Chapter 21

Eutrophication of the East African Great Lakes

Mbachi Ruth Msomphora
Norwegian College of Fishery Science
University of Tromsø
N-9037 Tromsø, NORWAY
mbachi@stud.nfh.uit.no

21.1 Introduction

The Great lakes of east Africa have similar characteristics. They are perhaps the best-known lakes in the world for their faunal diversity. From a limnological perspective, the distinguishing attributes of these lakes are their large size and tropical location. Their diversity may be attributed to these features, along with their great age, e.g. Lake Malawi has existed in the rift valley for over two million years (Brooks, 1950; Hecky, 1984). Despite their shared characteristics, there are some major limnological differences among Africa's three largest lakes. Compared to Lake Malawi and Tanganyika, Lake Victoria is substantially shallower, younger geologically and has faster water renewal times (Hecky, 1984; Bootsma & Hecky, 1993). Lake Malawi and Tanganyika are similar in morphology and transparency, and are both meromictic, but they are markedly different with regard to hydrology, nutrient dynamics (Hecky & Bugenyi, 1992), plankton composition (Hecky & Kling, 1987), and trophic structure (Hecky, 1984). In contrast to Lake Tanganyika, Lake Malawi consists of a single basin with the greatest depth of about 785 m (Table 21.1). Lake Malawi is about 560 km long and greatest width of about 75 km. It is about 1/3 of the total geographical area of the country (Figure 21.1). Nearly 25% of Lake Malawi belongs to Mozambique and they call it Lake Niassa. In Tanzania Lake Malawi is still called its colonial name, Lake Nyasa (Figure 21.1). Victoria is the largest lake by area in Africa (second largest in the world) but with only one-third the volume of that of Lake Malawi (Table 21.1). Lake Tanganyika is the deepest of these three East African Great Lakes and has the biggest volume of about 18,900 km^3 (Table 21.1). The effects of the anthropogenic activities on these lakes may be quite different.

Human benefits gained from Lake Malawi, Tanganyika and Victoria include:

1. Water supply for consumption, agriculture, industry, and hydroelectricity production

2. Fish production, which serves as a source of protein or food in general and cash income

Table 21.1: Morphometric and hydrological data for Africa's three largest lakes. Source: a - Gonfiantini et al. (1979). b - Rzoska (1976). c - Owen et al. (1990). d - Coullter and Spigel (1991). e - Eccles (1979). f - Bootsma and Hecky (1993).i

	Malawi	Tanganyika	Victoria
Catchment Area (km^2)	100,500 f	220,000 f	195,000 f
Lake Area (km^2)	28,000 f	32,600 f	68,800 f
Maximum Depth (m)	785a	1470a	79a
Mean Depth (m)	292a	580a	40 f
Volume (km^3)	8,400a	18,900a	2,760b
Outflow (O) (km^3 y^{-1})	11c	2,7d	20b
Inflow (I) (km^3 y^{-1})	29c	14d	20b
Precipitation (P) (km^3 y^{-1})	39c	29d	100b
Evaporation (km^3 y^{-1})	55e	44d	100b
Flushing time (V/O) (years)	750 f	7,000 f	140 f
Residence time ($V/(P+1)$ (years)	140 f	440 f	23 f

3. Aesthetic value, which attracts tourists, biodiversity which supports an aquarium trade in cichlid fishes, and has other noneconomic benefits

4. Scientific value.

Such benefits may perish with the current human activities, which are already threatening these values. In Lake Victoria it is likely that hundreds of haplochromine cichlids have gone extinct in the past decade. Only three species are currently harvested in any numbers (Hecky, 1993). The loss of this trophically diverse group of fishes and reduction to extreme trophic simplicity can be a hypothesis to explain other change in the food web. For example, eutrophication is likely to be considered as one of the effects due to such trophic changes.

Human activities that threaten the lakes include agriculture, urban development, tourism, industrial development, over-fishing, and other human activities in the catchments and alien species introduction. Of special concern are the possible oil exploration activities in Lake Malawi and Tanganyika. However, other phenomena, especially the increase in human and livestock population since the colonialism and following state development, must also be considered. This development together with anticipated sensitivity to eutrophication of the tropical Great Lakes because of their 'endless summer', warm deep water and dominance of direct precipitation in their water budget Hecky & Bugenyi (1992) must be carefully considered.

