Phytoplankton community structure and succession in the water column of Lake Naivasha, Kenya: a shallow tropical lake

David S. Hubble[1,*] & David M. Harper
Department of Biology, University of Leicester, Leicester LE1 7RH, U.K.
[1]*Ecological Monitoring & Research, 7 Ainsley Gardens, Eastleigh, Hampshire SO50 4NX, U.K.*
*Author for correspondence. E-mail: dshubble@yahoo.com

Key words: succession, cyanobacteria, diatom, *Aulacoseira*

Abstract

Lake Naivasha is a shallow freshwater lake in the Rift Valley of Kenya. Since the 1980s, when the lake showed a seasonal shift between diatom and cyanobacterial dominance it has become moderately eutrophic. Its algal assemblage is now dominated by a persistent *Aulacoseira italica* population both numerically and in terms of contribution to overall primary production. Algal and cyanobacterial counts were used to derive Simpson's diversity, succession rate and total community succession, focusing on the 10 most numerically abundant taxa. 170 species were identified, 43 of which were in common with the 143 found in 1979–80, before the increase in trophic state. Most diatoms are indicators of moderate to high nutrient conditions. There is little horizontal or vertical variation in successional processes throughout the lake and although the absolute abundance of cells varies widely, proportional composition is relatively stable. In Crescent Island lagoon, the only regularly stratified site, hypolimnetic succession rates are lower than those in the epilimnion. Overall, community composition is controlled by mixing (and hence light regime) and nutrient availability. With 'endless summer' conditions and full mixing, there is a successional pattern of 'muted seasonality' adapted to physical instability and environmental stability.

Introduction

Lake Naivasha, in common with many tropical African lakes, experiences fluctuating water-levels which influence its area and productivity (Harper, 1991). It also shows continually changing limnology through rainfall fluctuations in the catchment (Vincent et al., 1979). Its limnology and productivity may also be affected by human intervention in the form of lakeside agriculture through papyrus clearance, drainage and application of fertilisers (Johnson et al., 1998) coupled with the effects of species introductions (Harper, 1991). These changes affect the aquatic plant ecology in terms of macrophyte species and distribution and phytoplankton biomass (Harper, 1992). Due to nutrient inputs, Lake Naivasha can now also be considered moderately eutrophic (Harper et al., 1993). Before eutrophication in the 1980s it exhibited

lower but more seasonally variable biomass compared with temperate lakes, with a seasonal shift between diatoms and cyanobacteria (Kalff & Watson, 1986). This paper examines the planktonic community and the degree of succession which now occurs.

In general, tropical lakes show cyanobacterial dominance during droughts and falling water levels, and diatom dominance during periods of inflow and mixing (Harris & Baxter, 1996). Rapid monsoon dilution may affect community structure as physico-chemical conditions are rapidly changed. The work of Lewis (1978) on Lake Lanao in the Philippines gives a clear description of how a small number of chemical and physical factors may control succession in a deeper, stratified seasonal lake. The succession from dominance by diatoms and cryptomonads to chlorophytes, followed by cyanobacteria and finally dinoflagellates was seen to be promoted by increased

sunlight availability, reduced nutrient availability and greater water-column stability.

Site description

Lake Naivasha is a shallow freshwater lake situated in warm and semi-arid conditions in the eastern Rift Valley of Kenya, lying within an enclosed basin at an altitude of approximately 1890 m. Rainfall is bimodal with peaks during April and October but shows inter-annual irregularity and an annual evapotranspiration rate which exceeds local rainfall (Harper et al., 1995). Regular sampling sites on Lake Naivasha (Fig. 1) were chosen to provide a range of potential influences on light regime and resulting conditions.

The sample sites were as follows:
1. Crescent Island Lagoon – a deep (ca. 18 m) almost completely enclosed sub-basin.
2. Malewa River inflow – a shallow (ca. 2 m) turbid area where the River Malewa enters Lake Naivasha.
3. Rema Island – an inshore area about 4 m deep away from any inflow.
4. Open Water – the central area of the lake which is well mixed with less shore effects than the rest of the lake. It is about 5 m deep.
5. Hippo Point – A well-mixed inshore site, about 6 m deep.
6. Oloidien Bay – a well-mixed bay average depth 3 m with little agriculture or horticulture nearby, and furthest the main sediment input from the River Malewa.

The final four sites – RI, OW, HP and Bay – are used as replicates of the 'Main lake'.

