O. Müller	Nav psl	*Navicula pseudolanceolata* Lange-Bertalot
Aul ita	*Aulacoseira italica* (Ehrenberg) Simonsen	Nav pup	*Navicula pupula* Kützing
Aul gra	*Aulacoseira granulata* (Ehrenberg) Simonsen	Nav rhy	*Navicula rynchocephala* Kützing
Cal bac	*Caloneis bacillum* (Grunow) Cleve	Nav sem	*Navicula seminulum* Grunow
Cal lep	*Caloneis leptosoma* (Grunow) Krammer	Nav sub	*Navicula* cf. *subminuscula* Manguin
Coc plc	*Cocconeis placentula* Ehrenberg	Nav tri	*Navicula tripunctata* (O.F. Müller) Bory
Cyc dub	*Cyclostephanos dubius* (Fricke) Round	Nav var	*Navicula variostriata* Krasske
Cyc men	*Cyclotella meneghiniana* Kützing	Nav vir	*Navicula viridula* (Kützing) Ehrenberg
Cyc oce	*Cyclotella ocellata* Pantocsek	Nav vul	*Navicula vulpina* Kützing
Cyc ste	*Cyclotella stelligera* Cleve & Grunow	Nit acc	*Nitzschia acicularis* (Kützing) W. Smith
Cym sol	*Cymatopleura solea* (Brébisson) W. Smith	Nit amp	*Nitzschia amphibia* Grunow
Cym ces	*Cymbella cesatii* (Rabenhorst) Grunow	Nit dis	*Nitzschia dissipata* (Kützing) Grunow
Cym elg	*Cymbella elginensis* Krammer	Nit fon	*Nitzschia fonticola* Grunow
Cym sil	*Cymbella silesiaca* Bleisch	Nit gra	*Nitzschia gracilis* Hantzch
Cym tum	*Cymbella tumidula* Grunow	Nit han	*Nitzschia hantzschiana* Rabenhorst
Dia ten	*Diatoma tenuis* Agardh	Nit int	*Nitzschia intermedia* Hantsch
Eun pec	*Eunotia pectinalis* (Dillwyn) Rabenhorst	Nit lac	*Nitzschia lacustris* Hustedt
Fra bre	*Fragilaria brevistriata* Grunow	Nit lin	*Nitzschia linearis* (Agardh) W. Smith
Fra cac	*Fragilaria capucina* Desmazières	Nit mic	*Nitzschia microcephala* Grunow
Fra cap	*Fragilaria capucina* var. *vaucheriae* (Kützing) Lange-Bertalot	Nit nya	*Nitzschia nyassensis* O. Müller
Fra con	*Fragilaria construens* (Ehrenberg) Grunow	Nit pal	*Nitzschia palea* (Kützing) W. Smith
Fra csu	*Fragilaria construens* f. *subsalina* (Hustedt) Hustedt	Nit sig	*Nitzschia sigmoidea* (Nitzsch) W. Smith
Fra coe	*Fragilaria construents* var. *exigua* (W. Smith) Hustedt	Nit sub	*Nitzschia subacicularis* Hustedt
Fra pit	*Fragilaria pinnata* var. *trigona* (Brun & Héribaud) Hustedt	Pin car	*Pinnularia cardinalis* (Ehrenberg) W. Smith
Fra uln	*Fragilaria ulna* (Nitzsch) Lange-Bertalot	Pin alp	*Pinnularia* cf. *alpina* W. Smith
Fra ber	*Fragilaria berolinensis* (Lemmermann) Lange-Bertalot	Pin div	*Pinnularia divergens* W. Smith
Fru rho	*Frustulia rhomboides* (Ehrenberg) De Toni	Pin gib	*Pinnularia gibba* Ehrenberg
Gom acu	*Gomphonema acuminatum* Ehrenberg	Pin sub	*Pinnularia subcapitata* Gregory
Gom ast	*Gomphonema angustatum* (Kützing) Rabenhorst	Rhi vic	*Rhizosolenia victoriae* Schröder
Gom ang	*Gomphonema angustum* Agardh	Rho gru	*Rhopalodia gibberula* (Ehrenberg) O. Müller
Gom cla	*Gomphonema clavatum* Ehrenberg	Sta nob	*Stauroneis nobilis* Schumann
Gom gra	*Gomphonema gracile* Ehrenberg	Sta obt	*Stauroneis obtusa* Lagrstedt
Gom oli	*Gomphonema olivaceum* (Hornemann) Brébisson	Ste ast	*Stephanodiscus astraea* (Ehrenberg) Grunow
Gom par	*Gomphonema parvulum* (Kützing) Kützing	Sur lin	*Surirella linearis* W. Smith
Gom tra	*Gomphonema truncatum* Ehrenberg	Syn cun	*Synedra cunningtonii* G.S. West
Gop ung	*Gomphonitzschia ungeri* Grunow		
Gyr acu	*Gyrosigma acuminatum* (Kützing) Rabenhorst		
Han vir	*Hantzchia virgata* (Roper) Grunow		

Diatom species richness, diversity, evenness and dominance varied greatly across the sampling stations (Figure 6.2). Higher values of species richness and diversity occurred in the shallower stations of the Nyanza Gulf and decreased in the open lake. Absolute values of species richness in the gulf varied from 7 to 45 observed at Station 3 in November 1999 and Station 10 in December 1999 respectively. In the open lake, species richness varied between 4 and 35 recorded at Station 32 and Station 54 respectively.

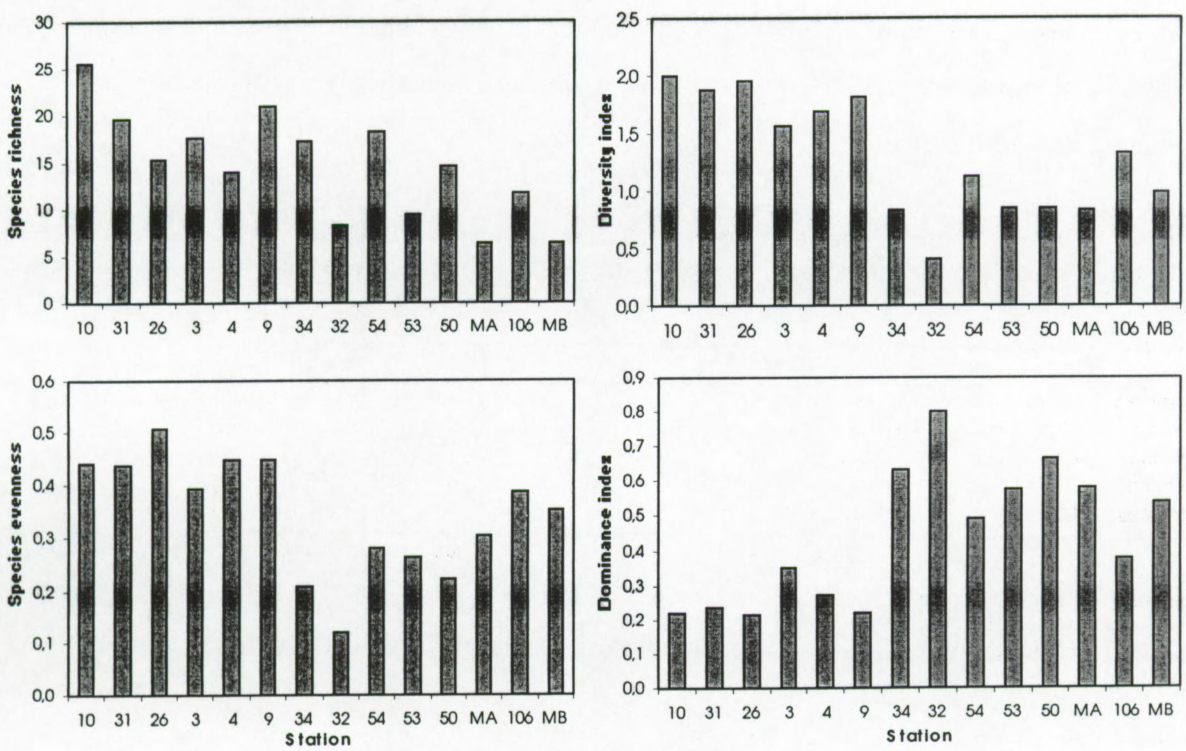

Figure 6.2. Horizontal distribution of mean values for species richness, diversity, evenness and dominance of diatoms in the surface waters of Lake Victoria (Kenya).

The highest species diversity, 2.5, was observed at Station 10 in December 1999 and the lowest in the gulf was 1.0 at Station 3 in November 1999. A much lower value of 0.6 was found at station 34, the confluence of the gulf and the open lake. Species diversity in the open lake ranged between 0.2 and 1.7.

The Nyanza Gulf had higher species evenness in all the stations (Figure 6.2). Evenness decreased in the deeper waters of Stations 34 and 32 and it increased slightly in the shallower near shore waters of the northern part of the lake. A further increase in evenness was observed in the southern stations of the open lake (MA, 105, MB). Absolute values of evenness in the Nyanza Gulf varied between 0.4 and 0.6 and in the open lake, from 0.1 to 0.6.

Higher values of dominance index were observed in the open lake especially in the deeper waters, than in the Nyanza Gulf. Dominance index values varied from 0.2 to 1.0 in the open lake at stations MB and 32 in November 1999 respectively. In the Nyanza Gulf, dominance index ranged from 0.1 to 0.5.

Significant correlations were observed between all the measures of diversity (Table 6.3). There were strong correlations between diversity and species richness and between diversity and evenness. The relationship between richness and evenness was low but significant ($p<0.05$). Dominance index was strongly correlated negatively with species richness, evenness and dominance.

Table 6.3. **Spearman rank correlation coefficient matrix for indices of diatom species numbers, richness,** diversity index, evenness and dominance (n = 42, significant correlations are shown as $^*p<0.05$; $^{***}p<0.001$).

	Species richness	Diversity	Evenness	Dominance
Species richness	1			
Diversity	0.71***	1		
Evenness	0.39*	0.90***	1	
Dominance	-0.64***	-0.98***	-0.92***	1

6.4.3. Relationships between diatom species diversity and environmental variables

Species richness, diversity and evenness were highly correlated significantly with conductivity (Table 6.4). Dominance index was also highly correlated negatively with conductivity. High and significant correlations were also observed between species diversity and evenness with silicate. Dominance was highly correlated negatively with conductivity and silicate. Low but significant correlations were also observed between the diversity measures with lake depth, Secchi depth and phosphate.

Table 6.4. Correlation analysis (Spearman rank correlation coefficient) between species richness, diversity, evenness and dominance, and environmental variables (significant correlations are shown as *p<0.05; **p<0.01; ***p<0.001).

Environmental variable	Richness	Diversity	Evenness	Dominance
Lake depth	-0.42**	-0.45**	-0.37	0.41**
Secchi depth	-0.27	-0.38*	-0.33*	0.34*
Turbidity	0.27	0.27	0.17	-0.24
Temperature	0.10	0.11	0.15	-0.09
Dissolved oxygen	-0.18	-0.10	-0.04	0.09
pH	**-0.28**	**-0.25**	**-0.17**	0.22
Total alkalinity	**0.01**	**0.21**	**0.26**	-0.20
Total hardness	-0.25	0.09	0.27	-0.13
Conductivity	**0.64*****	**0.70*****	**0.53*****	**-0.63*****
Phosphate-phosphorus	-0.42**	-0.37*	-0.23	0.37*
Nitrate-nitrogen	0.03	0.10	0.14	-0.11
Silicate	0.37	**0.66*****	**0.63*****	**-0.64*****
Chlorophyll *a*	0.10	0.05	0.01	-0.04

6.4.4. Classification of diatoms

The TWINSPAN divided the diatom community into two main groups comprising the Nyanza Gulf and the open lake. The assemblages of the Nyanza Gulf are placed on the left side of the TWINSPAN dendrogram (Figure 6.2) with *Aulacoseira agassizii, Cyclotella meneghiniana, Nitzschia fonticola,* and *Cyclostephanos dubius* as indicator species. A few samples from the open lake were also included in the Nyanza Gulf group due to presence of similar species compositions. The assemblages from the open lake appear on the right side of the dendrogram and *Nitzschia acicularis* was the indicator species for this group. Subsequent subdivisions resulted in 7 TWINSPAN groups. Table 6.5 gives the indicator species at different splitting levels. A summary of data on environmental variables in each TWINSPAN group is given in Table 6.6.

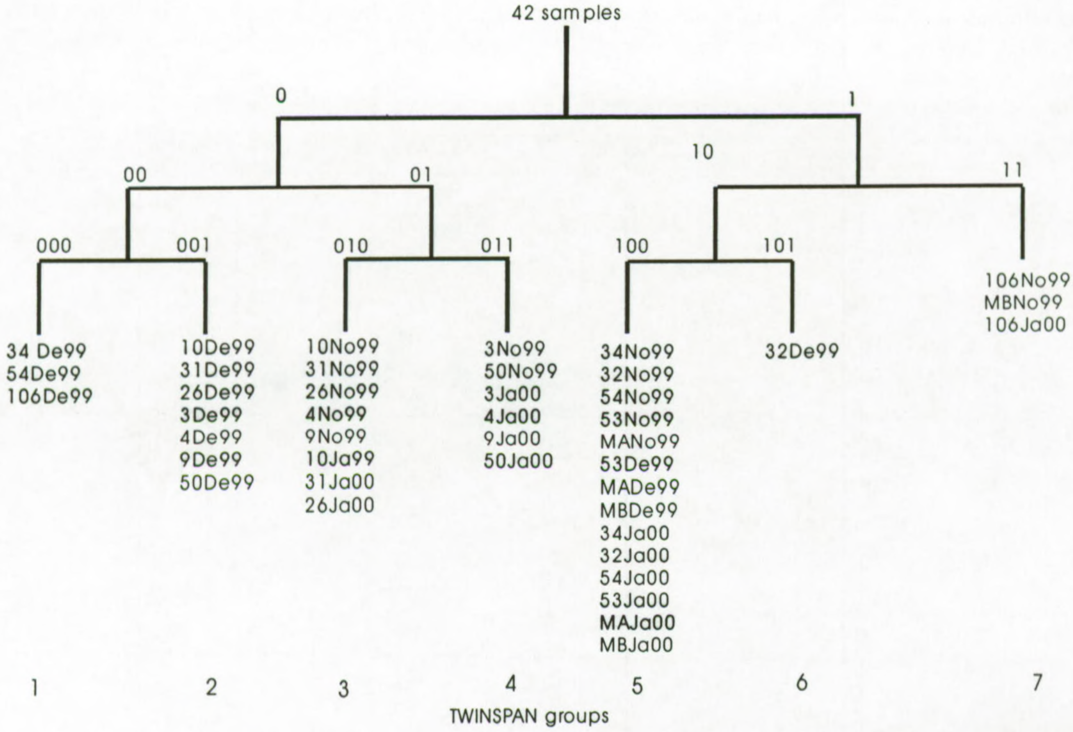

Figure 6.3. TWINSPAN classification of samples based on relative abundance of diatoms of 42 samples from Lake Victoria (Kenya part). subsequent splitting levels are shown and their indicator species are given in table 6.5.

Table 6.5. Indicator species for various splitting levels of the TWINSPAN analysis

Splitting level	Number of samples	Indicator species
0	24	*Aulacoseira agassizii, Cyclotella meneghiniana, Nitzschia fonticola, Cyclostephanos dubius*
00	10	*Navicula digitoradiata*
000	3	*Cyclostephanos dubius*
010	8	*Aulacoseira agassizii, A. nyassensis, A. granulata, Cyclotella meneghiniana*
011	5	*Nitzschia fonticola*
101	1	*Amphora ovalis*
1	18	*Nitzschia acicularis*
11	3	*Aulacoseira granulata*

TWINSPAN group 1 (level 000) n = 3)) contains samples from the open lake stations 34, 54 and 106 collected in December 1999. The indicator species was *Cyclostephanos dubius* and the most preferential species were *Navicula variostriata* and *Nitzschia acicularis*. These samples are grouped with samples from stations of the Nyanza Gulf because of high abundance of species such as *Nitzschia palea, N. lacustris* and *Cyclostephanos dubius* that are also common in the Nyanza Gulf. The samples had on average, low turbidity, moderate ionic content, high nutrients (phosphate and nitrate) and low silicate.

Table 6.6. Mean values of some of the environmental variables for the TWINSPAN groups.

TWINSPAN group	Secchi (m)	Turbid. (NTU)	Temp. (°C)	DO (mg l^{-1})	PH	Alkal. (mg l^{-1})	Cond. (μg l^{-1})	Hardn. (mg l^{-1})	Chl *a* (μg l^{-1})	PO_4-P (µg l^{-1})	NO_3-N (µg l^{-1})	SiO_2 (mg l^{-1})
Group 1 (n=3)	1.1	14	26.1	7.0	8.3	47	108	60	19	65	45	3
Group 2 (n=7)	0.8	27	26.8	5.8	8.3	68	146	53	24	52	57	19
Group 3 (n=8)	0.8	12	19.7	5.1	6.3	38	86	44	15	47	35	4
Group 4 (n=6)	0.7	23	26.0	5.7	8.0	66	158	54	25	32	47	12
Group 5 (n=14)	1.3	13	26.0	6.7	8.2	45	116	38	14	53	40	3
Group 6 (n=1)	1.4	12	26.0	6.9	9.2	32	107	43	20	87	13	1
Group 7 (n=3)	1.1	18	26.3	6.9	7.7	45	106	51	15	66	79	7

TWINSPAN group 2 (level 001) n = 7)) contains samples from mainly shallow stations in the Nyanza Gulf collected in December 1999. One sample of Station 50 from the open lake and collected in December 1999 is included here. The most preferential species for this group include *Aulacoseira ambigua, Cyclotella ocellata* and *C. meneghiniana*. The waters have higher turbidity, higher ionic content and lower dissolved oxygen than group 1.

TWINSPAN group 3 (level 010) n = 8)) contains samples from only the Nyanza Gulf collected mainly in November 1999. Two samples collected in January also occur in this group. The indicator species were *Aulacoseira agassizii, A. nyassensis, A. granulata, and Cyclotella meneghiniana*. The waters have on average low turbidity, small Secchi depth, medium lake depth, low dissolved oxygen and low ionic content.

TWINSPAN group 4 (level 011) n = 6)) comprises samples from stations 3, 4, 9 in the Nyanza Gulf and two samples from Station 50 of the open lake collected in November 1999 and January 2000 respectively. The indicator species was *Nitzschia fonticola*. The samples represent shallow waters with high turbidity, low dissolved oxygen and high ionic content.

TWINSPAN group 5 (level 100) n = 14)) contains samples from the open lake (and Rusinga channel) mainly collected in November 1999 and January 2000. The indicator species was *Amphora ovalis*. *Stephanodiscus astraea* was among the most preferential species. The samples are from waters with low turbidity, relatively high pH, moderate ionic content, high concentrations of phosphate, moderate nitrate and low silicate.

TWINSPAN group 6 (level 101) n = 1)) has only one sample from the open lake station 32 collected in December 1999. *Cyclotella meneghiniana* was the most preferential species. The sample is from waters with the lowest turbidity when compared with the other groups, high transparency, high pH, moderate ionic content, high phosphate and very low silicate.

TWINSPAN group 7 (level 11) n = 3)) contains samples form only the southernmost stations (106 and MB) of the open lake sampled in December 1999 and in January 2000. The indicator species was *Aulacoseira granulata* and the most preferential species were *A. nyassensis* and *Cocconeis placentula*. The waters have on average moderate turbidity, moderate ionic content and high phosphates.

6.4.5. Ordination of the diatoms

Detrended Correspondence Analysis (DCA) ordination of all the 42 samples and 106 diatom species gave a length of gradient for the first axis of 3.504 indicating that the samples were well separated and species well dispersed. This also suggests that the samples and species had a predetermined structure.

Table 6.7. Results of ordination by Detrended Correspondence Analysis (DCA) of data on diatoms in Lake Victoria.

Axes	1	2	3	4	Total inertia
Eigenvalues	0.715	0.544	0.257	0.119	3.591
Lengths of gradient	3.504	3.248	2.677	1.739	
Cumulative % variance of species data	19.9	35.1	42.2	45.6	
Sum of all unconstrained eigenvalues					3.591

Table 6.8. Results of ordination by Canonical Correspondence Analysis (CCA) of data on diatoms in Lake Victoria with the 13 environmental variables.

Axes	1	2	3	4	Total inertia
Eigenvalues	0.555	0.271	0.197	0.174	3.624
Species-environment correlations	0.893	0.714	0.703	0.719	
Cumulative % variance of species data	15.3	22.6	28.2	33.0	
Cumulative % variance of species-environment correlations	34.5	61.3	63.6	74.4	
Sum of all unconstrained eigenvalues					3.624
Sum of all canonical eigenvalues					1.609

Only species with relative abundance of 1% or more were used in the CCA and the final data set comprised 44 species, 42 samples and 13 environmental variables. The results show that

Table 6.10. CCA weighted correlation matrix for the 13 environmental variables used in the CCA analysis.

	Lake depth	Secchi	Turb.	Temp.	Oxyg.	pH	Alka.	Cond.	Hard.	Chlo.	PO_4-P	NO_3-N	SiO_2
Lake depth	1.0000												
Secchi	**0.6374**	1.0000											
Turb.	**-0.5877**	**-0.7551**	1.0000										
Temp.	-0.2408	-0.1571	0.2050	1.0000									
Oxyg.	0.2507	0.0509	0.0101	-0.0490	1.0000								
pH	0.3216	0.2231	-0.0908	0.1606	0.0592	1.0000							
Alka.	-0.2719	-0.4199	0.1147	0.1478	-0.2154	-0.1816	1.0000						
Cond.	-0.3964	-0.4404	0.1764	0.0747	-0.3207	-0.1958	0.4591	1.0000					
Hard.	-0.2142	-0.3017	0.0975	0.0549	-0.1522	0.0795	**0.6135**	0.1494	1.0000				
Chlo.	-0.0910	-0.0347	0.1953	0.2279	0.0514	0.3020	-0.0527	-0.1278	0.0025	1.0000			
PO_4-P	0.1968	0.1088	0.0934	0.2061	0.2080	0.1387	-0.2278	-0.4545	0.0504	0.0255	1.0000		
NO_3-N	-0.0831	-0.0124	0.1362	0.5197	-0.2063	-0.0159	0.0009	-0.0275	-0.0057	-0.1083	0.0058	1.0000	
SiO_2	-0.3289	-0.4029	0.2427	0.2421	-0.2467	-0.1855	0.3673	**0.5327**	0.3605	0.0095	-0.3081	0.1977	1.0000

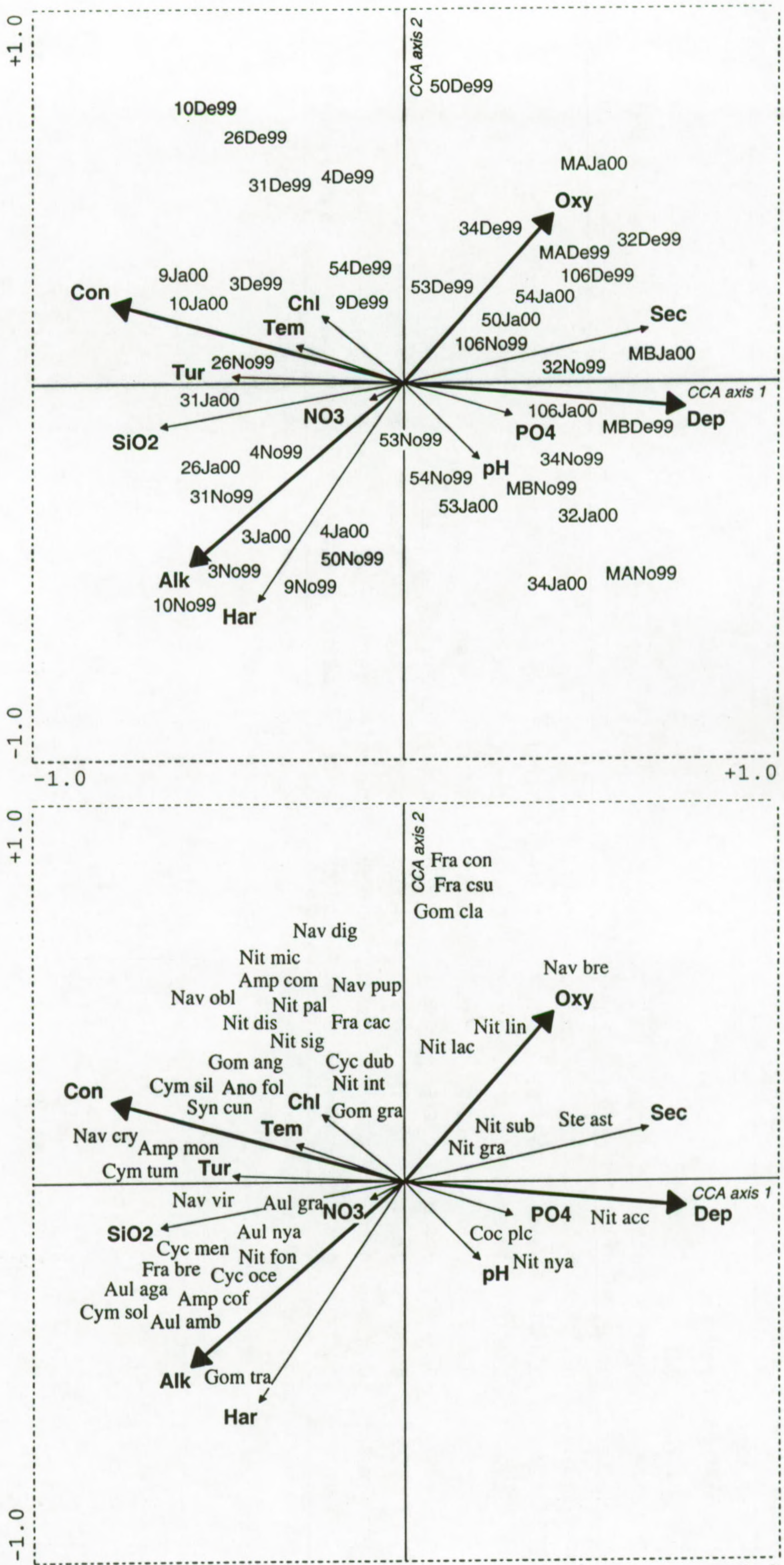

Figure 6.4. Biplot of scores of environmental variables and sample scores (a) and spcies scores (b) of the canonical correspondence analysis (CCA) with 42 samples and 13 environmental variables

CCA axis 1 represents a strong gradient as indicated by an eigenvalue of 0.55 (Table 6.8). The overall variance in the species dispersion was 3.624. The cumulative variance of the species-environment correlations was high indicating that the environmental variables measured have a high influence on the species dispersion.

The Monte Carlo Permutation Tests were significant for both the first canonical axis and all the canonical axes ($p<0.05$). Forward selection in the CCA identified four variables as significant ($p<0.05$) in explaining the variation in species distribution: lake depth, dissolved oxygen, conductivity and alkalinity. All the four environmental variables were still significant in a final CCA ($p<0.05$) and therefore they strongly explained the distribution of the diatoms in Lake Victoria.

CCA axis 1 represents a gradient of lake depth and to a lesser extends Secchi depth and phosphate (Figure 6.4, Table 6.9). The gradient of oxygen is almost intermediate between CCA axis 1 and axis 2. These two main gradients (lake depth and oxygen) showed their greatest variation towards the open lake.

Table 6.9. Weighted correlation matrix showing the relationship between species axis and the 23 environmental variables used in the CCA.

	Axis 1	Axis 2	Axis 3	Axis 4
Lake depth	**0.6698**	-0.0466	0.0641	-0.0694
Secchi depth	**0.5842**	0.1012	-0.0697	-0.0507
Turbidity	-0.4147	0.0130	0.0840	-0.1694
Temperature	-0.2604	0.0722	-0.0861	-0.2818
Oxygen	0.3580	0.3177	0.3107	-0.1096
PH	0.1805	-0.1467	-0.1577	-0.2514
Total alkalinity	**-0.5121**	-0.3467	0.1714	-0.0375
Conductivity	**-0.7028**	0.1514	-0.0100	0.0694
Hardness	-0.3516	-0.4157	0.0864	-0.0722
Chlorophyhll a	-0.1968	0.1268	-0.0295	0.2127
Phosphate-phosphorus	0.2587	-0.0637	-0.2672	-0.3316
Nitrate-nitrogen	-0.0817	-0.0316	0.0466	-0.2060
Silicate	**-0.5864**	-0.0852	0.3522	-0.0645

Conductivity was highly correlated negatively with CCA axis 1. Silicate and turbidity were also correlated negatively with CCA axis 1, while total alkalinity was correlated negatively to both CCA axis 1 and axis 2. These variables had maximum variation in the Nyanza Gulf.

Secchi depth was highly correlated with lake depth and both environmental variables were negatively correlated with turbidity (Table 6.10). Other environmental variables that were highly correlated included alkalinity with hardness, and conductivity with silicate.

As with the results of the TWINSPAN analysis, samples from the open lake (Figure 6.4, right side) are separated from the ones of the Nyanza Gulf (left side) in the CCA. A few samples from the open lake are also included with the ones from the Nyanza Gulf. Although the distributions of samples from the same station are well separated, samples collected in the same sampling trip appear close to each other.

Scores of diatom species that are highly correlated to CCA axis 1 are distributed on the right side of the ordination diagram (Figure 6.4 b, Table 6.2 for full species names). Those that prefer surface of deep waters also associated with high transparency and concentration of phosphate include species such as *Nitzschia acicularis, N. nyassensis, Stephanodiscus astraea* and *Cocconeis placentula* (Figure 6.4 b, bottom right). Species with high scores on the gradient of dissolved oxygen and also occurring in surface of deep waters include *Nitzschia linearis* and *N. lacustris* (Figure 6.4, upper right).

A large number of species have scores negatively correlated to CCA axis 1. They can be divided into two sub-groups. The first subgroup is have high scores on the gradient of conductivity and associated with increasing silicate, turbidity and temperature. This sub-group comprises species such as *Navicula cryptocephala, N. viridula, Amphora Montana, Cymbella tumidula, C. silesiaca, Synedra cunningtonii, Aulacosira granulata* and *Cyclotella meneghiniana*. A seemingly large group of species have their scores close to the gradient of conductivity, temperature and Chloropyll *a* (close to axis 2). They include *Navicula digitoradiata, N. pupula* and *Nitzschia microcephala.*

The second subgroup is highly correlated with gradient of alkalinity (Figure 6.4, bottom left), also associated with increasing hardness. The species most influenced by increasing alkalinity include *Gomphonema truncutum, Cymatopleura solea, Aulacoseira agassizii, A. ambigua* and *Amphora coffeaeformis.*

6.5. DISCUSSION

The results of this study show that species richness, diversity and evenness increased with increase in conductivity (ion content) in the Nyanza Gulf. High concentrations of silicate also seem to contribute to the high diversity and evenness but not to richness. However, a combination of factors may be involved in determining the patterns in the measures of diversity. Our data also included physical changes such as lake depth, transparency, turbidity and chemical changes such as alkalinity, dissolved oxygen and other nutrients (nitrates and phosphate). Variations in these environmental variables occurred between stations and between the Nyanza Gulf and main lake. The difference in diatom species composition is therefore a reflection of their adaptations to the different water types.

Many species could prefer the seemingly high concentrations of ions and nutrients especially silicate in the Nyanza Gulf, in addition to higher temperature. Species such as *Aulacoseira* spp. were the dominant diatoms in most samples of the Nyanza Gulf whereas *Nitzschia acicularis* dominated in the open lake. This difference may be explained by the fact that *Aulacoseira* spp. are thick-walled and therefore able to withstand more turbid and low light conditions in the Nyanza Gulf, whereas, *Nitzschia acicularis* is thin-walled and more efficient at utilizing the low concentration of silicate in the open lake. The adaptation of the latter species to low silicate conditions allows it to grow to high proportions contributing to the high values of dominance index and low diversity in the open lake.

Many factors may play an important role in determining species diversity. Rao, *et al.* (1988) reports increase in temperature and nutrients led to a general increase in diversity of plankton in general in Lake Rangasagar in India. This is also true for Nyanza Gulf where nutrient levels and temperatures are high. Higher species diversity in the shallow waters is due to suspension of a mixture of benthic forms and other diatoms from the littoral zone.

A separation of the diatom community between the Nyanza Gulf and the open lake reflects differences in environmental conditions. Talling (1966 b, 1987) observed similar patterns and found clear differences in phytoplankton in Lake Victoria between inshore shallow waters and off shore areas of the open lake in early 1960s. More recently, Lung'ayia *et al.* (2000) also found separation of the phytoplankton community into assemblages of the Nyanza Gulf and the open lake in 1994 and 1995. These patterns are related to differences in water quality and although there may be differences in the species assemblages, the structural arrangements seem to remain the same over long periods.

In this study, variations in the diatom assemblages were significantly explained by conductivity, alkalinity, dissolved oxygen and lake depth. Our results seem to agree with those of Laing & Smol (2000) who also found gradients of conductivity, alkalinity and depth to influence distribution of diatoms in circumpolar lakes in Russia. Laing & Smol (2000) related the effects of these variables to variations in ion-regulation mechanisms and osmotic stress. Conductivity and alkalinity have also been identified as among important factors that influence distributions in diatom communities in lakes in the East African region (Gasse *et al.* 1983; Gasse, 1986).

Higher conductivity and alkalinity values in shallow waters of the Nyanza Gulf indicate that in addition to the sources from weathering processes and ion transport from the catchments, there are also inputs of pollutants from the various sources including industrial discharges, urban runoff and other activities.

Lake depth, a physical factor and other variables associated with its gradient significantly influence the diatom community in Lake Victoria. The surfaces of the deeper waters in the open lake are associated with low ionic content, lower turbidity, low silicate but high concentration of phosphate. These conditions may favor the small and thin-walled diatoms such as *Nitzschia acicularis*, while in the shallow areas with their numerous micro-habitats encourage growth different forms of diatoms as indicated by higher diversity.

Previously, high levels of dissolved oxygen occurred in the surface waters due to high photosynthetic rates by phytoplankton (Hecky, 1993; Mugidde, 1993). Our data on dissolved oxygen ranging 5.5 to 7.6 mg O_2 mg l^{-1} appear lower than recent measurements in the same stations ranging 6 to 11 mg O_2 l^{-1} in June 1996 (Lung'ayia *et al.*, 2001). Decrease in levels of dissolved oxygen in the 1990s was due to decomposing algae in bottom waters of deep parts of the lake (Hecky *et al.*, 1994; Ochumba & Kibaara, 1989). The decreasing levels even in surface layers now observed could in addition be due to presence of water hyacinth and decomposition of the large quantities of the dead plant matter. Large mats of the water hyacinth plants occasionally cover many areas of the Nyanza Gulf, especially in the bays for long periods. Physical cover prevents atmospheric exchange of oxygen whereas; products of respiration and decomposition processes may result in waters with very low levels of oxygen. Transportation of such oxygen poor-waters by currents may contribute to the low oxygen levels in other parts of the lake.

Oxygen is produced during aerobic respiration by autotrophs and it consumed during decomposition of organic matter (Lampert & Sommer, 1997). The level of oxygen can be an approximate indicator of water quality and gradient of oxygen can roughly reflect levels of saprobity. However, our data set is too small and limited by time and space of collection. There is clear need to for more evaluation of saprobity status of the lake by also combining other variables such as Biochemical oxygen demand (BOD), now that the water hyacinth has become a more or less permanent resident of the lake.

One of the methods applied in attempts to control further proliferation of the water hyacinth includes shredding the plant into pulp and dumping it back into the lake. Although there is lack of information on the effects of this practice, accumulation of the shredded dead plant matter in the bottom waters may enhance oxygen consumption in decomposition processes resulting in further oxygen depletions now generally observed in shallow waters.

Similar diatom compositions seem to characterize some localities that are far separated from each other, pointing to similarities in environmental conditions. Some samples from the open lake, for examples, occurred in the same TWINSPAN groups as for the ones of the Nyanza Gulf. Presence of samples from the main lake with close similarity with the ones of the Nyanza Gulf was also observed on the ordination scores. However, the presence of the samples from the open lake in the assemblages of the Nyanza Gulf may also represent some mixing of the two water masses. Samples collected in the same month also appear close together also indicating that seasonality may be important in the distribution of the diatoms in the lake.

Seemingly, high phosphate concentrations were observed in the surface of the open Lake Victoria. According to Holtzman & Lehman (1998) elevated phosphate concentrations in the offshore waters of the lake are due to recent inputs of minerals resulting from weathering processes and erosion from increasingly deforested land, that seem to have accelerated from late in the 19th century. However, sedimentation rates of this mineral seem to be low due to absence of fast-sinking diatoms (Hotzman & Lehman, 1998), enhancing remineralisation and recycling of this nutrient, for example through release by grazers in the surface waters during activities of feeding on phytoplankton, feces and decomposition processes.

Release of phosphates from sediments is also known to be a significant feature of lakes with anoxic hypolimnia (Nurnberg, 1984). The bottom waters of Lake Victoria are increasingly becoming anoxic and the relatively higher concentrations of phosphate in the open waters could be through release from sediments. Near shore, phosphate is transformed biologically into particulate organic forms in algal biomass (and recently in water hyacinth) and this may explain the low concentrations of inorganic phosphate (PO_4-P) in the Nyanza Gulf.