21.2 Differences in the hydrology of Lake Malawi, Victoria and Tanganyika

As indicated above Lake Victoria is much shallower than Lake Malawi and Tanganyika, which have an anoxic deep hypolimnion, hence the monimolimnia[1] of these two latter lakes are N sinks. Very little ammonia regenerated in the monimolimnia reaches the euphotic zone (Figure 21.3),

[1] Monimolimnion is technichally the same as the hypolimnion; i.e. the deepest layer in the lake. In most lakes that mix once or twice y^{-1}, it is called the hypolimnion. But in lakes that are permanently stratified, it is called the monimolimnion

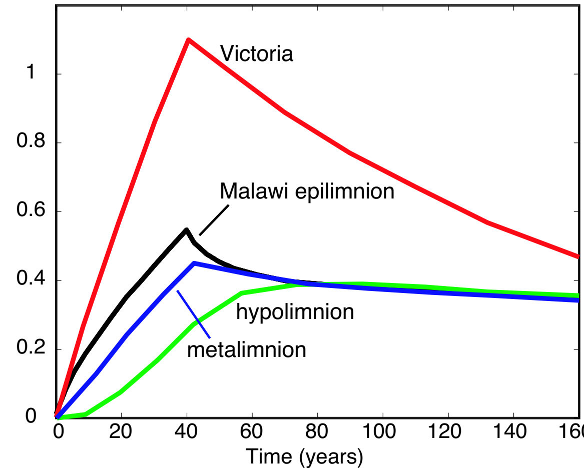

Figure 21.2: Pollution scenario for Lake Victoria and Malawi, in which all inflow rivers contain 5 μg l^{-1} pollutant for 40 years, followed by complete cessation of pollution input. The model uses the hydrology parameters of Table 21.1; it assumes that the only loss of pollutant is via outflow and that all inflow enters the epilimnion (Bootsma & Hecky, 1999; Gonfiantini *et al.*, 1979).

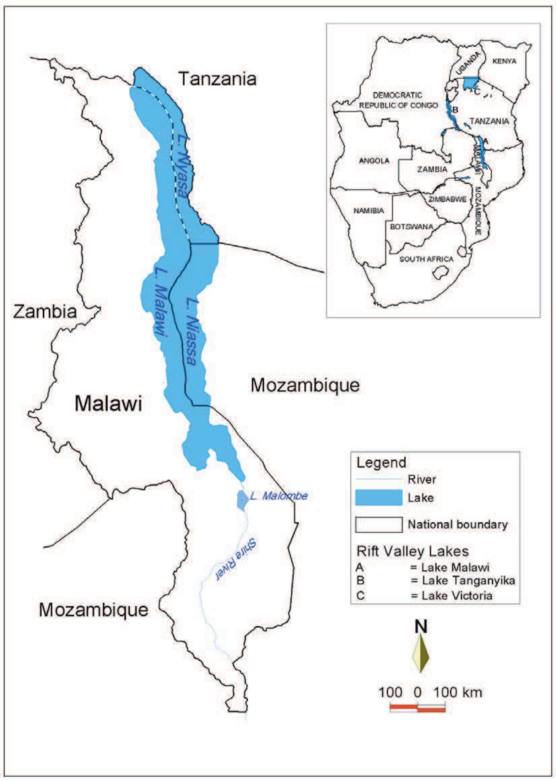

Figure 21.1: Map of Malawi showing the position of Lake Malawi and the bordering countries. The position of Lake Malawi in relation to Lakes Tanganyika and Victoria is also shown on the Map of Southern Africa (http://www.ramsar.org).

because it is oxidized to nitrate when it mixes with oxic waters (Bootsma & Hecky, 1999). Lake Victoria in total is currently experiencing eutrophication and its many once common species are no longer found there and maybe extinct. This is not yet true for Lake Malawi and Tanganyika except locally. This demonstrates that the biodiversity vulnerability is not only a function of eutrophication, pollution etc, but also depends on the hydrology of the water body.

The Nile outflow from Lake Victoria is almost twice greater than the Shire flow from Lake Malawi (nearly proportional to the difference in catchment area of the two lakes). Hence the flushing time of Victoria is much smaller (Table 21.1). As a consequence the concentration of introduced pollutants can rise much more quickly in Lake Victoria, but it will also recover much more quickly if their supply would cease (Figure 21.2). On the Great Lakes scale, Lake Erie in North America is the best-known case of substantial recovery from pollution (Sweeney, 1993). Lake Erie is like Victoria, large and shallow, but its flushing time is on the order of five years, allowing it to flush out excess dissolved nutrients and contaminants relatively rapidly (Bootsma & Hecky, 1999). It would take many years for Lake Malawi to recover if it ever experienced pollution concentrations comparable to those that occurred in Lake Erie and what is currently being experienced in Lake Victoria. As such the ability to predict the effects and decisions on how to prevent or mitigate the effect of pollution requires an understanding of the specific limnology of each aquatic system. For Lake Malawi and Tanganyika prevention is the only realistic and affordable policy for maintaining the lakes in healthy condition and insuring their continued beneficial use by the people.