Methods

Samples were taken from 4/12/97 to 21/10/98, at depths of 0, 1, 3 and 7 m using a 1.5-l messenger-activated Institute of Oceanographic Sciences (IOS) sampler. This was used to over-fill sample bottles to prevent trapping of air. Water samples were passed through a 200-μm screen in the laboratory, and then all algal and cyanobacterial taxa were identified to species where possible with a compound microscope at ×400 magnification. Counts were made to genus level in most cases as identification of all individuals to species was often impossible and/or excessively time-consuming. Two taxa were grouped more broadly
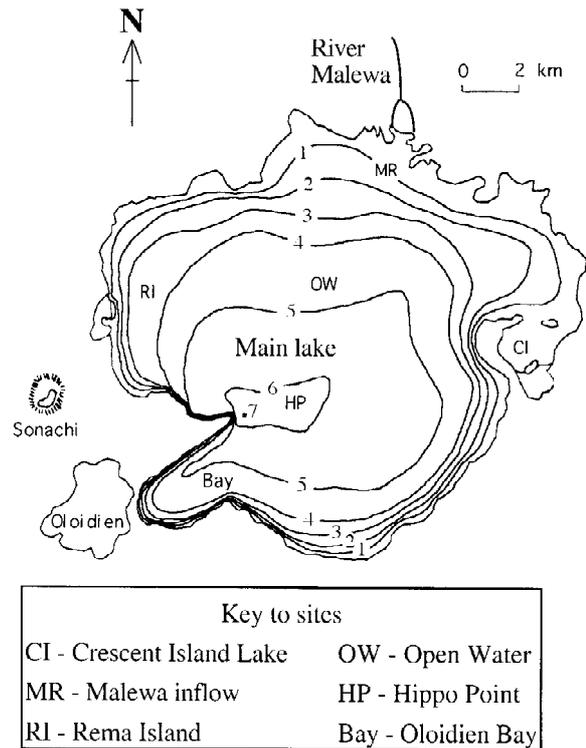
Figure 1. Map of Lake Naivasha with sampling sites and 1991 depth contours (m). From Hickley et al. (2002).

(flagellates, cyanobacteria), as the aim was a broad overview of planktonic succession rather than an in-depth study of community structure. Previous work, albeit on British rivers (Hawkes, 1979), has shown that generic groupings can clarify otherwise complex community changes by reducing the number of groups requiring monitoring. This reduces complexity due to species-specific environmental requirements, although the species forming a group must show broadly similar characteristics to avoid oversimplification. Counting was undertaken using an eyepiece graticule and sedimentation chamber with a Zeiss Axiovert 100 inverted microscope (Zeiss, Germany). Cells were identified and counted along random transects covering 200 whole graticule areas. Cells were counted which were wholly within the area or touching the right or bottom edge. A multiplication factor then gave counts ml^{-1} Flagellates and cyanobacteria form two broad functional groups. The most important groups (those which form 10% or more of total cell numbers at any time) were considered separately to identify any succession for a given sample site. Cyanobacteria were counted as numbers of colonies. Some species were
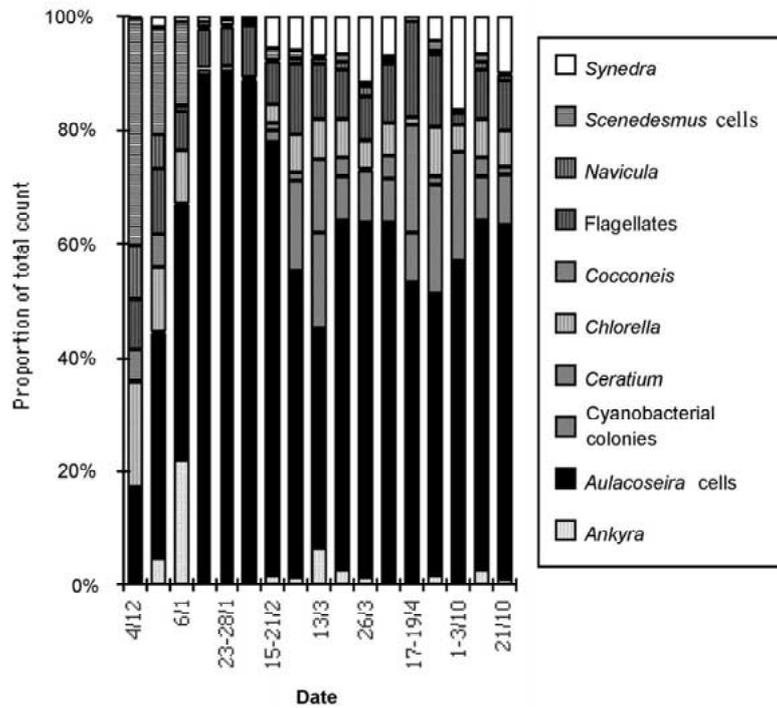
Figure 2. Main lake algal succession4/12/97–21/10/98.

present in such small numbers that they did not feature in analysis of succession.

Simpson's Diversity scores were calculated for all samples counted and analyses performed between sites and depths to investigate both horizontal and vertical spatial variation in the algal community. The index (Simpson, 1949) was

$$D = \Sigma P_i^2,$$

where P_i is the proportional numerical abundance of each species i.

To measure community change, estimates of succession rate were calculated (Jassby & Goldman, 1974; Lewis, 1976). These integrate changes in biomass or abundance over time through summation of such changes for each species as a proportion of the whole community. The Jassby & Goldman (1974) succession rate (R_s) was

$$R_s = \sqrt{\{\Sigma (\mathrm{d}c_i/\mathrm{d}t)^2\}},$$

where

$$c_i(t) = b_i(t)/\sqrt{\{\Sigma b_i(t)^2\}}$$

and

$$b_i(t)$$

is the numerical abundance of species i at time t with n possible species.