Among the diatoms listed by Talling (1966b), as important and dominant in Lake Victoria in 1960-61 include *Aulacoseira nyassensis, A. agassizii* and *Stephanodiscus astrea*, which occurred when levels of soluble reactive silica were high. Depletion of silica since the 1960-61 is estimated to be a loss by a factor of more than 10 (Hecky, 1993) seems to have become very prominent in the 1980s (Verschuren *et al.*, 1998). The loss of silica is due to increased loading of phosphorus and nitrogen (Hecky *et al.*, 1996). Subsequent increase in primary production increases rate of sinking of dead diatoms from the epilimnion and burial in the sediments. Consequently, diatom species, mainly *Aulacoseira* spp., which have high requirements for silica, have declined. An upsurge and domination of the phytoplankton by blue-green algae due to eutrophication has also occurred. *Nitzschia acicularis*, with thin cell walls and therefore able to utilize the low silica now available in the offshore waters has replaced *Aulacoseira* spp. as the dominant diatom especially in the open lake.

In previous studies *Aulacoseira* is reported be more or less confined at the mouths of major rivers (Ochumba & Kibaara, 1989; Lung'ayia *et al.*, 2000; Lung'ayia, in press, Lake Victoria International Conference, 2000). In the present study, *Aulacoseira granulata* was the most abundant diatom in the most of the Nyanza Gulf stations while *A. nyassensis and A. agassizii* occurred in low abundance. *Nitzschia acicularis* was the most abundant diatom in the open lake.

6.6. CONCLUSIONS

The results of this study reveal differences in environmental conditions and diatom assemblages between the Nyanza Gulf and the open lake. The Nyanza Gulf is generally shallow with high ionic content and high concentrations of nitrate and silicate. The environment in the gulf seems conducive to many diatom species resulting in higher species richness, diversity and evenness when compared to the open lake. *Aulacoseira* spp. are among the dominant diatoms in the gulf.

The open lake has generally water with greater depths, high oxygen, and high transparency, rich in phosphate but poor in silicate. *Nitzschia acicularis* is the most important diatom in the open lake. The two major groupings of diatoms (Nyanza Gulf versus open lake) are split further into smaller groups of assemblages with similar species.

The variations in diatom distributions are partly explained by morphometric features, in this case lake depth. This when combined with other environmental variables (i.e., dissolved oxygen, etc.) strongly influence distribution of the diatoms. The importance of variables associated with pollution such as conductivity and alkalinity in diatom distribution, may allow evaluation of the response of the lake to both inorganic and organic pollution.

Influence of dissolved oxygen may provide a good indication of the present changing conditions in the lake. Oxygen seems to increase towards the open lake probably due to high turbulence and algal photosynthetic activity. However, large mats of water hyacinth and related decomposition and respiration process in the bays where the plant is normally resident may contribute to low levels of oxygen in shallow waters of the gulf. Although the data on dissolved oxygen reveal little about the levels of organic pollution, there is clear need to for more evaluation saprobity status of the lake by also combining other variables such as biochemical oxygen demand. Such data could also be essential in determining possible contribution of water hyacinth and other sources to organic pollution in the lake.

This study has contributed to understanding of diatom diversity and influencing factors in Lake Victoria. The significant correlations between species distribution and environmental variables show the suitability of diatoms as indicators of water quality in Lake Victoria.

However, there is need to consider sampling at regular intervals and over an extended period in order to include elements of seasonality in future analyses.

Chapter 7

General concluding remarks

A major objective of this study was to find out whether the distribution of epilithic diatoms in rivers Nyando, Kibos and Kisat in the catchments of Lake Victoria could reflect the environmental conditions in the three rivers. Secondly, we wanted to find out if the distribution patterns of diatoms in the surface of Lake Victoria were also explained by environmental conditions.

In the first study, an attempt was made to identify and describe the diatom composition in order to determine available assemblage characteristics and diversity. In order to try to infer the water quality from the patterns seen only from data on diatoms, we used

In the second study, weighted averages of known diatom ecological indicator values were used in order to evaluate the ecological water quality of the rivers investigated from the patterns seen on data from diatoms only.

Finally, the data was processed using multivariate analyses to find out the correlations between diatom species and environmental variables and to identify variables that are the most important in influencing diatom species distribution both in rivers Nyando, Kibos and Kisat, and in Lake Victoria.

The upstream reaches of the rivers Kibos and Nyando are characterized by high altitude associated with low ionic content, low trophic state and low dead organic contaminants. The water quality is degraded downstream of these two rivers and in River Kisat because of inputs from agricultural runoff, industrial effluents and municipal sewage. The changes in water quality affect species composition of the diatoms

The results show that Nyando, Kibos and Kisat have a diverse and abundant diatom flora. In total 224 taxa were identified from all the three rivers when they are combined. Spatial and temporal distribution of the species was observed due to both geographical and factors and changes in chemical and physical variables.

Diatom assemblages in the upstream of Kibos and Nyando to some extend, are composed of species sensitive to pollution including *Gomphonema* cf. *angusta*, *Navicula* cf. *heimansioides*, and N. *schroeteri*. These were followed in mid-reaches by species that can tolerate intermediate pollution levels including *Cocconeis placentula* var. *lineata*, *Amphora montana* and *Gomphonema parvulum*. In the highly polluted waters of Kisat, species that are known to tolerate pollution including *Nitzschia palea* were dominant.

Some differences were also observed in the measures of diversity. Species richness, diversity and evenness were generally higher in upstream areas especially in Kibos where ionic content and nutrient enrichments were low. These measures of diversity declined downstream due to eutrophication and organic pollution, which affects growth of most species of diatoms. The range in mean values of species richness (19 to 38) and diversity (1.3 to 2.6) for the rivers are comparable with results of similar studies elsewhere in the tropics. Higher values of these indices occurred in Kibos while lower values occurred in Kisat.

Low but significant relationships occurred between the diversity measures and environmental variables. This indicated that diversity might reflect changes in the whole community in response to changes in water quality. Diversity also showed variations with time probably because of climatic variations.

The patterns in species diversity fitted well with that for diatom ecological indicator values. High percentages of the diatom species identified for the three rivers have known ecological indicator values. The upstream sections of the relatively "clean" river Kibos were characterized by species with low ecological values of saprobity, oxygen requirements, trophic state and nitrogen uptake metabolism.

Diatom assemblages with medium saprobity, oxygen requirements, trophic state and nitrogen uptake metabolism ecological indicator values characterized the Nyando, while Kisat had species with high values. For example, the mean values for saprobity, for Kibos ranged from 1.5 to 2.0, followed by Nyando (2.0 to 2.7) and Kisat had the highest values (2.9 to 3.4).

The indicator values clearly explained the ecological status of the rivers. Saprobity values for the rivers for example, were highly correlated with BOD_5 ($r = 0.89$, $p<0.001$) and with other variables associated with pollution including hardness (r = 0.7), conductivity (r = 0.8) and total dissolved solids. The high correlations between the diatom indicator values and the environmental variables measured in this study and between the indicator values suggest that they can help determine the ecological status of the water in the rivers due to eutrophication, organic loads and other pollutants. The saprobity indicator values after Van Dam *et al.* (1994) gave the same information as the pollution sensitivity index (IPS) (Coste 2001, unpublished) that is still being developed for use in Europe.

Using multivariate techniques, we found that the distribution of diatoms was explained by both geographical, chemical and physical environment. In the rivers, the diatom community was separated into two major groups: the less polluted Kibos and Nyando, separately from the more polluted Kisat. *Navicula exigua, N. schroeteri* and *Gyrosigma scalproides* were the indicator species for the first broad group comprising samples from Kibos and Nyando. Conductivity, alkalinity, oxygen, silicate and altitude seem to explain a large amount of the variations shown in data of diatoms from the rivers. These major variables in combination with other variables can help us to define environmental conditions using the diatom data. The multivariate methods also identified species that strongly indicate particular conditions.

Data on diatoms from the surface waters of Lake Victoria also showed that species distributions were influenced by environmental variables. Unlike in the rivers, species richness, diversity and evenness seems to increase with increase in ionic content and trophic state especially in the Nyanza Gulf. This may indicate that the levels of the related variables (i.e., conductivity, alkalinity) is still low and has not reached levels, which can limit diatom growth. Conductivity and alkalinity were higher in the Nyanza Gulf when compared to the open lake. The low ionic content in the open lake seems to affect diatom species diversity but encourage domination by species such as *Nitzschia acicularis* that may efficiently utilize the low amounts of silicate.

The diatom community in Lake Victoria was separated into two groups. The first group includes assemblages of the Nyanza Gulf characterized by waters with high conductivity, high alkalinity and associated with high silicate and turbidity. Important species included robust *Aulacoseira* spp. The open lake was characterized by deep waters with increasing levels of dissolved oxygen, high transparency and phosphate but low silicate. The waters were dominated by the thin-walled *Nitzschia acicularis*. Conductivity, alkalinity, oxygen and lake depth explained the largest amount of variation in diatom assemblages in the lake.

Although we have not made any major comparisons between the data on epilithic diatoms from the rivers and the diatoms in the surface of the lake, the results indicate that diatoms can reflect very well the status of the environmental conditions are they are good indicators of water quality in both rivers and lake. Epilithic diatoms were considered in the rivers as opposed to "plankton" diatoms in the lake. However, there were some close resemblances in the different assemblages. *Navicula* and *Nitzschia* were the most represented genera in both the rivers and lake ecosystems, while other important genera included *Fragilaria* and *Gomphonema*. A second similarity between the rivers and the lake is that conductivity; alkalinity and dissolved oxygen were among the most important environmental variables that explained the dispersion in the diatom assemblages.

Our data was collected rather irregularly in rivers Kibos, Nyando and Kisat, and over a short duration in Lake Victoria. More data is required at regular interval and it should be spread over a long period for results that are more conclusive and taking seasonality into consideration.

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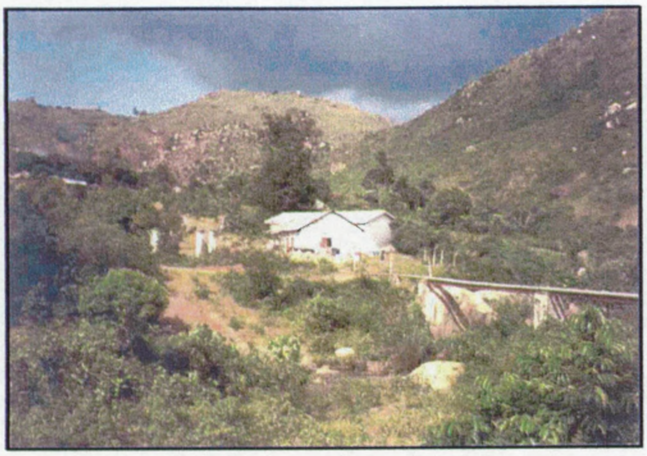
Annexes

Annex 2

Plate 2.1 – 2.4. Photographs showing some of the sampling stations and characteristics of rivers Nyando, Kibos and Kisat.



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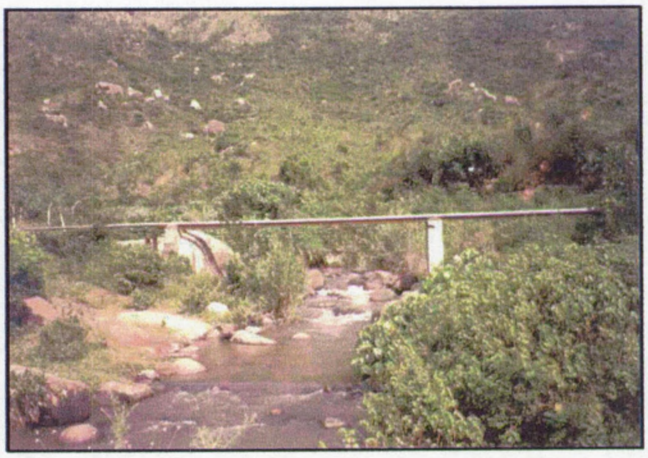

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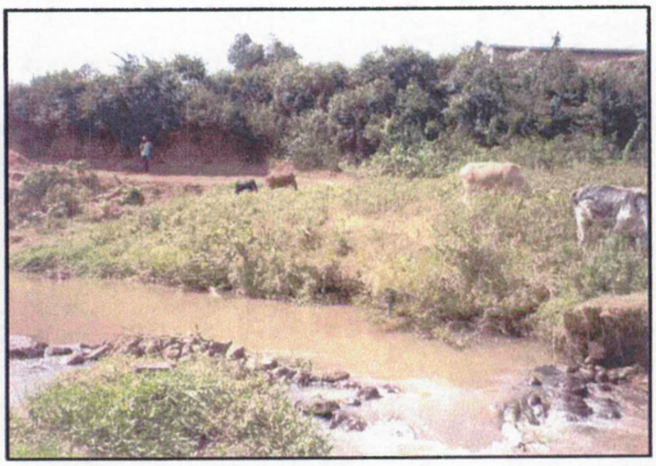

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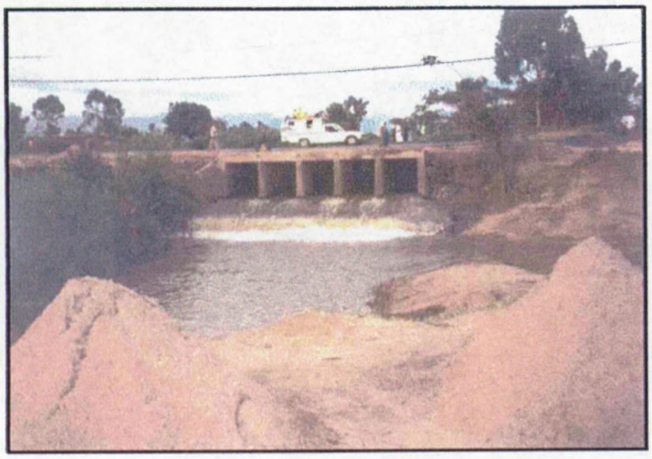
Plate 2.1

1. Station K1 - Kajulu: (a) valley and water pump house and (b) sampling point with water pipe overhead.
2. Cultivated fields near river uptream of Station K2— Riverside, and (a) cattle grazing on river bank at Station K2.
3. Station K3 - Wathorego: (a) banks with dense cover of reeds and (b) sand excavation site downstream.



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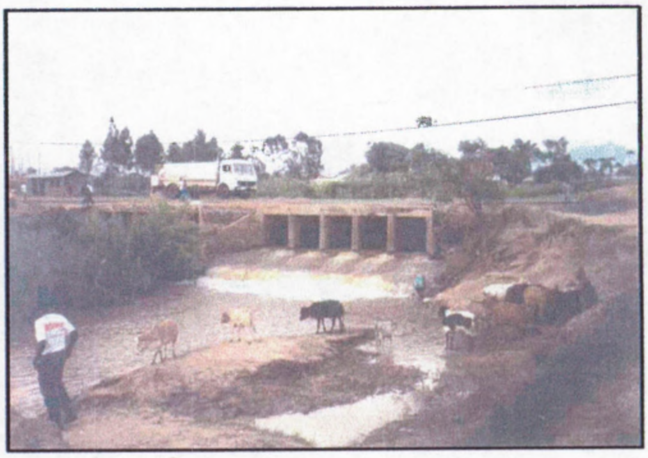

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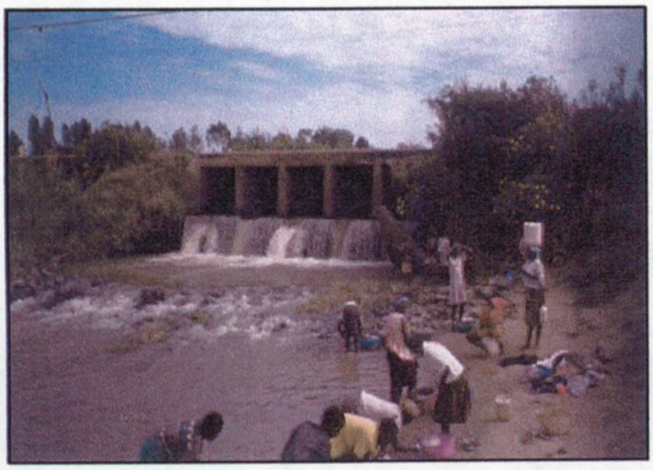

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3 a

3 b

Plate 2.2

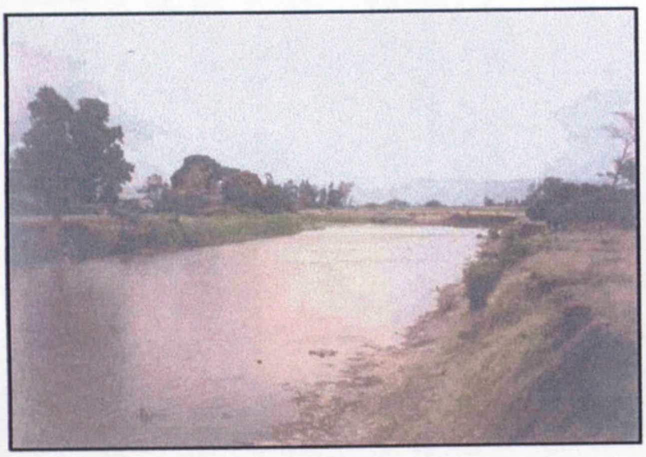
1. Station K4 - Nyamasaria: (a) sand from river-bed (b) cattle going to drink from the river and © laundry activies, etc.

2. Station N1 - Muhoroni,

3. Station N2 - Awasi-Chemelil Bridge, at low level in 3b.

1 a

1 b



2

2b

3a

3b

Plate 2.3

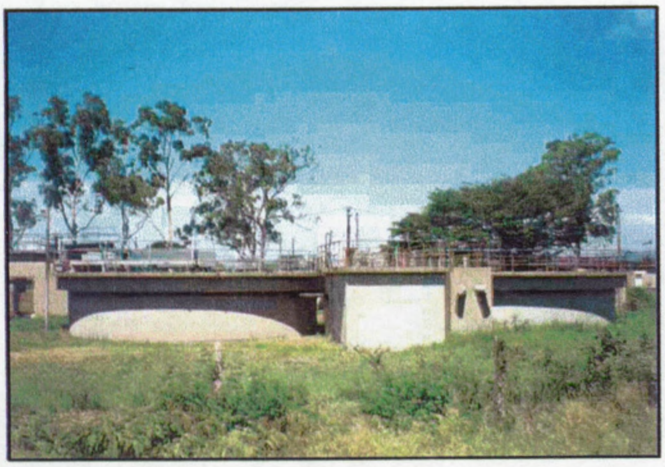
1. Station N3—Ogilo Bridge (a) Stampling station and (b) line with weight for estimation of depth

2. Station N4—Ahero (a) sampling station (b) collection of samples and other measurements

3. (a) Small spring near source of River Kisat.and (b) effluents from factory near Obunga-mbuta (Station C2)

1 a

1b



2a

2b

3a

3b

Plate 2.4

1. Station C3—Kodhu kotur: (a) direct discharge of effluents from factory upstream (b) downstream of C3.

2. (a) Municipal sewage plant upstream of Station C4 (Golf course) and (b) Golf course—Station C4.

3. Downstream of Station C4 and water hyacinth near mouth of the Kisat .

Annex 3

Plates 1 – 18. Light microscopy digital images of some taxa of diatoms in rivers Nyando, Kibos and Kisat.

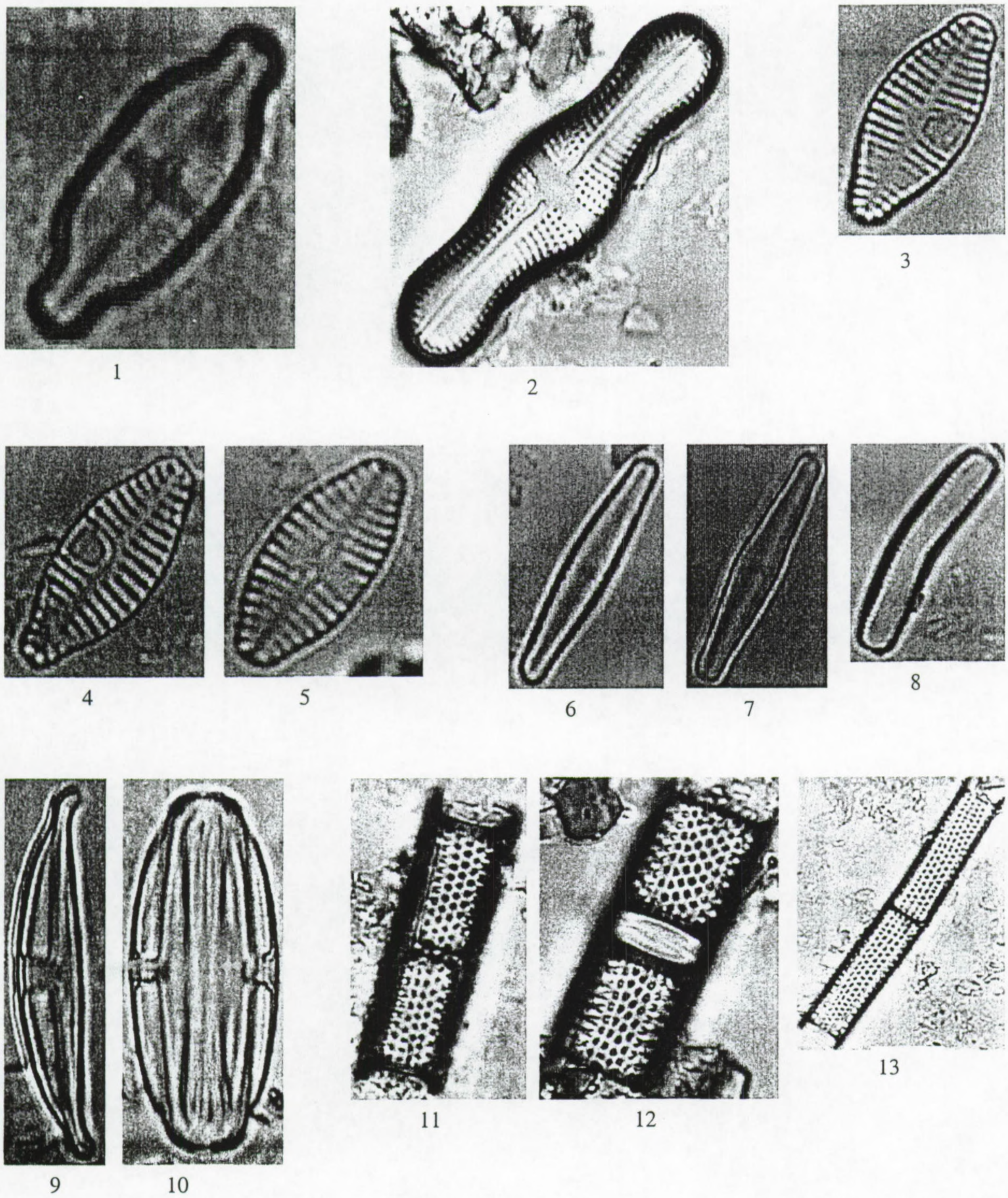


Plate 1

1. *Achnanthes exigua* Grunow. L: 13.8, W: 5.5, striae: 26 in 10 μm.

2. *Achnanthes inflata* (Kützing) Grunow. L: 41.5, W: 11, striae: 12 in 10 μm.

3-5. *Achnanthes lanceolata* (Brébisson) Grunow. L: 13.9-15.1, W: 5.8-7, striae: 14-16 in 10 μm.

6-8. *Achnanthes* cf. *minutissima* Kützing. L: 10.4-19.6, W: 2.6-4.8.

9-10. *Amphora montana* Krasske. L26.6-27.6, W: 5.4, striae: 23-24 in 10 μm.

11-13. *Aulacoseira granulata* (Ehrenberg) Simonsen. L: 11.6-18.4, W: 4.7-6.8, areolae 10-11 in 10 μm, rows of areolae 10-12 in 10 μm.

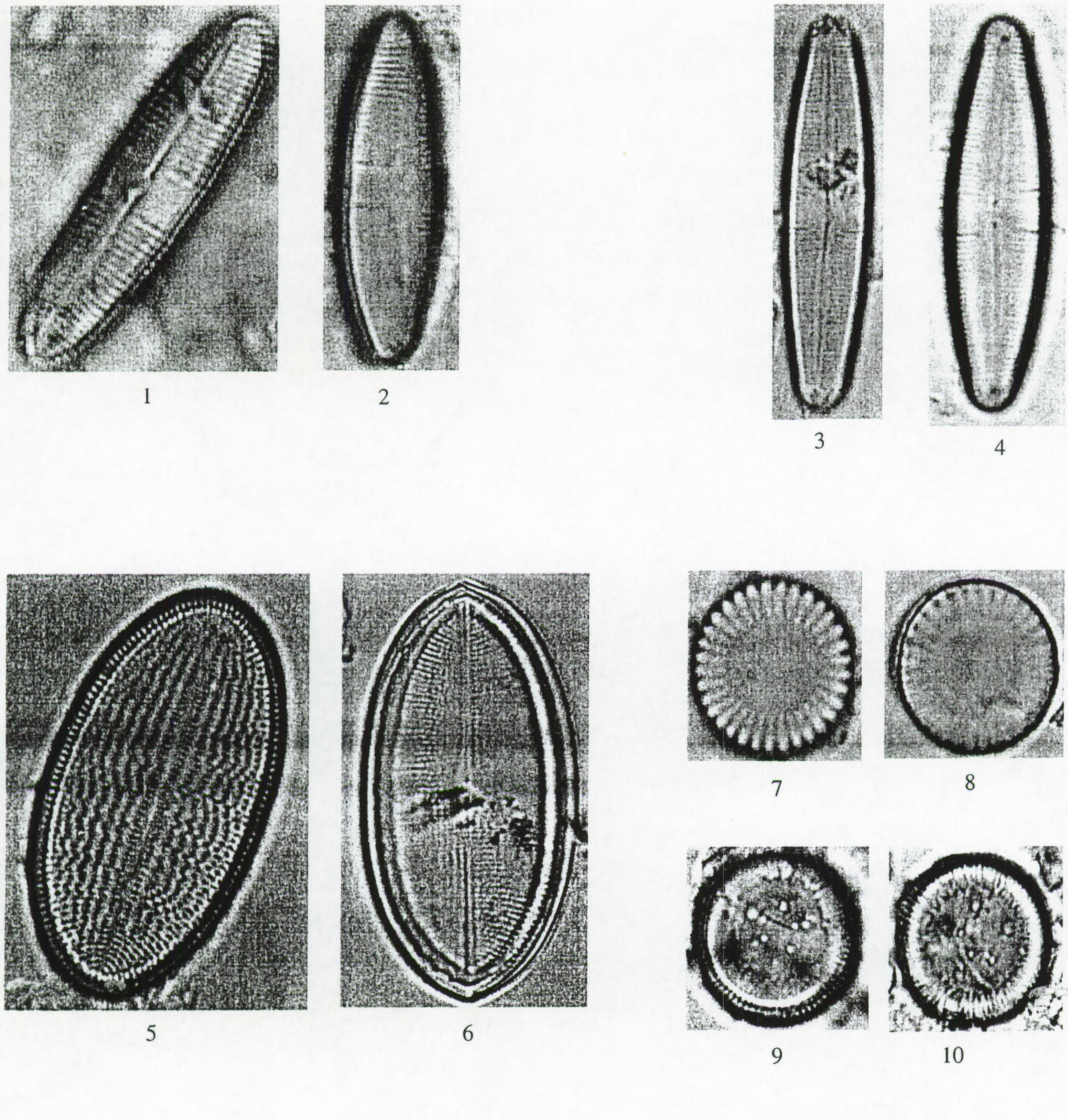


Plate 2

1-2. *Caloneis bacillum* (Grunow) Cleve. L: 23-26.4, W:5.9-6.5, striae: 20-23 in 10 μm.

3-4. *Caloneis molaris* (Grunow) Krammer. L: 29-32, W: 6.3-6.5, striae: 20-22 in 10 μm.

5-6. *Cocconeis placentula* var. *lineata* (Ehrenberg) Van Heurck. L: 40-42.1, W: 20-25, striae: 16-21 in 10 μm.

7-8. *Cyclotella meneghiniana* Kützing. D: 12-12.6, striae: 8-9 in 10 μm.

9-10. *Cyclotella ocellata* Pantocsek. D: 13-14.7, striae: 14 in 10 μm.

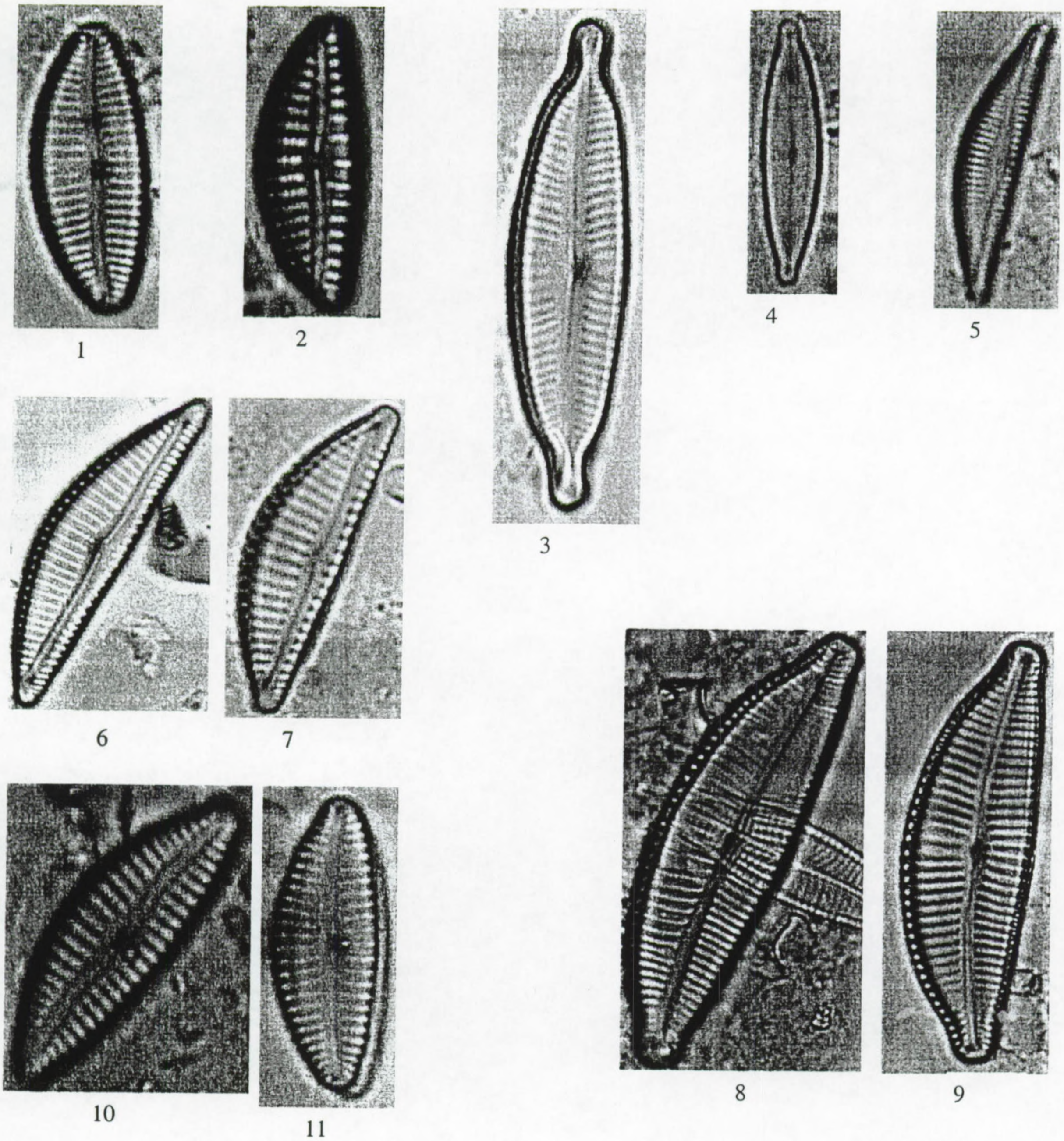


Plate 3

1. *Cymbella affinis* Kützing. L: 22.4, W: 8.4, striae: 11 dorsal, 13 ventral in 10 μm.

2. *Cymbella alpina* Grunow. L: 20.7, W: 7.4, striae: 7 dorsal, 9 ventral in 10 μm.

3. *Cymbella amphicephala* Naegeli. L: 38, W: 9, striae: 11 dorsal, 13 ventral in 10 μm.

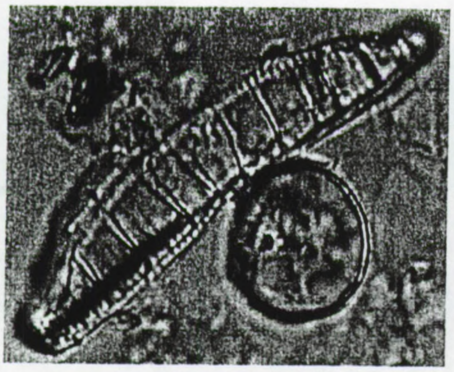
4. *Cymbella delicatula* Kützing. L:24.7, W: 5, striae: 16 dorsal, 18 ventral in 10 μm.

5. *Cymbella falaisensis* (Grunow) Krammer-Lange-Bertalot. L: 18.3, W: 3.9, striae: 10 dorsal, 13 ventral in 10 μm.

6-7. *Cymbella silesiaca* Bleisch. L: 22-37.7, W: 6.5-9, striae: 10 dorsal, 13 ventral in 10 μm.

8-9. *Cymbella tumidula* Grunow. L: 19.6-25.2, W: 6-9.3, striae: 12 dorsal, 13-14 ventral in 10 μm.

10-11. *Cymbella turgidula* (Brébisson) Van Heurck. L: 43.4-47.6, W: 12.7-14.1, striae: 12 dorsal, 15 ventral in 10 μm.



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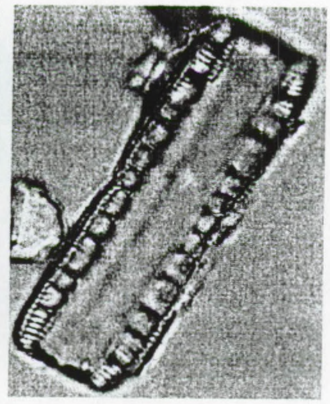

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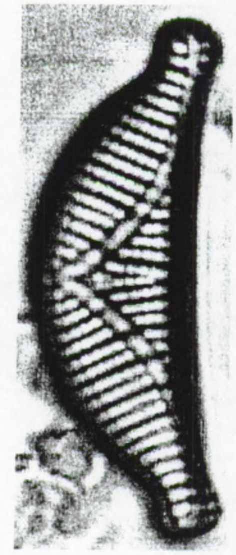

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Plate 4

1-2. *Epithemia adnata* (Brébisson) Kützing. L: 38-40.6, W: 6.6, striae: 13 in 10 μm.

3. *Epithemia sorex* Kützing. L: 27, W: 7.6, striae: 12 in 10 μm.

4. *Eunotia minor* (Kützing) Grunow. L: 34, W: 4.8, striae: 10 in 10 μm.

5. *Eunotia pectinalis* (Dillwyn) Rabenhorst. L: 30, W: 3.8, striae: 8 in 10 μm.

6-7. *Frustulia rhomboides* (Ehrenberg) De Toni. L: 45.5-46, W: 11-11.7, striae: 24-26 in 10 μm.