21.3 Limiting nutrients in Lake Malawi, Victoria and Tanganyika

While P is the nutrient most often limiting algal growth and biomass in most fresh water systems, this is not necessary the case in tropical lakes. In Lakes Malawi, Tanganyika, and Victoria, concentrations of N and P in surface waters are low (Figure 21.3). Talling and Talling (1965) suggested that low nitrate concentrations in Lake Victoria indicated a potential for N limitation. While phytoplankton in Lake Victoria appears slightly deficient in N, neither N nor P appears to be limiting, based on Redfield ratios. Similarly, particulate nutrient ratios in Lake Malawi suggest N and P deficiency. Evidence suggests that photosynthesis in Lake Victoria is now light limited, but in Lake Malawi Guildford et al. (1994) found that phytoplankton growth is rarely controlled by light. Little work has been done to identify limiting nutrients in Lake Tanganyika, but the fact that the N: P regeneration ratio is close to 16:1 (Hecky *et al.*, 1991), the optimal ratio for phytoplankton, suggests that also this lake is not limited by these nutrients.

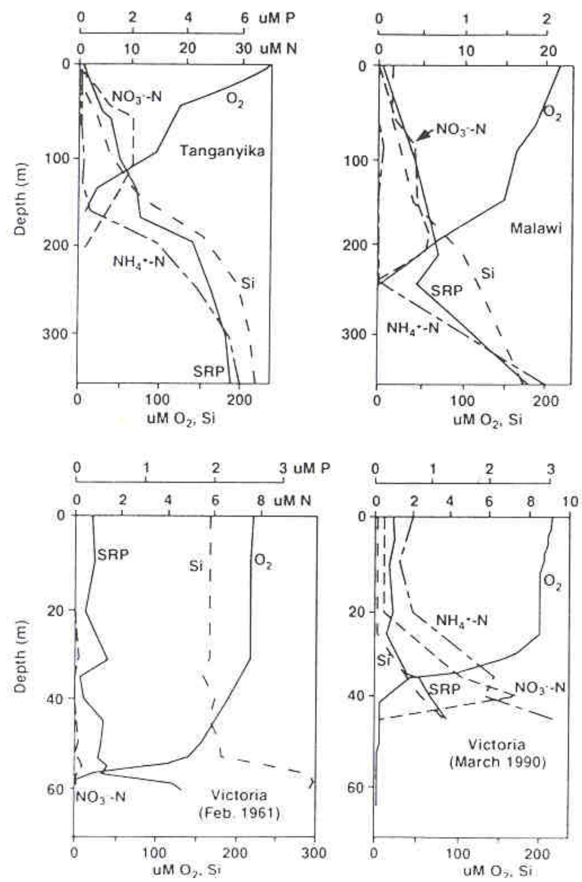

Figure 21.3: Nutrient and oxygen profiles for the three African Great Lakes. SRP = soluble reactive phosphorus (it is mostly phosphate, also called orthophosphate). (Bootsma & Hecky, 1993).

21.4 Eutrophication in Lake Victoria as compared to Lake Malawi and Tanganyika

In Africa, burning, deforestation and increasing agricultural activities are all results of increased population density, which have negative impacts in the East-African Great Lakes region. Compared to Lake Victoria, in Lake Malawi and Tanganyika these effects are currently undetectable (Bootsma & Hecky, 1999) because the latter lakes have steep near-shore topographies (Figure 21.4). They are susceptible to soil erosion after disturbance (for example the northeast shores of Lake Tanganyika) but are not attractive for dense human population or cattle grazing. Hence the Lake Victoria catchment is much more densely populated than the other African Great Lakes (Figure 21.5). Nevertheless, cultivation and deforestation increasingly takes place in the latter lakes. A potential exists for land degradation, local increase in sediments and nutrient inputs in the very near future except for the extreme end of Tanganyika where near-shore population densities are presently low around the entire lake (Figure 21.5).

The introduction of the Nile perch in the 1950's and of the water hyacinth in Lake Victoria has also contributed greatly to the dramatic shifts in the lake's ecosystem during the past few years. Currently the presence of water hyacinth has also been reported in Lake Malawi, within the vicinity of Sugar Corporation of Malawi-Dwangwa Mill and Ethanol Company Limited and in the Shire River, the outlet of Lake Malawi (Figure 21.1). This may be of great concern to Lake Malawi. If population growth trend continues at the current rate (2.8% y^{-1}) in Malawi, cultivation (e.g. sugar plantation) and deforestation on steep slopes including industrialisation along the lakeshore will definitely lead into increased river runoff. This may result in more nutrient and sediment loading in the lake. Certainly the density of people occupying a catchment and the type of land-use (e.g. agriculture) they employ, will determine the effect the population can have on a lake.