Jassby-Goldman measurements do not include directional aspects of succession, therefore using the above equations but weighting all species equally gives the formula derived by Lewis (1976):

$$R_s = \Sigma i \frac{|\{b_i(t_1)/B(t_1)\} - \{b_i(t_2)/B(t_2)\}|}{(t_2 - t_1)},$$

where $b_i(t)$ is the abundance of species i at time t and $B(t)$ is the size of the community at time t.

Results

The 170 identified species (and eight identified to genus only) are listed in the Appendix. The taxa most abundant were; *Ankyra, Aulacoseira*, cyanobacteria, *Ceratium, Chlorella, Cocconeis*, flagellates, *Navicula, Scenedesmus* and *Synedra* (Fig. 2). This shows *Aulacoseira* dominance in main lake surface water for

Table 1. Succession rate profiles for site CI

Depth (m)	12/12–6/1	6/1–16/1	17/4–12/5	3/10–13/10	Mean
0	0.055	0.062	0.035	0.076	0.057
1		0.066	0.022	0.018	0.035
3	0.052	0.067		0.011	0.043
7	0.027	0.040	0.027	0.029	0.031
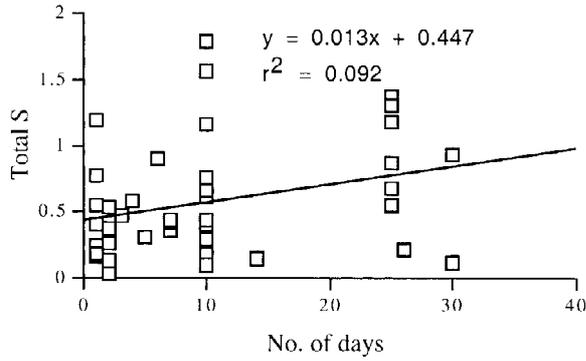
Figure 3. Regression of succession against time.

most of the sampling period, although early in this period *Scenedesmus* was more important whilst other taxa contributed variably to the algal assemblage.

Succession rate

Figure 3 illustrates the weak relationship ($r^2 = 0.092$) and non-significant correlation ($C_p = 0.304$, df = 40, $p > 0.05$) between total succession values (*S*-total) and period. For site CI, a profile of *S*-total values was developed (Fig. 4), showing that community fluctuations were greater at the surface than deeper in the water column. This is also clearly illustrated by successional rate (Table 1) indicating that surface fluctuations were not only greater in magnitude, but also occured more rapidly, than those lower down the water column.

Table 2. Mean planktonic diversity values

Site	Mean diversity	Site	Mean diversity
Main, surface	0.55	CI, 1 m	0.48
MR, surface	0.64	CI, 3 m	0.44
CI, surface	0.62	CI, 7 m	0.42
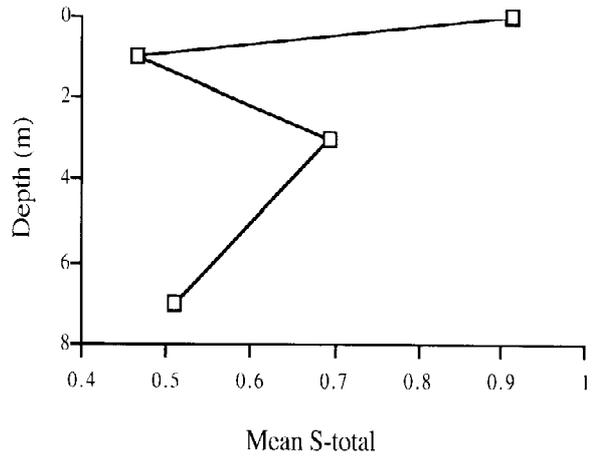
Figure 4. Profiles of total succession for Crescent island lagoon (CI).
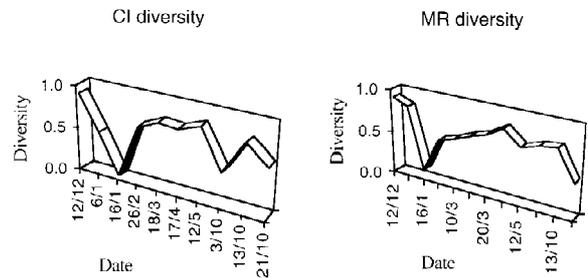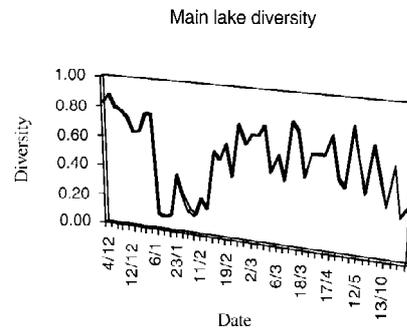
Figure 5. Simpson's Diversity, 4/12/97–21/10/98.

Diversity

Figure 5 shows Simpson's diversity over time for all sites. Table 2 shows mean values for a number of sites and depths. Site CI is investigated in profile due to its temporarily stratified nature (Hubble, 2000), whilst MR and Main sites are fully mixed (Hubble, 2000), showing no significant vertical variation.