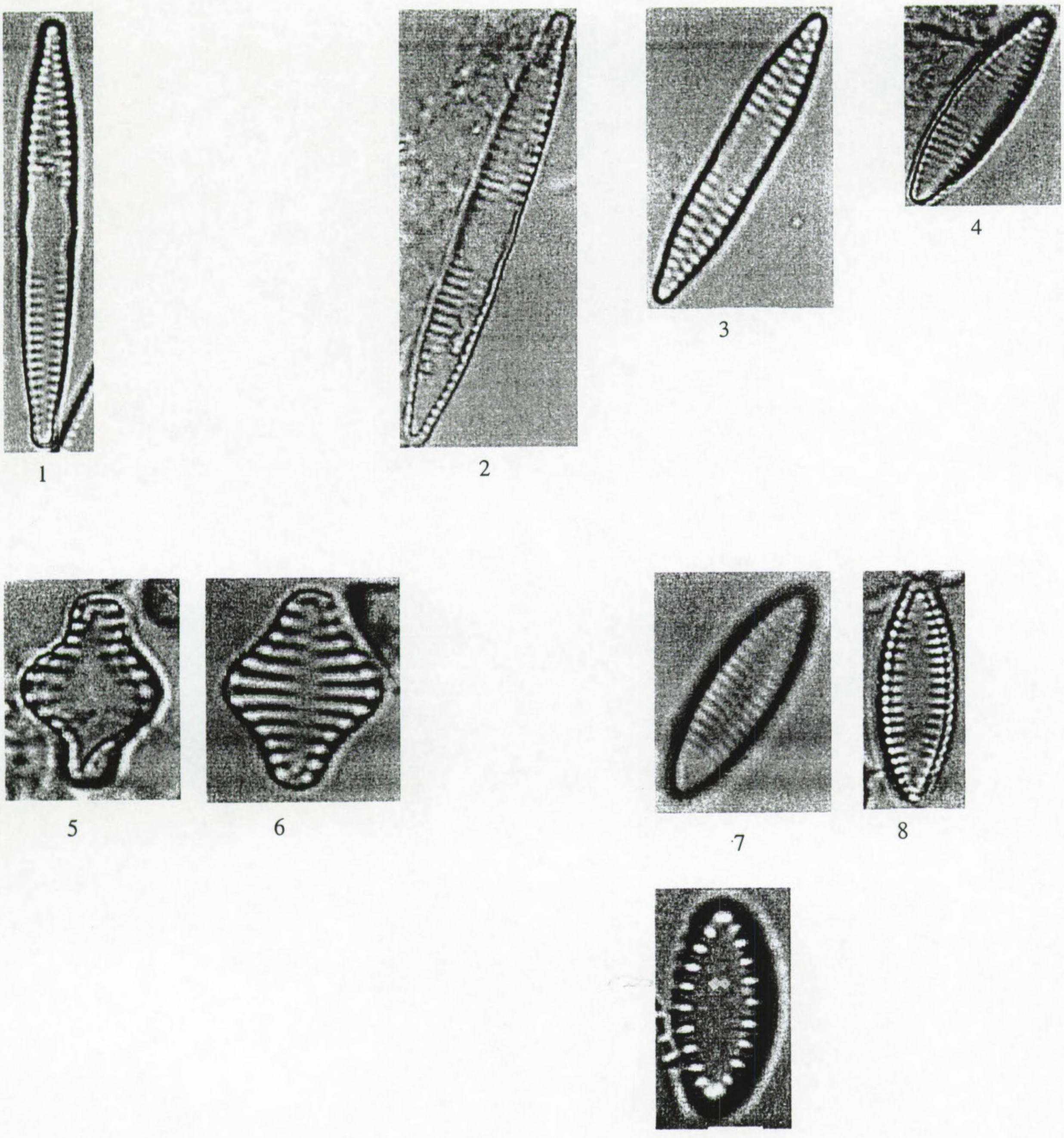


Plate 5

1. *Fragilaria bidens* Heiberg. L: 35, W: 3.7, striae: 11 in 10 μm.

2-4. *Fragilaria capucina* var. *vaucheriae* (Kützing) Lange-Bertalot L: 20-23, W: 4.2-6, striae: 12-15 in 10 μm.

5-6. *Fragilaria construens* (Ehrenberg) Grunow. L: 9.7-11.2, W: 6.3, striae: 13 in 10 μm.

7-8. *Fragilaria construens* f. *subsalina* (Hustedt) Hustedt. L: 12.5-16, W: 4.3-5.1, striae: 14-17 in 10 μm.

9. *Fragilaria pinnata* Ehrenberg L: 10.2, W: 3.8, striae: 11 in 10 μm.

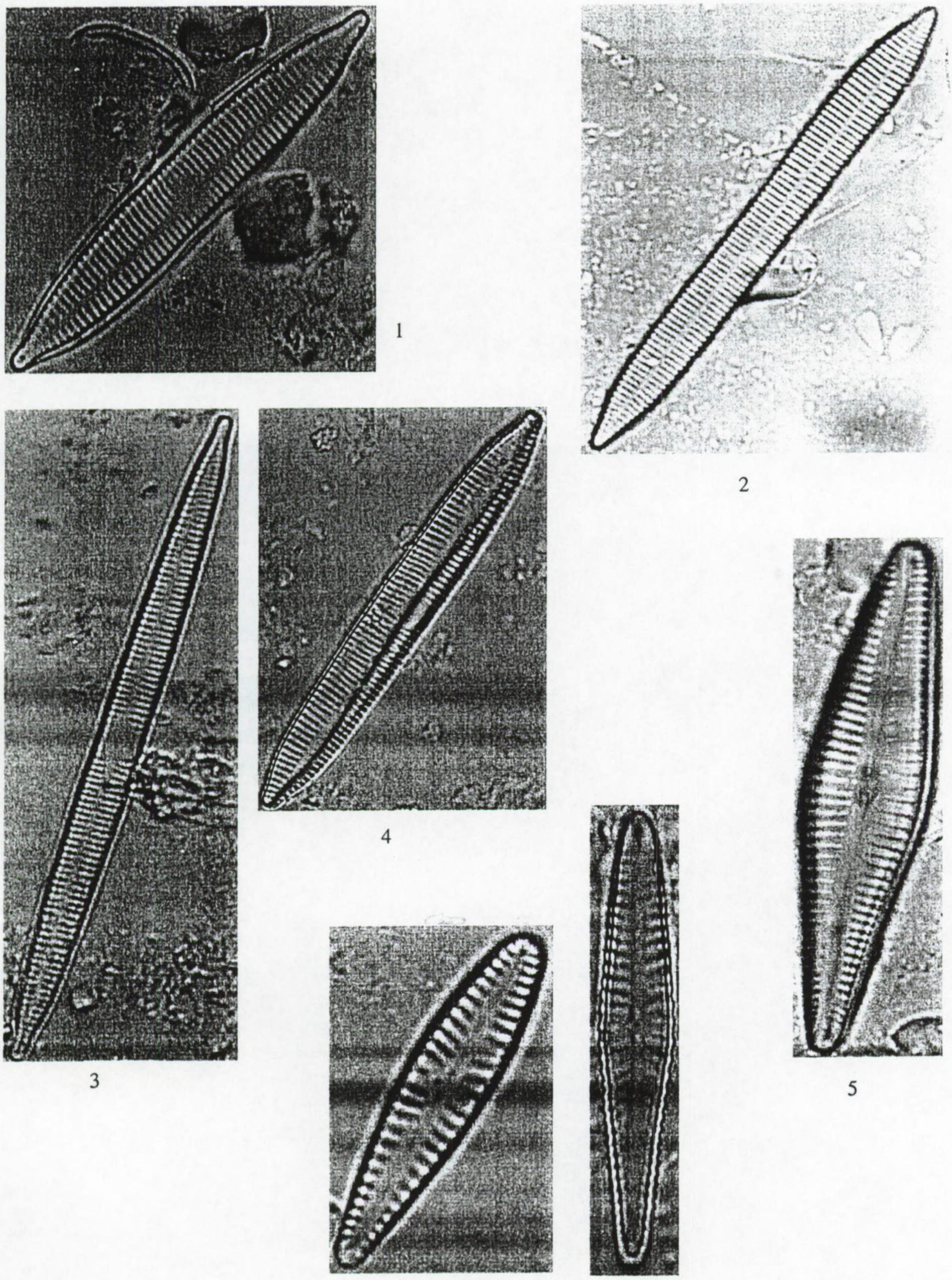


Plate 6

1-4. *Fragilaria ulna* (Nitzsch) Lange-Bertalot. L: 44-98.4, W: 3.5-8, striae: 11-12 in 10 μm.

5. *Gomphonema affine* Kützing. L: 49.4, W: 12.7, striae: 9 in 10 μm.

6-7. *Gomphonema* cf. *angustum* Agardh. L: 20.7-23, W: 5.5-8.5, striae: 14-15 in 10 μm.

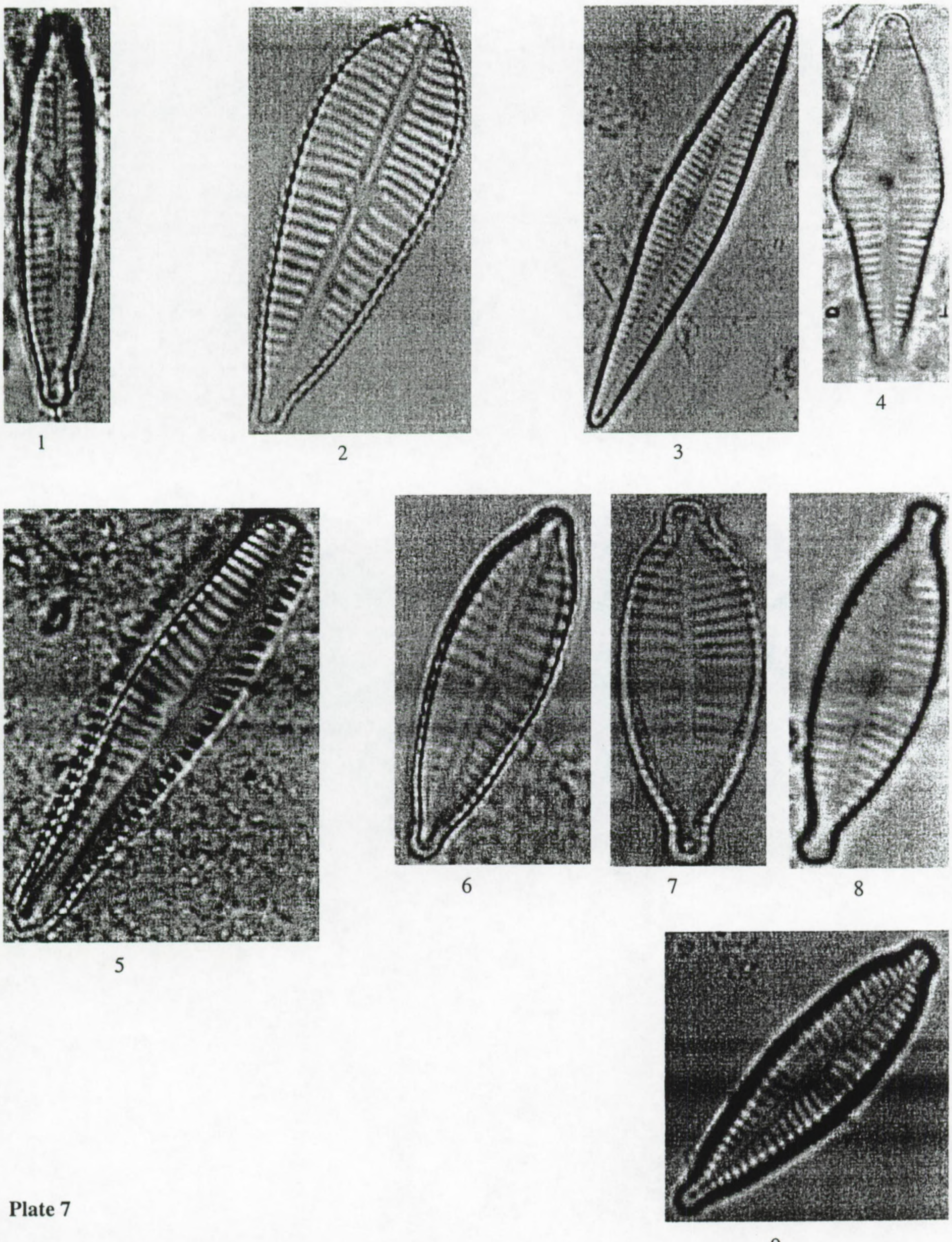


Plate 7

1. *Gomphonema angustatum* .(Kützing) Rabenhorst. L: 28, W: 5.5, striae: 11 in 10

2. *Gomphonema augur* Ehrenberg. L: 97, W: 35.8, striae: 7 in 10 µm.

3-4. *Gomphonema gracile* Ehrenberg. L: 29.4-35, W: 5-9.1, striae: 14-18 in 10 µm.

5. *Gomphonema olivaceum* (Hornemann) Brébisson. L: 36.3, W: 8.5, striae: 10 in 10 µm.

6-9. *Gomphonema parvulum* Kützing. L: 19.7-28, W: 5.3-7.6, striae: 13-17 in 10 µm.

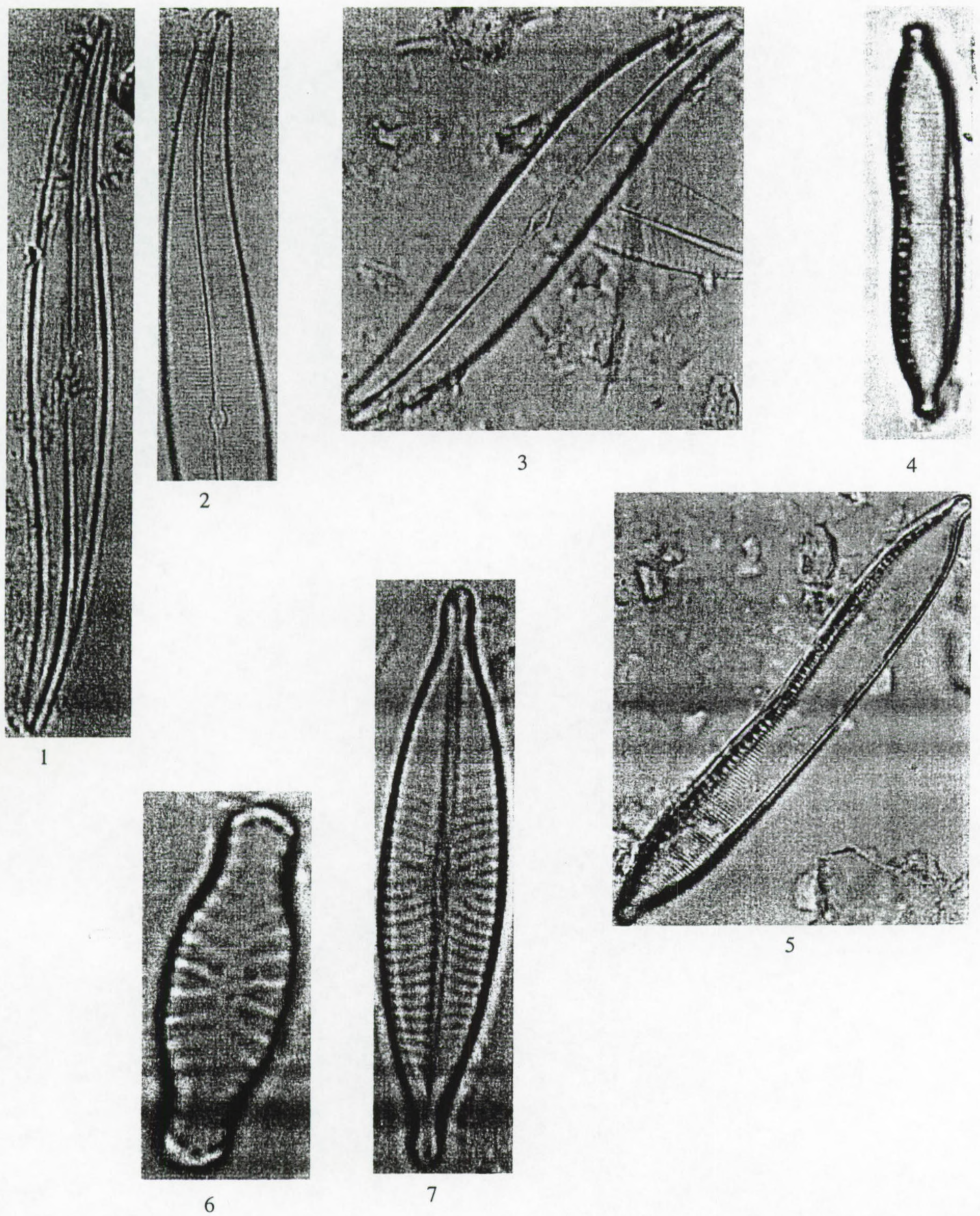


Plate 8

1-2. *Gyrosigma acuminatum* (Kützing) Rabenhorst. L: 108, W: 12, striae: 17 in 10 μm.

3. *Gyrosigma scalproides* (Rabenhorst) Cleve. L: 56.2, W: 8.7, striae: 22 in 10 μm.

4-5. *Hantzschia amphioxys* (Ehrenberg) Grunow. L: 32.1-75, W: 5.3-8.3, fibulae: 9 in 10 μm, striae: 21 in 10 μm.

6. *Navicula capitata* Ehrenberg. L:17.9, W:6.3, striae: 8 in 10 μm.

7. *Navicula capitatoradiata* Germain. L: 35, W: 9.7, striae: 13 in 10 μm.

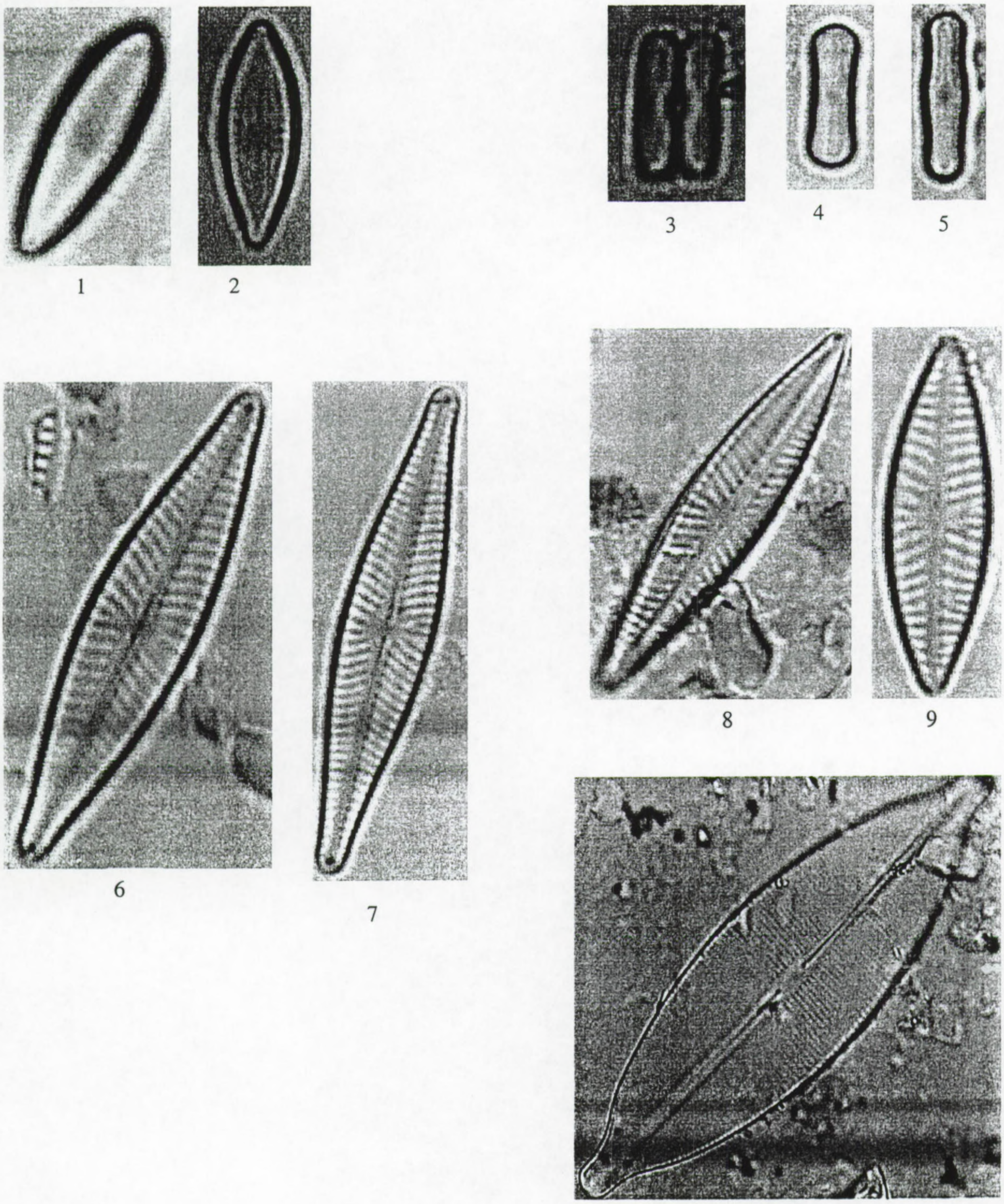


Plate 9

1-2. *Navicula* cf. *confervacea (*Kützing) Grunow L: 14, W: 5.3.

3-5. *Navicula contenta* Grunow. L: 6.6-11.9, W: 1.9-2.8.

6-7. *Navicula cryptocephala* Kützing. L: 26.1-40.4, W: 5.6-6.7, striae: 13-16 in 10 µm.

8-9. *Navicula cryptotenella* Lange-Bertalot. L: 21.3-31.2, W: 6.5-6.9, striae: 13-14 in 10 µm.

10. *Navicula cuspidata* (Kützing) Kützing. L: 67.7, W: 20.2, striae: 17 in 10 µm.

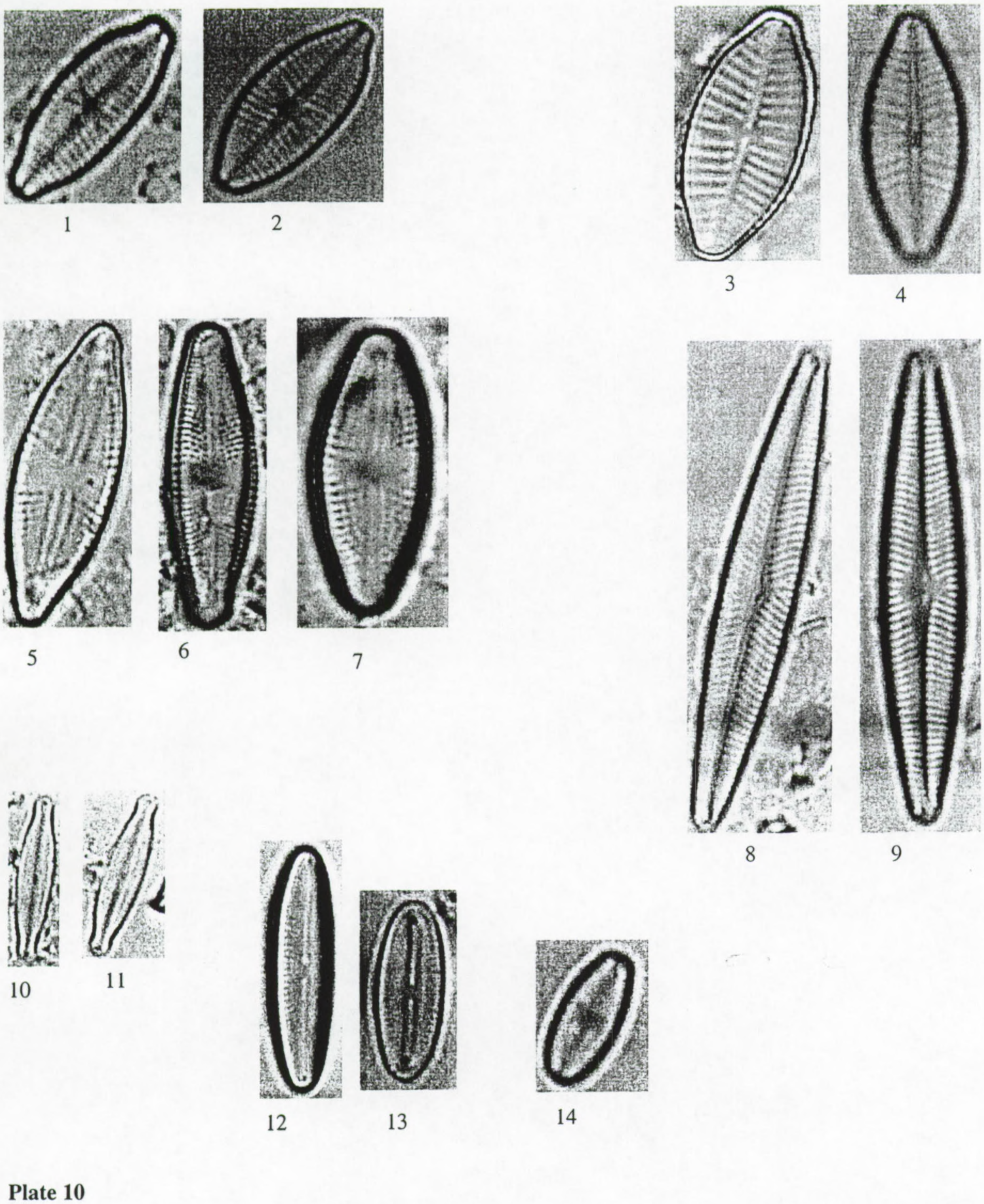


Plate 10

1-2. *Navicula* cf. *exigua* (Gregory) Grunow. L: 14.4-15.5, W: 5.8-6.6, striae: 16-18 in 10 μm.

3-4. *Navicula gastrum* (Ehrenberg) Kützing. L: 15.7-19.3, W: 7-9.3, striae: 12-13 in 10 μm.

5-7. *Navicula* cf. *goeppertiana* (Bleisch) H. L. Smith. L: 17.4-28, W: 6.8-7.2, striae: 17-21 in 10 μm.

8-9. *Navicula* cf. *heimansioides* Lange-Bertalot. L: 38, W: 6.7, striae: 15-16 in 10 μm.

10-11. *Navicula* cf. *impexa* Hustedt. L: 17.1-19.1, W: 4.2-4.8.

12-13. *Navicula* cf. *insociabilis* Krasske. L: 11-22.5, W: 5.5-5.6, striae: 17-21 in 10 μm.

16. *Navicula* cf. *minima* Grunow. L: 8.6, W: 4.1

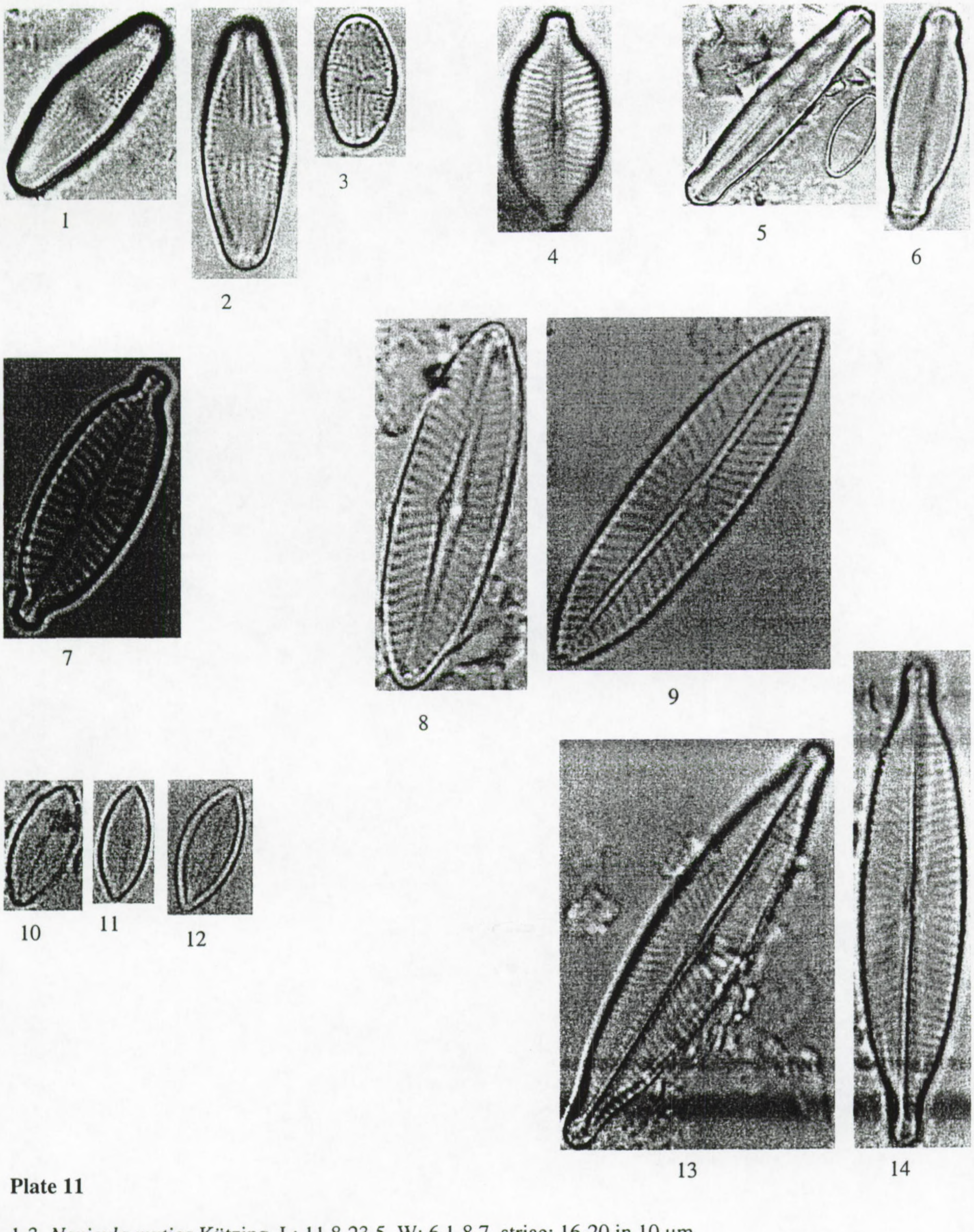


Plate 11

1-3. *Navicula mutica* Kützing. L: 11.8-23.5, W: 6.1-8.7, striae: 16-20 in 10 μm.

4. *Navicula* cf. *perlatoides* (O. Müller) Hustedt. L: 23, W:10, striae: 15 in 10 μm.

5-6. *Navicula pupula* Kützing. L: 30-42.6, W: 6.8-8.1, striae: 17-21 in 10 μm.

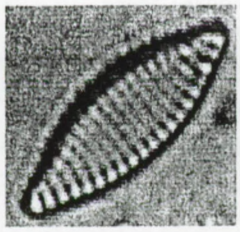
7. *Navicula pseudanglica* Lange-Bertalot. L: 24.6, W: 8.8, striae: 11 in 10 μm.

8-9. *Navicula schroeteri* Meister. L. 26-30.6, W: 5.8-7.7, striae: 12-14 in 10 μm.

10-12. *Navicula subminuscula* Manguin. L: 9.6-11, W: 4.3-5.3, striae: 16-20 in 10 μm.

13-14. *Navicula viridula* (Kützing) Ehrenberg. L: 36-41, W: 7.8-9.4, striae: 12-14 in 10 μm.

1



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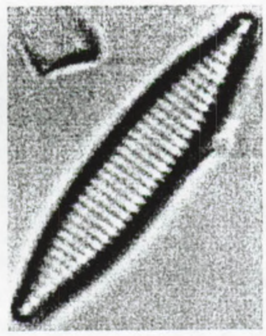

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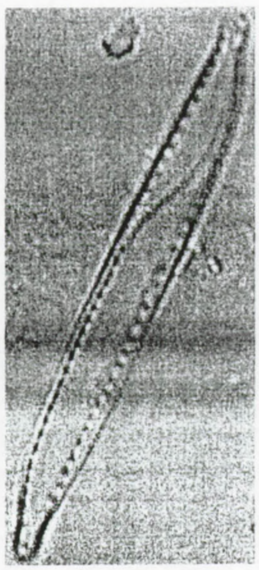

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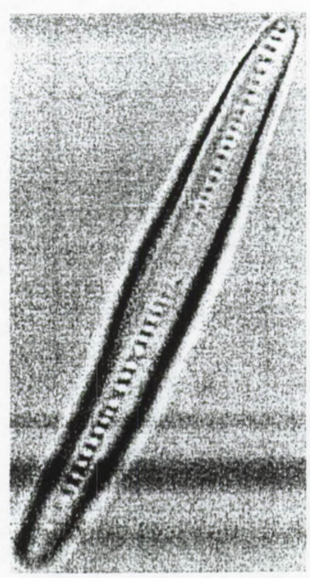

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Plate 12

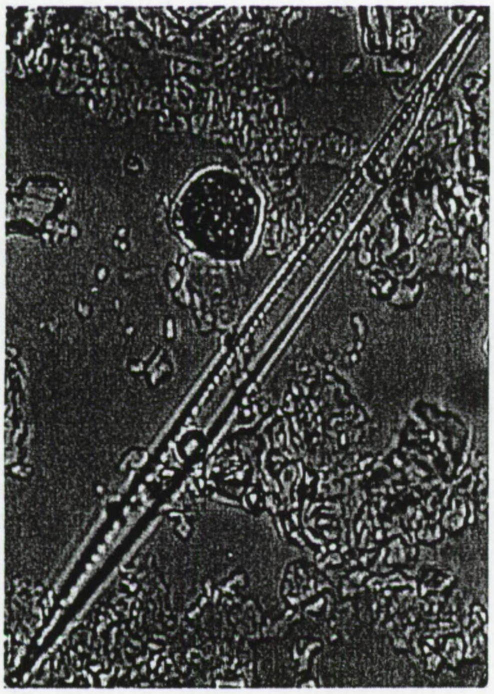
1. *Nitzschia acicularis* (Kützing) W. Smith. L: 66, W: 3.4.

2-3. *Nitzschia amphibia* Grunow. L: 12.3-23, W: 5.1-5.2, striae: 17 in 10 µm.

4-5. *Nitzschia calida* Grunow. L: 35-43.2, W: 8.1-10.7, fibulae: 10-11 in 10 µm.

6-7. *Nitzschia clausii* Hantzsch. L: 45, W: 3.9, fibulae: 9-12 in 10 µm.

8-9. *Nitzschia dissipata* (Kützing) Grunow. L: 26-43, W: 4.8-5.2, fibulae: 9-10 in 10 µm.



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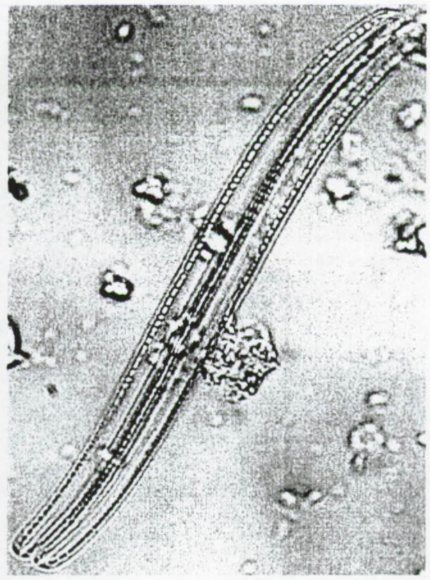

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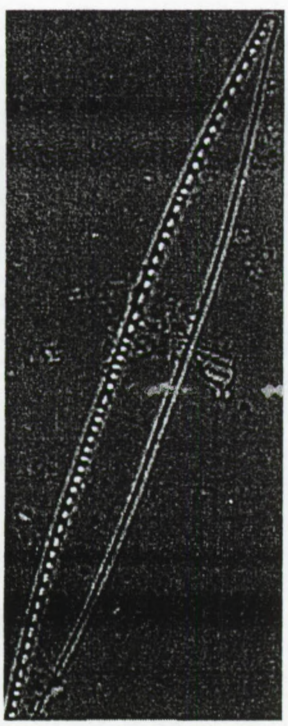

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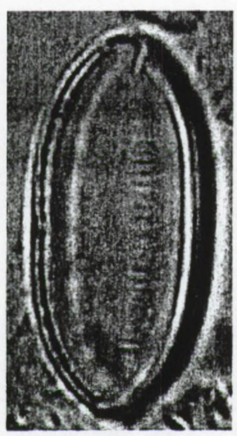

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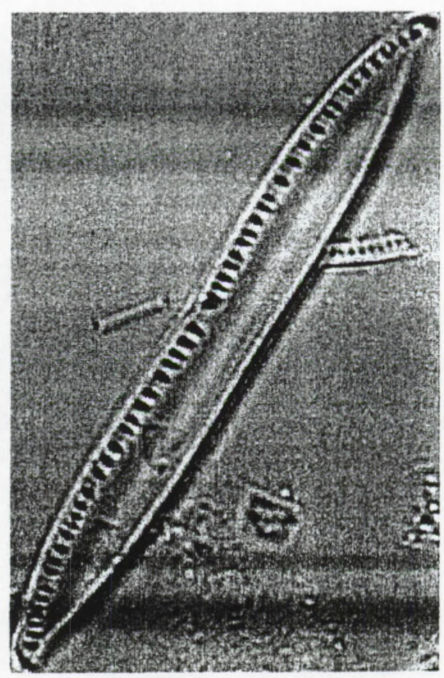

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Plate 13

1-2. *Nitzschia* cf. *flexa* Schuman. L: 59.4, W: 3.8, fibulae: 12 in 10 μm.

3. *Nitzschia frustulum* (Kützing) Grunow. L: 21.7, W: 3, fibulae: 12 in 10 μm.

4. *Nitzschia inconspicua* Grunow. L: 11, W: 4, fibulae: 10 in 10 μm.

5. *Nitzschia intermedia* Hantzsch. L: 67, W: 5.8, fibulae: 11 in 10 μm.

6. *Nitzschia levidensis* (W. Smith) Grunow. L: 20, W: 9.7, fibulae: 12 in 10 μm.

7. *Nitzschia linearis* (Agardh) W. Smith. L: 47, W: 6.4, fibulae: 11 in 10 μm.