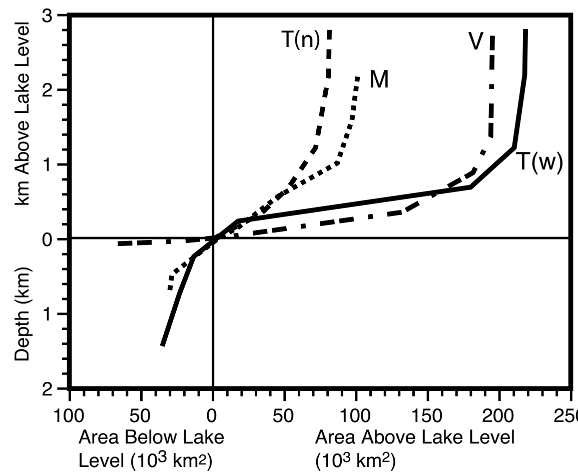

Figure 21.4: Hypsographic curves for the three lakes and their drainage basins. $T_{(w)}$ = entire Tanganyika drainage basins. A separate curve for the Tanganyika drainage basin ($T_{(n)}$) was determined by excluding the eastern plains (area east of dashed line) in order to provide a more accurate description of near shore topography. Note changing scales on each axis. (Bootsma & Hecky, 1993).

21.5 Effects of Eutrophication in Lake Malawi, Tanganyika and Victoria

Eutrophication may result into increased sedimentation, which may lead into a rise of the anoxic boundary layer (Figure 21.3), increased bottom water oxygen demand and greater light attenuation. This will reduce the depth of the euphotic zone. Such effects may result in shrinkage of available fish habitat and is detrimental to fisheries. A change in phytoplankton species composition may also result. The nature of these changes will be determined by the absolute and relative input rates of N, P and Si, by hydrodynamics, and by the complex interplay between internal nutrient cycling and the trophic structure. In the Laurentian Great Lakes, eutrophication has been observed to result in lower Si concentrations (Schelske *et al.*, 1988) due to rapid growth and subsequent sedimentation of diatom frustules in rivers. The in-

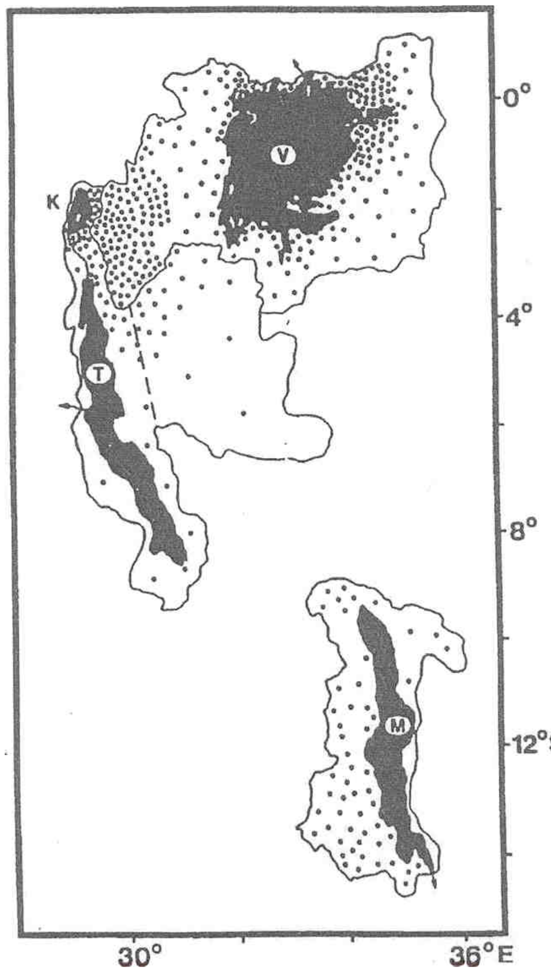

Figure 21.5: Human population densities in the drainage basin of African's largest three lakes. One dot = 100,000 persons. V = Victoria; K = Kivu; T = Tanganyika; M = Malawi (Bootsma & Hecky, 1999).

creased productivity in Lake Victoria during 1991 (Mugidde 1993) relative to 1960–1961 (Talling, 1965, 1966) appears to have had the same effect (Figure 21.3). While diatoms were still abundant in Lake Victoria during 1990, they consisted primary of thinly silicified *Nitzschia* (Bootsma & Hecky, 1993), where as Talling (1986) reported dominance by *Melosira*, a large heavily silicified diatom (which is now absent except perhaps in marginal bays where Si remains available from inflowing streams).