All sites show a similar pattern of temporal diversity change, with troughs in January 1998 when
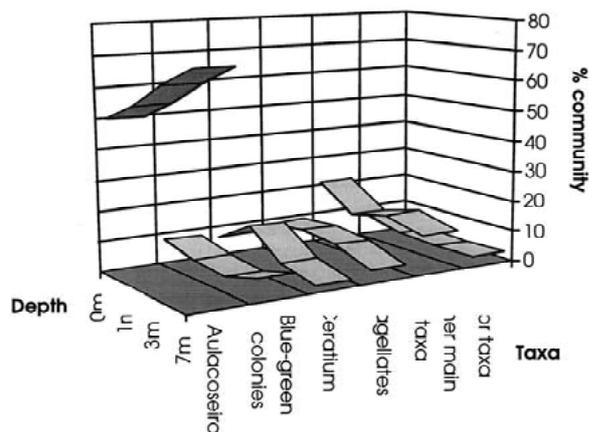
Figure 6. Phytoplankton community composition at Crescent Island lagoon (site CI).

there was almost total domination by an abundant population of *Aulacoseira*. Diversity was however similar between sites, with an overall mean of 0.60, and maxima generally occurring when *Aulacoseira* densities were relatively low.

There are no significant differences in diversity between sites, suggesting that the processes affecting diversity act equally throughout the lake. Sites CI and Main lake are not significantly correlated, and regression is closest between sites MR and Main lake, possibly due to the different hydrological regime found at site CI. Figure 6 shows depth profiles of community composition at site CI. The percentage composition of main taxa in the main lake correlates with that at site CI at all depths ($p < 0.001$). Although absolute abundance of taxa may vary, proportional community structure is therefore closely linked both vertically and between sites.

Aulacoseira formed approximately 50% of the surface community and 70% at a depth of 7 m. 'Other main taxa' (those which are sometimes dominant or sub-dominant) formed 10–20% of the community, with the remaining groups in small, fairly equal proportions. Comparing Fig. 5 with Fig. 7, community succession, shows that low diversity periods equated to high *Aulacoseira* periods as this genus comprised over 90% of the algal community at times. Such periods occurred during January and October 1998, whilst high diversity – low *Aulacoseira* periods are seen during December 1997 and April–May 1998. Vertical differences at site CI (Tables 2 and 3) show that hypolimnetic diversity is lower than that in the epilimnion, probably due to the more physically stressed conditions caused primarily by light attenuation. The

most significant differences are between 0m and the other depths although diversity reduced with depth as *Aulacoseira* dominance increased.

Discussion

Comparison with the 170 species and eight genera identified during this study and the 143 taxa identified by Kalff & Watson (1986) during 1979–80 shows 43 species common to both studies. No relationship was found between species abundance and algal biomass, the latter used as a measure of lake trophy in the earlier study. More species have been found in this study than by Kalff & Watson (loc cit), but it is important to note that species richness may be underestimated even for large samples of a speciose community (Lande, 1996). This is because in natural assemblages, increased competition amongst individuals in a community can lead to competitive exclusion. Thus as the density of individuals increases, richness does not increase with sample size as much as expected (Goldberg & Esterbrook, 1998) as seen in dense *Ceratium* populations in Lake Naivasha (Hubble, 2000). Cox (1996) gives details of diatom species' environmental requirements. Of the 47 diatom species identified with known environmental requirements, 35 are either widespread or found in waters of moderate to enriched electrolyte or nutrient conditions (eutrophic). Of the remainder, 5 indicate moderate electrolyte or nutrient conditions (mesotrophic) and 7 indicate low to moderate electrolyte or nutrient conditions (oligotrophic). The oligotrophic species such as *Fragilaria capucina* were rarely found, and only in small numbers. Oligotrophic conditions probably no longer exist following the water level decline between 1980 and 1987, which allowed land to be cultivated with subsequent inundation of that land (Harper et al., 1993), hence such populations may be merely relics, although *F. capucina* is known to exist as a number of ecological races.

Overall succession from diatoms and cryptomonads to chlorophytes, cyanobacteria and finally dinoflagellates may be largely controlled by a small number of key factors (Lewis, 1979) and promoted by high insolation, reduced nutrient availability and reduced mixing. Work at Lake Kinneret, Israel (Pollingher 1981) also indicates that low sinking rates and high nutrient availability are favourable as diversity increased during mixed and high nutrient periods, whilst it was minimal during periods of strong physical, chemical and biological stress. This indicates that in

Table 3. Site CI diversity comparison between sampling depths

Cp (prob)	r^2(one-tailed probability)			
	CI 0 m	CI 1 m	CI 3 m	CI 7 m
CI 0 m		0.736 (0.029)	0.576 (0.035)	0.564 (0.021)
CI 1 m	0.858 (0.01)		0.946 (0.045)	0.876 (0.078)
CI 3 m	0.759 (0.05)	0.972 (<0.001)		0.888 (0.387)
CI 7 m	0.751 (0.05)	0.936 (<0.001)	0.942 (0.01)	