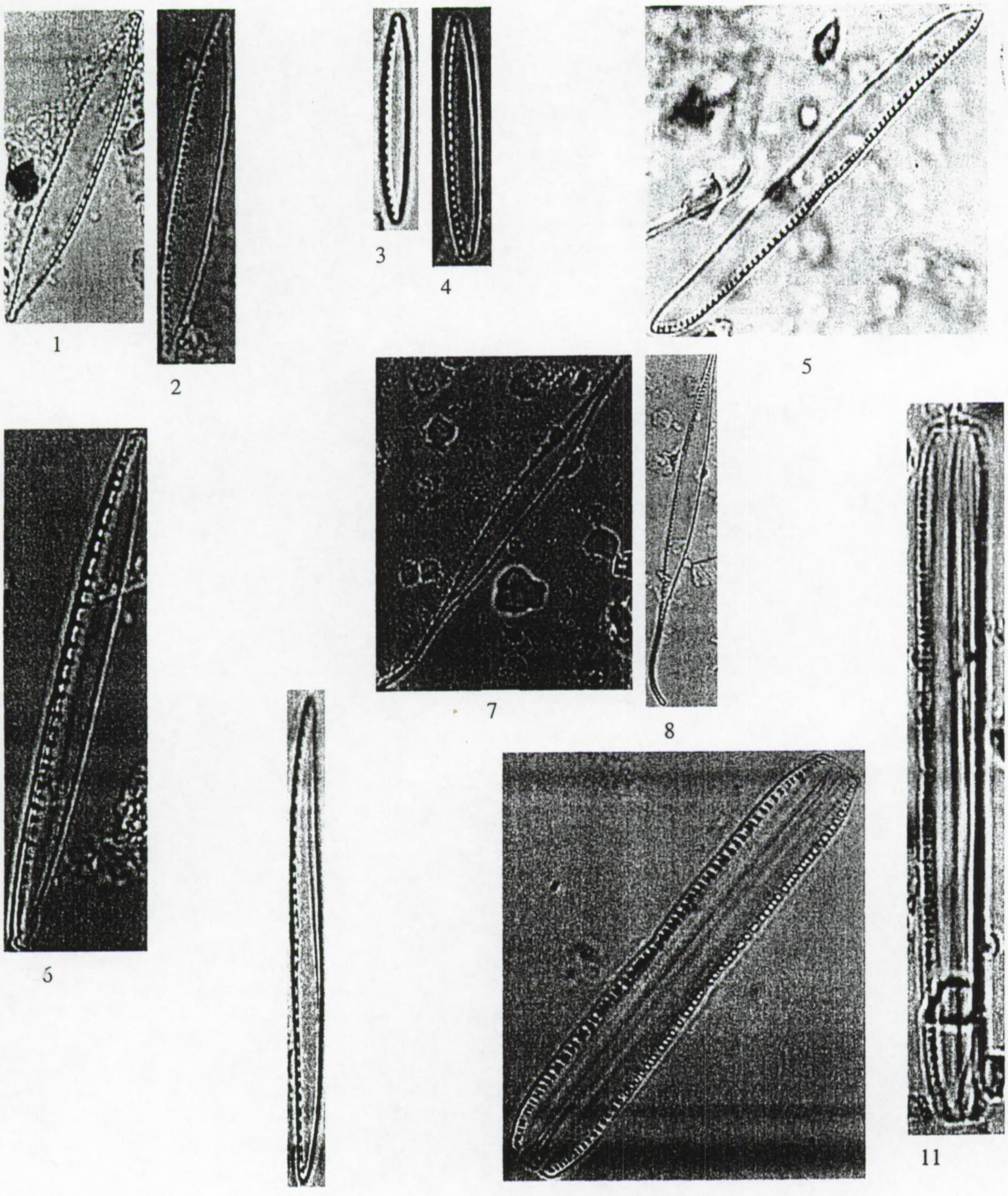


Plate 14

1-2. *Nitzschia palea* (Kützing) W. Smith. L: 36.5-41, W: 5.4-5.5, fibulae: 12-13 in 10 µm.

3-4. *Nitzschia perminuta* (Grunow) M. Paragallo. L: 24-24, W: 2.9-3.3, fibulae: 13 in 10 µm.

5. *Nitzschia obtusa* W. Smith. L: 38.7, W: 7.5., fibulae: 11 in 10 µm.

6. *Nitzschia recta* Hantzch. L: 46.4, W: 4, fibulae: 7 in 10 µm.

7-8. *Nitzschia reversa* W. Smith. L: 67-78, W: 4.-4.6, fibulae: 13 in 10 µm.

9. *Nitzschia scalpelliformis* Grunow. L:39, W: 5, fibulae: 10 in 10 µm.

10-11. *Nitzschia sigmoidea* (Nitzsch) W. Smith. 67-102.5, W: 8.7-10, fibulae: 8 in 10 µm.

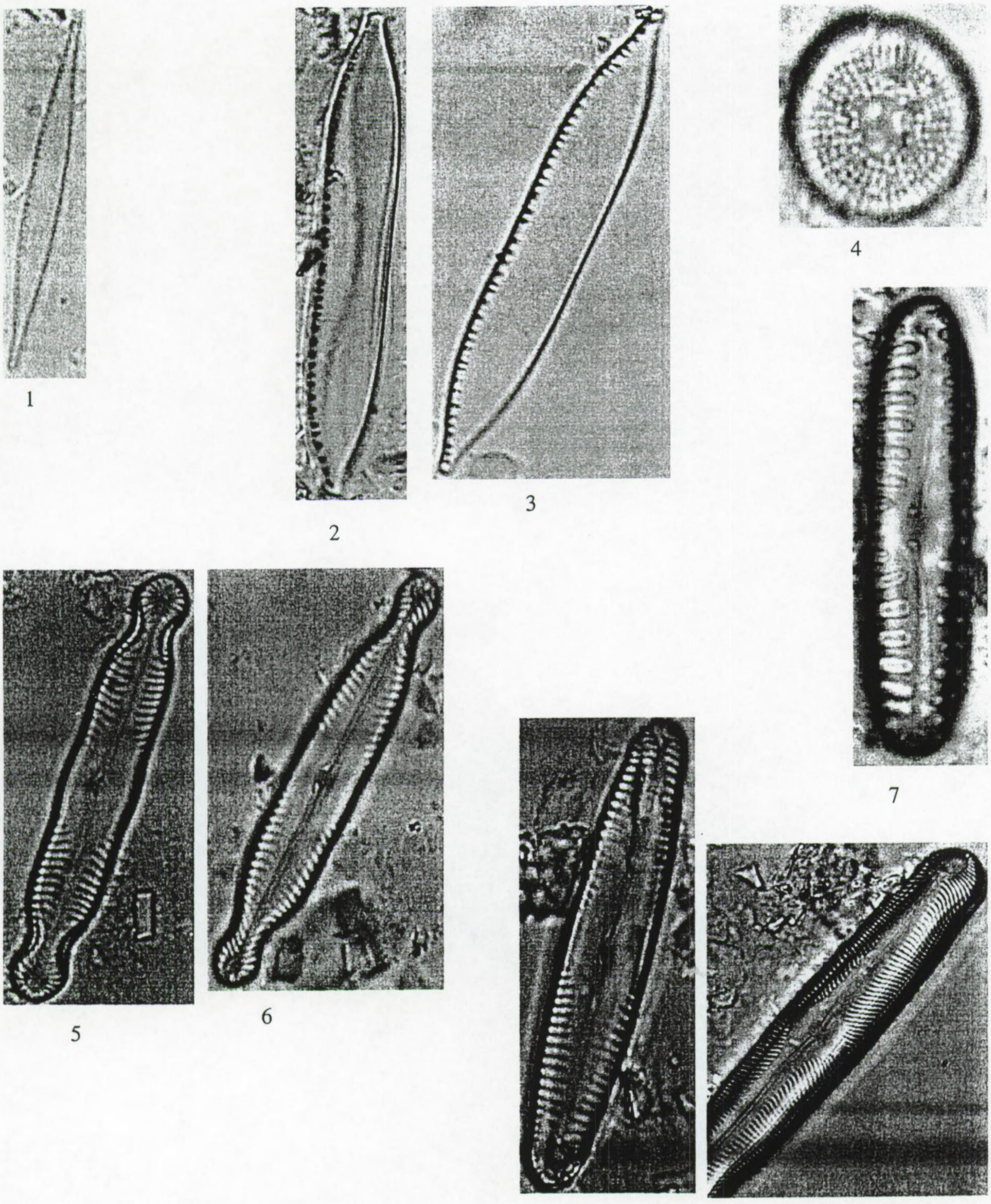


Plate 15

1. *Nitzschia subacicularis* Hustedt. L: 30.9, W: 3.1, fibulae: 15 in 10 µm.

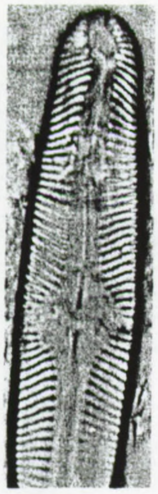
2-3. *Nitzschia umbonata* (Ehrenberg) Lange-Bertalot. L: 50.5-50.8, W: 7.5-7.7, fibulae: 9-10 in 10 µm.

4. *Orthoseira dendroteres* (Ehrenberg) Crawford. D: 11.4.

5-6. *Pinnularia braunii* (Grunow) Cleve. L: 49-53.5, W: 8-10.1, striae: 11-12 in 10 µm.

7. *Pinnularia borealis* Ehrenberg. L: 31.4, W: 8.7, striae: 6 in 10 µm.

8-9. *Pinnularia gibba* Ehrenberg. L: 49.2-82, W: 9-13.2, striae: 10-12 in 10 µm.



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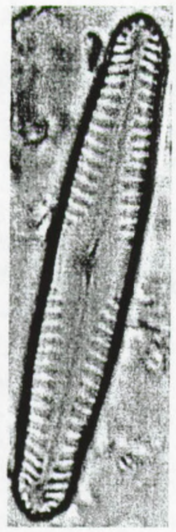

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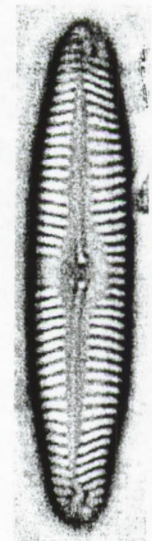

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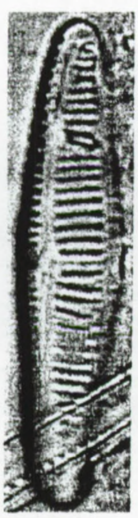

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6

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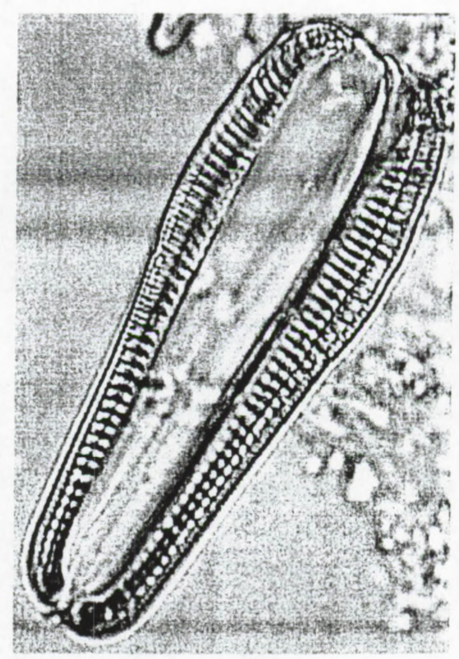


8

Plate 16

1. *Pinnularia gibba* var. *mesogongyla* (Ehrenberg) Hustedt. L: 61.2, W: 13.5, striae: 11 in 10 μm.

2. *Pinnularia microstauron* (Ehrenberg) Cleve. L: 41.5, W: 7.3, striae: 10 in 10 μm.

3. *Pinnularia obscura Krasske*. L: 22, W: 3.4, striae: 14 in 10 μm.

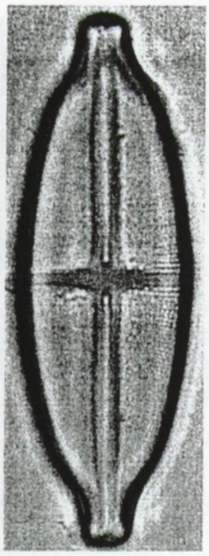
4. *Pinnularia subrostrata* (A. Cleve) Cleve-Euler. L: 37, W: 6.4, striae: 12 in 10 μm.

5-6. *Rhoicosphenia* cf. *abbreviata* (Agardh) Lange-Bertalot. L: 37.5, W: 7.5, striae: 15 in 10 μm.

7. *Rhopalodia gibba* (Ehrenberg) O. Müller. L: 76, W: 7.6.

8. *Rhopalodia hirundiniformis* O. Müller. L: 37.8, W: 14.1.

1



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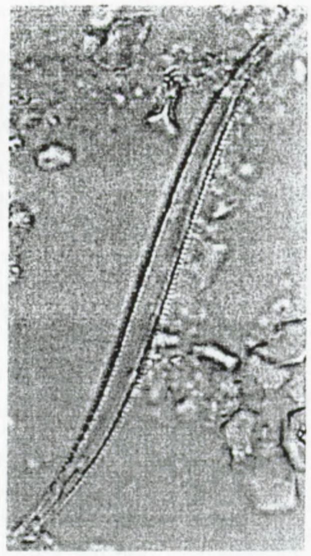

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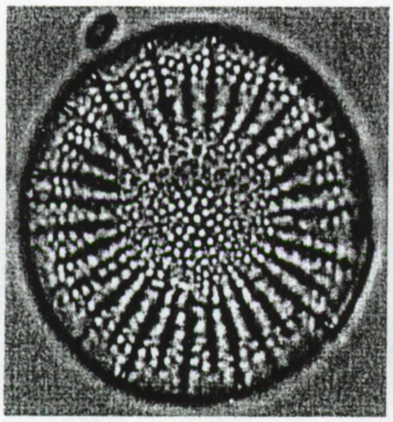

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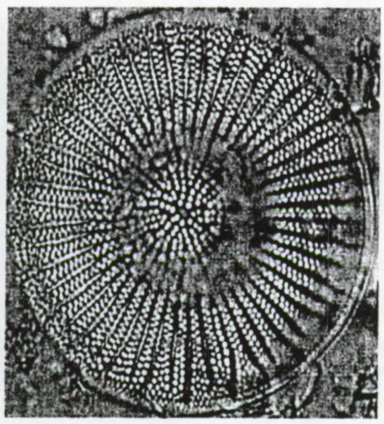


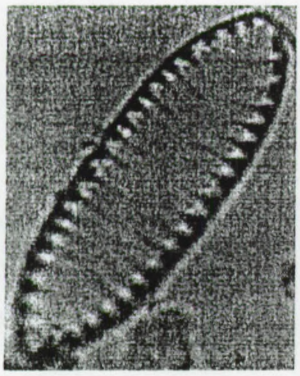
5

Plate 17

1-2. *Stauroneis anceps* Ehrenberg. L: 50-53, W: 14.5-17, striae: 27-29 in 10 μm.

3. *Stenopterobia curvula* (W. Smith) Krammer. L: 65.1, W: 4.1.

4-5. *Stephanodiscus rotula* (Kützing) Hendey. D: 26.



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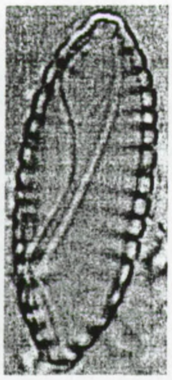

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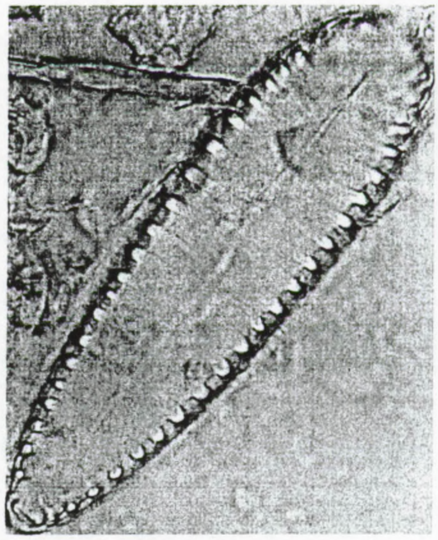

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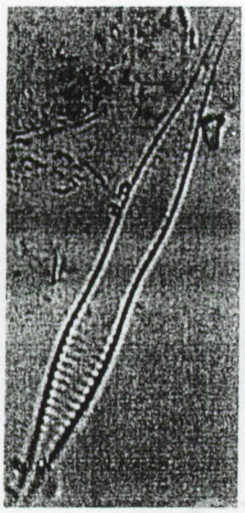

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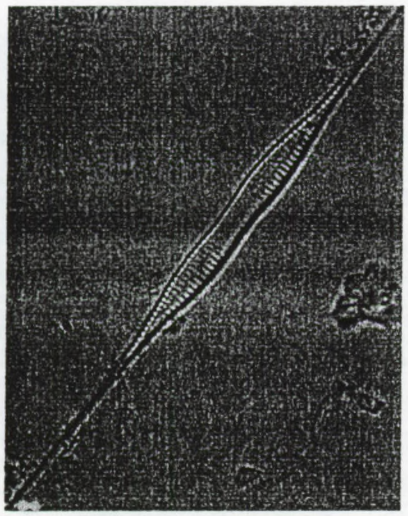

5

Plate 18

1-2. *Surirella angusta* Kützing L: 21-22.2, W: 7.3-11, striae: 23-25 in 10 μm.

3. *Surirella splendida* (Ehrenberg) Kützing. L: 74.2, W: 20.9.

4-5. *Synedra cunningtonii* G.S. West. L: 43.4-80, W: 3.9-4.3.

Annex 3

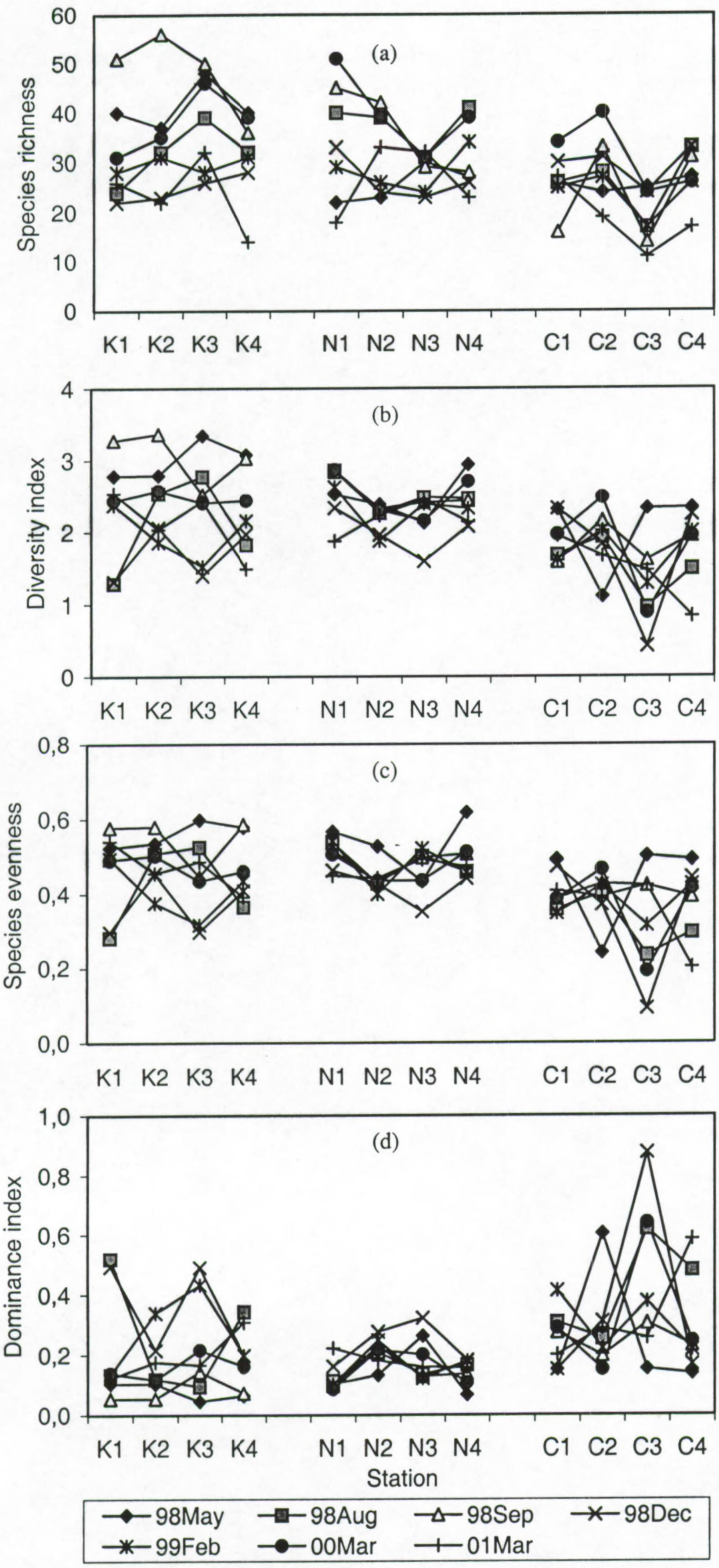

Figure 3.1.(a) Species richness, (b) Shannon and Weaver diversity index, (c) species evenness and **(d) Simpson's dominance index of epilithic diatoms in rivers Kibos (K1-K4), Nyando (N1-N4)** and Kisat (C1-C4) during the various sampling times.

Annex 4

Table 4.1. List of taxa in rivers Kibos, Nyando and Kisat and their ecological indicator values according to Van Dam *et al.* 1994. S = saprobity, O = oxygen requirements, T = trophic state, N = nitrogen uptake metabolism, M = moisture, R = pH, H = salinity, - = missing value. Taxa lacking the indicator values are given at end of table.

R	H	N	O	S	T	M	Taxon name
3	2	1	1	1	3	4	*Achnanthes bioretii* Germain
4	2	2	3	3	5	3	*Achnanthes* cf. *lanceolata* (Brébisson) Grunow
3	2	2	1	2	7	3	*Achnanthes* cf. *minutissima* Kützing
3	1	1	1	1	1	1	*Achnanthes daonensis* Lange-Bertalot
5	4	-	-	-	-	-	*Achnanthes delicatula* (Kützing) Grunow
4	2	2	1	2	7	3	*Achnanthes exigua* Grunow
3	1	1	1	1	1	3	*Achnanthes flexella* (Kützing) Brun
-	2	-	-	-	-	-	*Achnanthes inflata* (Kützing) Grunow
3	2	1	1	1	1	3	*Achnanthes oblongella* Oestrup
4	2	1	1	1	4	-	*Achnanthes ploenensis* Hustedt
4	2	2	2	4	2	2	*Amphipleura pellucida* (Kützing) Kützing
4	2	2	3	3	5	3	*Amphora coffeaeformis* (Agardh) Kützing
-	4	-	-	-	5	3	*Amphora commutata* Grunow
4	2	2	1	2	5	4	*Amphora montana* Krasske
4	2	2	2	2	5	1	*Amphora ovalis* (Kützing) Kützing
5	3	2	3	4	5	3	*Amphora veneta* Kützing
4	2	2	3	2	5	1	*Aulacoseira ambigua* (Grunow) Simonsen
4	2	2	3	2	5	1	*Aulacoseira granulata* (Ehrenberg) Simonsen
4	2	1	2	2	4	2	*Caloneis bacillum* (Grunow) Cleve
3	1	1	1	1	2	4	*Caloneis leptosoma* (Grunow) Krammer
3	1	-	-	-	-	4	*Caloneis molaris* (Grunow) Krammer
3	1	1	1	1	3	4	*Caloneis pulchra* Messikommer
4	2	2	3	2	5	2	*Cocconeis placentula* var. *lineata* (Ehrenberg) Van Heurck
4	3	3	5	4	5	2	*Cyclotella meneghiniana* Kützing
4	1	1	1	1	4	1	*Cyclotella ocellata* Pantocsek
-	2	-	-	-	-	1	*Cyclotella stelligera* Cleve & Grunow
4	2	1	1	2	5	2	*Cymbella affinis* Kützing
4	1	1	1	1	1	5	*Cymbella alpina* Grunow
3	2	1	1	1	2	3	*Cymbella amphicephala* Naegeli
3	1	1	1	1	1	3	*Cymbella cesatii* (Rabenhorst) Grunow
4	1	1	1	1	1	3	*Cymbella delicatula* Kützing
-	1	1	1	1	1	-	*Cymbella descripta* (Hustedt) Krammer & Lange-Bertalot
-	1	1	1	1	2	3	*Cymbella falaisensis* (Grunow) Krammer & Lange-Bertalot
2	1	1	1	1	2	3	*Cymbella gracilis* (Ehrenberg) Kützing
4	2	-	-	-	-	-	*Cymbella mesiana* Cholnoky
4	2	1	1	1	4	3	*Cymbella microcephala* Grunow
3	2	2	2	2	5	2	*Cymbella naviculliformis* (Auerswald) Cleve
4	2	1	1	2	5	1	*Cymbella prostrata* (Berkeley) Cleve
3	2	2	3	3	7	1	*Cymbella silesiaca* Bleisch
4	1	1	1	1	1	4	*Cymbella similis* Krasske
4	2	1	1	1	4	1	*Cymbella tumidula* Grunow
4	2	1	1	1	-	3	*Cymbella turgidula* (Brébisson) Van Heurck
4	2	1	1	1	3	3	*Diploneis elliptica* (Kützing) Cleve
4	2	1	1	1	-	4	*Diploneis ovalis* (Hilse) Cleve

Table 4.1 (continued).

R	H	N	O	S	T	M	Taxon name
5	2	1	2	2	4	2	*Epithemia adnata* (Kützing) Brébisson
4	2	-	-	1	3	3	*Epithemia argus* (Ehrenberg) Kützing
5	2	1	2	2	5	2	*Epithemia sorex* Kützing
6	2	2	2	2	7	3	*Eunotia bilunaris* (Ehrenberg) Mills
1	2	2	2	3	7	3	*Eunotia exigua* (Brébisson) Rabenhorst
2	1	1	1	1	2	2	*Eunotia faba* Ehrenberg
2	1	1	1	1	2	3	*Eunotia glacialis* Meister
2	1	-	-	-	1	3	*Eunotia intermedia* (Krasske) Nörpel & Lange-Bertalot
2	1	-	-	1	-	4	*Eunotia minor* (Kützing) Grunow
2	1	2	1	2	3	3	*Eunotia pectinalis* (Dillwyn) Rabenhorst
2	1	1	1	1	2	3	*Eunotia praerupta* Ehrenberg
3	1	2	1	2	1	3	*Eunotia soleirolii* (Kützing) Rabenhorst
4	2	1	1	2	5	2	*Fragilaria bidens* Heiberg
3	2	-	-	2	3	-	*Fragilaria capucina* var. *vaucheriae* (Kützing) Lange-Bertalot
4	2	1	1	2	4	1	*Fragilaria construens* (Ehrenberg) Grunow
4	3	2	1	1	4	1	*Fragilaria construens* f. *subsalina* (Hustedt) Hustedt
4	2	2	1	2	4	1	*Fragilaria construens* f. *venter* Ehrenberg
3	1	1	1	1	1	2	*Fragilaria exigua* Grunow
4	2	1	1	2	4	2	*Fragilaria parasitica* (W. Smith) Grunow
4	2	2	1	2	7	3	*Fragilaria pinnata* Ehrenberg
4	4	2	3	3	5	3	*Fragilaria pulchella* (Ralfs) Lange-Bertalot
2	1	1	1	1	2	2	*Fragilaria tenera* (W. Smith) Lange-Bertalot
4	2	2	3	4	7	2	*Fragilaria ulna* (Nitzsch) Lange-Bertalot
2	1	1	1	1	1	2	*Frustulia rhomboides* (Ehrenberg) De Toni
2	1	1	1	1	1	2	*Frustulia rhomboides* var. *viridula* (Brébisson) Cleve
4	2	2	1	2	4	3	*Frustulia vulgaris* Thwaites) De Toni
4	2	1	1	2	3	3	*Gomphonema affine* Kützing
4	2	1	1	1	1	-	*Gomphonema angustum* Agardh
4	2	1	1	2	4	1	*Gomphonema augur* Ehrenberg
3	1	1	1	1	4	2	*Gomphonema clavatum* Ehrenberg
3	2	1	1	1	3	3	*Gomphonema gracile* Ehrenberg
-	2	-	-	-	-	-	*Gomphonema insigne* Gregory
5	2	2	2	2	5	1	*Gomphonema olivaceum* (Hornemann) Brébisson
3	2	3	4	4	5	3	*Gomphonema parvulum* (Kützing) Kützing
5	2	2	3	2	5	2	*Gyrosigma acuminatum* (Kützing) Rabenhorst
3	2	2	2	3	7	4	*Hantzschia amphioxys* (Ehrenberg) Grunow
2	1	1	1	1	1	-	*Hantzschia elongata* (Hantzsch) Grunow
2	1	1	1	1	2	3	*Navicula leptostriata* Jørgensen
4	2	4	5	5	6	2	*Navicula accomoda* Hustedt
3	2	-	-	-	-	3	*Navicula agrestis* Hustedt
3	-	1	1	-	-	4	*Navicula brekkaensis* Petersen
4	2	2	3	3	4	3	*Navicula capitata* Ehrenberg
4	2	2	3	2	4	3	*Navicula capitata* var. *hungarica* (Grunow) Ross
4	2	2	3	3	5	1	*Navicula capitatoradiata* Germain
-	2	-	-	-	7	-	*Navicula cari* Ehrenberg
							Navicula cf. *confervacea* (Kützing) Grunow
2	1	1	1	1	2	-	*Navicula* cf. *heimansioides* Lange-Bertalot

Table 4.1 (continued).

R	H	N	O	S	T	M	Taxon name
4	2	-	1	1	-	4	*Navicula* cf. *kotschyi* Grunow
4	2	3	4	4	5	3	*Navicula* cf. *minima* Grunow
4	1	-	-	2	1	4	*Navicula* cf. *minuscula* Grunow
4	2	4	2	4	6	4	*Navicula* cf.*atomus* (Kützing) Grunow
4	2	2	3	3	5	4	*Navicula cinta* (Ehrenberg) Ralfs
4	3	2	1	2	5	-	*Navicula cohnii* (Hilse) Lange-Bertalot
4	2	2	1	2	7	4	*Navicula contenta* Grunow
3	2	2	3	3	7	2	*Navicula cryptocephala* Kützing
4	2			2	7	2	*Navicula cryptotenella* Lange-Bertalot
4	2	2	3	3	5	1	*Navicula cuspidata* (Kützing) Kützing
4	2	2	2	2	5	3	*Navicula elginensis* (Gregory) Ralfs
4	3	-	-	-	5	2	*Navicula erifuga* Lange-Bertalot
4	1	1	1	2	5	2	*Navicula exigua* (Gregory) Grunow
-	-	-	-	-	-	5	*Navicula gallica* (W. Smith) Lagerstedt
4	2	2	2	2	5	1	*Navicula gastrum* (Ehrenberg) Kützing
4	2	3	4	4	5	3	*Navicula* cf. *goeppertiana* (Bleisch) H. L. Smith
3	1	1	1	1	3	4	*Navicula insociabilis* Krasske
3	1	1	1	1	3	2	*Navicula laevissima* Kützing
2	1	1	1	1	-	4	*Navicula lapidosa* Krasske
4	2	3	2	3	5	3	*Navicula monoculata* Hustedt
3	3	2	1	3	5	4	*Navicula mutica* Kützing
4	2	2	2	2	5	1	*Navicula oblonga* Kützing
4	2	2	1	2	4	2	*Navicula pseudanglica* Lange-Bertalot
5	2	1	1	-	-	-	*Navicula pseudotuscula* Hustedt
3	2	2	3	3	4	2	*Navicula pupula* Kützing
5	3	3	3	3	5	2	*Navicula pygmaea* Kützing
4	2	2	4	2	7	2	*Navicula rhynchocephala* Kützing
3	2	1	1	1	3	4	*Navicula saxophila* Bock
4	3	-	1	2	5	3	*Navicula schroeteri* Meister
3	2	3	4	4	5	3	*Navicula seminulum* Grunow
4	2	4	4	4	5	3	*Navicula* cf. *subminuscula* Manguin
4	2	2	2	3	5	1	*Navicula viridula* (Kützing) Ehrenberg
3	2	1	1	1	4	1	*Neidium affine* (Ehrenberg) Pfitzer
3	2	-	-	-	2	3	*Neidium ampliatum* (Ehrenberg) Krammer
1	1	1	1	1	1	1	*Neidium densestriatum* (østrup) Krammer
-	-	1	-	-	-	-	*Neidium productum* (W. Smith) Cleve
4	2	4	4	3	5	1	*Nitzschia acicularis* (Kützing) W. Smith
4	2	3	3	3	5	3	*Nitzschia amphibia* Grunow
3	-	1	1	1	3	1	*Nitzschia angustata* Grunow
3	3	-	3	2	5	3	*Nitzschia brevissima* Grunow
-	3	-	-	-	5	-	*Nitzschia calida* Grunow
4	4	-	-	4	6	3	*Nitzschia capitellata* Hustedt
4	4	2	2	3	5	3	*Nitzschia clausii* Hantzsch
4	2	2	2	2	4	3	*Nitzschia dissipata* (Kützing) Grunow
4	4	3	3	3	5	3	*Nitzschia filiformis* (W. Smith) Van Heurck

Table 4.1 (continued)

R	H	N	O	S	T	M	Taxon name
3	2	-	-	1	-	3	*Nitzschia flexa* Schumann
4	2	2	2	2	4	1	*Nitzschia fonticola* Grunow
4	3	4	3	2	5	3	*Nitzschia frustulum* (Kützing) Grunow
3	2	-	2	3	5	1	*Nitzschia fruticosa* Hustedt
3	1	-	2	2	3	1	*Nitzschia* cf. *gracilis* Hantzch
3	1	1	1	1	3	4	*Nitzschia hantzschiana* Rabenhorst
4	3	3	3	3	5	3	*Nitzschia inconspicua* Grunow
3	2	-	-	2	5	1	*Nitzschia intermedia* Hantzsch
4	4	-	-	-	5	3	*Nitzschia lanceolata* W. Smith
4	3	2	3	3	5	1	*Nitzschia levidensis* (W. Smith) Grunow
4	2	2	2	2	4	3	*Nitzschia linearis* (Agardh) W. Smith
4	2	2	2	2	4	3	*Nitzschia linearis* var. *tenuis* (W. Smith) Grunow
3	2	-	1	2	3	3	*Nitzschia nana* Grunow
3	2	4	4	5	6	3	*Nitzschia palea* (Kützing) W. Smith
4	2	1	1	1	2	3	*Nitzschia perminuta* (Grunow) M. Paragallo
4	2	2	2	2	7	1	*Nitzschia recta* Hantzsch
4	3	-	-	-	5	2	*Nitzschia scalaris* (Ehrenberg) W. Smith
4	4	2	3	3	5	2	*Nitzschia sigma* (Kützing) W. Smith
4	2	2	3	2	5	2	*Nitzschia sigmoidea* (Nitzsch) W. Smith
4	2	1	1	2	7	2	*Nitzschia subacicularis* Hustedt
4	-	-	-	-	-	-	*Nitzschia thermaloides* Hustedt
4	3	2	3	3	5	3	*Nitzschia tryblionella* Hantzsch
3	2	4	5	5	6	3	*Nitzschia umbonata* (Ehrenberg) Lange-Bertalot
2	2	-	4	2	4	4	*Pinnularia acoricola* Hustedt
3	1	-	3	1	2	3	*Pinnularia acrosphaeria* Rabenhorst
3	2	2	1	2	2	4	*Pinnularia borealis* Ehrenberg
1	1	-	-	1	1	-	*Pinnularia braunii* (Grunow) Cleve
3	1	-	-	1	1	3	*Pinnularia divergens* W. Smith
2	1	-	-	-	1	4	*Pinnularia divergentissima* (Grunow) Cleve
3	2	2	3	3	7	2	*Pinnularia gibba* Ehrenberg
3	1	-	-	-	-	-	*Pinnularia gibba* var. *mesogongyla* (Ehrenberg) Hustedt
3	1	-	-	1	7	4	*Pinnularia intermedia* (Lagerstedt) Cleve
2	1	-	1	1	1	5	*Pinnularia lata* (Brébisson) W. Smith
3	2	2	3	2	7	3	*Pinnularia microstauron* (Ehrenberg) Cleve
2	1	1	1	1	1	3	*Pinnularia nobilis* Ehrenberg
3	2	1	1	1	-	4	*Pinnularia obscura* Krasske
2	2	2	3	2	2	3	*Pinnularia subcapitata* Gregory
3	2	2	3	2	7	3	*Pinnularia viridis* (Nitzch) Ehrenberg
4	2	2	2	2	5	2	*Rhoicosphaenia abbreviata* (Agardh) Lange-Bertalot
4	3	-	-	-	-	-	*Rhopalodia brebisonii* Krammer
5	2	1	3	2	5	3	*Rhopalodia gibba* (Ehrenberg) O. Müller
4	3	-	1	-	-	3	*Rhopalodia gibberula* (Ehrenberg) O. Müller
3	2	2	2	2	4	2	*Stauroneis anceps* Ehrenberg
3	2	2	3	2	4	2	*Stauroneis phoenicenteron* (Nitzsch) Ehrenberg
2	1	1	1	1	1	2	*Stenopterobia curvula* (W. Smith) Krammer

Table 4.1 (continued).