Eutrophication in lakes often results in cynobacteria dominance, although others factors such as temperature (Varis, 1991), light (Zevenboom *et al.*, 1982), and pH (Shapiro, 1973) may also affect the competitive ability of these organisms. This scenario is apparent in Lake Victoria. Relative to that observed during 1960–1961 (Talling, 1966), evidence of increased nutrient input (Hecky, 1993) is accompanied by higher cyanobacteria biomass (Ochumba & Kibaara, 1989). Because denitrification will minimise the influence of additional N input in Lakes Tanganyika and Malawi, eutrophication in these lakes will result in a greater increase in P available than N availability, and the significance of N-fixing cyanobacteria would also increase in these lakes. Such a shift in phytoplankton species composition might result in a lower efficiency of energy transfer to higher trophic levels, since cyanobacteria are generally considered a poor food source (Lampert, 1981; Heerkloss *et al.*, 1984; Haney, 1987). However the ability of some Tilapiines (*Tilapia* and *Oreochromis* species) to digest cyanobacteria (Moriarty, 1973; McDonald, 1987), suggests that eutrophication may result in a more productive fishery dominated by herbivorous fishes. While this would be beneficial with regards to food production (Tilapiines), such an environment would not be favourable for zooplanktivorous fish species, since cyanobacteria are a poor food source for zooplankton.

21.6 Particular eutrophication issues to consider for Lake Malaw

The major sources of nutrients such as N and P to Lake Malawi are rivers (Figure 21.6) and atmospheric deposition (Bootsma & Hecky, 1999). Almost all silica entering the lake comes from its tributary rivers. For the epilimnion, both rivers and vertical mixing are important silica sources.

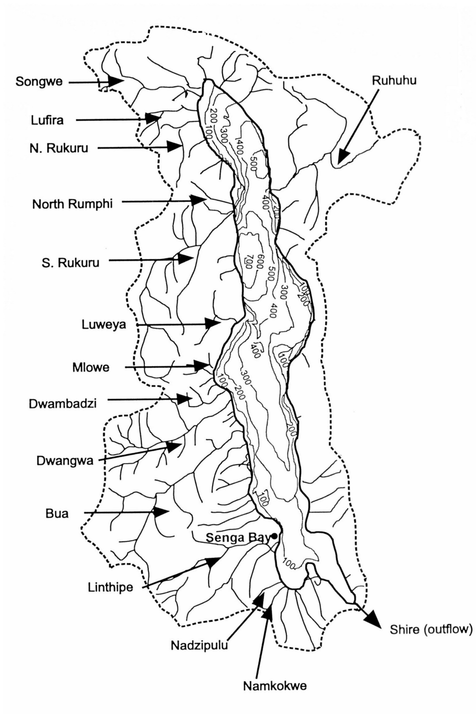

Figure 21.6: General geology and river systems in the Lake Malawi catchment (www.science.uwaterloo.ca).

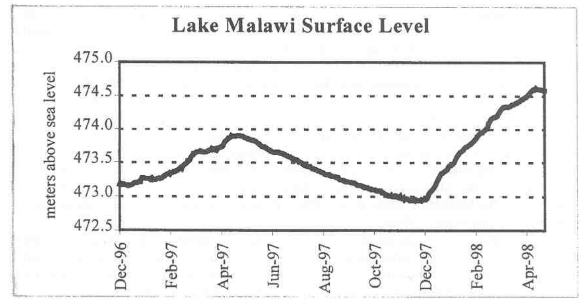

Figure 21.7: Lake levels variability from December 1996 to April 1998. A significant increase in lake level followed a large early season inflow in December 1997 (Bootsma & Hecky, 1999).

21.6.1 Main source of nutrients in Lake Malawi

Rivers

River inflow responds to climatic variability and exhibits large shifts in runoff. The rainy season experiences large inflows, while in the dry or winter season the inflow decreases strongly. The lake surface levels also follow this pattern (Figure 21.7). This may also magnify the loading of nutrients and sediments, especially from river basins with extensive deforestation and agriculture. The annual precipitation regulates for the annual variability of inflow. This is also the case with the runoff and nutrient loading in other lakes or enclosed seas e.g. the Baltic Sea (Vagstad *et al.*, 2001).