df = 5 for comparisons with CI 3 m; df = 6 for other comparisons.
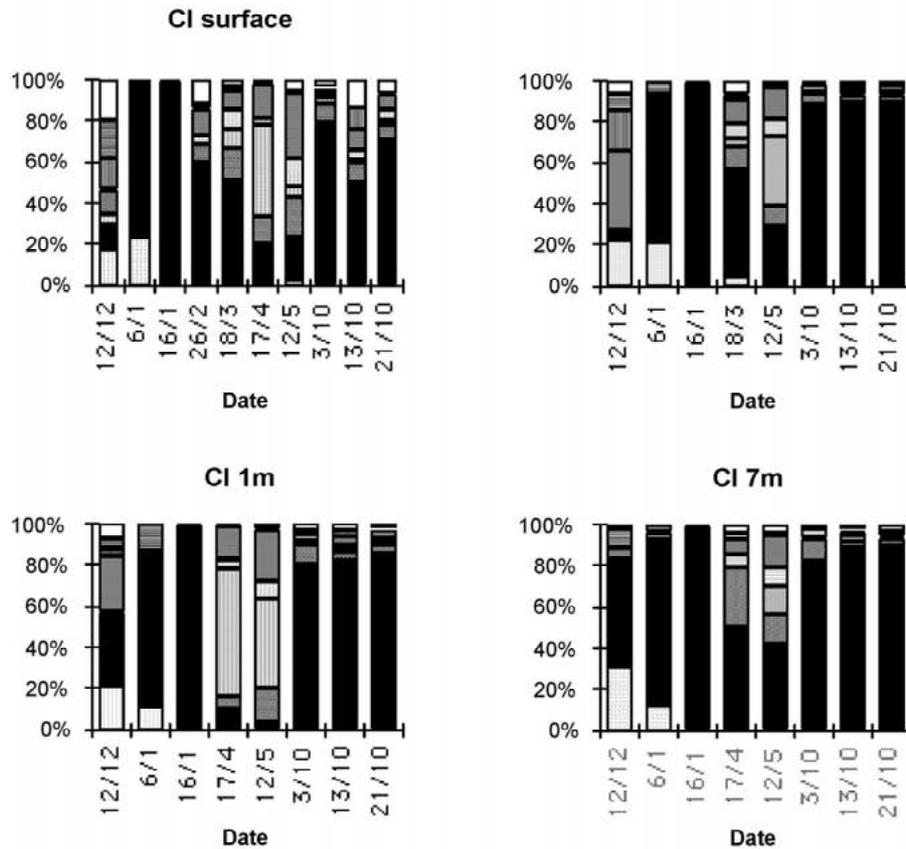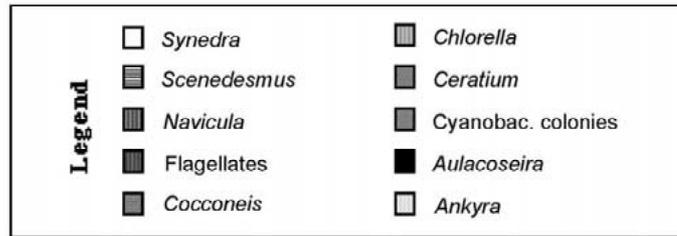
Figure 7. Community succession at Crescent Island lagoon (site CI).

early succession, low sinking rates and high nutrient availability favour low SA:V species (e.g. *Aulacoseira*) whereas nutrient depletion and low turbulence favour high SA:V species (e.g., *Microcystis*) which can scavenge scarce nutrients. The favouring of diatoms is seen both from palaeolimnology (Richardson & Richardson, 1972) and more recently (Melack, 1979, Kalff & Watson, 1986) in Lake Naivasha where there was an almost permanent early successional state. Lind (1968) stated that Lake Naivasha was dominated by *Aulacoseira ambigua* but no explanation of phytoplankton periodicity was made, although for the Sasumua and Ruiru reservoirs in Kenya it was considered to be controlled by rainfall. *Aulacoseira* is now the most important algal genus, both numerically and in terms of its contribution to overall primary productivity (Hubble, 2000).

Melack (1979) separated phytoplankton seasonality in tropical lakes into three broad categories. The most common pattern is that of pronounced seasonal fluctuations corresponding with differences due to rains, rivers or mixing. This was seen in Lake Oloidien and sometimes Crescent Island lagoon where mixing was predominant with minimal river inflow. Developing this idea, a second pattern consists of 'muted seasonality' due to the presence of buffer fringes, perennial rivers and sufficient internal recycling of nutrients. Diel variations are thus greater than longer-term changes, as conditions of 'endless summer' are found (Kilham & Kilham, 1990); this pattern is seen in Lake Naivasha. This means that as the same phytoplankton assemblages can persist for many days, species must be adapted to the full range of environmental variation. Phytoplankton communities may therefore experience both physical *instability* due to the mixed state of the water column and environmental *stability* as this mixing provides a certain light regime and prevents sedimentation loss. This form of 'continuous disturbance' is paralleled in ecosystems such as continually grazed grasslands where succession may be considered a function of 'vital attributes' (Noble & Slatyer, 1980). Around its persistent assemblages, Lake Naivasha did show wide short-term community variations such as temporary *Chlorella* dominance and wind-driven concentrations of *Ceratium* (Hubble, 2000). These occurred despite rapid physical and chemical turnover, and the idea that brevity of the mixing period may restrict species fluctuations (Ganf & Horne, 1975). The dominant or 'central' form of the assemblage however remained stable. This form of seasonality is contrary to the first

pattern where there is seasonal succession because species composition changes as conditions change, with species better adapted to the new conditions becoming dominant. A final pattern, not seen in Lake Naivasha, is that of 'multiple stable points' in the form of persistent assemblages with occasional abrupt shifts between them.