R	H	N	O	S	T	M	Taxon name
2	1	1	1	1	1	1	*Stenopterobia delicatissima* (Lewis) Brébisson
4	2	2	2	2	5	3	*Surirella angusta* Kützing
4	2	-	-	1	5	2	*Surirella bifrons* Ehrenberg
4	2	-	-	2	5	1	*Surirella biseriata* Brébisson
4	3	-	-	-	-	-	*Surirella brebisonii* Krammer & Lange-Bertalot
4	2	-	1	1	4	1	*Surirella* cf. *capronii* Brébisson
3	2	-	-	2	2	3	*Surirella linearis* W. Smith
4	4	2	4	3	5	3	*Surirella ovalis* Brébisson
4	2	-	2	2	4	2	*Surirella splendida* (Ehrenberg) Kützing
							Achnanthes trinodis (W. Smith) Grunow
							Amphora holsatica Hustedt
							Capartogramma crucicula (Grunow ex Cleve) Ross
							Cymatopleura solea (Brébisson) W. Smith
							Cymbella elginensis Krammer
							Diploneis alpina Meister
							Eunotia crista-galli Cleve
							Eunotia didyma Grunow
							Gomphocymbella beccari (Grunow) Forti
							Gomphonema clevei Fricke
							Gomponema angustatum (Kützing) Rabenhorst
							Gyrosigma scalproides (Rabenhorst) Cleve
							Melosira cf. *moniliformis* (O.F. Müller) Agardh
							Navicula cf. *impexa* Hustedt
							Navicula heufleriana (Grunow) Cleve
							Navicula jaagii Meister
							Navicula muticopsis Van Heurck
							Navcula perlatoides (O. Müller) Hustedt
							Navicula spinifera Bock
							Neidium ladogensis (Cleve) Foged
							Nitzschia acicularioides Hustedt
							Nitzschia acuminata (W. Smith) Grunow
							Nitzschia nyassensis O. Müller
							Nitzschia obtusa var. *kurzii* Rabenhorst ex Cleve & Möller
							Nitzschia prolongata Hustedt
							Nitzschia reversa Hantzsch
							Nitzschia scalpelliformis Grunow
							Nitzschia speciosa Hustedt
							Orthoseira cf. *dendroteres* (Ehrenberg) Crawford
							Pinnularia similis Hustedt
							Pinnularia subrostrata (A. Cleve) Clive-Euler
							Pinnularia superdivergentissima Chaumont & Germain
							Rhopalodia hirundiniformis O. Müller
							Rhopalodia rupestris (W. Smith) Krammer
							Stephanodiscus rotula (Kützing) Hendey
							Synedra cunningtonii G.S. West

Table 4.2. List of taxa in rivers Kibos, Nyando and Kisat and their pollution sensitivity Value SV (5 = very sensitive, 1 = very resistant) and weight of the indicator W (1 = bad indicator; 3 = good indicator) according to Coste (2001, unpublished).

Name of taxa	SV	W
Achnanthes bioretii Germain	5	3
Achnanthes cf. *lanceolata* (Brébisson) Grunow	4.6	1
Achnanthes cf. *minutissima* Kützing	5	1
Achnanthes daonensis Lange-Bertalot	5	2
Achnanthes delicatula (Kützing) Grunow	3	3
Achnanthes exigua Grunow	4	1
Achnanthes flexella (Kützing) Brun	5	3
Achnanthes inflata (Kützing) Grunow	4	3
Achnanthes oblongella Oestrup	4.5	1
Achnanthes ploenensis Hustedt	5	2
Achnanthes trinodis (W. Smith) Grunow	5	3
Amphipleura pellucida (Kützing) Kützing	5	3
Amphora coffeaeformis (Agardh) Kützing	2	3
Amphora commutata Grunow	2	3
Amphora holsatica Hustedt	2	1
Amphora montana Krasske	2.8	1
Amphora ovalis (Kützing) Kützing	3	1
Amphora veneta Kützing	1	2
Aulacoseira ambigua (Grunow) Simonsen	3	1
Aulacoseira granulata (Ehrenberg) Simonsen	2.9	1
Caloneis bacillum (Grunow) Cleve	4	2
Caloneis leptosoma (Grunow) Krammer	5	1
Caloneis molaris (Grunow) Krammer	4	3
Caloneis pulchra Messikommer	0	0
Capartograma crucicula (Grunow ex Cleve) Ross	4.9	3
Cocconeis placentula var. *lineata* (Ehrenberg) Van Heurck	5	1
Cyclotella meneghiniana Kützing	2	1
Cyclotella ocellata Pantocsek	3	1
Cyclotella stelligera Cleve & Grunow	4.2	1
Cymatopleura solea (Brébisson) W. Smith	4	2
Cymbella affinis Kützing	4	2
Cymbella alpina Grunow	5	3
Cymbella amphicephala Naegeli	5	2
Cymbella cesatii (Rabenhorst) Grunow	0	0
Cymbella delicatula Kützing	5	2
Cymbella descripta (Hustedt) Krammer & Lange-Bertalot	5	2
Cymbella elginensis Krammer	5	3
Cymbella falaisensis (Grunow) Krammer & Lange-Bertalot	5	2
Cymbella gracilis (Ehrenberg) Kützing	5	2
Cymbella mesiana Cholnoky	5	3
Cymbella microcephala Grunow	4	2
Cymbella naviculliformis (Auerswald) Cleve	3.8	3
Cymbella prostrata (Berkeley) Cleve	4	3
Cymbella silesiaca Bleisch	5	2
Cymbella similis Krasske	5	3

Table 4.2 (continued).

Name of taxa	SV	W
Cymbella tumidula Grunow	4	2
Cymbella turgidula (Brébisson) Van Heurck	4	2
Diploneis alpina Meister	4	2
Diploneis elliptica (Kützing) Cleve	5	2
Diploneis ovalis (Hilse) Cleve	4	2
Epithemia adnata (Kützing) Brébisson	4	3
Epithemia argus (Ehrenberg) Kützing	5	3
Epithemia sorex Kützing	4	2
Eunotia bilunaris (Ehrenberg) Mills	5	2
Eunotia crista-galli Cleve	0	0
Eunotia didyma Grunow	0	0
Eunotia exigua (Brébisson) Rabenhorst	5	2
Eunotia faba Ehrenberg	5	3
Eunotia glacialis Meister	4	2
Eunotia intermedia (Krasske) Nörpel & Lange-Bertalot	4	1
Eunotia minor (Kützing) Grunow	4.6	1
Eunotia pectinalis (Dillwyn) Rabenhorst	5	2
Eunotia praerupta Ehrenberg	5	1
Eunotia soleirolii (Kützing) Rabenhorst	5	3
Fragilaria bidens Heiberg	5	1
Fragilaria capucina var. *vaucheriae* (Kützing) Lange-Bertalot	3.4	1
Fragilaria construens (Ehrenberg) Grunow	4	1
Fragilaria construens f. *subsalina* (Hustedt) Hustedt	3	1
Fragilaria construens f. *venter* Ehrenberg	4	1
Fragilaria exigua Grunow	5	2
Fragilaria parasitica (W. Smith) Grunow	4	1
Fragilaria pinnata Ehrenberg	4	1
Fragilaria pulchella (Ralfs) Lange-Bertalot	3	3
Fragilaria tenera (W. Smith) Lange-Bertalot	4	2
Fragilaria ulna (Nitzsch) Lange-Bertalot	3	1
Frustulia rhomboides (Ehrenberg) De Toni	5	2
Frustulia rhomboides var. *viridula* (Brébisson) Cleve	5	3
Frustulia vulgaris Thwaites) De Toni	4	3
Gomphocymbella beccari (Grunow) Forti	5	3
Gomphonema affine Kützing	4	3
Gomphonema angustatum (Kützing) Rabenhorst*	3	1
Gomphonema cf. *angustum* Agardh	5	1
Gomphonema augur Ehrenberg	3	3
Gomphonema clavatum Ehrenberg	5	2
Gomphonema clevei Fricke	5	3
Gomphonema gracile Ehrenberg	4.2	1
Gomphonema insigne Gregory	4	2
Gomphonema olivaceum (Hornemann) Brébisson	4.6	1
Gomphonema parvulum (Kützing) Kützing	2	1
Gyrosigma acuminatum (Kützing) Rabenhorst	4	3
Gyrosigma scalproides (Rabenhorst) Cleve	2	3
Hantzschia amphioxys (Ehrenberg) Grunow	1.5	3
Hantzschia elongata (Hantzsch) Grunow	4	3
Melosira cf. *moniliformis* (O.F. Müller) Agardh	2.5	2
Navicula accomoda Hustedt	1	3

Table 4.2 (continued)

Name of taxa	SV	W
Navicula agrestis Hustedt	3	1
Navicula cf.atomus (Kützing) Grunow	2.2	1
Navicula brekkaensis Petersen	5	2
Navicula capitata Ehrenberg	4	1
Navicula capitata var. *hungarica* (Grunow) Ross	4	1
Navicula capitatoradiata Germain	3	2
Navicula cari Ehrenberg	4	3
Navicula cinta (Ehrenberg) Ralfs	3	1
Navicula cohnii (Hilse) Lange-Bertalot	2	2
Navicula cf. *confervacea* (Kützing) Grunow	0	0
Navicula contenta Grunow	4	1
Navicula cryptocephala Kützing	3.5	2
Navicula cryptotenella Lange-Bertalot	4	1
Navicula cuspidata (Kützing) Kützing	2.6	3
Navicula elginensis (Gregory) Ralfs	4	2
Navicula erifuga Lange-Bertalot	2	3
Navicula exigua (Gregory) Grunow	0	0
Navicula gallica (W. Smith) Lagerstedt	5	2
Navicula gastrum (Ehrenberg) Kützing	5	2
Navicula cf. *goeppertiana* (Bleisch) H. L. Smith	2	2
Navicula cf. *heimansioides* Lange-Bertalot	5	2
Navicula heufleriana (Grunow) Cleve	0	0
Navicula cf. *impexa* Hustedt	0	0
Navicula insociabilis Krasske	3	2
Navicula jaagii Meister	5	3
Navicula cf. *kotschyi* Grunow	3	3
Navicula laevissima Kützing	5	1
Navicula lapidosa Krasske	5	2
Navicula cf. *minima* Grunow	2.2	1
Navicula cf. *minuscula* Grunow	0	0
Navicula monoculata Hustedt	3	2
Navicula mutica Kützing	2	2
Navicula muticopsis Van Heurck	0	0
Navicula oblonga Kützing	5	3
Navicula cf. *perlatoides* (O. Müller) Hustedt	0	0
Navicula pseudanglica Lange-Bertalot	3	2
Navicula pseudotuscula Hustedt	0	0
Navicula pupula Kützing	2.6	2
Navicula pygmaea Kützing	2	3
Navicula saxophila Bock	4	1
Navicula schroeteri Meister	2	3
Navicula seminulum Grunow	1.5	2
Navicula spinifera Bock	0	0
Navicula cf. *subminuscula* Manguin	2	1
Navicula viridula (Kützing) Ehrenberg	3	3
Neidium affine (Ehrenberg) Pfitzer	4	3
Neidium ampliatum (Ehrenberg) Krammer	5	3
Neidium densestriatum (østrup) Krammer	5	3
Neidium ladogensis (Cleve) Foged	4	2
Neidium productum (W. Smith) Cleve	4	2
Nitzschia acicularioides Hustedt*	3	2
Nitzschia acicularis (Kützing) W. Smith	2	2

Table 4.2 (continued)

Name of taxa	SV	W
Nitzschia acuminata (W. Smith) Grunow	2	3
Nitzschia amphibia Grunow	2	2
Nitzschia angustata Grunow	3.8	3
Nitzschia brevissima Grunow	2	3
Nitzschia calida Grunow	2.3	2
Nitzschia capitellata Hustedt	1	3
Nitzschia clausii Hantzsch	2.8	3
Nitzschia dissipata (Kützing) Grunow	4.5	3
Nitzschia filiformis (W. Smith) Van Heurck	3	3
Nitzschia fonticola Grunow	3.5	1
Nitzschia frustulum (Kützing) Grunow	2	1
Nitzschia fruticosa Hustedt	2	2
Nitzschia cf. *gracilis* Hantzch	3	2
Nitzschia hantzschiana Rabenhorst	5	2
Nitzschia inconspicua Grunow	2.8	1
Nitzschia intermedia Hantzsch	1	3
Nitzschia lanceolata W. Smith	0	0
Nitzschia levidensis (W. Smith) Grunow	2	2
Nitzschia linearis (Agardh) W. Smith	3	2
Nitzschia linearis var. *tenuis* (W. Smith) Grunow	3	2
Nitzschia nana Grunow	4	2
Nitzschia nyassensis O. Müller	0	0
Nitzschia obtusa W. Smith	2	3
Nitzschia palea (Kützing) W. Smith	1	3
Nitzschia perminuta (Grunow) M. Paragallo	5	1
Nitzschia prolongata Hustedt	3	2
Nitzschia recta Hantzsch	3	2
Nitzschia reversa Hantzsch	1.8	2
Nitzschia scalaris (Ehrenberg) W. Smith	3	3
Nitzschia scalpelliformis Grunow	3	3
Nitzschia sigma (Kützing) W. Smith	2	3
Nitzschia sigmoidea (Nitzsch) W. Smith	3	2
Nitzschia speciosa Hustedt	0	0
Nitzschia subacicularis Hustedt	3	3
Nitzschia thermaloides Hustedt	2	3
Nitzschia tryblionella Hantzsch	2	3
Nitzschia umbonata (Ehrenberg) Lange-Bertalot	1	3
Orthoseira cf. *dendroteres* (Ehrenberg) Crawford	5	2
Pinnularia acoricola Hustedt	5	2
Pinnularia acrosphaeria Rabenhorst	5	3
Pinnularia borealis Ehrenberg	5	3
Pinnularia braunii (Grunow) Cleve	5	3
Pinnularia divergens W. Smith	5	2
Pinnularia divergentissima (Grunow) Cleve	5	2
Pinnularia gibba Ehrenberg	5	2
Pinnularia gibba var. mesogongyla (Ehrenberg) Hustedt	5	1
Pinnularia intermedia (Lagerstedt) Cleve	5	2
Pinnularia lata (Brébisson) W. Smith	5	2
Pinnularia microstauron (Ehrenberg) Cleve	0	0
Pinnularia nobilis Ehrenberg	5	2
Pinnularia obscura Krasske	3	1

Table 4.2 (continued)

Name of taxa	SV	W
Pinnularia similis Hustedt	0	0
Pinnularia subcapitata Gregory	5	2
Pinnularia subrostrata (A. Cleve) Cleve-Euler	4.5	2
Pinnularia superdivergentissima Chaumont & Germain	0	0
Pinnularia viridis (Nitzch) Ehrenberg	4	2
Rhoicosphenia abbreviata (Agardh) Lange-Bertalot	4	1
Rhopalodia brebisonii Krammer	0	0
Rhopalodia gibba (Ehrenberg) O. Müller	5	3
Rhopalodia gibberula (Ehrenberg) O. Müller	5	3
Rhopalodia hirundiniformis O. Müller	0	0
Rhopalodia rupestris (W. Smith) Krammer	0	0
Stauroneis anceps Ehrenberg	5	3
Stauroneis phoenicenteron (Nitzsch) Ehrenberg	5	3
Stenopterobia curvula (W. Smith) Krammer	5	3
Stenopterobia delicatissima (Lewis) Brébisson	5	3
Stephanodiscus rotula (Kützing) Hendey	2.5	1
Surirella angusta Kützing	4	1
Surirella bifrons Ehrenberg	4	2
Surirella biseriata Brébisson	4.5	3
Surirella brebisonii Krammer & Lange-Bertalot	3	2
Surirella cf. *capronii* Brébisson	3	1
Surirella linearis W. Smith	5	2
Surirella ovalis Brébisson	2	2
Surirella splendida (Ehrenberg) Kützing	5	2
Synedra cunningtonii G.S. West	0	0

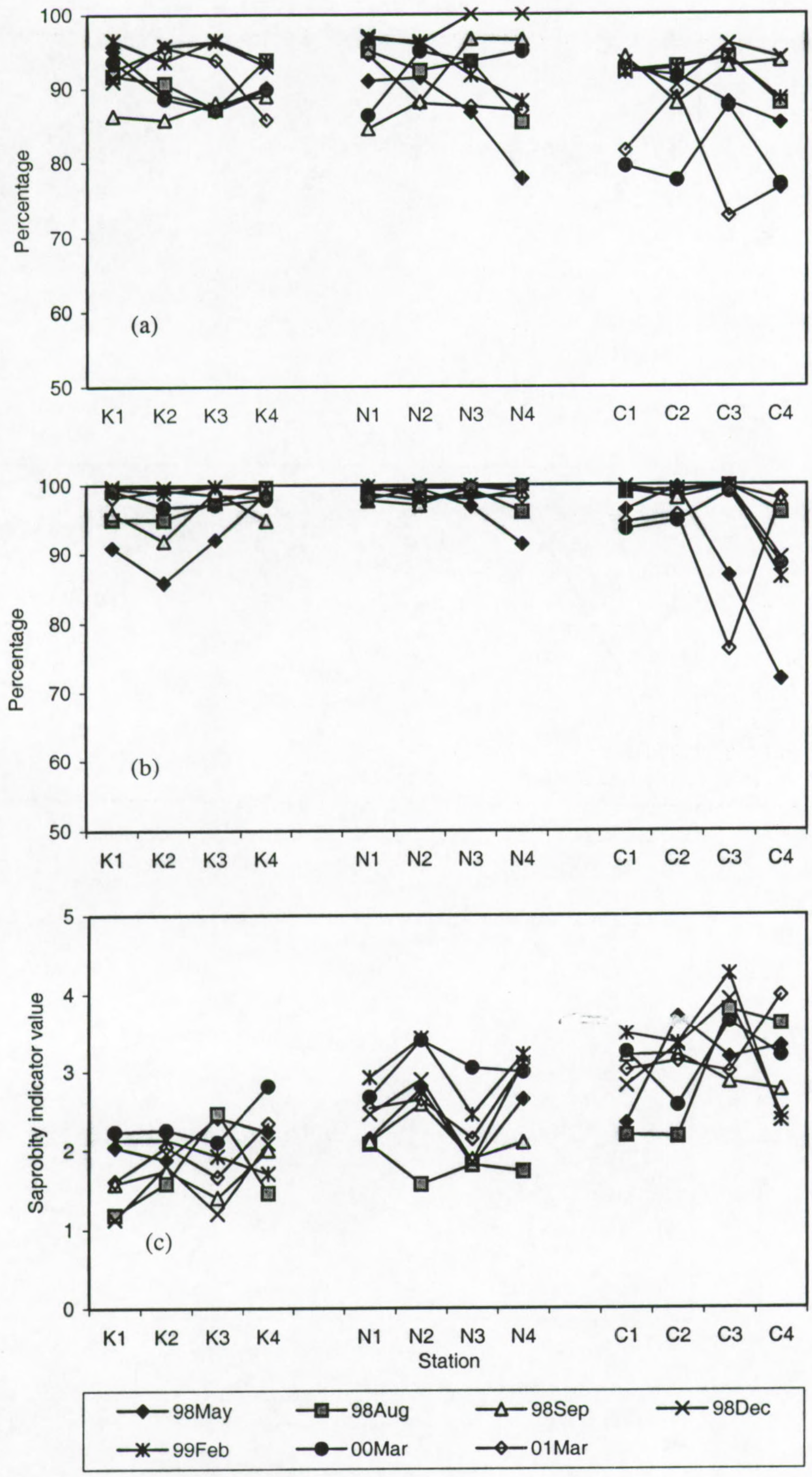

Figure 4.1.(a) Percentage diatom taxa with saprobity indicator values, (b) percentage frustules with S-values and (c) calculated S-values in rivers Kibos (K1-K4), Nyando (N1-N4) and Kisat (C1-C4) at the various sampling times.

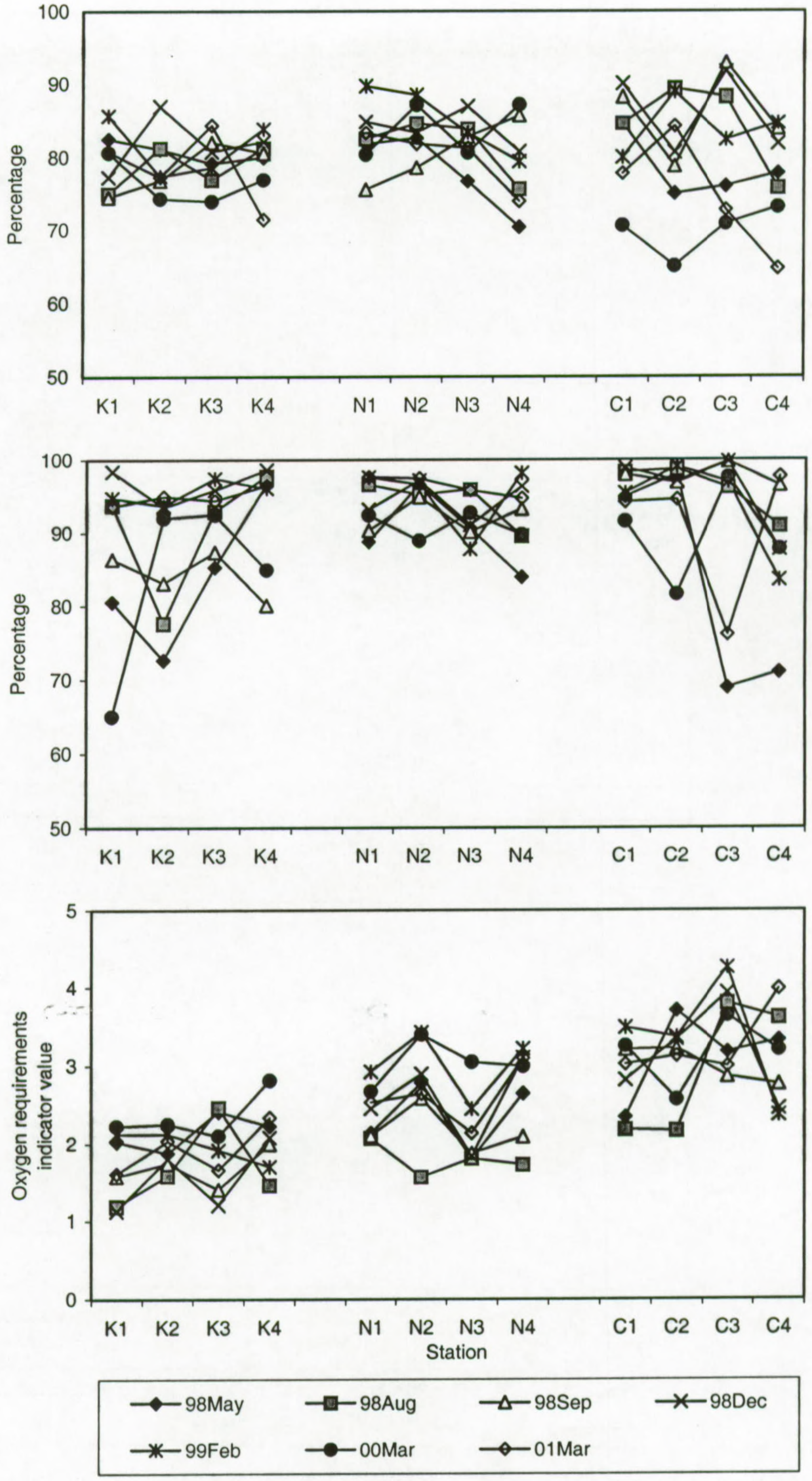

Figure 4.2.(a) Percentage taxa of diatoms with oxygen requirements indicator values, (b) percentage frustules with O-values and (c) calculated O-values in rivers Kibos (K1-K4), Nyando (N1-N4) and Kisat (C1-C4) at the various sampling times.

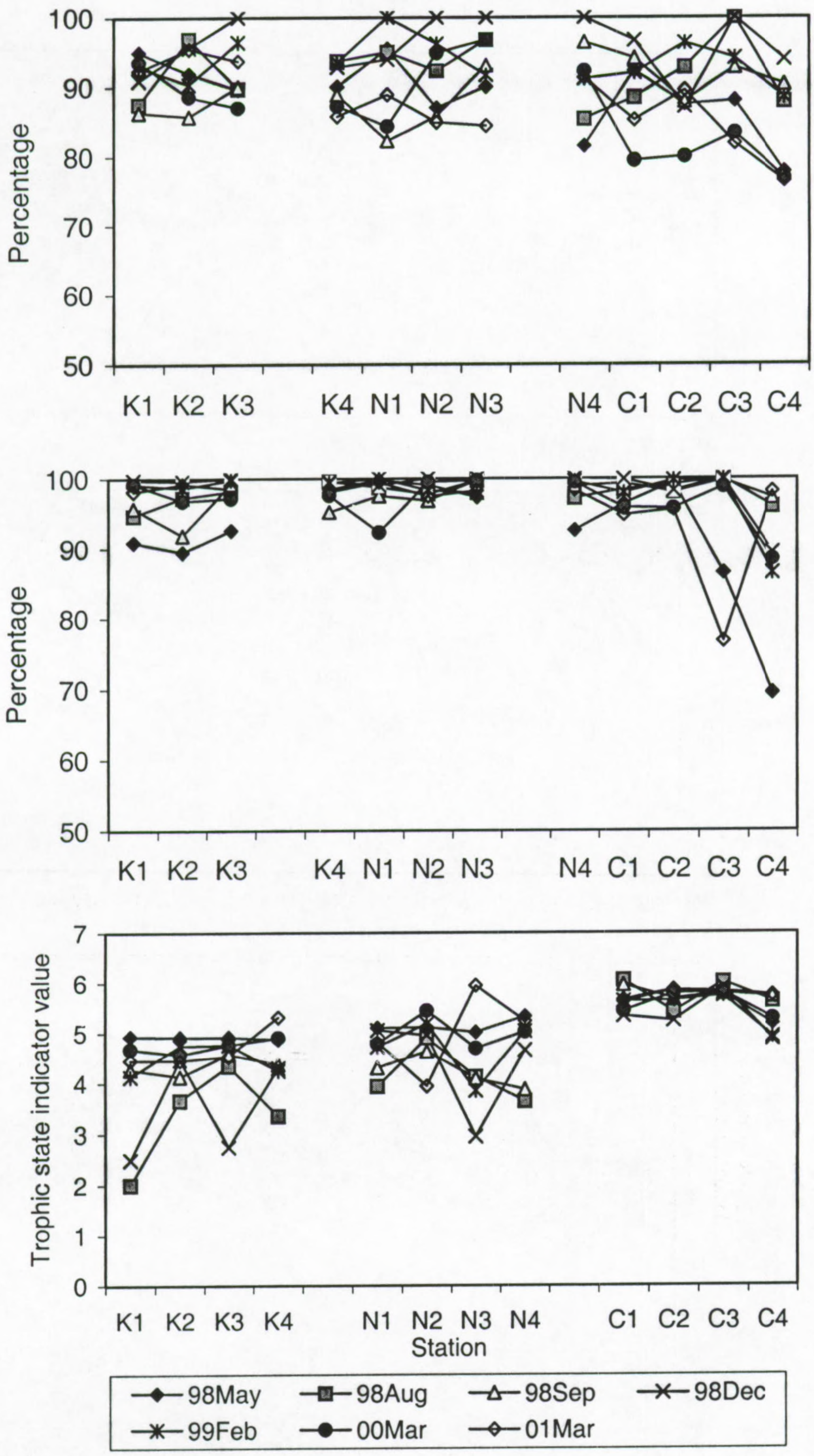

Figure 4.3. (a) Percentage taxa of diatoms with Trophic state indicator values, (b) percentage frustules with T-values and (c) calculated T-values in rivers Kibos (K1-K4 Nyando (N1-N4) and Kisat (C1-C4) at the various sampling times.

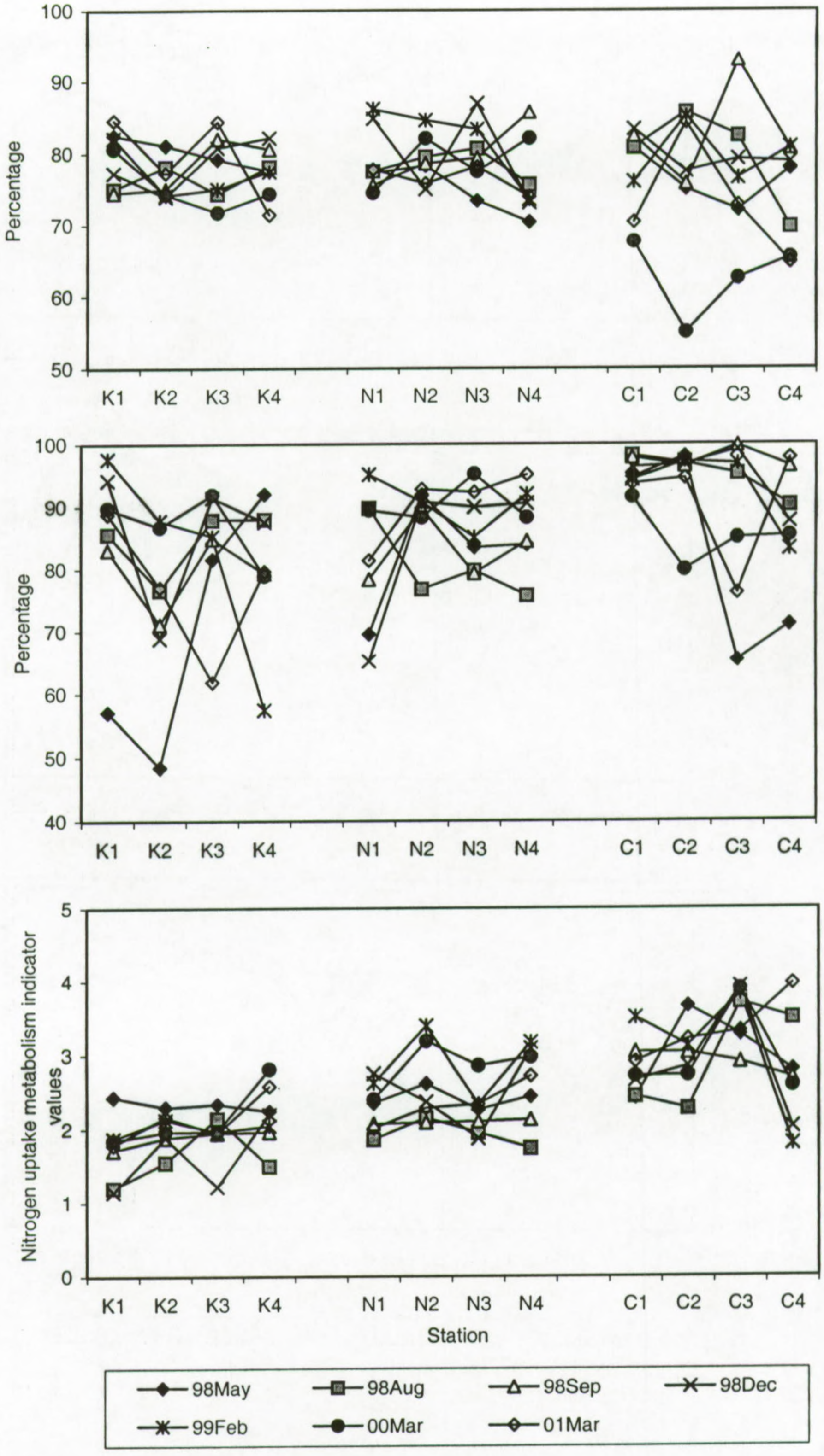

Figure 4.4.(a) Percentage taxa with Trophic state indicator values, (b) percentage frustules with T-values and (c) calculated T-values in rivers Kibos (K1-K4), Nyando (N1-N4) and Kisat (C1-C4) at the various sampling times.

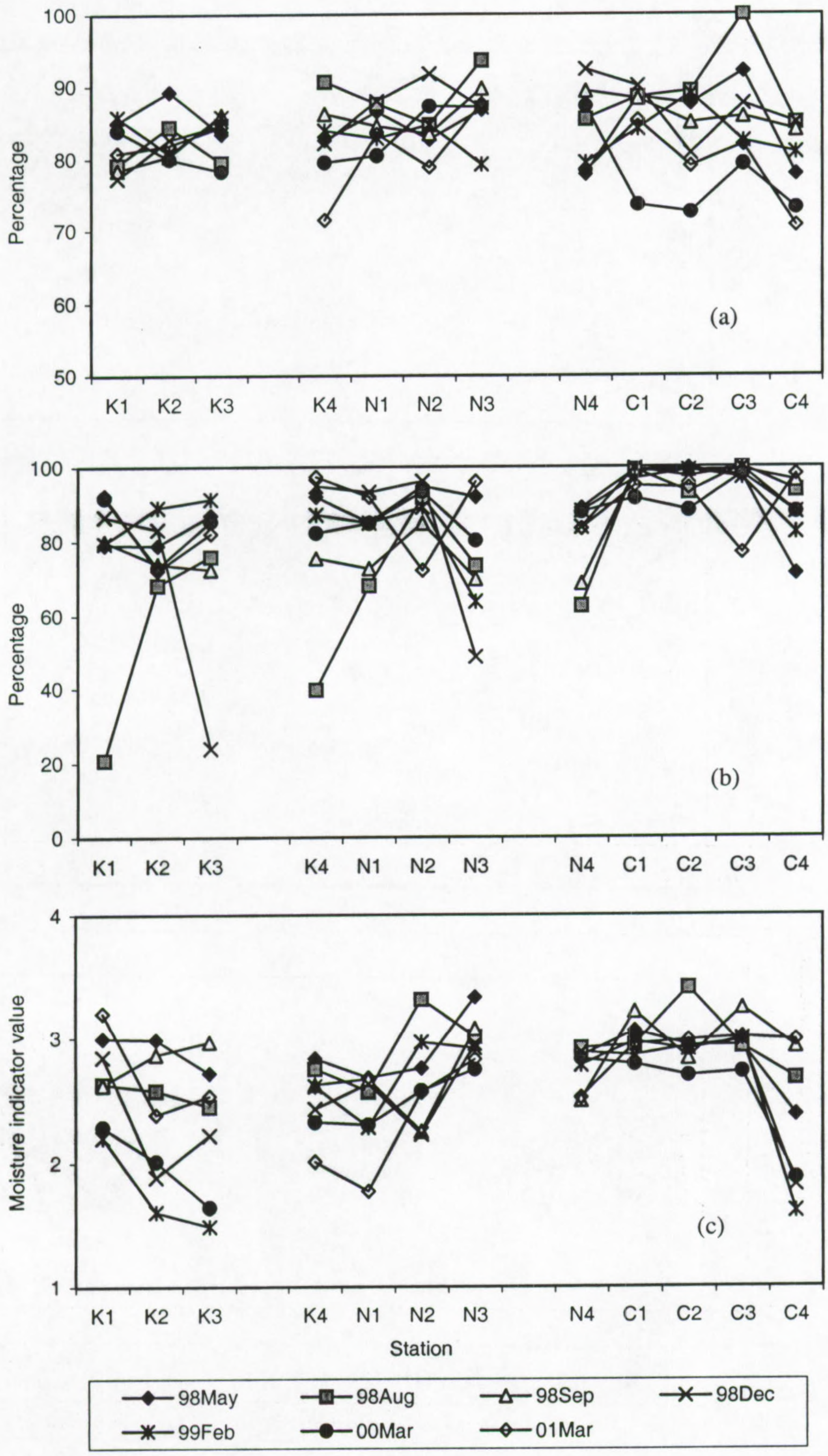

Figure 4.5. (a) Percentage taxa with Moisture indicator values, (b) percentage frustules with M-values and (c) calculated M-values in rivers Kibos (K1-K4), Nyando (N1-N4) and Kisat.(C1-C4) at the various sampling times.

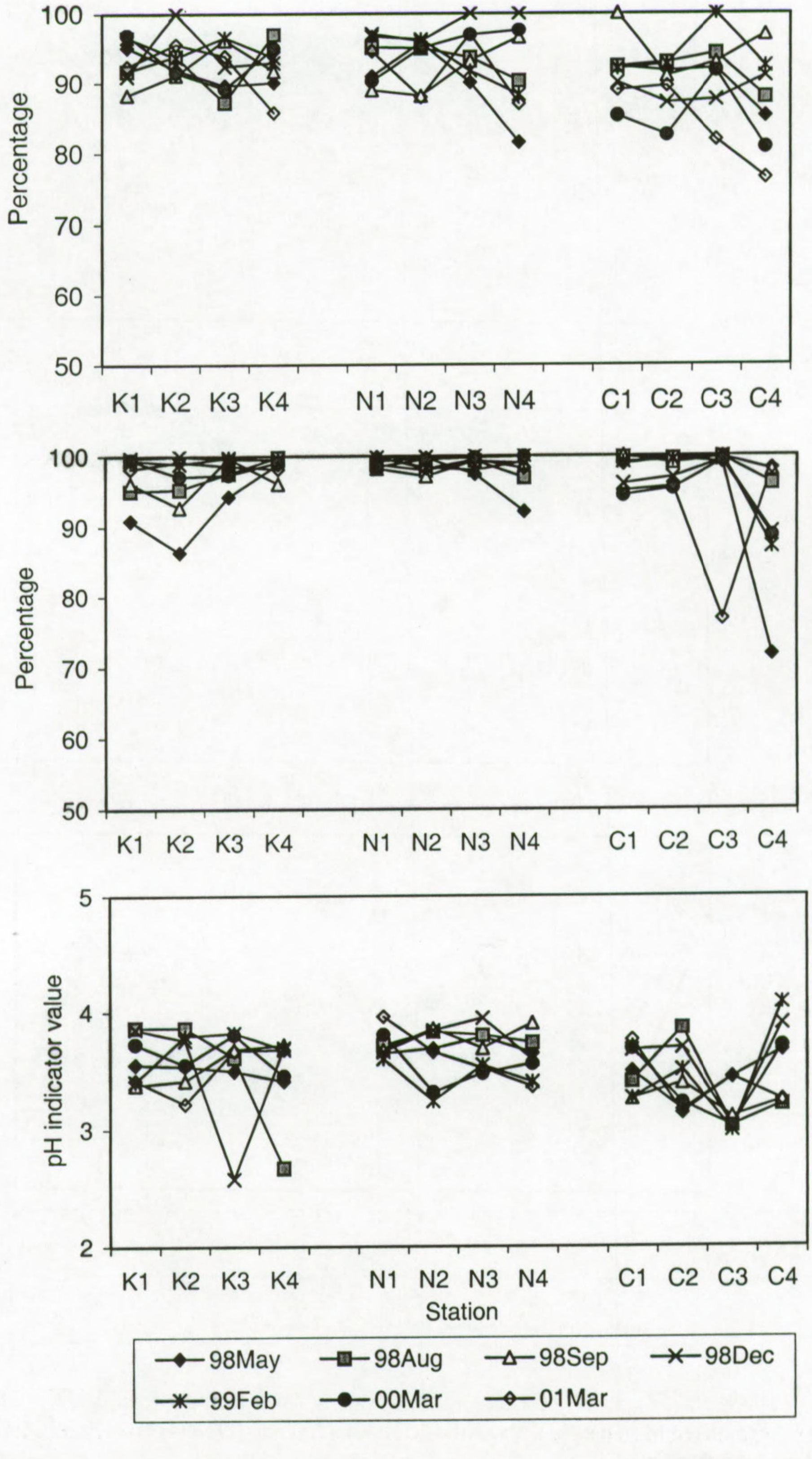

Figure 4.6. (a) Percentage taxa with pH indicator values, (b) percentage frustules with pH indicator values and (c) calculated pH indicator values in rivers Kibos (K1-K4), Nyando (N1-N4) and Kisat (C1-C4) at the various sampling times.