A comparison of the 1997 loading with previous estimates of Lake Malawi (Table 21.2) clearly indicates that river loading may play a much more significant role in nutrient loading to the mixed layer of the lake than previously thought. Bootsma and Hecky (1999) reported that sediment and sediment-bound nutrient load is higher in the lake through rivers, which are heavily impacted, (Linthipe, Songwe and Dwangwa Rivers) than rivers that are lightly impacted (Mlowe, Luweya and Dwambazi Rivers; See Figure 21.6. The Linthipe, Songwe and Dwangwa Rivers are heavily impacted because of intensive land-use practices in their catchments. The catchments are characterised with more agricultural activities (e.g. intensive sugar plantation along Dwangwa River) and deforestation, and greater population densities compared to catchments of the lightly impacted rivers. Besides, such rivers are heavily impacted because of topography, urbanisation and improper sewage treatment and disposal (e.g. direct disposal of sewage and industrial waste into rivers). When industries dispose their organic waste, the biological oxygen demand (BOD) can be higher than the recommended (20 mg l^{-1} for the treatment works and 5 mg l^{-1} for the stream), (Anonymous, 1995). The levels of ammonia detected in the receiving waters of Lake Malawi from ethanol effluents are reported to be above the recommended levels for most species in water, ranging between 0.6 to 2 mg l^{-1} (Msomphora, 2000). Even the management of clinical waste seems to be a problem in Malawi. In several basins such practices can alter the patterns of river nutrient/sediment transport. Hence the dilution capacity level of the lake's large water volume may no longer be effective.

Table 21.2: Comparison of 1997 N and P loading estimates with previous estimates. All units are in mmol m^{-2} of lake surface area. Source: Bootsma and Hecky (1993; 1999).

	1997 estimate	Previous estimate
Total dissolved phosphorous	1.195	1.51
Suspended phosphorous	9.08	1.91
Total phosphorous	10.28	3.42
Total dissolved nitrogen	22.87	23
Suspended nitrogen	178.6	12
Total nitrogen	201.5	35
Soluble reactive silica	298.8	220

Atmospheric deposition

According to Bootsma and Hecky (1999), a larger portion of atmospheric carbon and N deposition in the lake is in the form of soluble organic compounds. Soluble and particulate P deposition is similar in magnitude, with much of the soluble P being organic. Atmospheric deposition of nutrients in to the lake surface is primarily in the form of dry deposition. For instance, mean daily dry deposition is almost twice the mean daily wet deposition (Table 21.3). This may be due to less dust during the rainy season, when the ground is wetter and there is greater vegetation coverage. It is also reported that concentration of solute and particulate nutrients in rainwater near Lake Malawi are not particularly high relative to industrial regions or some other parts of Africa. However higher than average NH_4^+, NO_3^-, and K^+ concentration, suggests that burning is having a significant effect on atmospheric chemistry around the lake. High P deposition may also be linked to burning practises. But although the direct effect of the deposition of these solutes on the lake may not be negative, the burning and soil exposure is. These observations may potentially result in negative impact, such as siltation, accelerated flux of nutrients from soil to the lake, and a decreased and a more variable water supply from rivers as described above.

21.6.2 Nutrient cycles in Lake Malawi

Nutrients are renewed in the photic zone of Lake Malawi by vertical transport from the nutrient-rich deep waters. However, most of the time the algae are experiencing balanced growth with their biomass limited by grazing and adequate nutrients supplied through regeneration. The algae community in the lake is adapted to a low, but relatively steady supply of nutrients supplied through the mechanisms of regeneration by grazers and continuous introduction of nutrients from below the epilimnion by mixing. Conducting nutrient enrichment experiments, Bootsma and Hecky (1999) revealed that if nutrients increased in Lake Malawi, chlorophyll a concentrations would increase too and algae species composition would change. Further evidence was seen during January and February (rainy season when the river runoff increases) in the Linthipe River, which is one of the most important nutrient suppliers to the lake. With increasing nutrient loading of P relative to N, the algae community was affected and the chlorophyll a concentration increased. As such it is likely that increased P input to the lake, due to increased erosion, will disrupt the balanced algae growth and favour the development of N fixing, filamentous cyanobacteria such as *Anabaena* species. *Anabaena* blooms were observed in the southern portion of the lake in March and April of 1997 and 1998 (Bootsma & Hecky, 1999).