Hypolimnetic succession rates are also notably lower and less variable than those of surface waters due to two main factors:

1. There is greater physical stability found below the surface as the largely wind-driven mixing processes have a smaller effect deeper in the water column. In the temporarily stratified Crescent Island lagoon, diversity is however significantly correlated between samples from 0 and 7 m, suggesting that there is only partial separation.

2. There is reduced productivity below the optimal photosynthetic depth of approximately 0.5–0.75 m, and therefore community fluctuations are slowed by the reduced rates of cellular division, and overall lower numbers of algal cells.

Such rates of succession (as well as indices of ecosystem stability) change as succession progresses as the resulting increased order leads to system predictability and pre-adaptation. There are changes in phytoplankton community structure; however, no stages are seen which correlate with nutrient levels. Lake Naivasha is moderately eutrophic and shows diatom dominance with dinoflagellate and cyanobacterial subdominance. It therefore fits with the mesotrophic stage expected in temperate waters as many phytoplanktonic species are found across a range of latitudes. Considerable fluctuations in nutrient levels were measured (Hubble, 2000), but as the pattern of temperate oligotrophic–eutrophic succession is not seen, they are not large enough to constitute a change in trophic state.

In summary, the lake is now dominated by *Aulacoseira* following eutrophication, probably due to land use changes in the early 1980s. As well as the seasonal pattern of dominance, the species present have also largely changed since eutrophication began to occur, and most diatoms found are indicative of moderate to high nutrient levels. Large community fluctuations are seen but these are temporary with the community rapidly reverting to its *Aulacoseira*-dominated state. As the lake experiences the 'endless summer' conditions of the tropics and is well-mixed, there is strong spatial homogeneity in the phytoplankton community as its composition is controlled by light regime and nutrient availability. Changes in successional processes and

community structure are therefore determined by the combination of tropical conditions and human intervention, with the phytoplankton community acting as an indicator of trophic state.

References

Cox, E. J., 1996. Identification of Freshwater Diatoms from Live Material. Chapman & Hall, London.

Ganf, G. G. & A.J. Horne, 1975. Diurnal stratification, photosynthesis and nitrogen-fixation in a shallow, equatorial lake (Lake George, Uganda). Freshwat. Biol. 5: 13–39.

Goldberg, D. E. & G. F. Estabrook, 1998. Separating the effects of number of individuals sampled and competition on species diversity: an experimental and analytic approach. J. Ecol. 86: 983–988.

Harper, D. M., 1991. Primary production in Lake Naivasha, Kenya. Verh. Int. Ver. Theor. angew. Limnol. 24: 1112–1116.

Harper, D. M., 1992. The ecological relationships of aquatic plants at Lake Naivasha, Kenya. Hydrobiologia 232: 65–71.

Harper, D. M., G. Phillips, A. Chilvers, N. Kitaka & K. Mavuti, 1993. Eutrophication prognosis for Lake Naivasha, Kenya. Verh. Int. Ver. theor. angew. Limnol. 25: 861–865.

Harper, D. M., C. Adams & K. Mavuti, 1995. The aquatic plant communities of the Lake Naivasha wetland, Kenya: pattern, dynamics and conservation. Wetlands Ecol. Manage. 3: 111–123.

Harris, G. P. & G. Baxter, 1996. Interannual variability in phytoplankton biomass and species composition in a subtropical reservoir. Freshwat. Biol. 35: 545–560.

Hawkes, H. A., 1979. Invertebrates as indicators of river quality. In James, A. & L. Evison (eds), Biological Indicators of Water Quality. Wiley, Chichester.

Hubble, D. S., 2000. Controls on primary production in Lake Naivasha, a shallow tropical freshwater. PhD thesis, Leicester University, UK.

Jassby, A. D. & C. R Goldman, 1974. A quantitative measure of succession rate and its application to the phytoplankton of lakes. Am. Nat. 108: 688–693.

Johnson, G., D. M. Harper & K. Mavuti, 1998. Information for the sustainable management of shallow lakes: Lake Naivasha, Kenya. In Harper, D. M. & T. Brown (eds), The Sustainable Management of Tropical Catchments. Wiley, Chichester.

Kalff, J. & S. Watson, 1986. Phytoplankton and its dynamics in two tropical lakes: a tropical and temperate zone comparison. Hydrobiologia 138: 161–176.

Kilham, P. & S. S. Kilham, 1990. Endless summer: internal loading processes dominate nutrient cycling in tropical lakes. Freshwat. Biol. 23: 379–389.

Lande, R., 1996. Statistics and partitioning of species diversity, and similarity among multiple communities. Oikos 76: 5–13.

Lewis, W. M., 1976. Analysis of succession in a tropical phytoplankton community and a new measure of succession rate. Am. Nat. 112: 401–14.

Lewis, W. M., 1978. Dynamics and succession of the phytoplankton in a tropical lake. Journal of Ecology 66: 849–80.