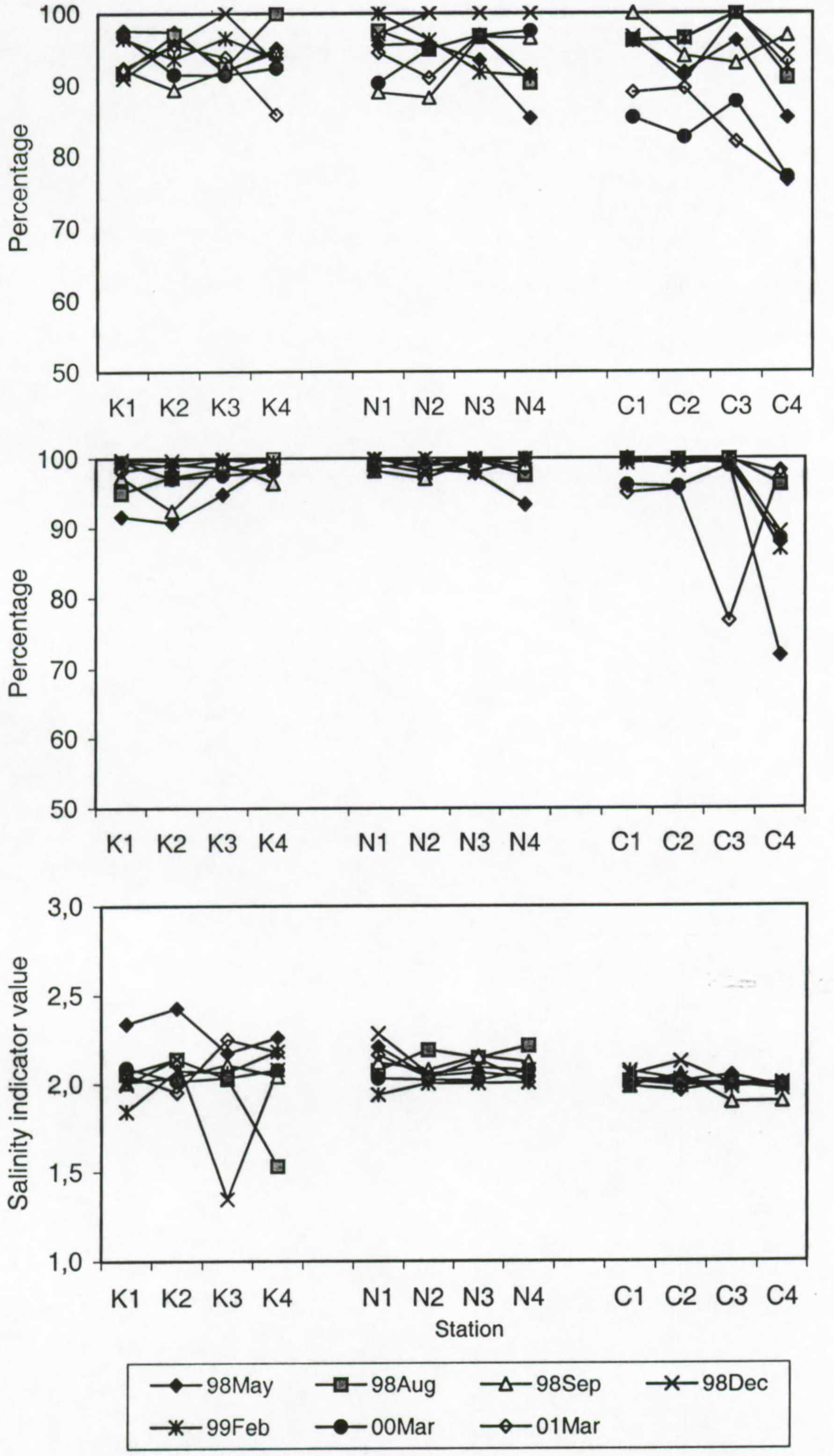

Figure 4.7.(a) Percentage taxa with salinity indicator values, (b) percentage frustules with H-values and (c) calculated H-values in rivers Kibos (K1-K4), Nyando (N1-N4) and Kisat.(C1-C4) at the various sampling times.

Annex 5

Table 5.1. List of diatom taxa of rivers Kibos, Nyando and Kisat, and their codes used in TWINSPAN and CCA analysis.

Code	Taxon	Code	Taxon
Ach bio	*Achnanthes bioretii* Germain	Cym tum	*Cymbella tumidula* Grunow
Ach lan	*Achnanthes* cf. *lanceolata* (Brébisson) Grunow	Cym tur	*Cymbella turgidula* (Brébisson) Van Heurck
Ach min	*Achnanthes* cf. *minutissima* Kützing	Dip alp	*Diploneis alpina* Meister
Ach dao	*Achnanthes daonensis* Lange-Bertalot	Dip ell	*Diploneis elliptica* (Kützing) Cleve
Ach del	*Achnanthes delicatula* (Kützing) Grunow	Dip ova	*Diploneis ovalis* (Hilse) Cleve
Ach exi	*Achnanthes exigua* Grunow	Epi adn	*Epithemia adnata* (Kützing) Brébisson
Ach fle	*Achnanthes flexella* (Kützing) Brun	Epi arg	*Epithemia argus* (Ehrenberg) Kützing
Ach inf	*Achnanthes inflata* (Kützing) Grunow	Epi sor	*Epithemia sorex* Kützing
Ach obl	*Achnanthes oblongella* Øestrup	Eun bil	*Eunotia bilunaris* (Ehrenberg) Mills
Ach plo	*Achnanthes ploenensis* Hustedt	Eun cri	*Eunotia crista*-galli Cleve
Ach tri	*Achnanthes trinodis* (W. Smith) Grunow	Eun did	*Eunotia didyma* Grunow
Amp pel	*Amphipleura pellucida* (Kützing) Kützing	Eun exi	*Eunotia exigua* (Brébisson) Rabenhorst
Amp cof	*Amphora coffeaeformis* (Agardh) Kützing	Eun fab	*Eunotia faba* Ehrenberg
Amp com	*Amphora commutata* Grunow	Eun gla	*Eunotia glacialis* Meister
Amp hol	*Amphora holsatica* Hustedt	Eun int	*Eunotia intermedia* (Krasske) Nörpel & Lange-Bertalot
Amp mon	*Amphora montana* Krasske	Eun min	*Eunotia minor* (Kützing) Grunow
Amp ova	*Amphora ovalis* (Kützing) Kützing	Eun pec	*Eunotia pectinalis* (Dillwyn) Rabenhorst
Amp ven	*Amphora veneta* Kützing	Eun pra	*Eunotia praerupta* Ehrenberg
Aul amb	*Aulacoseira ambigua* (Grunow) Simonsen	Eun sol	*Eunotia soleirolii* (Kützing) Rabenhorst
Aul gra	*Aulacoseira granulata* (Ehrenberg) Simonsen	Fra bid	*Fragilaria bidens* Heiberg
Cal bac	*Caloneis bacillum* (Grunow) Cleve	Fra cap	*Fragilaria capucina* var. *vaucheriae* (Kützing) Lange-Bertalot
Cal lep	*Caloneis leptosoma* (Grunow) Krammer	Fra con	*Fragilaria construens* (Ehrenberg) Grunow
Cal mol	*Caloneis molaris* (Grunow) Krammer	Fra csu	*Fragilaria construens* f. *subsalina* (Hustedt) Hustedt
Cal pul	*Caloneis pulchra* Messikommer	Fra cve	*Fragilaria construens* f. *venter* Ehrenberg
Coc pla	*Cocconeis placentula* var. *lineata* (Ehrenberg) Van Heurck	Fra exi	*Fragilaria exigua* Grunow
Cyc men	*Cyclotella meneghiniana* Kützing	Fra par	*Fragilaria parasitica* (W. Smith) Grunow
Cyc oce	*Cyclotella ocellata* Pantocsek	Fra pin	*Fragilaria pinnata* Ehrenberg
Cyc ste	*Cyclotella stelligera* Cleve & Grunow	Fra pul	*Fragilaria pulchella* (Ralfs) Lange-Bertalot
Cym sol	*Cymatopleura solea* (Brébisson) W. Smith	Fra ten	*Fragilaria tenera* (W. Smith) Lange-Bertalot
Cym aff	*Cymbella affinis* Kützing	Fra uln	*Fragilaria ulna* (Nitzsch) Lange-Bertalot
Cym alp	*Cymbella alpina* Grunow	Fru rho	*Frustulia rhomboides* (Ehrenberg) De Toni
Cym amp	*Cymbella amphicephala* Naegeli	Fru rvi	*Frustulia rhomboides* var. *viridula* (Brébisson) Cleve
Cym ces	*Cymbella cesatii* (Rabenhorst) Grunow	Fru vul	*Frustulia vulgaris* (Thwaites) De Toni
Cym del	*Cymbella delicatula* Kützing	Gom bec	*Gomphocymbella beccari* (Grunow) Forti
Cym des	*Cymbella descripta* (Hustedt) Krammer & Lange-Bertalot	Gom aff	*Gomphonema affine* Kützing
Cym elg	*Cymbella elginensis* Krammer	Gom ast	*Gomphonema angustatum* (Kützing) Rabenhorst
Cym fal	*Cymbella falaisensis* (Grunow) Krammer & Lange-Bertalot	Gom ang	*Gomphonema angustum* Agardh
Cym gra	*Cymbella gracilis* (Ehrenberg) Kützing	Gom aug	*Gomphonema augur* Ehrenberg
Cym mes	*Cymbella mesiana* Cholnoky	Gom cla	*Gomphonema clavatum* Ehrenberg
Cym mic	*Cymbella microcephala* Grunow	Gom cle	*Gomphonema* clevei Fricke
Cym nav	*Cymbella naviculliformis* (Auerswald) Cleve	Gom gra	*Gomphonema gracile* Ehrenberg
Cym pro	*Cymbella prostrata* (Berkeley) Cleve	Gom ins	*Gomphonema insigne* Gregory
Cym sil	*Cymbella silesiaca* Bleisch	Gom oli	*Gomphonema olivaceum* (Hornemann) Brébisson
Cym sim	*Cymbella similis* Krasske		

Table 5.1. (continued).

Code	Taxon	Code	Taxon
Gom par	*Gomphonema parvulum* (Kützing) Kützing	Nav pse	*Navicula pseudanglica* Lange-Bertalot
Gyr acu	*Gyrosigma acuminatum* (Kützing) Rabenhorst	Nav pdo	*Navicula pseudotuscula* Hustedt
Gyr sca	*Gyrosigma scalproides* (Rabenhorst) Cleve	Nav pup	*Navicula pupula* Kützing
Han amp	*Hantzschia amphioxys* (Ehrenberg) Grunow	Nav pyg	*Navicula pygmaea* Kützing
Han elo	*Hantzschia elongata* (Hantzsch) Grunow	Nav sax	*Navicula saxophila* Bock
Mel mon	*Melosira* cf. *moniliformis* (O.F. Müller) Agardh	Nav sch	*Navicula schroeteri* Meister
Nav lep	*Navicula leptostriata* Jørgensen	Nav sem	*Navicula seminulum* Grunow
Nav acc	*Navicula accomoda* Hustedt	Nav spi	*Navicula spinifera* Bock
Nav agr	*Navicula agrestis* Hustedt	Nav sub	*Navicula* cf. *subminuscula* Manguin
Nav bre	*Navicula brekkaensis* Petersen	Nav vir	*Navicula viridula* (Kützing) Ehrenberg
Nav cap	*Navicula capitata* Ehrenberg	Nei aff	*Neidium affine* (Ehrenberg) Pfitzer
Nav chu	*Navicula capitata* var. *hungarica* (Grunow) Ross	Nei amp	*Neidium ampliatum* (Ehrenberg) Krammer
Nav cto	*Navicula capitatoradiata* Germain	Nei den	*Neidium densestriatum* (østrup) Krammer
Nav car	*Navicula cari* Ehrenberg	Nei lad	*Neidium ladogensis* (Cleve) Foged
Nav hei	*Navicula* cf. *heimansioides* Lange-Bertalot	Nei pro	*Neidium productum* (W. Smith) Cleve
Nav imp	*Navicula* cf. *impexa* Hustedt	Nit aci	*Nitzschia acicularioides* Hustedt
Nav kot	*Navicula* cf. *kotschyi* Grunow	Nit acc	*Nitzschia acicularis* (Kützing) W. Smith
Nav min	*Navicula* cf. *minima* Grunow	Nit acu	*Nitzschia acuminata* (W. Smith) Grunow
Nav mcu	*Navicula* cf. *minuscula* Grunow	Nit amp	*Nitzschia amphibia* Grunow
Nav ato	*Navicula* cf.*atomus* (Kützing) Grunow	Nit ang	*Nitzschia angustata* Grunow
Nav cin	*Navicula cinta* (Ehrenberg) Ralfs	Nit bre	*Nitzschia brevissima* Grunow
Nav cof	*Navicula* cf. *confervacea* (Kützing) Grunow	Nit cal	*Nitzschia calida* Grunow
Nav coh	*Navicula cohnii* (Hilse) Lange-Bertalot	Nit cap	*Nitzschia capitellata* Hustedt
Nav con	*Navicula contenta* Grunow	Nit cla	*Nitzschia clausii* Hantzsch
Nav cry	*Navicula cryptocephala* Kützing	Nit dis	*Nitzschia dissipata* (Kützing) Grunow
Nav cte	*Navicula cryptotenella* Lange-Bertalot	Nit fil	*Nitzschia filiformis* (W. Smith) Van Heurck
Nav cus	*Navicula cuspidata* (Kützing) Kützing	Nit fle	*Nitzschia flexa* Schumann
Nav elg	*Navicula elginensis* (Gregory) Ralfs	Nit fon	*Nitzschia fonticola* Grunow
Nav eri	*Navicula erifuga* Lange-Bertalot	Nit fru	*Nitzschia frustulum* (Kützing) Grunow
Nav exi	*Navicula exigua* (Gregory) Grunow	Nit fti	*Nitzschia fruticosa* Hustedt
Nav gal	*Navicula gallica* (W. Smith) Lagerstedt	Nit gra	*Nitzschia* cf. *gracilis* Hantzch
Nav gas	*Navicula gastrum* (Ehrenberg) Kützing	Nit han	*Nitzschia hantzschiana* Rabenhorst
Nav goe	*Navicula* cf. *goeppertiana* (Bleisch) H. L. Smith	Nit inc	*Nitzschia inconspicua* Grunow
Nav heu	*Navicula heufleriana* (Grunow) Cleve	Nit int	*Nitzschia intermedia* Hantzsch
Nav ins	*Navicula insociabilis* Krasske	Nit lan	*Nitzschia lanceolata* W. Smith
Nav jaa	*Navicula jaagii* Meister	Nit lev	*Nitzschia levidensis* (W. Smith) Grunow
Nav lae	*Navicula laevissima* Kützing	Nit lin	*Nitzschia linearis* (Agardh) W. Smith
Nav lap	*Navicula lapidosa* Krasske	Nit lte	*Nitzschia linearis* var. tenuis (W. Smith) Grunow
Nav mon	*Navicula monoculata* Hustedt	Nit nan	*Nitzschia nana* Grunow
Nav mut	*Navicula mutica* Kützing	Nit nya	*Nitzschia nyassensis* O. Müller
Nav mco	*Navicula muticopsis* Van Heurck	Nit obt	*Nitzschia obtusa* W. Smith
Nav obl	*Navicula oblonga* Kützing	Nit pal	*Nitzschia palea* (Kützing) W. Smith
Nav per	*Navicula* cf. *perlatoides* (O. Müller) Hustedt	Nit per	*Nitzschia perminuta* (Grunow) M. Paragallo

Table 5.1. (continued).

Code	Taxon	Code	Taxon
Nit pro	*Nitzschia prolongata* Hustedt	Pin sim	*Pinnularia similis* Hustedt
Nit rec	*Nitzschia recta* Hantzsch	Pin sub	*Pinnularia subcapitata* Gregory
Nit rev	*Nitzschia reversa* Hantzsch	Pin sro	*Pinnularia subrostrata* (A. Cleve) Clive-Euler
Nit sca	*Nitzschia scalaris* (Ehrenberg) W. Smith	Pin sup	*Pinnularia superdivergentissima* Chaumont & Germain
Nit scp	*Nitzschia scalpelliformis* Grunow	Pin vir	*Pinnularia viridis* (Nitzch) Ehrenberg
Nit sig	*Nitzschia sigma* (Kützing) W. Smith	Rho abb	*Rhoicosphaenia abbreviata* (Agardh) Lange-Bertalot
Nit smo	*Nitzschia sigmoidea* (Nitzsch) W. Smith	Rho bre	*Rhopalodia brebisonii* Krammer
Nit spe	*Nitzschia speciosa* Hustedt	Rho gib	*Rhopalodia gibba* (Ehrenberg) O. Müller
Nit sub	*Nitzschia subacicularis* Hustedt	Rho gru	*Rhopalodia gibberula* (Ehrenberg) O. Müller
Nit the	*Nitzschia thermaloides* Hustedt	Rho rup	*Rhopalodia rupestris* (W. Smith) Krammer
Nit try	*Nitzschia tryblionella* Hantzsch	Rho hir	*Rhopalodia hirundiniformis* O. Müller
Nit umb	*Nitzschia umbonata* (Ehrenberg) Lange-Bertalot	Sch cru	*Schizostauron crucicula* Grunow ex Cleve
Ort den	*Orthoseira* cf. *dendroteres* (Ehrenberg) Crawford	Sta anc	*Stauroneis anceps* Ehrenberg
Pin aco	*Pinnularia acoricola* Hustedt	Sta pho	*Stauroneis phoenicenteron* (Nitzsch) Ehrenberg
Pin acr	*Pinnularia acrosphaeria* Rabenhorst	Ste cur	*Stenopterobia curvula* (W. Smith) Krammer
Pin bor	*Pinnularia borealis* Ehrenberg	Ste del	*Stenopterobia delicatissima* (Lewis) Brébisson
Pin bra	*Pinnularia braunii* (Grunow) Cleve	Ste rot	*Stephanodiscus rotula* (Kützing) Hendey
Pin div	*Pinnularia divergens* W. Smith	Sur ang	*Surirella angusta* Kützing
Pin dge	*Pinnularia divergentissima* (Grunow) Cleve	Sur bif	*Surirella bifrons* Ehrenberg
Pin gib	*Pinnularia gibba* Ehrenberg	Sur bis	*Surirella biseriata* Brébisson
Pin gme	*Pinnularia gibba* var. *mesogongyla* (Ehrenberg) Hustedt	Sur bre	*Surirella brebisonii* Krammer & Lange-Bertalot
Pin int	*Pinnularia intermedia* (Lagerstedt) Cleve	Sur cap	*Surirella* cf. *capronii* Brébisson
Pin lat	*Pinnularia lata* (Brébisson) W. Smith	Sur lin	*Surirella linearis* W. Smith
Pin mic	*Pinnularia microstauron* (Ehrenberg) Cleve	Sur ova	*Surirella ovalis* Brébisson
Pin nob	*Pinnularia nobilis* Ehrenberg	Sur spl	*Surirella splendida* (Ehrenberg) Kützing
Pin obs	*Pinnularia obscura* Krasske	Syn cun	*Synedra cunningtonii* G.S. West

Table 5.2. Classification of samples resulting from TWINSPAN analysis of diatoms from rivers Kibos, Nyando and Kisat (given up to level 4). Indicator species shown in bold. Two-way table for species available on request.

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                         CLASSIFICATION OF SAMPLES

DIVISION    1  (N=    84)         i.e. group *
Eigenvalue: 0.2633  at iteration   5
INDICATORS and their signs:
Nav exi  1(-)   Nav sch  2(-)   Gyr sca  1(-)
Maximum indicator score for negative group  -1
Minimum indicator score for positive group   0

ITEMS IN NEGATIVE GROUP   2  (N =    56)         i.e. group *0
K1My98    K2My98    K3My98    K4My98    N1My98    N2My98    N3My98    N4My98
K1Au98    K2Au98    K3Au98    K4Au98    N1Au98    N2Au98    N3Au98    N4Au98
K1Se98    K2Se98    K3Se98    K4Se98    N1Se98    N2Se98    N3Se98    N4Se98
K1De98    K2De98    K3De98    K4De98    N1De98    N2De98    N3De98    N4De98
K1Fe99    K2Fe99    K3Fe99    K4Fe99    N1Fe99    N2Fe99    N3Fe99    N4Fe99
K1Mr00    K2Mr00    K3Mr00    K4Mr00    N1Mr00    N2Mr00    N3Mr00    N4Mr00
K1Mr01    K2Mr01    K3Mr01    K4Mr01    N1Mr01    N2Mr01    N3Mr01    N4Mr01

MISCLASSIFIED NEGATIVES (N =     1)
N2Mr00

ITEMS IN POSITIVE GROUP   3  (N =    28)         i.e. group *1
C1My98    C2My98    C3My98    C4My98    C1Au98    C2Au98    C3Au98    C4Au98
C1Se98    C2Se98    C3Se98    C4Se98    C1De98    C2De98    C3De98    C4De98
C1Fe99    C2Fe99    C3Fe99    CFe499    C1Mr00    C2Mr00    C3Mr00    C4Mr00
C1Mr01    C2Mr01    C3Mr01    C4Mr01

NEGATIVE PREFERENTIALS
Ach lan 1( 17,   3) Amp com 1( 14,   3) Coc pla 1( 48,   6) Cym sil 1( 32,   8)
Fra csu 1( 19,   3) Fru rho 1( 13,   1) Gom aff 1( 12,   0) Gom ang 1( 55,  13)
Gom gra 1( 23,   1) Gom oli 1( 27,   3) Gyr acu 1( 13,   0) Gyr sca 1( 38,   0)
Nav cto 1( 17,   1) Nav hei 1( 40,   1) Nav con 1( 20,   2) Nav cry 1( 41,   8)
Nav dec 1( 44,   0) Nav gas 1( 12,   3) Nav mut 1( 21,   1) Nav pup 1( 33,   7)
Nav sch 1( 54,  13) Nit per 1( 20,   2) Nit rec 1( 14,   3) Nit smo 1( 47,  11)
Sta anc 1( 20,   0) Sur ang 1( 34,   3) Sur spl 1( 14,   0) Coc pla 2( 16,   0)
Gom ang 2( 33,   1) Gom par 2( 24,   4) Nav hei 2( 15,   0) Nav sch 2( 39,   0)
Nav sub 2( 15,   3) Nav vir 2( 17,   0)

POSITIVE PREFERENTIALS
Ach exi 1( 15,  21) Aul gra 1( 11,  22) Cal mol 1(  5,   7) Cyc oce 1(  8,  11)
Cym ces 1(  5,   7) Cym fal 1(  2,   8) Epi adn 1(  1,   7) Eun pec 1( 10,  16)
Fra pin 1(  5,   8) Gom gro 1(  2,   8) Nav cus 1(  6,   6) Nit cla 1(  4,  16)
Nit scp 1(  0,  10) Nit umb 1(  5,  15) Pin bra 1( 14,  18) Rho gib 1(  2,   9)
Ste rot 1(  7,   9) Syn cun 1(  1,   6) Ach min 2( 14,  14) Aul gra 2(  0,   6)
Nav goe 2(  2,  15) Nav goe 3(  0,   6) Nit pal 3(  6,  16) Nit pal 4(  0,   8)

NON-PREFERENTIALS
Ach min 1( 46,  26) Amp mon 1( 34,  12) Cal bac 1( 14,   8) Cyc men 1( 18,   6)
Fra cap 1( 51,  14) Fra uln 1( 45,  21) Gom par 1( 55,  27) Han amp 1( 31,  12)
Nav cte 1( 47,  12) Nav goe 1( 26,  25) Nav sub 1( 38,  10) Nav vir 1( 52,  14)
Nit amp 1( 30,  21) Nit dis 1( 23,   8) Nit fle 1(  9,   7) Nit gra 1( 11,  10)
Nit inc 1(  7,   6) Nit lin 1( 13,   6) Nit pal 1( 55,  28) Nit pal 2( 35,  24)
          --------  E N D   O F   L E V E L   1 --------
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DIVISION    2  (N=    56)         i.e. group *0
Eigenvalue: 0.1693  at iteration   6
INDICATORS and their signs:
Nav con  1(+)   Nav mut  1(+)   Amp com  1(+)   Gom gra  1(+)
Maximum indicator score for negative group   1
Minimum indicator score for positive group   2

ITEMS IN NEGATIVE GROUP   4  (N =    36)         i.e. group *00
N1My98    N2My98    K1Au98    N4Se98    K1De98    K2De98    K3De98    K4De98
N1De98    N2De98    N3De98    N4De98    K1Fe99    K2Fe99    K3Fe99    K4Fe99
N1Fe99    N2Fe99    N3Fe99    N4Fe99    K1Mr00    K2Mr00    K3Mr00    K4Mr00
N1Mr00    N2Mr00    N3Mr00    N4Mr00    K1Mr01    K2Mr01    K3Mr01    K4Mr01
N1Mr01    N2Mr01    N3Mr01    N4Mr01

BORDERLINE NEGATIVES      (N =     1)
K3De98

MISCLASSIFIED NEGATIVES (N =     2)
N1My98    K3Mr00
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ITEMS IN POSITIVE GROUP   5  (N =    20)          i.e. group *01
K1My98    K2My98    K3My98    K4My98    N3My98    N4My98    K2Au98    K3Au98
K4Au98    N1Au98    N2Au98    N3Au98    N4Au98    K1Se98    K2Se98    K3Se98
K4Se98    N1Se98    N2Se98    N3Se98

BORDERLINE POSITIVES     (N =    1)
N3My98

NEGATIVE PREFERENTIALS
Gyr acu 1(  11,    2)  Nav cto 1(  15,    2)  Nit int 1(   8,    1)  Nit lin 1(  11,    2)
Sur ang 1(  28,    6)  Sur spl 1(  14,    0)  Nav hei 2(  12,    3)  Nav sub 2(  14,    1)
Nav vir 2(  16,    1)

POSITIVE PREFERENTIALS
Ach lan 1(   8,    9)  Ach exi 1(   7,    8)  Ach fle 1(   3,    5)  Ach inf 1(   1,    6)
Amp com 1(   3,   11)  Amp mon 1(  16,   18)  Aul gra 1(   2,    9)  Cal bac 1(   4,   10)
Cal lep 1(   0,    4)  Cal mol 1(   0,    5)  Cyc oce 1(   2,    6)  Cym ces 1(   1,    4)
Dip ell 1(   0,    5)  Eun pec 1(   2,    8)  Fru rho 1(   3,   10)  Fru vul 1(   1,    4)
Gom gra 1(   8,   15)  Han amp 1(  14,   17)  Nav con 1(   3,   17)  Nav cus 1(   2,    4)
Nav mut 1(   6,   15)  Nit acc 1(   1,    6)  Nit fle 1(   2,    7)  Nit lev 1(   2,    4)
Nit rec 1(   5,    9)  Pin bor 1(   0,    6)  Pin bra 1(   6,    8)  Pin div 1(   1,    6)
Pin sub 1(   0,    5)  Pin sro 1(   0,    5)  Ach min 2(   6,    8)  Amp mon 2(   2,    5)
Fra uln 2(   2,    5)  Nav mut 2(   0,    7)

NON-PREFERENTIALS
Ach min 1(  26,   20)  Coc pla 1(  29,   19)  Cyc men 1(   9,    9)  Cym sil 1(  24,    8)
Fra cap 1(  33,   18)  Fra csu 1(  13,    6)  Fra uln 1(  26,   19)  Gom aff 1(   6,    6)
Gom ang 1(  35,   20)  Gom oli 1(  19,    8)  Gom par 1(  35,   20)  Gyr sca 1(  22,   16)
Nav agr 1(   4,    4)  Nav hei 1(  28,   12)  Nav cry 1(  29,   12)  Nav cte 1(  29,   18)
Nav dec 1(  28,   16)  Nav gas 1(   7,    5)  Nav goe 1(  15,   11)  Nav ins 1(   5,    4)
Nav pup 1(  22,   11)  Nav sch 1(  35,   19)  Nav sub 1(  26,   12)  Nav vir 1(  36,   16)
Nit amp 1(  16,   14)  Nit dis 1(  12,   11)  Nit fru 1(   8,    3)  Nit gra 1(   6,    5)
Nit pal 1(  35,   20)  Nit per 1(  12,    8)  Nit smo 1(  28,   19)  Sta anc 1(  13,    7)
Coc pla 2(  11,    5)  Gom ang 2(  20,   13)  Gom par 2(  15,    9)  Nav sch 2(  22,   17)
Nit pal 2(  21,   14)  Gom ang 3(   4,    4)
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DIVISION    3  (N=    28)         i.e. group *1
Eigenvalue: 0.2722  at iteration  11
INDICATORS and their signs:
Aul gra  2(+)
Maximum indicator score for negative group   0
Minimum indicator score for positive group   1

ITEMS IN NEGATIVE GROUP   6  (N =    22)          i.e. group *10
C1My98    C2My98    C3My98    C1Au98    C2Au98    C3Au98    C1Se98    C2Se98
C3Se98    C1De98    C2De98    C3De98    C1Fe99    C2Fe99    C3Fe99    C1Mr00
C2Mr00    C3Mr00    C1Mr01    C2Mr01    C3Mr01    C4Mr01

ITEMS IN POSITIVE GROUP   7  (N =     6)          i.e. group *11
C4My98    C4Au98    C4Se98    C4De98    CFe499    C4Mr00

NEGATIVE PREFERENTIALS
Ach exi 1(  19,    2)  Amp mon 1(  11,    1)  Cal mol 1(   7,    0)  Cyc men 1(   6,    0)
Eun pec 1(  16,    0)  Gom gro 1(   8,    0)  Nav cry 1(   8,    0)  Nav sub 1(   9,    1)
Nav vir 1(  14,    0)  Nit cal 1(   5,    0)  Nit lin 1(   6,    0)  Nit smo 1(  10,    1)
Ach min 2(  13,    1)  Nit amp 2(   5,    0)  Nav goe 3(   6,    0)

POSITIVE PREFERENTIALS
Coc pla 1(   1,    5)  Cyc oce 1(   7,    4)  Dip ell 1(   0,    3)  Epi adn 1(   1,    6)
Epi sor 1(   1,    3)  Fra con 1(   1,    4)  Fra csu 1(   1,    2)  Fra pin 1(   2,    6)
Nit fru 1(   3,    2)  Nit gra 1(   6,    4)  Nit inc 1(   2,    4)  Nit scp 1(   6,    4)
Rho gib 1(   5,    4)  Rho ver 1(   1,    2)  Ste rot 1(   3,    6)  Aul gra 2(   0,    6)
Epi adn 2(   0,    2)  Fra con 2(   0,    2)  Fra pin 2(   0,    2)  Ste rot 2(   0,    4)
Aul gra 3(   0,    3)


NON-PREFERENTIALS
Ach min 1(  21,    5)  Aul gra 1(  16,    6)  Cal bac 1(   6,    2)  Cym ces 1(   5,    2)
Cym fal 1(   7,    1)  Cym sil 1(   6,    2)  Fra cap 1(  10,    4)  Fra uln 1(  16,    5)
Gom ang 1(   9,    4)  Gom par 1(  21,    6)  Han amp 1(  10,    2)  Nav cte 1(   9,    3)
Nav cus 1(   5,    1)  Nav goe 1(  20,    5)  Nav pup 1(   6,    1)  Nav sch 1(  11,    2)
Nit amp 1(  16,    5)  Nit cla 1(  14,    2)  Nit dis 1(   6,    2)  Nit fle 1(   6,    1)
Nit pal 1(  22,    6)  Nit umb 1(  11,    4)  Pin bra 1(  13,    5)  Syn cun 1(   4,    2)
Nav goe 2(  13,    2)  Nit pal 2(  19,    5)  Nit pal 3(  14,    2)  Nit pal 4(   7,    1)

           --------  E N D   O F   L E V E L   2 --------

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DIVISION    4  (N=    36)         i.e. group *00
Eigenvalue: 0.1804  at iteration  13
INDICATORS and their signs:
Nit amp  1(+)   Gom par  2(+)   Cym sil  1(+)   Nav cto  1(+)   Nit per  1(-)
Maximum indicator score for negative group   0
Minimum indicator score for positive group   1
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 ITEMS IN NEGATIVE GROUP   8  (N =    13)          i.e. group *000
 K1Au98    K1De98    K3De98    K4De98    N3De98    K1Fe99    K2Fe99    K3Fe99
 K4Fe99    K1Mr00    K1Mr01    K2Mr01    K4Mr01

 MISCLASSIFIED NEGATIVES (N =    2)
 K1Mr00    K2Mr01

 ITEMS IN POSITIVE GROUP   9  (N =    23)          i.e. group *001
 N1My98    N2My98    N4Se98    K2De98    N1De98    N2De98    N4De98    N1Fe99
 N2Fe99    N3Fe99    N4Fe99    K2Mr00    K3Mr00    K4Mr00    N1Mr00    N2Mr00
 N3Mr00    N4Mr00    K3Mr01    N1Mr01    N2Mr01    N3Mr01    N4Mr01

 BORDERLINE POSITIVES     (N =    4)
 N1My98    N4Se98    K2Mr00    K3Mr01

 NEGATIVE PREFERENTIALS
Ach fle 1(   3,    0) Gyr acu 1(   6,    5) Nav cap 1(   3,    2) Nav ins 1(   4,    1)
Nit per 1(   9,    3) Sur amp 1(   3,    2) Nav vir 3(   3,    2)

 POSITIVE PREFERENTIALS
Ach exi 1(   1,    6) Amp mon 1(   2,   14) Coc pla 1(   6,   23) Cym sil 1(   5,   19)
Cym tur 1(   0,    6) Gom gra 1(   1,    7) Nav cto 1(   1,   14) Nav imp 1(   1,    6)
Nav goe 1(   3,   12) Nav hal 1(   1,    5) Nav pup 1(   4,   18) Nav pyg 1(   0,    5)
Nit amp 1(   1,   15) Nit fru 1(   1,    7) Nit gra 1(   0,    6) Nit lin 1(   2,    9)
Coc pla 2(   2,    9) Gom ang 2(   4,   16) Gom par 2(   0,   15) Nav sub 2(   1,   13)
Nit pal 3(   0,    6)
NON-PREFERENTIALS
Ach lan 1(   3,    5) Ach min 1(  10,   16) Cyc men 1(   2,    7) Fra cap 1(  12,   21)
Fra csu 1(   6,    7) Fra uln 1(   7,   19) Gom aff 1(   3,    3) Gom ang 1(  12,   23)
Gom oli 1(   9,   10) Gom par 1(  13,   22) Gyr sca 1(  11,   11) Han amp 1(   6,    8)
Nav hei 1(  13,   15) Nav cry 1(  12,   17) Nav cte 1(  11,   18) Nav dec 1(  12,   16)
Nav gas 1(   3,    4) Nav sch 1(  13,   22) Nav sub 1(   7,   19) Nav vir 1(  13,   23)
Nit dis 1(   6,    6) Nit int 1(   3,    5) Nit pal 1(  12,   23) Nit smo 1(   7,   21)
Sta anc 1(   6,    7) Sur ang 1(   9,   19) Sur spl 1(   4,   10) Nav hei 2(   5,    7)
Nav sch 2(   9,   13) Nav vir 2(   8,    8) Nit pal 2(   6,   15)
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 DIVISION    5  (N=    20)          i.e. group *01
 Eigenvalue: 0.1972  at iteration   8
 INDICATORS and their signs:
 Fru rho   1(-)   Nit rec  1(+)   Amp mon  2(+)
 Maximum indicator score for negative group    0
 Minimum indicator score for positive group    1