Table 21.3: Comparison of daily dry and wet deposition of carbon, nitrogen, phosphorous and silicon. Source: Bootsma and Hecky (1993; 1999). Total C Total N Total P Total Si

	Total C	Total N	Total P	Total Si
Mean Wet Dep. (μmol m^{-2} event 1997/98)	2465	431	14.2	115
Mean Dry Dep. (μmol m^{-2} event 1997/98)	2570	560	24.7	155

21.6.3 Recent ecological changes in Lake Malawi

There have been quite a few changes in the quantitative phytoplankton flora of Lake Malawi, which creates concern, besides the fish kills reported now and then due to probably ethanol effluents spillage, pesticides and some chemicals from the Sugar Corporation of Malawi-Dwangwa Mill into the lake. Usually there are fish kills due to pesticides and herbicides when knapsacks sprayers are washed or cleaned in the water courses (per.comm). The filamentous chlorophytes of the *Mougoetia/Oedogonium* complex has occurred since the 1960's, but it has been ignored until now. *Planktolyngbya tallingi* has been reported to be appearing in the southern portion of the lake, where it has replaced the dominant species, *Planktolyngbya nyassensis*. This is an indication for increasing nutrient availability and poor light conditions. The filamentous blue-green alga, *Cylindrospermopsis raciborski*, which has toxic forms, has also been reported. This is of concern because usually such algae are typical climax species in highly eutrophic situations. *Anabaena* species blooms are currently reported to be reoccurring, especially inshore in the vicinity of the Linthipe River, during the end of rainy season (March–April). In the past this species was reported to occur only in October–November. The co-occurrence of the dinoflagellates *Peridinium* species with the *Anabaena* species bloom in at least one bloom is also worrisome as both taxa have forms, which can produce toxins (Bootsma and Heckey 1999). Even if such changes in the phytoplankton community composition may yet appear minor, they are indications that greater changes may follow. Due to fragmentary, qualitative and discontinuous availability of earlier studies, the interpretation of data is difficult. It could just reflect natural variability. In Lake Victoria qualitative analysis of phytoplankton did not occur until after dramatic changes had occurred. By then the phytoplankton community had changed within decades to a eutrophic assemblage dominated by potentially toxic blue-green algal species (Mugidde, 1992).

Summary

Several of the African Great Lakes are distinctive for their very long water residence time >100 years. Incoming nutrients will be retained within the lakes and recovery will be slow even if inputs are reduced. While changes in chemistry and plankton composition of Lake Malawi have not been extreme to date, strong eutrophication is already happening in Lake Victoria, where damage has reduced its biological wealth and human misery may follow (Baskin, 1992). It could be advisable to prevent this happening to Lake Malawi and Tanganyika.

References

ANONYMOUS. 1995. *Blantyre City Assembly report*. Tech. rept. Blantyre City Assembly.

BASKIN, J. M. 1992. Oil and African Great Lakes. *Mitt. Internat. Verein. Limnol.*, **23**, 71–77.

BOOTSMA, H. A., & HECKY, R. E. 1993. Conservation of the African Great Lakes: a limnological perspective. *Conservation Biology*, **7**, 644–656.

Bootsma, H. A., & Hecky, R. E. (eds). 1999. *Water Quality Report. Lake Malawi/Nyssa Biodiversity Conservation Project.*

Brooks, J. L. 1950. Speciation in ancient lakes. *Quart. Rev. Biol.*, **25**, 30–60, 131–176.

Coulter, G. W., & Spigel, R. H. 1991. Hydrodynamics. *Pages 3–24 of:* Coulter, G. W. (ed), *Lake Tanganyika and it's life.* Oxford, England: Oxford University Press.

Gonfiantini, R., Zuppi, G. M., Eccle, D. H., & Ferro, W. 1979. Isotope investigation of Lake Malawi. *Pages 195–207 of: Isotopes in Lake Studies.* Vienna: International Atomic Energy Agency.

Guildford, S. J., Hendzel, L. L., Kling, H. J., Fee, E. J., Robinson, G. C. C., Hecky, R. E., & Kasian, S. E. M. 1994. Effects of lake size on phytoplankton nutrient status. *Canadian Journal of Fishery and Aquatic Science*, **51**, 2769–2782.

Haney, J. F. 1987. Field studies on zooplankton – cyanobacteria interactions. *New Zealand Journal of Marine and Freshwater Research*, **21**, 467–475.

Hecky, R. E. 1984. African Lakes and their trophic efficiencies: a temporal perspective. *Pages 467–475 of:* Meyers, D. G., & Strickler, J. R. (eds), *Trophic interaction within aquatic ecosystems.* Rome: American Association for the Advancement of Science.

Hecky, R. E. 1993. The eutrophication in Lake Victoria. *Verhandlungen Internationalis Vereingung Für Theoretische and Angewandte Limnologie*, **25**, 39–48.