Lewis, W. M., 1979. Zooplankton Community Analysis: Studies on a Tropical System. Springer, New York.

Lind, E. M., 1968. Notes on the distribution of phytoplankton in some Kenya waters. Br. Phycol. Bull. 3(3): 481–493.

Melack, J. M., 1979. Temporal variability of phytoplankton in tropical lakes. Oecologia 44: 1–7.

Noble, I. R. & R. O. Slatyer, 1980. The use of vital attributes to predict successional changes in plant communities subject to recurrent disturbances. Vegetation 43: 5–21.

Pollingher, U., 1981. The structure and dynamics of the phytoplankton assemblages in Lake Kinneret, Israel. J. Plankton Res. 3(1): 93–105.

Richardson, J. L. & A. E. Richardson, 1972. History of an African Rift lake and its climatic implications. Ecol. Monogr. 42: 499–534.

Simpson, E. H., 1949. Measurement of diversity. Nature 163: 688.

Vincent, C., T. Davies & A. Beresford, 1979. Recent changes in the level of Lake Naivasha, Kenya, as an indicator of equatorial westerlies over East Africa. Climate Change 2: 175–189.

Appendix 1. Algal species identified 1996–8

Phylum Cyanophyta
Order Chroococcales (14 spp.)
 Aphanothece caldariorum Richter
 Aphanothece ellipsoidea Schröder
 Aphanothece nidulans Richter
 Chlorogloea microcystoides Geitler
 Chroococcus limneticus Lemmermann
 Chroococcus turgidus (Kützing) Nägeli
 Gloeothece rupestris (Lyngbye) Bornet
 Merismopedia convoluta Brébisson
 Merismopedia geminata Lagerstedt
 Merismopedia tenuissima Lemmermann
 Microcystis aeruginosa (Kützing) Kützing
 Microcystis biformis (A. Braun) Rabenhorst
 Microcystis elachista (W. & G.S.West) Starmach
 Microcystis viridis (A. Braun) Lemmermann

Order Nostocales (= Oscillatoriales) (11 spp.)
 Anabaena sphaerica Bornet & Flahault
 Anabaena spiroides (Lemmermann) Elenkin
 Anabaenopsis circularis (G.S. West) Müller
 Borzia trilocularis Cohn
 Lyngbya epiphytica Gardner
 Lyngbya muralis Kützing
 Lyngbya sp.
 Nostoc parmelioides Kützing
 Oscillatoria jenneri (Hassall) Kützing
 Oscillatoria sp.
 Spirulina subsalsa Oersted

Phylum Chrysophyta
Order Ochromonadales (2 spp.)
 Didymochrysis paradoxa Pascher
 Mallomonas leboimei Bourrelly

Order Chromulinales (7 spp.)
 Chromulina pyriformis Playfair
 Chrysococcus rufescens Skuja
 Chrysomonas ellipsoidea Skvortzov
 Chrysospora fenestrata Pascher
 Epicystis peridinearum Pascher
 Gloeochrysis pyrenigerum Pascher
 Ochromonas viridis Bourrelly

Phylum Bacillariophyta
Order Achnanthales (5 spp.)
 Achnanthes brevipes Agardh
 Achnanthes exigua Grunow
 Achnanthes inflata Kützing
 Achnanthes minutissima Kützing
 Diatomella hustedtii Manguin

Appendix 1. Continued

Order Coscinodiscales (6 spp.)
 Aulacoseira ambigua (Grunow) Simonsen
 Aulacoseira granulata (Ehrenberg) Simonsen
 Aulacoseira italica (Ehrenberg) Simonsen
 Cyclotella meneghiniana Kützing
 Cyclotella stelligera Cleve & Grunow
 Stephanodiscus neoastraea Håkannson & Hickel
Order Diatomales (11 spp.)
 Cocconeis placentula Ehrenberg
 Diatoma ehrenbergii Kützing
 Diatoma tenuis Agardh
 Fragilaria capucina Desmazières
 Rhoicosphenia curvata (Kützing) Grunow
 Synedra acus Kützing
 Synedra berolinensis Lemmermann
 Synedra capitata Ehrenberg
 Synedra pulchella Kützing
 Synedra ulna (Nitzsch) Ehrenberg
 Synedra sp.
Order Eunotiales (2 spp.)
 Eunotia denticula (Brébisson) Rabenhorst
 Eunotia monodon (Gregory) W.Smith
Order Naviculales (45 spp.)
 Amphora communata Grunow
 Amphora ovalis Kützing
 Caloneis amphisbaena (Bory) Cleve
 Cymatopleura solea (Brébisson) W.Smith
 Cymbella lacustris (Agardh) Cleve
 Cymbella prostrata (Berkeley) Cleve
 Denticula pelagica Hustedt
 Denticula thermalis Kützing
 Diploneis didyma (Ehrenberg) Cleve
 Encyonema minutum (Hilse in Rabenhorst) D.G.Mann
 Encyonema prostratum (Berkeley) Kützing
 Epithemia turgida (Ehrenberg) Kützing
 Gomphonema acuminatum Ehrenberg
 Gomphonema augur Ehrenberg
 Gomphonema truncatum (= constrictum) Ehrenberg
 Gomphonema olivaceum (Hornemann) Brébisson
 Gyrosigma attenuatum (Kützing) Rabenhorst
 Navicula capitata Ehrenberg
 Navicula cryptocephala Kützing
 Navicula cuspidata Kützing
 Navicula gibbula Cleve
 Navicula lanceolata (C. Agardh) Kützing
 Navicula pygmaea Kützing
 Navicula protractoides Hustedt
 Navicula radiosa Kützing
 Navicula schoenfeldii Hustedt
 Navicula scutelloides W. Smith
 Navicula trivialis Lange-Bertalot