 ITEMS IN NEGATIVE GROUP  10  (N =    11)          i.e. group *010
 K1My98    K2My98    K3My98    K4My98    K4Au98    K1Se98    K2Se98    K3Se98
 K4Se98    N1Se98    N2Se98

 ITEMS IN POSITIVE GROUP  11  (N =     9)          i.e. group *011
 N3My98    N4My98    K2Au98    K3Au98    N1Au98    N2Au98    N3Au98    N4Au98
 N3Se98

 MISCLASSIFIED POSITIVES (N =    1)
 K2Au98

 NEGATIVE PREFERENTIALS
Ach lan 1(   7,    2) Ach exi 1(   6,    2) Ach inf 1(   5,    1) Amp cof 1(   3,    0)
Cal bac 1(   8,    2) Cyc men 1(   7,    2) Cym ces 1(   4,    0) Fra con 1(   3,    0)
Fra csu 1(   6,    0) Fru rho 1(   9,    1) Nav agr 1(   4,    0) Nav min 1(   3,    0)
Nav gas 1(   4,    1) Nav ins 1(   4,    0) Nav mon 1(   3,    0) Nit fle 1(   5,    2)
Nit fru 1(   3,    0) Nit lev 1(   3,    1) Pin bor 1(   5,    1) Pin gib 1(   3,    0)
Pin sro 1(   5,    0) Sta anc 1(   6,    1) Sur ang 1(   5,    1) Ach min 2(   7,    1)
Nav hei 2(   3,    0) Nav mut 2(   6,    1)



 POSITIVE PREFERENTIALS
Ach fle 1(   1,    4) Ach plo 1(   0,    2) Ach tri 1(   1,    2) Amp com 1(   4,    7)
Amp hol 1(   0,    2) Cal lep 1(   0,    4) Eun min 1(   1,    2) Gom aug 1(   0,    2)
Nav cto 1(   0,    2) Nav imp 1(   0,    2) Nit cla 1(   1,    2) Nit gra 1(   1,    4)
Nit inc 1(   1,    2) Nit rec 1(   2,    7) Nit sig 1(   0,    2) Nit umb 1(   0,    2)
Pin div 1(   2,    4) Amp mon 2(   0,    5) Fra uln 2(   1,    4) Amp mon 3(   0,    2)
Gom ang 3(   0,    4)

 NON-PREFERENTIALS
Ach min 1(  11,    9) Amp mon 1(  11,    7) Aul gra 1(   5,    4) Cal mol 1(   3,    2)
Coc pla 1(  10,    9) Cyc oce 1(   4,    2) Cym sil 1(   4,    4) Dip ell 1(   2,    3)
Eun pec 1(   5,    3) Fra cap 1(  11,    7) Fra uln 1(  11,    8) Fru vul 1(   2,    2)
Gom aff 1(   3,    3) Gom ang 1(  11,    9) Gom gra 1(   9,    6) Gom oli 1(   4,    4)
Gom par 1(  11,    9) Gyr sca 1(   9,    7) Han amp 1(  11,    6) Nav hei 1(   7,    5)
Nav con 1(  10,    7) Nav cry 1(   8,    4) Nav cte 1(  11,    7) Nav cus 1(   2,    2)
Nav dec 1(  10,    6) Nav goe 1(   5,    6) Nav mut 1(   9,    6) Nav pup 1(   7,    4)
Nav sch 1(  11,    8) Nav sub 1(   6,    6) Nav vir 1(  10,    6) Nit acc 1(   4,    2)
Nit amp 1(   7,    7) Nit dis 1(   5,    6) Nit pal 1(  11,    9) Nit per 1(   5,    3)
Nit smo 1(  11,    8) Pin bra 1(   5,    3) Pin sub 1(   3,    2) Coc pla 2(   3,    2)
Gom ang 2(   6,    7) Gom par 2(   5,    4) Nav sch 2(   9,    8) Nit pal 2(   7,    7)
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 DIVISION    6  (N=     22)          i.e. group *10
 Eigenvalue: 0.2141  at iteration   8
 INDICATORS and their signs:
 Pin dge  1(+)
 Maximum indicator score for negative group   0
 Minimum indicator score for positive group   1

 ITEMS IN NEGATIVE GROUP  12   (N =     21)          i.e. group *100
 C1My98    C2My98    C3My98    C1Au98    C2Au98    C3Au98    C1Se98    C2Se98
 C3Se98    C1De98    C2De98    C3De98    C1Fe99    C2Fe99    C3Fe99    C1Mr00
 C2Mr00    C3Mr00    C1Mr01    C2Mr01    C4Mr01

 ITEMS IN POSITIVE GROUP  13   (N =      1)          i.e. group *101
 C3Mr01

 NEGATIVE PREFERENTIALS
Amp mon 1(  11,    0)  Aul gra 1(  16,    0)  Cal bac 1(   6,    0)  Cal mol 1(   7,    0)
Cyc men 1(   6,    0)  Cyc oce 1(   7,    0)  Cym ces 1(   5,    0)  Cym fal 1(   7,    0)
Cym sil 1(   6,    0)  Eun pec 1(  16,    0)  Fra cap 1(  10,    0)  Fra uln 1(  16,    0)
Gom ang 1(   9,    0)  Gom gro 1(   8,    0)  Han amp 1(  10,    0)  Nav cry 1(   8,    0)
Nav cte 1(   9,    0)  Nav cus 1(   5,    0)  Nav goe 1(  20,    0)  Nav sch 1(  11,    0)
Nav vir 1(  14,    0)  Nit amp 1(  16,    0)  Nit cal 1(   5,    0)  Nit dis 1(   6,    0)
Nit fle 1(   6,    0)  Nit gra 1(   6,    0)  Nit lin 1(   6,    0)  Nit scp 1(   6,    0)
Nit smo 1(  10,    0)  Nit umb 1(  11,    0)  Pin bra 1(  13,    0)  Rho gib 1(   5,    0)
Nav goe 2(  13,    0)  Nit amp 2(   5,    0)  Nav goe 3(   6,    0)  Nit pal 3(  14,    0)
Nit pal 4(   7,    0)

 POSITIVE PREFERENTIALS
Nav imp 1(   3,    1)  Nav pup 1(   5,    1)  Nav sub 1(   8,    1)  Nit fil 1(   1,    1)
Nit rev 1(   1,    1)  Pin dge 1(   0,    1)  Nav imp 2(   0,    1)  Nav sub 2(   2,    1)
Ach min 3(   3,    1)  Nav sub 3(   0,    1)

 NON-PREFERENTIALS
Ach min 1(  20,    1)  Ach exi 1(  18,    1)  Gom par 1(  20,    1)  Nit cla 1(  13,    1)
Nit pal 1(  21,    1)  Ach min 2(  12,    1)  Nit pal 2(  18,    1)
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 DIVISION    7  (N=      6)          i.e. group *11
 Eigenvalue: 0.3543  at iteration 177
 INDICATORS and their signs:
 Ach lan  1(+)
 Maximum indicator score for negative group   0
 Minimum indicator score for positive group   1

 ITEMS IN NEGATIVE GROUP  14   (N =      5)          i.e. group *110
 C4My98    C4Au98    C4De98    CFe499    C4Mr00

 ITEMS IN POSITIVE GROUP  15   (N =      1)          i.e. group *111
 C4Se98

 NEGATIVE PREFERENTIALS
Ach exi 1(   2,    0)  Amp mon 1(   1,    0)  Aul amb 1(   1,    0)  Cal bac 1(   2,    0)
Cyc ste 1(   1,    0)  Cym alp 1(   1,    0)  Cym ces 1(   2,    0)  Cym fal 1(   1,    0)
Cym mic 1(   1,    0)  Cym sil 1(   2,    0)  Dip ell 1(   3,    0)  Epi arg 1(   1,    0)
Epi sor 1(   3,    0)  Eun gla 1(   1,    0)  Fra csu 1(   2,    0)  Fra cve 1(   1,    0)
Fra par 1(   1,    0)  Fru rho 1(   1,    0)  Mel mon 1(   1,    0)  Nav lep 1(   1,    0)
Nav cto 1(   1,    0)  Nav imp 1(   1,    0)  Nav mcu 1(   1,    0)  Nav cus 1(   1,    0)
Nav gas 1(   1,    0)  Nav pup 1(   1,    0)  Nav pyg 1(   1,    0)  Nav sch 1(   2,    0)
Nav sub 1(   1,    0)  Nit cla 1(   2,    0)  Nit dis 1(   2,    0)  Nit fil 1(   1,    0)
Nit fle 1(   1,    0)  Nit fon 1(   1,    0)  Nit fti 1(   1,    0)  Nit obt 1(   1,    0)
Nit pus 1(   1,    0)  Nit scp 1(   4,    0)  Nit smo 1(   1,    0)  Nit the 1(   1,    0)
Nit umb 1(   4,    0)  Pin gme 1(   1,    0)  Pin mic 1(   1,    0)  Pin obs 1(   1,    0)
Rho ver 1(   2,    0)  Syn cun 1(   2,    0)  Epi adn 2(   2,    0)  Fra con 2(   2,    0)
Fra pin 2(   2,    0)  Nav goe 2(   2,    0)  Nit scp 2(   1,    0)  Ste rot 2(   4,    0)
Aul gra 3(   3,    0)  Nit pal 4(   1,    0)


 POSITIVE PREFERENTIALS
Ach lan 1(   0,    1)  Ach del 1(   0,    1)  Amp cof 1(   0,    1)  Dip ova 1(   0,    1)
Fra ten 1(   0,    1)  Han amp 1(   1,    1)  Nav cte 1(   2,    1)  Nav ins 1(   0,    1)
Nit acc 1(   0,    1)  Nit fru 1(   1,    1)  Nit sig 1(   0,    1)  Pin bor 1(   0,    1)
Ach min 2(   0,    1)  Han amp 2(   0,    1)  Nav ins 2(   0,    1)  Nit pal 3(   1,    1)

 NON-PREFERENTIALS
Ach min 1(   4,    1)  Aul gra 1(   5,    1)  Coc pla 1(   4,    1)  Cyc oce 1(   3,    1)
Epi adn 1(   5,    1)  Fra cap 1(   3,    1)  Fra con 1(   3,    1)  Fra pin 1(   5,    1)
Fra uln 1(   4,    1)  Gom ang 1(   3,    1)  Gom par 1(   5,    1)  Nav goe 1(   4,    1)
Nit amp 1(   4,    1)  Nit gra 1(   3,    1)  Nit inc 1(   3,    1)  Nit pal 1(   5,    1)
Pin bra 1(   4,    1)  Rho gib 1(   3,    1)  Ste rot 1(   5,    1)  Aul gra 2(   5,    1)
Nit pal 2(   4,    1)

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DIVISION     8  (N=     13)          i.e. group *000
Eigenvalue: 0.2608  at iteration   6
INDICATORS and their signs:
Nav vir  2(+)   Fra uln  1(+)   Gom oli  1(-)
Maximum indicator score for negative group   0
Minimum indicator score for positive group   1

ITEMS IN NEGATIVE GROUP  16  (N =     6)          i.e. group *0000
K1Au98    K1De98    K3De98    K4De98    N3De98    K1Mr01

ITEMS IN POSITIVE GROUP  17  (N =     7)          i.e. group *0001
K1Fe99    K2Fe99    K3Fe99    K4Fe99    K1Mr00    K2Mr01    K4Mr01

NEGATIVE PREFERENTIALS
Ach fle 1(   3,    0)  Fra bid 1(   2,    0)  Fru rho 1(   2,    0)  Gom aff 1(   3,    0)
Gom oli 1(   6,    3)  Nav ins 1(   3,    1)  Nit dis 1(   4,    2)  Rho abb 1(   2,    0)
Gom ang 2(   3,    1)  Nit per 2(   2,    0)  Gom ang 3(   2,    0)  Nit per 3(   2,    0)
Gom ang 4(   2,    0)

POSITIVE PREFERENTIALS
Ach lan 1(   0,    3)  Cyc men 1(   0,    2)  Cym tum 1(   0,    2)  Dip ova 1(   0,    2)
Fra uln 1(   1,    6)  Nav cap 1(   0,    3)  Nav elg 1(   0,    2)  Nav pup 1(   0,    4)
Nit cap 1(   0,    2)  Nit int 1(   0,    3)  Nit smo 1(   2,    5)  Sur spl 1(   0,    4)
Coc pla 2(   0,    2)  Nav hei 2(   1,    4)  Nav vir 2(   1,    7)  Nav vir 3(   0,    3)
Nav vir 4(   0,    2)

NON-PREFERENTIALS
Ach min 1(   6,    4)  Coc pla 1(   3,    3)  Cym sil 1(   2,    3)  Fra cap 1(   6,    6)
Fra csu 1(   3,    3)  Gom ang 1(   6,    6)  Gom par 1(   6,    7)  Gyr acu 1(   2,    4)
Gyr sca 1(   4,    7)  Han amp 1(   2,    4)  Nav hei 1(   6,    7)  Nav cry 1(   6,    6)
Nav cte 1(   5,    6)  Nav dec 1(   6,    6)  Nav gas 1(   1,    2)  Nav goe 1(   1,    2)
Nav sch 1(   6,    7)  Nav sub 1(   4,    3)  Nav vir 1(   6,    7)  Nit pal 1(   5,    7)
Nit per 1(   5,    4)  Sta anc 1(   3,    3)  Sur amp 1(   1,    2)  Sur ang 1(   4,    5)
Nav sch 2(   4,    5)  Nit pal 2(   2,    4)
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DIVISION     9  (N=     23)          i.e. group *001
Eigenvalue: 0.2135  at iteration   6
INDICATORS and their signs:
Nav mut  1(-)   Pin bra  1(-)
Maximum indicator score for negative group  -2
Minimum indicator score for positive group  -1

ITEMS IN NEGATIVE GROUP  18  (N =     3)          i.e. group *0010
K2Mr00    K3Mr00    K4Mr00

ITEMS IN POSITIVE GROUP  19  (N =    20)          i.e. group *0011
N1My98    N2My98    N4Se98    K2De98    N1De98    N2De98    N4De98    N1Fe99
N2Fe99    N3Fe99    N4Fe99    N1Mr00    N2Mr00    N3Mr00    N4Mr00    K3Mr01
N1Mr01    N2Mr01    N3Mr01    N4Mr01

NEGATIVE PREFERENTIALS
Ach lan 1(   3,    2)  Ach inf 1(   1,    0)  Cal bac 1(   1,    3)  Cyc oce 1(   1,    1)
Cym elg 1(   1,    0)  Eun bil 1(   1,    1)  Eun pec 1(   1,    0)  Eun pra 1(   1,    0)
Fra csu 1(   2,    5)  Gom aff 1(   1,    2)  Gom aug 1(   1,    0)  Gom gro 1(   1,    1)
Gyr acu 1(   3,    2)  Han amp 1(   2,    6)  Nav agr 1(   2,    1)  Nav cap 1(   2,    0)
Nav ato 1(   1,    0)  Nav cin 1(   1,    0)  Nav coh 1(   2,    1)  Nav con 1(   1,    2)
Nav elg 1(   2,    1)  Nav hal 1(   2,    3)  Nav ins 1(   1,    0)  Nav jaa 1(   1,    0)
Nav mut 1(   3,    1)  Nav sue 1(   1,    1)  Nit aci 1(   1,    3)  Nit fle 1(   1,    0)
Nit fru 1(   3,    4)  Nit int 1(   3,    2)  Nit rec 1(   2,    2)  Nit sca 1(   1,    0)
Nit the 1(   1,    2)  Pin bra 1(   3,    1)  Pin gib 1(   1,    0)  Pin int 1(   1,    0)
Pin obs 1(   1,    0)  Ste rot 1(   2,    2)  Sur ova 1(   1,    2)  Fra cap 2(   1,    2)
Nav cry 2(   2,    1)  Nav vir 2(   3,    5)  Nit int 2(   1,    1)  Nav vir 3(   1,    1)


POSITIVE PREFERENTIALS
Ach min 1(   1,   15)  Cyc men 1(   0,    7)  Cym tur 1(   0,    6)  Nav cto 1(   0,   14)
Nav imp 1(   0,    6)  Nav gas 1(   0,    4)  Nav sub 1(   1,   18)  Nit amp 1(   0,   15)
Nit cal 1(   0,    4)  Nit dis 1(   0,    6)  Nit gra 1(   0,    6)  Nit lin 1(   0,    9)
Nit pus 1(   0,    4)  Ach min 2(   0,    4)  Gom par 2(   0,   15)  Nav sub 2(   0,   13)

NON-PREFERENTIALS
Ach exi 1(   1,    5)  Amp mon 1(   1,   13)  Coc pla 1(   3,   20)  Cym sil 1(   3,   16)
Fra cap 1(   3,   18)  Fra uln 1(   3,   16)  Gom ang 1(   3,   20)  Gom gra 1(   1,    6)
Gom oli 1(   1,    9)  Gom par 1(   3,   19)  Gyr sca 1(   2,    9)  Nav hei 1(   3,   12)
Nav cry 1(   3,   14)  Nav cte 1(   2,   16)  Nav dec 1(   3,   13)  Nav goe 1(   2,   10)
Nav pup 1(   3,   15)  Nav pyg 1(   1,    4)  Nav sch 1(   3,   19)  Nav vir 1(   3,   20)
Nit pal 1(   3,   20)  Nit smo 1(   3,   18)  Sta anc 1(   1,    6)  Sur ang 1(   2,   17)
Sur spl 1(   2,    8)  Coc pla 2(   1,    8)  Gom ang 2(   3,   13)  Nav hei 2(   1,    6)
Nav sch 2(   2,   11)  Nit pal 2(   2,   13)  Nit pal 3(   1,    5)
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DIVISION   10  (N=     11)          i.e. group *010
Eigenvalue: 0.2471  at iteration   22
INDICATORS and their signs:
Cym sil  1(+)
Maximum indicator score for negative group    0
Minimum indicator score for positive group    1

ITEMS IN NEGATIVE GROUP  20  (N =     7)          i.e. group *0100
K4Au98    K1Se98    K2Se98    K3Se98    K4Se98    N1Se98    N2Se98

ITEMS IN POSITIVE GROUP  21  (N =     4)          i.e. group *0101
K1My98    K2My98    K3My98    K4My98

NEGATIVE PREFERENTIALS
Aul amb 1(  2,    0)  Aul gra 1(  4,    1)  Cym ces 1(  4,    0)  Eun pec 1(  4,    1)
Fra con 1(  3,    0)  Fra pin 1(  2,    0)  Fru vul 1(  2,    0)  Nav agr 1(  4,    0)
Nav ato 1(  2,    0)  Nav coh 1(  2,    0)  Nav cus 1(  2,    0)  Nav goe 1(  4,    1)
Nav mon 1(  3,    0)  Nav sem 1(  2,    0)  Nav sue 1(  2,    0)  Nit dis 1(  4,    1)
Nit fle 1(  5,    0)  Nit fru 1(  3,    0)  Nit lev 1(  3,    0)  Nit per 1(  5,    0)
Nit the 1(  2,    0)  Ort den 1(  2,    0)  Pin div 1(  2,    0)  Pin dge 1(  2,    0)
Pin gib 1(  3,    0)  Pin mic 1(  2,    0)  Pin sro 1(  4,    1)  Pin sup 1(  2,    0)
Rho abb 1(  2,    0)  Ach min 2(  6,    1)  Coc pla 2(  3,    0)  Gom ang 2(  5,    1)
Nav hei 2(  3,    0)  Nav dec 2(  2,    0)

POSITIVE PREFERENTIALS
Ach lan 1(  3,    4)  Ach exi 1(  2,    4)  Ach fle 1(  0,    1)  Ach inf 1(  2,    3)
Amp com 1(  1,    3)  Cal mol 1(  1,    2)  Cyc men 1(  3,    4)  Cym sil 1(  0,    4)
Dip ell 1(  0,    2)  Eun min 1(  0,    1)  Gom aff 1(  1,    2)  Nav min 1(  1,    2)
Nav pyg 1(  0,    1)  Nit int 1(  0,    1)  Nit nya 1(  0,    1)  Pin bra 1(  2,    3)
Pin sub 1(  0,    3)  Rho rup 1(  0,    1)  Sta anc 1(  2,    4)  Ste cur 1(  0,    2)
Cal bac 2(  0,    1)  Cyc men 2(  0,    2)  Fra cap 2(  0,    2)  Fra uln 2(  0,    1)
Gom par 2(  2,    3)  Gyr sca 2(  0,    2)  Han amp 2(  0,    2)  Nav mut 2(  2,    4)
Nit acc 2(  0,    1)  Nav sch 3(  0,    1)

NON-PREFERENTIALS
Ach min 1(  7,    4)  Amp cof 1(  2,    1)  Amp mon 1(  7,    4)  Cal bac 1(  4,    4)
Coc pla 1(  6,    4)  Cyc oce 1(  2,    2)  Cym aff 1(  1,    1)  Fra cap 1(  7,    4)
Fra csu 1(  3,    3)  Fra uln 1(  7,    4)  Fru rho 1(  5,    4)  Gom ang 1(  7,    4)
Gom gra 1(  5,    4)  Gom oli 1(  3,    1)  Gom par 1(  7,    4)  Gyr acu 1(  1,    1)
Gyr sca 1(  5,    4)  Han amp 1(  7,    4)  Nav hei 1(  4,    3)  Nav cle 1(  1,    1)
Nav con 1(  6,    4)  Nav cry 1(  5,    3)  Nav cte 1(  7,    4)  Nav dec 1(  7,    3)
Nav gas 1(  3,    1)  Nav ins 1(  2,    2)  Nav mut 1(  5,    4)  Nav pup 1(  5,    2)
Nav sch 1(  7,    4)  Nav sub 1(  4,    2)  Nav vir 1(  7,    3)  Nit acc 1(  2,    2)
Nit amp 1(  5,    2)  Nit lin 1(  1,    1)  Nit pal 1(  7,    4)  Nit rec 1(  1,    1)
Nit smo 1(  7,    4)  Pin bor 1(  3,    2)  Ste rot 1(  1,    1)  Sur ang 1(  3,    2)
Nav sch 2(  6,    3)  Nit pal 2(  4,    3)
*************************************************************************************

DIVISION   11  (N=      9)          i.e. group *011
Eigenvalue: 0.2942  at iteration    6
INDICATORS and their signs:
Gom oli  1(+)
Maximum indicator score for negative group    0
Minimum indicator score for positive group    1

ITEMS IN NEGATIVE GROUP  22  (N =     5)          i.e. group *0110
N3My98    N4My98    N2Au98    N3Au98    N3Se98

BORDERLINE NEGATIVES       (N =     1)
N3Au98

ITEMS IN POSITIVE GROUP  23  (N =     4)          i.e. group *0111
K2Au98    K3Au98    N1Au98    N4Au98

NEGATIVE PREFERENTIALS
Ach obl 1(  1,    0)  Amp mon 1(  5,    2)  Cal bac 1(  2,    0)  Cal mol 1(  2,    0)
Cyc oce 1(  2,    0)  Cym fal 1(  1,    0)  Cym sil 1(  3,    1)  Epi adn 1(  1,    0)
Epi sor 1(  1,    0)  Fru rho 1(  1,    0)  Nav imp 1(  2,    0)  Nav cry 1(  3,    1)
Nav cte 1(  5,    2)  Nav gas 1(  1,    0)  Nav mco 1(  1,    0)  Nav obl 1(  1,    0)
Nav sub 1(  5,    1)  Nei aff 1(  1,    0)  Nit bre 1(  1,    0)  Nit cla 1(  2,    0)
Nit fil 1(  1,    0)  Nit gra 1(  3,    1)  Nit lev 1(  1,    0)  Nit pus 1(  1,    0)
Nit sig 1(  2,    0)  Nit try 1(  1,    0)  Ort den 1(  1,    0)  Pin bor 1(  1,    0)
Rho gru 1(  1,    0)  Ste rot 1(  1,    0)  Sur ang 1(  1,    0)  Sur bif 1(  1,    0)
Ach min 2(  1,    0)  Amp mon 2(  5,    0)  Nav cry 2(  1,    0)  Nav cte 2(  1,    0)
Nav goe 2(  1,    0)  Nav mut 2(  1,    0)  Nav sub 2(  1,    0)  Nit pal 2(  5,    2)
Amp mon 3(  2,    0)

POSITIVE PREFERENTIALS
Ach lan 1(  0,    2)  Ach exi 1(  0,    2)  Ach fle 1(  1,    3)  Ach inf 1(  0,    1)
Amp pel 1(  0,    1)  Amp hol 1(  0,    2)  Amp ven 1(  0,    1)  Cym pro 1(  0,    1)
Dip ell 1(  1,    2)  Eun min 1(  0,    2)  Eun pec 1(  1,    2)  Fru rvi 1(  0,    1)
Fru vul 1(  0,    2)  Gom aff 1(  1,    2)  Gom ast 1(  0,    1)  Gom aug 1(  0,    2)
Gom gra 1(  2,    4)  Gom oli 1(  0,    4)  Han amp 1(  2,    4)  Nav bre 1(  0,    1)
Nav hei 1(  1,    4)  Nav cus 1(  0,    2)  Nav pup 1(  1,    3)  Nav spi 1(  0,    1)
Nit dis 1(  2,    4)  Nit fti 1(  0,    1)  Nit lan 1(  0,    1)  Nit sca 1(  0,    1)
Nit umb 1(  0,    2)  Pin bra 1(  0,    3)  Pin div 1(  1,    3)  Sta anc 1(  0,    1)
Sta pho 1(  0,    1)  Sur bis 1(  0,    1)  Sur ova 1(  0,    1)  Coc pla 2(  0,    2)
```

```
Gom oli 2(   0,    1)  Nav dec 2(   0,    1)

 NON-PREFERENTIALS
Ach min 1(   5,    4)  Ach plo 1(   1,    1)  Ach tri 1(   1,    1)  Amp com 1(   3,    4)
Aul gra 1(   2,    2)  Cal lep 1(   2,    2)  Coc pla 1(   5,    4)  Cyc men 1(   1,    1)
Fra cap 1(   4,    3)  Fra uln 1(   4,    4)  Gom ang 1(   5,    4)  Gom par 1(   5,    4)
Gyr sca 1(   4,    3)  Nav cto 1(   1,    1)  Nav con 1(   4,    3)  Nav dec 1(   4,    2)
Nav goe 1(   4,    2)  Nav mut 1(   3,    3)  Nav sch 1(   4,    4)  Nav vir 1(   3,    3)
Nit acc 1(   1,    1)  Nit amp 1(   3,    4)  Nit fle 1(   1,    1)  Nit inc 1(   1,    1)
Nit pal 1(   5,    4)  Nit per 1(   2,    1)  Nit rec 1(   4,    3)  Nit smo 1(   4,    4)
Pin sub 1(   1,    1)  Fra uln 2(   2,    2)  Gom ang 2(   3,    4)  Gom par 2(   2,    2)
Nav sch 2(   4,    4)  Gom ang 3(   2,    2)
*****************************************************************************************

 DIVISION   12  (N=    21)         i.e. group *100
 Eigenvalue: 0.1974  at iteration  25
 INDICATORS and their signs:
 Nit pal  4(+)
 Maximum indicator score for negative group  0
 Minimum indicator score for positive group  1

 ITEMS IN NEGATIVE GROUP  24   (N =   13)         i.e. group *1000
 C1My98    C3My98    C1Au98    C2Au98    C1Se98    C2Se98    C3Se98    C1De98
 C2De98    C2Fe99    C1Mr00    C2Mr00    C1Mr01

 ITEMS IN POSITIVE GROUP  25   (N =    8)         i.e. group *1001
 C2My98    C3Au98    C3De98    C1Fe99    C3Fe99    C3Mr00    C2Mr01    C4Mr01

 MISCLASSIFIED POSITIVES (N =    1)
 C2Mr01

 NEGATIVE PREFERENTIALS
Cal mol 1(   7,    0)  Cym fal 1(   6,    1)  Cym sil 1(   5,    1)  Cym tum 1(   3,    0)
Eun did 1(   3,    0)  Gom ang 1(   9,    0)  Han amp 1(   8,    2)  Nav vir 1(  11,    3)
Nit cal 1(   4,    1)  Nit cla 1(  10,    3)  Nit scp 1(   5,    1)  Nit smo 1(   9,    1)
Rho gib 1(   4,    1)  Sur ang 1(   3,    0)  Syn cun 1(   4,    0)  Ach min 2(  11,    1)
Nav goe 2(  11,    2)  Nit amp 2(   4,    1)  Ach min 3(   3,    0)  Nav goe 3(   6,    0)

 POSITIVE PREFERENTIALS
Amp com 1(   1,    2)  Cym ces 1(   2,    3)  Nav imp 1(   1,    2)  Nav cus 1(   2,    3)
Nit pal 3(   6,    8)  Nit pal 4(   0,    7)  Nit pal 5(   0,    4)

 NON-PREFERENTIALS
Ach min 1(  13,    7)  Ach exi 1(  12,    6)  Amp mon 1(   7,    4)  Aul gra 1(  10,    6)
Cal bac 1(   4,    2)  Cyc men 1(   4,    2)  Cyc oce 1(   5,    2)  Eun pec 1(  10,    6)
Fra cap 1(   5,    5)  Fra uln 1(   9,    7)  Gom gro 1(   4,    4)  Gom par 1(  12,    8)
Nav cry 1(   6,    2)  Nav cte 1(   6,    3)  Nav goe 1(  13,    7)  Nav ins 1(   3,    1)
Nav pup 1(   3,    2)  Nav sch 1(   7,    4)  Nav sub 1(   4,    4)  Nit amp 1(  12,    4)
Nit dis 1(   4,    2)  Nit fle 1(   4,    2)  Nit gra 1(   4,    2)  Nit lin 1(   3,    3)
Nit pal 1(  13,    8)  Nit umb 1(   5,    6)  Pin bra 1(   8,    5)  Pin gme 1(   3,    1)
Gom par 2(   2,    2)  Nit pal 2(  10,    8)
*****************************************************************************************

 DIVISION   13  (N=     1)         i.e. group *101
 Group too small for further division.

*****************************************************************************************

 DIVISION   14  (N=     5)         i.e. group *110
 Eigenvalue: 0.3916  at iteration   9
 INDICATORS and their signs:
 Ach min  1(-)
 Maximum indicator score for negative group  -1
 Minimum indicator score for positive group   0

 ITEMS IN NEGATIVE GROUP  28   (N =    4)         i.e. group *1100
 C4My98    C4De98    CFe499    C4Mr00

 ITEMS IN POSITIVE GROUP  29   (N =    1)         i.e. group *1101
 C4Au98

 NEGATIVE PREFERENTIALS
Ach min 1(   4,    0)  Amp mon 1(   1,    0)  Cal bac 1(   2,    0)  Cym alp 1(   1,    0)
Cym ces 1(   2,    0)  Cym fal 1(   1,    0)  Cym mic 1(   1,    0)  Eun gla 1(   1,    0)
Fra csu 1(   2,    0)  Fra cve 1(   1,    0)  Fra par 1(   1,    0)  Fru rho 1(   1,    0)
Gom ang 1(   3,    0)  Han amp 1(   1,    0)  Mel mon 1(   1,    0)  Nav lep 1(   1,    0)
Nav cto 1(   1,    0)  Nav imp 1(   1,    0)  Nav mcu 1(   1,    0)  Nav gas 1(   1,    0)
Nav pyg 1(   1,    0)  Nav sub 1(   1,    0)  Nit cla 1(   2,    0)  Nit dis 1(   2,    0)
Nit fil 1(   1,    0)  Nit fle 1(   1,    0)  Nit fru 1(   1,    0)  Nit fti 1(   1,    0)
Nit inc 1(   3,    0)  Nit obt 1(   1,    0)  Nit the 1(   1,    0)  Pin gme 1(   1,    0)
Pin obs 1(   1,    0)  Rho gib 1(   3,    0)  Syn cun 1(   2,    0)  Epi adn 2(   2,    0)
Fra con 2(   2,    0)  Fra pin 2(   2,    0)  Nav goe 2(   2,    0)  Nit scp 2(   1,    0)
Ste rot 2(   4,    0)  Aul gra 3(   3,    0)
```

```
POSITIVE PREFERENTIALS
Ach exi 1(   1,    1)  Aul amb 1(   0,    1)  Cyc oce 1(   2,    1)  Cyc ste 1(   0,    1)
Cym sil 1(   1,    1)  Dip ell 1(   2,    1)  Epi arg 1(   0,    1)  Epi sor 1(   2,    1)
Fra cap 1(   2,    1)  Fra con 1(   2,    1)  Nav cte 1(   1,    1)  Nav cus 1(   0,    1)
Nav pup 1(   0,    1)  Nav sch 1(   1,    1)  Nit fon 1(   0,    1)  Nit gra 1(   2,    1)
Nit pus 1(   0,    1)  Nit smo 1(   0,    1)  Pin mic 1(   0,    1)  Rho ver 1(   1,    1)
Nit pal 3(   0,    1)  Nit pal 4(   0,    1)

NON-PREFERENTIALS
Aul gra 1(   4,    1)  Coc pla 1(   3,    1)  Epi adn 1(   4,    1)  Fra pin 1(   4,    1)
Fra uln 1(   3,    1)  Gom par 1(   4,    1)  Nav goe 1(   3,    1)  Nit amp 1(   3,    1)
Nit pal 1(   4,    1)  Nit scp 1(   3,    1)  Nit umb 1(   3,    1)  Pin bra 1(   3,    1)
Ste rot 1(   4,    1)  Aul gra 2(   4,    1)  Nit pal 2(   3,    1)
*********************************************************************************

DIVISION   15  (N=      1)          i.e. group *111
Group too small for further division.