Hecky, R. E., & Bugenyi, F. W. B. 1992. Hydrology and chemistry of the African Great Lakes and water quality issues: problems and solutions. *Mitt. Internat. Verein. Limnol.*, **23**, 45–54.

Hecky, R. E., & Kling, H. J. 1987. Phytoplankton of the Great Lakes in the rift valley of Central Africa. *Arch. Hydrobiol.*, **25**, 467–475.

Hecky, R. E., Coulter, G. W., & Spigel, R. H. 1991. The nutrient regime. *Pages 76–89 of:* Coulter, G. W. (ed), *Lake Tanganyika and it's life.* Oxford University Press: Oxford.

Heerkloss, R. H., Arndt, J., Hellwing, U., Vietinghoff, F., Georgi, B., Wessel, B., & Schnese, W. 1984. Consumption and assimilation by zooplankton related to primary production in the Baltic coastal water inlet Barther Bodder. *Limnological*, **15**, 387–394.

Lampert, W. 1981. Inhibitory and toxic effects of blue-green algae on *Daphnia*. *International Revue der gesamten Hydrobiologie*, **66**, 285–298.

McDonald, M. E. 1987. Interaction between aphytoplanktivorous fish, *Oreochromis aureus*, and two unialgal forage populations. *Environmental Biology of Fishes*, **18**, 229–234.

Moriarty, D. J. W. 1973. The physiology of digestion of blue-green algae in the cichlid fish, *Tilapia nilotica*. *Journal of Zoology*, **171**, 25–39.

Msomphora, M. R. 2000. *Effects of ethanol distillery effluents on the water quality of the receiving waters of Lake Malawi during rainly season.* BSc thesis, University of Malawi.

Mugidde, R. 1992. *Changes in phytoplankton primary production and biomass in Lake Victoria (Uganda).* M.Sc. thesis, University of Manitoba.

Ochumba, P. B. O., & Kibaara, D. I. 1989. Observation on blue-green algal blooms in the open water of Lake Victoria, Kenya. *African Journal of Ecology*, **27**, 23–34.

Owen, R. B., Crossley, R., Johnson, T. C., Tweddle, D., Kornfeld, I., Davison, S., Eccle, D. H., & Engström, D. E. 1990. Major low levels of Lake Malawi and their implications for speciation rates in cichlid fishes. *Proceedings of the Royal Society of London, B*, **240**, 519–553.

Rzóska, J. 1976. Lake Victoria, physical features, general remarks on chemistry and biology. *Pages 167–175 of:* Rzóska, J. (ed), *The Nile, biology of an ancient river.* The Hague: W. Junk Publishers.

Schelske, C. L., Robbins, J. A., Gardner, W. D., Conley, D. J., & Bourbonniere, R. A. 1988. Sediment records of biogeochemical responses to anthropogenic perturbations of nutrient cycles in Lake Ontario. *Canadian Journal of Fishery and Aquatic Science*, **45**, 1291–1303.

Shapiro, J. 1973. Blue-green algae: why they become dominant? *Science*, **179**, 382–384.

Sweeney, R. A. 1993. Introduction: 'Dead' Sea of North America? — Lake Erie int he 1960s and 70s. *Journal of Great Lakes Research*, **19**, 198–199.

Talling, J. F. 1965. The photosynthetic activity of phytoplankton in East African Lakes. *Intern. Revue ges. Hydrobiol.*, **50**, 1–32.

Talling, J. F. 1966. The annual cycle of stratification and phytoplankton growth in Lake Victoria, East Africa. *Intern. Revue ges. Hydrobiol.*, **51**, 545–621.

Talling, J. F. 1986. The seasonality of phytoplankton in African lakes. *Hydrobiologia*, **138**, 139–160.

Talling, J. F., & Talling, I. B. 1965. The chemical composition of African Lake water. *Intern. Revue ges. Hydrobiol.*, **40**, 421–463.

Vagstad, N., Stålnacke, P., Andersen, H. E., Deelstra, J., Gustafson, A., Ital, A., Jansons, V., Kyllmar, K., Loigu, E., Rekolainen, S., Tumas, R., & Vuorenmaa, J. 2001. Nutrient losses from agriculture in the Nordic and Baltic Countries. *Tema Nord*, **591**, 11–49.

Varis, O. 1991. Associations between the lake phytoplankton community and growth factors — a canonical correlation analysis. *Hydrobiologia*, **21**, 209–216.

Zevenboom, W., De Vaate, A. B., & Mur, L. R. 1982. Assessment of factors limiting growth rate of *Oscillatoria agardhii* in hypertrophic Lake Wolderwijd, 1978, by use of physiological indicators. *Limnology and Oceanography*, **27**, 39–52.