98

Navicula tuscula (Ehrenberg) Grunow
Navicula sp.
Neidium ampliatum (Ehrenberg) Krammer
Nitzschia acicularis (Kützing) W. Smith
Nitzschia amphibia Grunow
Nitzschia fonticola Grunow
Nitzschia linearis (Agardh) W. Smith
Nitzschia palea (Kützing) W. Smith
Nitzschia pusilla Grunow
Nitzschia sp.
Pinnularia maior Ehrenberg
Pinnularia viridis (Nitzsch) Ehrenberg
Rhopalodia gibba (Ehrenberg) O. Müller
Stauroneis anceps Ehrenberg
Surirella angusta Kützing
Surirella linearis W. Smith
Tryblionella apiculata Gregory

Phylum Chlorophyta
Order Volvocales (4 spp.)
Chlamydomonas debaryana Gorosch
Chlamydomonas ovalis Pascher
Chlorotriangulum minutum Kufferath
Dunaliella lateralis Pascher & Jahoda
Order Chlorococcales (37 spp.)
Acanthosphaera zachariasi (Geitler) Lemmermann
Ankistrodesmus falcatus (Chodat) Lemmermann
Ankistrodesmus gelifactum (Chodat) Bourrelly
Ankyra ancora (G.M. Smith) Fott
Ankyra judai (G.M. Smith) Fott
Botryococcus braunii Kützing
Botryosphaera sudetica (Lemmermann) Chodat
Characium ornithocephalum A. Braun
Chlorella miniata (Nägeli) Oltmanns
Chlorella vulgaris Beijerinck
Chlorococcum wimmeri (Rabenhorst) Starr
Chodatella ciliata (Lagerheim) Lemmermann
Chodatella quadriseta Lemmermann
Coelastrum microsporum Nägeli
Coelastrum reticulatum (Dangeard) Senn
Crucigenia quadrata Morren
Crucigenia tetrapedia (Korchikoff) Bourrelly
Dictyosphaerum pulchellum Wood
Euastropsis richteri (Schmidle) Lagerheim
Micractinium pusillum (Lund) Fresenius
Oocystidium ovale Korchikoff
Oocystis lacustris Chodat
Pediastrum boryanum Meyer
Pediastrum clathratum (Schröder) Lemmermann
Pediastrum duplex Meyer
Pediastrum tetras (Corda) Rabenhorst
Selenastrum bibraianum Reinsch
Scenedesmus crassus Chodat
Scenedesmus falcatus Chodat

Scenedesmus flexuosus (Lemmermann) Ahlstrom
Scenedesmus protuberans Fritsch & Rich
Scenedesmus tenuispina Chodat
Scenedesmus sp.
Sphaerocystis schroeteri Chodat
Tetraedron caudatum Lemmermann
Tetraedron limneticum (Skuja) Borge
Tetrastrum heteracanthum (Nordstedt) Chodat

Order Oedogoniales (3 spp.)
Oedogonium mammiferum Wittrock
Oedogonium minus Wittrock
Oedogonium sudanense Gautlièvre
Order Desmidiales (11 spp.)
Closterium acerosum (Schrank) Ehrenberg
Closterium acutum Brébisson
Closterium setaceum Grönblad
Cosmarium depressum Riverdin
Cosmarium meneghinii Brébisson
Gonatozygon monotaenium De Bary
Micrasterias tropica Nordstedt
Pleurodiscus africanus Bourrelly
Staurastrum lunatum Ralfs
Staurastrum sebaldi Krieger & Bourrelly
Staurodesmus dickei (Ralfs) Lillieroth

Phylum Euglenophyta
Order Euglenales (7 spp.)
Euglena polymorpha Dangeard
Euglena variabilis Klebs
Euglena viridis Ehrenberg
Phacus tortus (Lemmermann) Swirenko
Scytomonas pusillus Stein
Sphenomonas quadrangularis Stein
Strombomonas gibberosa (Playfair) Deflandre

Phylum Pyrrhophyta
Order Prorocentrales (2 spp.)
Gymnodinium inversum Nygaard
Gymnodinium sp.
Order Peridiniales (4 spp.)
Ceratium cornutum (Ehrenberg) Chapman & Bachmann
Ceratium hirundinella (O.F. Müller) Schrank
Peridiniopsis borgei Lemmermann
Peridinium volzii Lemmermann
Order Cryptomonadales (7 spp.)
Chroomonas acuta Ütermohl
Chroomonas minuta Skuja
Chroomonas rubra Geitler
Cryptomonas marssonii Skuja
Cryptomonas ovata Ehrenberg
Cryptomonas tetrapyrenoidosa Skuja
Tetragonidium verrucatum Pascher