               --------  E N D   O F   L E V E L   4 --------
```

```
000000000000000000000000000000000000000000000000000000000011111111111111111111111111111
000000000000000000000000000000000000000111111111111111111111000000000000000000000000111111
000000000000011111111111111111111111111100000000000011111111100000000000000000000001000001
000000111111100011111111111111111111111000000011110000011110000000000000001111111 00001
0111110011111  00000000000001111111100111111  00011  00011111111111100000111
 00011 00001  00001111111111100000011 00001          000001111100011
```

********** TWINSPAN completed **********

Table 5.3. Result of Detrended Correpondence Analysis (DCA) of data on diatoms in rivers Kibos, Nyando and Kisat.

****** Summary ******

Axes	1	2	3	4	Total inertia
Eigenvalues :	.613	.362	.302	.215	7.543
Lengths of gradient :	4.933	2.844	3.230	2.254	
Cumulative percentage variance of species data :	8.1	12.9	16.9	19.8	
Sum of all unconstrained eigenvalues					7.543

Table 5.4. Result of Canonical Correpondence Analysis (CCA) of data on diatoms in rivers Kibos, Nyando and Kisat (with all 16 environmental variables).

Weighted correlation matrix (weight = sample total)

	SPEC AX1	SPEC AX2	SPEC AX3	SPEC AX4	ENVI AX1	ENVI AX2	ENVI AX3	ENVI AX4
SPEC AX1	1.0000							
SPEC AX2	.0619	1.0000						
SPEC AX3	-.0627	-.0157	1.0000					
SPEC AX4	-.0968	-.0800	.0765	1.0000				
ENVI AX1	.9364	.0000	.0000	.0000	1.0000			
ENVI AX2	.0000	.8119	.0000	.0000	.0000	1.0000		
ENVI AX3	.0000	.0000	.8150	.0000	.0000	.0000	1.0000	
ENVI AX4	.0000	.0000	.0000	.7990	.0000	.0000	.0000	1.0000
Oxyg	-.6648	-.3664	.1340	.1237	-.7099	-.4514	.1644	.1548
Har	.6536	-.0538	-.3650	.1941	.6980	-.0662	-.4478	.2429
Alk	.5975	.1634	-.3954	.1063	.6380	.2012	-.4851	.1330
Con	.8539	.0403	-.1811	.1694	.9118	.0496	-.2221	.2120
Tur	-.0157	-.0877	-.4802	-.3518	-.0168	-.1080	-.5892	-.4403
NO3	-.1067	-.2134	-.0486	-.2814	-.1139	-.2628	-.0597	-.3522
PO4	.3066	.1705	-.1169	.2515	.3275	.2100	-.1434	.3148
SiO2	-.0469	-.2762	-.0514	-.1215	-.0501	-.3402	-.0630	-.1521
TSS	.1670	-.1667	-.4110	-.0525	.1783	-.2054	-.5043	-.0657
Alt	-.6143	-.1034	-.0052	.2943	-.6560	-.1274	-.0064	.3683
Wid	-.6288	.1393	-.4579	.0553	-.6715	.1716	-.5619	.0693
Dep	-.5373	-.1926	-.3815	-.1816	-.5738	-.2373	-.4681	-.2273
Vel	-.5873	.1466	-.3706	-.1675	-.6272	.1805	-.4548	-.2096
Dis	-.6842	.0578	-.4670	-.1009	-.7307	.0712	-.5730	-.1262
Tem	.5499	.0148	-.1423	.2015	.5872	.0182	-.1746	.2522
pH	-.4296	.1720	.1750	.1048	-.4587	.2118	.2147	.1312

	Oxyg	Har	Alk	Con	Tur	NO3	PO4	SiO2
Oxyg	1.0000							
Har	-.5146	1.0000						
Alk	-.5852	.8491	1.0000					
Con	-.6649	.8395	.8371	1.0000				
Tur	-.1674	.0135	.0490	-.0509	1.0000			
NO3	.1510	-.0019	.0379	-.1395	-.1190	1.0000		
PO4	-.3559	.4219	.4604	.4229	-.0134	-.1003	1.0000	
SiO2	-.0645	-.0122	-.0702	-.1089	.1071	.5290	-.2849	1.0000
TSS	-.1778	.2395	.1457	.1366	.7348	-.1299	.3871	-.0521
Alt	.4491	-.3799	-.3746	-.5060	-.1595	.0824	-.2221	.0351
Wid	.3909	-.3032	-.1839	-.4789	.4198	-.0739	-.1538	.0210
Dep	.4141	-.2455	-.2270	-.4574	.3642	.0737	-.2102	.0727
Vel	.1703	-.3022	-.1678	-.4682	.4446	.0372	-.3577	.1623
Dis	.3746	-.3404	-.2268	-.5496	.4811	.0095	-.2844	.1010
Tem	-.3482	.4742	.4606	.5789	-.0430	-.1443	.5608	-.2308
pH	.4248	-.4127	-.2300	-.3533	-.2563	.0807	-.3354	-.1240

	TSS	Alt	Wid	Dep	Vel	Dis	Tem	pH
TSS	1.0000							
Alt	-.2023	1.0000						
Wid	.2068	.3677	1.0000					
Dep	.2473	.1560	.6983	1.0000				
Vel	.0686	.4256	.6739	.4571	1.0000			
Dis	.1988	.3830	.9280	.7998	.8441	1.0000		
Tem	.2441	-.5005	-.3897	-.3051	-.5823	-.5083	1.0000	
pH	-.4036	.2112	.3005	.1979	.1281	.2481	-.1740	1.0000

Table 5.4 (continued)

N	name	(weighted) mean	stand. dev.	inflation factor
1	SPEC AX1	.0000	1.0679	
2	SPEC AX2	.0000	1.2317	
3	SPEC AX3	.0000	1.2270	
4	SPEC AX4	.0000	1.2516	
5	ENVI AX1	.0000	1.0000	
6	ENVI AX2	.0000	1.0000	
7	ENVI AX3	.0000	1.0000	
8	ENVI AX4	.0000	1.0000	
1	Oxyg	.6660	.3812	2.9913
2	Har	1.9793	.3418	6.4040
3	Alk	2.0762	.3406	9.7862
4	Con	2.4321	.3790	10.1605
5	Tur	2.0121	.5002	5.1709
6	NO3	2.0658	.8549	2.1015
7	PO4	1.6772	.8309	3.0199
8	SiO2	1.5392	.4843	1.9462
9	TSS	2.1816	.5660	4.7874
10	Alt	1200.2670	43.4420	2.0246
11	Wid	.6674	.5187	**78.3338**
12	Dep	-.2454	.3631	**37.1552**
13	Vel	-.5158	.4625	**66.6142**
14	Dis	-.0827	1.1714	**391.2468**
15	Tem	23.9360	3.5649	2.5562
16	pH	7.4233	.6811	2.0883

**** **Summary** ****

Axes	1	2	3	4	Total inertia
Eigenvalues :	.502	.295	.254	.191	7.971
Species-environment correlations :	.936	.812	.815	.799	
Cumulative percentage variance					
of species data :	6.3	10.0	13.2	15.6	
of species-environment relation:	22.7	36.0	47.4	56.1	
Sum of all unconstrained eigenvalues					7.971
Sum of all canonical eigenvalues					2.215

*** Unrestricted permutation ***

**** **Summary of Monte Carlo test** ****

Test of significance of first canonical axis: eigenvalue = .502
F-ratio = 4.508
P-value = .0050

Test of significance of all canonical axes : Trace = 2.215
F-ratio = 1.612
P-value = .0050

(199 permutations under reduced model)

Table 5.5. Result of Canonical Correpondence Analysis (CCA) of data on diatoms in rivers Kibos, Nyando and Kisat (with 12 environmental variables).

**** **Weighted correlation matrix** (weight = sample total) ****

	SPEC AX1	SPEC AX2	SPEC AX3	SPEC AX4	ENVI AX1	ENVI AX2	ENVI AX3	ENVI AX4
SPEC AX1	1.0000							
SPEC AX2	-.0339	1.0000						
SPEC AX3	-.0955	.0593	1.0000					
SPEC AX4	.0665	.0144	.0291	1.0000				
ENVI AX1	.9261	.0000	.0000	.0000	1.0000			
ENVI AX2	.0000	.7961	.0000	.0000	.0000	1.0000		
ENVI AX3	.0000	.0000	.7423	.0000	.0000	.0000	1.0000	
ENVI AX4	.0000	.0000	.0000	.7857	.0000	.0000	.0000	1.0000
Oxy	-.6791	.3218	.2185	.0448	-.7333	.4042	.2944	.0570
Har	.6745	.1907	-.1602	-.3329	.7283	.2395	-.2158	-.4237
Alk	.6219	-.0107	-.3087	-.3764	.6715	-.0134	-.4158	-.4790
Con	.8647	.0334	-.0242	-.2248	.9336	.0420	-.0326	-.2861
Tur	.0048	.2387	-.5252	.1419	.0052	.2999	-.7075	.1806
NO3	-.1058	.1843	-.1205	.2944	-.1143	.2315	-.1624	.3748
PO4	.3195	-.1223	.0004	-.3825	.3450	-.1536	.0005	-.4869
SiO2	-.0465	.2843	-.0176	.2583	-.0502	.3570	-.0237	.3287
TSS	.1856	.3117	-.2888	-.0645	.2004	.3915	-.3890	-.0821
Alt	-.6192	.1519	.0985	-.2502	-.6685	.1909	.1327	-.3184
Tem	.5633	.0396	.0280	-.2307	.6082	.0497	.0377	-.2937
PH	-.4345	-.2090	.1081	-.0918	-.4692	-.2625	.1456	-.1168

	Oxy	Har	Alk	Con	Tur	NO3	PO4	SiO2
Oxy	1.0000							
Har	-.5146	1.0000						
Alk	-.5852	.8491	1.0000					
Con	-.6649	.8395	.8371	1.0000				
Tur	-.1674	.0135	.0490	-.0509	1.0000			
NO3	.1510	-.0019	.0379	-.1395	-.1190	1.0000		
PO4	-.3559	.4219	.4604	.4229	-.0134	-.1003	1.0000	
SiO2	-.0645	-.0122	-.0702	-.1089	.1071	.5290	-.2849	1.0000
TSS	-.1778	.2395	.1457	.1366	.7348	-.1299	.3871	-.0521
Alt	.4491	-.3799	-.3746	-.5060	-.1595	.0824	-.2221	.0351
Tem	-.3482	.4742	.4606	.5789	-.0430	-.1443	.5608	-.2308
pH	.4248	-.4127	-.2300	-.3533	-.2563	.0807	-.3354	-.1240

	TSS	Alt	Tem	pH
TSS	1.0000			
Alt	-.2023	1.0000		
Tem	.2441	-.5005	1.0000	
pH	-.4036	.2112	-.1740	1.0000

N	name	(weighted) mean	stand. dev.	inflation factor
1	SPEC AX1	.0000	1.0798	
2	SPEC AX2	.0000	1.2561	
3	SPEC AX3	.0000	1.3472	
4	SPEC AX4	.0000	1.2728	
5	ENVI AX1	.0000	1.0000	
6	ENVI AX2	.0000	1.0000	
7	ENVI AX3	.0000	1.0000	
8	ENVI AX4	.0000	1.0000	
1	Oxy	.6660	.3812	2.5002
2	Har	1.9793	.3418	6.2754
3	Alk	2.0762	.3406	7.5296
4	Con	2.4321	.3790	7.4308
5	Tur	2.0121	.5002	4.1638
6	NO3	2.0658	.8549	1.7939
7	PO4	1.6772	.8309	2.6997
8	SiO2	1.5392	.4843	1.8529
9	TSS	2.1816	.5660	4.4057
10	Alt	1200.2670	43.4420	1.6779
11	Tem	23.9360	3.5649	2.2513
12	pH	7.4233	.6811	1.8532

Table 5.5 (continued).

****** Summary ******

Axes	1	2	3	4	Total inertia
Eigenvalues :	.490	.263	.208	.173	7.971
Species-environment correlations :	.926	.796	.742	.786	
Cumulative percentage variance					
of species data :	6.2	9.5	12.1	14.2	
of species-environment relation:	27.1	41.7	53.2	62.7	
Sum of all unconstrained eigenvalues					7.971
Sum of all canonical eigenvalues					1.807

*** Unrestricted permutation ***

****** Summary of Monte Carlo test ******

Test of significance of first canonical axis: eigenvalue = .490
F-ratio = 4.653
P-value = .0050

Test of significance of all canonical axes : Trace = 1.807
F-ratio = 1.735
P-value = .0050

(199 permutations under reduced model)

F Summary of test of significance for the 12 Environmental variables

	Conditional Effects			
Variable	Var.N	LambdaA	P	F
Con	4	0.45	**0.005***	4.86
Alk	3	0.18	**0.005***	2.04
Oxy	1	0.18	**0.005***	2.01
Tur	5	0.17	**0.005***	1.90
SiO2	8	0.15	**0.005***	1.71
Alt	10	0.14	**0.015***	1.59
Har	2	0.10	0.115	1.24
NO3	6	0.11	0.205	1.21
PO4	7	0.10	0.285	1.11
pH	12	0.09	0.325	1.11
Tem	11	0.08	0.645	0.87
TSS	9	0.06	0.905	0.70

Table 5.7. Result of Canonical Correpondence Analysis (CCA) of data on diatoms in rivers Kibos, Nyando and Kisat (with the 6 significant environmental variables).

**** **Weighted correlation matrix** (weight = sample total) ****

	SPEC AX1	SPEC AX2	SPEC AX3	SPEC AX4	ENVI AX1	ENVI AX2	ENVI AX3	ENVI AX4
SPEC AX1	1.0000							
SPEC AX2	-.0299	1.0000						
SPEC AX3	-.0802	.0359	1.0000					
SPEC AX4	-.0940	-.0573	.0491	1.0000				
ENVI AX1	.9192	.0000	.0000	.0000	1.0000			
ENVI AX2	.0000	.7719	.0000	.0000	.0000	1.0000		
ENVI AX3	.0000	.0000	.7306	.0000	.0000	.0000	1.0000	
ENVI AX4	.0000	.0000	.0000	.7017	.0000	.0000	.0000	1.0000
Oxy	-.6921	.3231	.1631	.0729	-.7529	.4185	.2232	.1040
Alk	.6251	-.0326	-.4058	.2487	.6800	-.0422	-.5555	.3543
Con	.8690	.0853	-.1145	.1789	.9453	.1105	-.1568	.2549
Tur	-.0174	.1542	-.5161	-.3805	-.0189	.1998	-.7064	-.5423
SiO2	-.0644	.2862	.0166	-.3030	-.0700	.3707	.0227	-.4318
Alt	-.6206	.1432	.0278	.3743	-.6751	.1856	.0380	.5334

	Oxy	Alk	Con	Tur	SiO2	Alt
Oxy	1.0000					
Alk	-.5852	1.0000				
Con	-.6649	.8371	1.0000			
Tur	-.1674	.0490	-.0509	1.0000		
SiO2	-.0645	-.0702	-.1089	.1071	1.0000	
Alt	.4491	-.3746	-.5060	-.1595	.0351	1.0000

N	name	(weighted) mean	stand. dev.	inflation factor
1	SPEC AX1	.0000	1.0879	
2	SPEC AX2	.0000	1.2954	
3	SPEC AX3	.0000	1.3687	
4	SPEC AX4	.0000	1.4251	
5	ENVI AX1	.0000	1.0000	
6	ENVI AX2	.0000	1.0000	
7	ENVI AX3	.0000	1.0000	
8	ENVI AX4	.0000	1.0000	
1	Oxy	.6660	.3812	2.0215
3	Alk	2.0762	.3406	3.5206
4	Con	2.4321	.3790	4.8663
5	Tur	2.0121	.5002	1.1571
8	SiO2	1.5392	.4843	1.0515
10	Alt	1200.2670	43.4420	1.4647

**** **Summary** ****

Axes	1	2	3	4	Total inertia
Eigenvalues :	.480	.235	.197	.131	7.971
Species-environment correlations :	.919	.772	.731	.702	
Cumulative percentage variance					
of species data :	6.0	9.0	11.4	13.1	
of species-environment relation:	37.9	56.4	72.0	82.3	
Sum of all unconstrained eigenvalues					7.971
Sum of all canonical eigenvalues					1.268

Table 5.6 (continued)

****** Summary of Monte Carlo test ******

Test of significance of first canonical axis: eigenvalue = .480
F-ratio = 4.933
P-value = .0050

Test of significance of all canonical axes : Trace = 1.268
F-ratio = 2.426
P-value = .0050

(199 permutations under reduced model)

F Summary of final test of significance for the 6 (significant) environmental variables

	Conditional Effects			
Variable	Var.N	LambdaA	P	F
Con	4	0.45	**0.005***	4.86
Alk	3	0.18	**0.005***	2.04
Oxy	1	0.18	**0.005***	2.01
Tur	5	0.17	**0.005***	1.90
SiO2	8	0.15	**0.010***	1.71
Alt	10	0.14	**0.025***	1.59

Annex 6

Table 6.1. Classification of samples resulting from TWINSPAN analysis of diatoms from Lake Victoria (Kenya part) (given up to level 3). Indicator species shown in bold. Two-way table for species available on request.

```
                         CLASSIFICATION OF SAMPLES

DIVISION    1  (N=    42)          i.e. group *
Eigenvalue: 0.3830  at iteration  48
INDICATORS and their signs:
Nit acc  4(+)   Aul aga  1(-)   Cyc men  1(-)   Nit fon  2(-)   Cyc dub  1(-)
Maximum indicator score for negative group  -1
Minimum indicator score for positive group   0

ITEMS IN NEGATIVE GROUP   2  (N =   24)          i.e. group *0
10No99   31No99   26No99   3No99    4No99    9No99    50No99   10De99
31De99   26De99   3De99    4De99    9De99    34De99   54De99   50De99
106De99  10Ja00   31Ja00   26Ja00   3Ja00    4Ja00    9Ja00    50Ja00

BORDERLINE NEGATIVES      (N =     1)
50No99

ITEMS IN POSITIVE GROUP   3  (N =   18)          i.e. group *1
34No99   32No99   54No99   53No99   MANo99   106No99  MBNo99   32De99
53De99   MADe99   MBDe99   34Ja00   32Ja00   54Ja00   53Ja00   MAJa00
106Ja00  MBJa00

BORDERLINE POSITIVES      (N =     2)
106No99  32De99

MISCLASSIFIED POSITIVES (N =     1)
MBNo99

NEGATIVE PREFERENTIALS
Aul aga 1(  20,    2)  Aul amb 1(  10,    1)  Coc plc 1(   6,    2)  Cyc dub 1(  13,    0)
Cyc men 1(  19,    3)  Cyc oce 1(  12,    0)  Cym sol 1(   7,    2)  Cym sil 1(  12,    0)
Fra cac 1(  10,    0)  Fra con 1(   8,    0)  Gom ang 1(   8,    1)  Nav dig 1(  10,    1)
Nit lac 1(   9,    1)  Nit lin 1(   6,    1)  Nit pal 1(  12,    2)  Nit verm1(  10,    1)
Syn cun 1(  15,    3)  Aul aga 2(   7,    0)  Aul nya 2(  14,    5)  Aul gra 2(  13,    3)
Cyc men 2(  12,    0)  Nit fon 2(  15,    1)  Nit lac 2(   6,    1)  Nit pal 2(   7,    0)
Aul nya 3(  10,    2)

POSITIVE PREFERENTIALS
Nit nya 1(   3,    7)  Nit acc 2(  10,   18)  Nit gra 2(   8,   14)  Ste ast 2(   1,    4)
Nit acc 3(   3,   16)  Nit acc 4(   2,   15)  Nit acc 5(   0,    9)

NON-PREFERENTIALS
Aul nya 1(  23,   14)  Aul gra 1(  21,   12)  Eun pec 1(   5,    2)  Nav lep 1(   5,    2)
Nav pup 1(  10,    4)  Nit acc 1(  23,   18)  Nit fon 1(  17,   11)  Nit gra 1(  21,   17)
Nit int 1(   3,    4)  Ste ast 1(  14,   15)

              --------  E N D   O F   L E V E L   1 --------

*****************************************************************************

DIVISION    2  (N=    24)          i.e. group *0
Eigenvalue: 0.3523  at iteration   5
INDICATORS and their signs:
Nav dig  1(-)
Maximum indicator score for negative group  -1
Minimum indicator score for positive group   0

ITEMS IN NEGATIVE GROUP   4  (N =   10)          i.e. group *00
10De99   31De99   26De99   3De99    4De99    9De99    34De99   54De99
50De99   106De99

BORDERLINE NEGATIVES      (N =     1)
4De99
```

```
ITEMS IN POSITIVE GROUP   5  (N =     14)          i.e. group *01
10No99    31No99    26No99    3No99     4No99     9No99     50No99    10Ja00
31Ja00    26Ja00    3Ja00     4Ja00     9Ja00     50Ja00

NEGATIVE PREFERENTIALS
Amp ped 1(   2,    0) Amp com 1(   2,    1) Amp ova 1(   4,    0) Ano fol 1(   2,    0)
Ast for 1(   2,    0) Cal lep 1(   2,    0) Coc plc 1(   5,    1) Cyc dub 1(   9,    4)
Cym ces 1(   3,    0) Cym elg 1(   4,    0) Eun pec 1(   3,    2) Fra cac 1(   6,    4)
Fra cap 1(   3,    0) Fra con 1(   5,    3) Gom ang 1(   8,    0) Gom cla 1(   2,    0)
Gom gra 1(   3,    0) Gom oli 1(   2,    0) Gop ung 1(   2,    0) Nav dig 1(  10,    0)
Nav gas 1(   3,    0) Nav obl 1(   2,    0) Nav pup 1(   7,    3) Nav rhy 1(   3,    0)
Nav tri 1(   2,    0) Nav var 1(   2,    0) Nav vir 1(   3,    1) Nit amp 1(   3,    0)
Nit dis 1(   4,    0) Nit int 1(   3,    0) Nit lac 1(   9,    0) Nit lin 1(   6,    0)
Nit mic 1(   3,    0) Nit nya 1(   3,    0) Nit pal 1(  10,    2) Nit sig 1(   2,    0)
Nit verm1(   9,    1) Pin car 1(   2,    0) Pin div 1(   3,    0) Pin sub 1(   3,    0)
Sta nob 1(   2,    0) Sta obt 1(   3,    0) Cyc dub 2(   3,    0) Nav dig 2(   4,    0)
Nit acc 2(   6,    4) Nit lac 2(   6,    0) Nit pal 2(   6,    1) Nav dig 3(   2,    0)
Nit acc 3(   3,    0) Nit acc 4(   2,    0)

POSITIVE PREFERENTIALS
Nav lep 1(   0,    5) Nit fon 1(   4,   13) Aul aga 2(   1,    6) Aul amb 2(   1,    3)
Nit fon 2(   3,   12) Nit gra 2(   2,    6) Nit fon 3(   0,    4)

NON-PREFERENTIALS
Aul aga 1(   6,   14) Aul amb 1(   5,    5) Aul nya 1(  10,   13) Aul gra 1(   8,   13)
Cyc men 1(   9,   10) Cyc oce 1(   5,    7) Cym sol 1(   4,    3) Cym sil 1(   5,    7)
Nav cry 1(   2,    2) Nit acc 1(  10,   13) Nit gra 1(   9,   12) Rhi vic 1(   2,    2)
Ste ast 1(   8,    6) Syn cun 1(   7,    8) Aul nya 2(   4,   10) Aul gra 2(   5,    8)
Cyc men 2(   5,    7) Cyc oce 2(   2,    2) Aul nya 3(   4,    6)
********************************************************************************

DIVISION    3  (N=     18)          i.e. group *1
Eigenvalue: 0.3002  at iteration   7
INDICATORS and their signs:
Aul gra   2(+)
Maximum indicator score for negative group    0
Minimum indicator score for positive group    1

ITEMS IN NEGATIVE GROUP   6  (N =     15)          i.e. group *10
34No99    32No99    54No99    53No99    MANo99    32De99    53De99    MADe99
MBDe99    34Ja00    32Ja00    54Ja00    53Ja00    MAJa00    MBJa00

BORDERLINE NEGATIVES        (N =      2)
MAJa00    MBJa00

ITEMS IN POSITIVE GROUP   7  (N =      3)          i.e. group *11
106No99   MBNo99    106Ja00

NEGATIVE PREFERENTIALS
Cyc men 1(   3,    0) Nav men 1(   3,    0) Nit nya 1(   7,    0) Rhi vic 1(   3,    0)
Syn cun 1(   3,    0) Nit acc 3(  15,    1) Nit acc 4(  15,    0) Nit acc 5(   9,    0)


POSITIVE PREFERENTIALS
Coc plc 1(   0,    2) Eun pec 1(   1,    1) Fra uln 1(   1,    1) Gyr acu 1(   0,    1)
Nav bre 1(   1,    1) Nav pup 1(   2,    2) Nit sig 1(   0,    1) Aul nya 2(   2,    3)
Aul gra 2(   0,    3) Coc plc 2(   0,    1) Nit fon 2(   0,    1) Aul nya 3(   0,    2)
Nit fon 3(   0,    1) Aul nya 4(   0,    1)

NON-PREFERENTIALS
Aul nya 1(  11,    3) Aul gra 1(   9,    3) Nit acc 1(  15,    3) Nit fon 1(   8,    3)
Nit gra 1(  14,    3) Nit int 1(   3,    1) Ste ast 1(  13,    2) Nit acc 2(  15,    3)
Nit gra 2(  11,    3) Ste ast 2(   3,    1)

              --------  E N D   O F   L E V E L   2 --------

********************************************************************************

DIVISION    4  (N=     10)          i.e. group *00
Eigenvalue: 0.3303  at iteration  10
INDICATORS and their signs:
Cyc dub   2(-)
Maximum indicator score for negative group  -1
Minimum indicator score for positive group   0
```

```
ITEMS IN NEGATIVE GROUP   8  (N =     3)          i.e. group *000
34De99    54De99    106De99

ITEMS IN POSITIVE GROUP   9  (N =     7)          i.e. group *001
10De99    31De99    26De99    3De99    4De99    9De99    50De99

NEGATIVE PREFERENTIALS
Ach hun 1(   1,    0)  Ach plo 1(   1,    0)  Amp ova 1(   2,    2)  Amp ven 1(   1,    0)
Ast for 1(   1,    1)  Cal lep 1(   1,    1)  Cym ces 1(   2,    1)  Fra cap 1(   2,    1)
Gom oli 1(   1,    1)  Han mar 1(   1,    0)  Mas smi 1(   1,    0)  Nav cle 1(   1,    0)
Nav cus 1(   1,    0)  Nav nya 1(   1,    0)  Nav var 1(   2,    0)  Nav vir 1(   2,    1)
Nav vul 1(   1,    0)  Pin alp 1(   1,    0)  Pin div 1(   2,    1)  Pin sub 1(   2,    1)
Rhi vic 1(   1,    1)  Sta nob 1(   1,    1)  Cyc dub 2(   3,    0)  Nit acc 2(   3,    3)
Nit gra 2(   1,    1)  Nit lac 2(   3,    3)  Ste ast 2(   1,    0)  Nit acc 3(   3,    0)
Nit acc 4(   2,    0)

POSITIVE PREFERENTIALS
Amp ped 1(   0,    2)  Amp com 1(   0,    2)  Ano fol 1(   0,    2)  Aul amb 1(   0,    5)
Cyc oce 1(   0,    5)  Cym elg 1(   0,    4)  Fra cac 1(   1,    5)  Fra con 1(   0,    5)
Gom cla 1(   0,    2)  Gop ung 1(   0,    2)  Nav cry 1(   0,    2)  Nav obl 1(   0,    2)
Nav rhy 1(   0,    3)  Nav tri 1(   0,    2)  Nit amp 1(   0,    3)  Nit dis 1(   0,    4)
Nit int 1(   0,    3)  Nit mic 1(   0,    3)  Nit sig 1(   0,    2)  Pin car 1(   0,    2)
Aul nya 2(   0,    4)  Cyc men 2(   0,    5)  Cyc oce 2(   0,    2)  Nav dig 2(   0,    4)
Nit fon 2(   0,    3)  Nit pal 2(   1,    5)  Aul nya 3(   0,    4)  Nav dig 3(   0,    2)

NON-PREFERENTIALS
Aul aga 1(   2,    4)  Aul nya 1(   3,    7)  Aul gra 1(   2,    6)  Coc plc 1(   2,    3)
Cyc dub 1(   3,    6)  Cyc men 1(   2,    7)  Cym sol 1(   1,    3)  Cym sil 1(   1,    4)
Eun pec 1(   1,    2)  Gom ang 1(   3,    5)  Gom gra 1(   1,    2)  Nav dig 1(   3,    7)
Nav gas 1(   1,    2)  Nav pup 1(   3,    4)  Nit acc 1(   3,    7)  Nit fon 1(   1,    3)
Nit gra 1(   3,    6)  Nit lac 1(   3,    6)  Nit lin 1(   2,    4)  Nit nya 1(   1,    2)
Nit pal 1(   3,    7)  Nit verm1(   2,    7)  Sta obt 1(   1,    2)  Ste ast 1(   3,    5)
Syn cun 1(   2,    5)  Aul gra 2(   1,    4)
*************************************************************************

DIVISION    5  (N=     14)          i.e. group *01
Eigenvalue: 0.3420  at iteration   5
INDICATORS and their signs:
Aul aga   2(-)   Aul nya  3(-)   Aul gra  2(-)   Cyc men  1(-)   Nit fon  3(+)
Maximum indicator score for negative group  -2
Minimum indicator score for positive group  -1

ITEMS IN NEGATIVE GROUP  10  (N =     8)          i.e. group *010
10No99    31No99    26No99    4No99    9No99    10Ja00    31Ja00    26Ja00

BORDERLINE NEGATIVES       (N =     2)
4No99     26Ja00

ITEMS IN POSITIVE GROUP  11  (N =     6)          i.e. group *011
3No99     50No99    3Ja00    4Ja00    9Ja00    50Ja00

NEGATIVE PREFERENTIALS
Aul amb 1(   5,    0)  Cyc men 1(   8,    2)  Cym sol 1(   3,    0)  Fra cac 1(   4,    0)
Gom ast 1(   2,    0)  Nav cry 1(   2,    0)  Nav lep 1(   4,    1)  Nit pal 1(   2,    0)
Aul aga 2(   6,    0)  Aul amb 2(   3,    0)  Aul nya 2(   8,    2)  Aul gra 2(   7,    1)
Aul nya 3(   6,    0)  Aul nya 4(   2,    0)

POSITIVE PREFERENTIALS
Cyc dub 1(   1,    3)  Rhi vic 1(   0,    2)  Syn cun 1(   3,    5)  Cyc oce 2(   0,    2)
Cyc oce 3(   0,    2)  Nit fon 3(   0,    4)  Cyc oce 4(   0,    2)  Nit fon 4(   0,    2)
Nit fon 5(   0,    2)

NON-PREFERENTIALS
Aul aga 1(   8,    6)  Aul nya 1(   8,    5)  Aul gra 1(   8,    5)  Cyc oce 1(   4,    3)
Cym sil 1(   5,    2)  Fra con 1(   2,    1)  Nav pup 1(   2,    1)  Nit acc 1(   7,    6)
Nit fon 1(   7,    6)  Nit gra 1(   7,    5)  Ste ast 1(   3,    3)  Cyc men 2(   5,    2)
Nit acc 2(   2,    2)  Nit fon 2(   6,    6)  Nit gra 2(   4,    2)
*************************************************************************

DIVISION    6  (N=     15)          i.e. group *10
Eigenvalue: 0.3308  at iteration   5
INDICATORS and their signs:
Amp ova   1(+)
Maximum indicator score for negative group   0
Minimum indicator score for positive group   1
```

```
 ITEMS IN NEGATIVE GROUP  12  (N =    14)          i.e. group *100
 34No99     32No99     54No99     53No99     MANo99     53De99     MADe99     MBDe99
 34Ja00     32Ja00     54Ja00     53Ja00     MAJa00     MBJa00

 BORDERLINE NEGATIVES     (N =     1)
 MBDe99

 ITEMS IN POSITIVE GROUP  13  (N =     1)          i.e. group *101
 32De99

 NEGATIVE PREFERENTIALS
Aul gra 1(   9,    0) Nav men 1(   3,    0) Nit fon 1(   8,    0) Nit int 1(   3,    0)
Nit nya 1(   7,    0) Rhi vic 1(   3,    0) Ste ast 1(  13,    0) Syn cun 1(   3,    0)
Ste ast 2(   3,    0) Nit acc 5(   9,    0)

 POSITIVE PREFERENTIALS
Amp ova 1(   0,    1) Cal lep 1(   0,    1) Cyc men 1(   2,    1) Cym sol 1(   1,    1)
Cym ces 1(   0,    1) Han mar 1(   0,    1) Nav dig 1(   0,    1) Nav pup 1(   1,    1)
Nit lac 1(   0,    1) Nit pal 1(   1,    1) Pin div 1(   0,    1) Nit lac 2(   0,    1)

 NON-PREFERENTIALS
Aul nya 1(  10,    1) Nit acc 1(  14,    1) Nit gra 1(  13,    1) Nit acc 2(  14,    1)
Nit gra 2(  10,    1) Nit acc 3(  14,    1) Nit acc 4(  14,    1)
******************************************************************************

 DIVISION    7  (N=      3)          i.e. group *11
 Group too small for further division.

             --------  E N D   O F   L E V E L   3 --------

******************************************************************************

0000000000000000000000000111111111111111
0000000000111111111111110000000000000000111
000111111100000000111111000000000000001
   0001111100000001000011011111111111111
       0011111         0000011111111
         00001         0111100000011

 ********** TWINSPAN completed **********
```

Table 6.2. Result of Detrended Correspondence Analysis (DCA) of diatom species from Lake Victoria

****** Summary ******

Axes		1	2	3	4	Total inertia
Eigenvalues	:	.715	.544	.257	.119	3.591
Lengths of gradient	:	3.504	3.248	2.677	1.739	
Cumulative percentage variance of species data	:	19.9	35.1	42.2	45.6	
Sum of all unconstrained eigenvalues						3.591

Table 6.3. Result of Canonical correspondence analysis (CCA) of diatom species from Lake Victoria

No samples omitted
Number of samples 42
Number of species 44
Number of occurrences 334

**** Weighted correlation matrix (weight = sample total) ****

	SPEC AX1	SPEC AX2	SPEC AX3	SPEC AX4	ENVI AX1	ENVI AX2	ENVI AX3	ENVI AX4
SPEC AX1	1.0000							
SPEC AX2	.0281	1.0000						
SPEC AX3	.0535	-.1800	1.0000					
SPEC AX4	-.1000	-.1161	.0982	1.0000				
ENVI AX1	.8930	.0000	.0000	.0000	1.0000			
ENVI AX2	.0000	.7139	.0000	.0000	.0000	1.0000		
ENVI AX3	.0000	.0000	.7030	.0000	.0000	.0000	1.0000	
ENVI AX4	.0000	.0000	.0000	.7186	.0000	.0000	.0000	1.0000
Dep	.6698	-.0466	.0641	-.0694	.7501	-.0652	.0912	-.0966
Sec	.5842	.1012	-.0697	-.0507	.6541	.1418	-.0991	-.0706
Tur	-.4147	.0130	.0840	-.1694	-.4643	.0182	.1195	-.2358
Tem	-.2604	.0722	-.0861	-.2818	-.2916	.1012	-.1225	-.3922
Oxy	.3580	.3177	.3107	-.1096	.4008	.4450	.4420	-.1525
pH	.1805	-.1467	-.1577	-.2514	.2021	-.2055	-.2242	-.3498
Alk	-.5121	-.3467	.1714	-.0375	-.5734	-.4856	.2438	-.0522
Con	-.7028	.1514	-.0100	-.0694	-.7869	.2120	-.0142	-.0966
Har	-.3516	-.4157	.0864	-.0722	-.3937	-.5823	.1229	-.1004
Chl	-.1968	.1268	-.0295	.2127	-.2203	.1777	-.0420	.2960
PO4	.2587	-.0637	-.2672	-.3316	.2897	-.0892	-.3801	-.4615
NO3	-.0817	-.0316	.0466	-.2060	-.0914	-.0443	.0663	-.2867
SiO2	-.5864	-.0852	.3522	-.0645	-.6566	-.1193	.5009	-.0897

	Dep	Sec	Tur	Tem	Oxy	pH	Alk	Con
Dep	1.0000							
Sec	.6374	1.0000						
Tur	-.5877	-.7551	1.0000					
Tem	-.2408	-.1571	.2050	1.0000				
Oxy	.2507	.0509	.0101	-.0490	1.0000			
pH	.3216	.2231	-.0908	.1606	.0592	1.0000		
Alk	-.2719	-.4199	.1147	.1478	-.2154	-.1816	1.0000	
Con	-.3964	-.4404	.1764	.0747	-.3207	-.1958	.4591	1.0000
Har	-.2142	-.3017	.0975	.0549	-.1522	.0795	.6135	.1494
Chl	-.0910	-.0347	.1953	.2279	.0514	.3020	-.0527	-.1278
PO4	.1968	.1088	.0934	.2061	.2080	.1387	-.2278	-.4545
NO3	-.0831	-.0124	.1362	.5197	-.2063	-.0159	.0009	-.0275
SiO2	-.3289	-.4029	.2427	.2421	-.2467	-.1855	.3673	.5327

	Har	Chl	PO4	NO3	SiO2
Har	1.0000				
Chl	.0025	1.0000			
PO4	.0504	.0255	1.0000		
NO3	-.0057	-.1083	.0058	1.0000	
SiO2	.3605	.0095	-.3081	.1977	1.0000

N	name	(weighted) mean	stand. dev.	inflation factor
1	SPEC AX1	.0000	1.1198	
2	SPEC AX2	.0000	1.4008	
3	SPEC AX3	.0000	1.4224	
4	SPEC AX4	.0000	1.3917	
5	ENVI AX1	.0000	1.0000	
6	ENVI AX2	.0000	1.0000	
7	ENVI AX3	.0000	1.0000	
8	ENVI AX4	.0000	1.0000	
1	Dep	.9243	.3800	2.7475
2	Sec	-.0155	.1817	4.0581
3	Tur	1.1781	.2749	3.6533
4	Tem	1.4182	.0125	2.4774
5	Oxy	6.4056	.7853	1.3498
6	pH	7.9963	.7027	1.7108
7	Alk	1.6983	.1267	2.7013
8	Con	2.1374	.0938	2.3393
9	Har	1.5391	.2306	2.5990
10	Chl	1.1284	.3019	1.4237
11	PO4	41.6137	25.7719	1.9333
12	NO3	1.5136	.3830	1.9228
13	SiO2	.6555	.5933	2.0628

****** Summary ******

Axes	1	2	3	4	Total inertia
Eigenvalues :	.555	.271	.197	.174	3.624
Species-environment correlations :	.893	.714	.703	.719	
Cumulative percentage variance					
of species data :	15.3	22.8	28.2	33.0	
of species-environment relation:	34.5	51.3	63.6	74.4	
Sum of all unconstrained eigenvalues					3.624
Sum of all canonical eigenvalues					1.609

1
*** Unrestricted permutation ***

****** Summary of Monte Carlo test ******

Test of significance of first canonical axis: eigenvalue = .555
F-ratio = 5.063
P-value = .0050

Test of significance of all canonical axes : Trace = 1.609
F-ratio = 1.719
P-value = .0050

(199 permutations under reduced model)

Final CCA output with the 4 significant variables

****** Summary ******

Axes	1	2	3	4	Total inertia
Eigenvalues :	.495	.216	.127	.069	3.624
Species-environment correlations :	.843	.650	.718	.496	
Cumulative percentage variance					
of species data :	13.6	19.6	23.1	25.0	
of species-environment relation:	54.5	78.3	92.3	100.0	
Sum of all unconstrained eigenvalues					3.624
Sum of all canonical eigenvalues					.908

F Summary selection of all 13 Environmental variables on diatoms of Lake Victoria

	Conditional Effects			
	Var.N	LambdaA	P	F
Variable	8	0.38	**0.005***	4.74
Con	7	0.20	**0.010***	2.48
Alk	1	0.17	**0.015***	2.28
Dep	5	0.16	**0.035***	2.14
Oxy	13	0.13	**0.060***	1.81
SiO2	11	0.11	0.120	1.54
PO4	10	0.07	0.430	1.09
Chl	6	0.09	0.245	1.17
pH	12	0.06	0.495	0.90
NO3	2	0.06	0.650	0.81
Sec	3	0.09	0.240	1.36
Tur	9	0.04	0.850	0.59
Har	4	0.05	0.840	0.62
Tem	8	0.38	0.840	0.62

F Summary of 4 significant environmental variables

	Conditional Effects			
	Var.N	LambdaA	P	F
Variable	8	0.38	**0.005***	4.74
Con	7	0.20	**0.005***	2.48
Alk	1	0.17	**0.015***	2.28
Dep	5	0.16	**0.035***	2.14
Oxy	8	0.38	**0.005***	4.74