

Chapter 7

Algal and Sedimentary Evidence for Recent Changes in the Water Quality and Limnology of Lake Malawi/Nyasa

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Introduction

The experience with eutrophication and contamination of the Laurentian Great Lakes and their slow recovery should convincingly demonstrate that great size alone is no guarantee against the degradation of the water and biological resource of Great Lakes that can be caused by human activity. The large volume of Lake Malawi/Nyasa will retard the rate at which changing quality of inflows and precipitation can cause detectable ecosystem alterations; but the very slow flushing of Malawi/Nyasa which has a water renewal time of over 700 years also means that any added nutrients or contaminants may remain in the system for a very long time (Figure 7.1; Bootsma and Hecky 1993). Consequently it is crucial to the conservation of the lake's biota, and its beneficial use by humans, that any negative changes in the lake's water quality be detected as early as possible in order to prevent further degradation and minimize the time required to effect costly restoration. In the absence of continuous monitoring of the limnology and water quality of the lake, proxy evidence, such as contained in the sedimentary record, for change must be used to determine if Malawi/Nyasa may already be exhibiting any change in nutrient or contaminant loading which might affect its beneficial uses and biodiversity.

Recent studies in Lake Victoria (Hecky 1993, Mugidde 1993, Lipiatou et al. 1996, Verschuren et al 1998) have demonstrated significant changes in the water quality of that lake due to nutrient

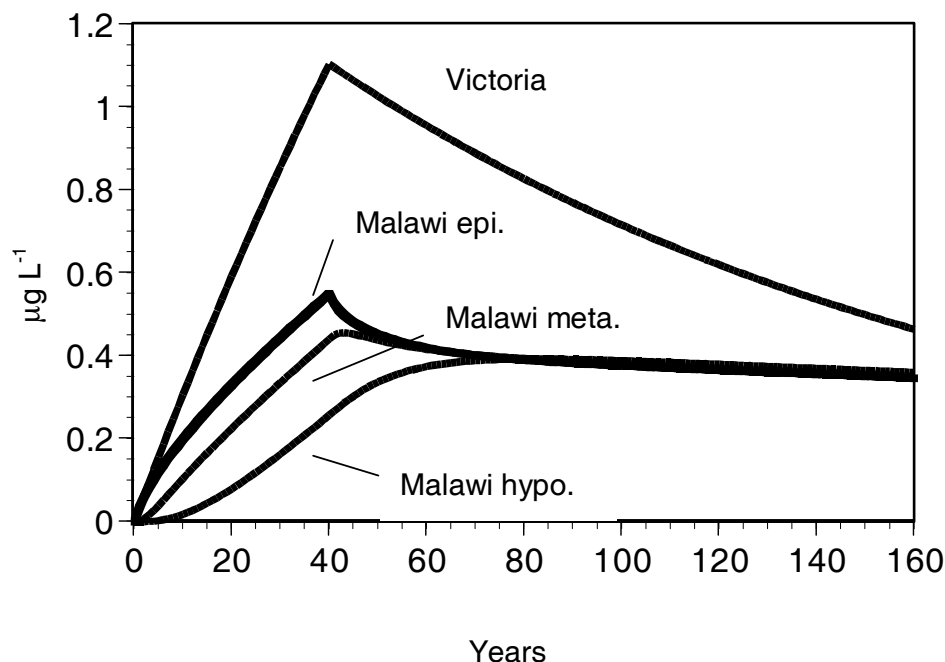


Figure 7.1. A simple pollution scenario comparing responses of Lake Victoria and Lake Malawi/Nyasa to a similar pollution input ($5 \mu\text{g L}^{-1}$ in all tributary rivers), followed by cessation of input at 40 years. Note initial differences in concentration but similar concentrations after 150 years. Malawi epi. = epilimnion, meta. = metalimnion, hypo. = hypolimnion. (From Bootsma and Hecky 1993).

enrichment (eutrophication), the effects of eutrophication on algal abundance, species composition and primary productivity (Mugidde 1993, Kling et al 1999), effects of eutrophication on the diversity of endemic haplochromines (Seehausen et al. 1998), and the sensitivity of the lake's accumulating sediment to record these changes in the lake's water quality (Lipiatou et al. 1996, Verschuren et al. 1998). Cohen et al (1996) have similarly shown that changing suspended sediment loads in the northernmost portion of Lake Tanganyika can affect habitat quality for endemic haplochromine fishes and affect their distribution. In Lake Victoria the assessment of the likelihood of significant changes in water quality was made possible by the existence of excellent and complete limnological data sets on algal populations, nutrient chemistry, light penetration and primary production available from the 1950's and 1960's (Hecky 1993, Mugidde 1993, Kling et al. 1998). These historic data and the recent observations made with comparable methodologies validated the record of recent change available from paleolimnological reconstructions of microfossil and chemical changes in sediment cores from Lake Victoria (Lipiatou et al. 1996; Verschuren et al. 1998). In Lake Malawi/Nyasa earlier records of water chemistry are quite fragmentary prior to the 1990's (Bootsma 1993; Patterson and Kachinjika 1995) so it is difficult to establish direct evidence of changing lake conditions which might be due to eutrophication or increased sediment loading. Therefore, only indirect evidence is available to determine if the water quality of Lake Malawi/Nyasa is beginning to show evidence of changes in nutrient, contaminant and sediment concentrations which might be related to human activity and which might affect the use of this valuable water resource and its marvelous biodiversity.

Some of the earliest biological observations on Lake Malawi/Nyasa were lists of algal species and qualitative descriptions of early phytoplankton collections. Microscopic algae live in intimate association with the water environment, have specific and in some cases well-defined environmental requirements and have been widely used as indicators of water quality. Early collections from Lake

Malawi/Nyasa are somewhat biased to larger species because of the mesh size of nets used to collect samples and they are incomplete in their time and space coverage compared to modern sampling. But allowances can be made for these shortcomings, and floristic analyses can be made to see if there is evidence for substantial change in the phytoplankton flora. A similar analysis in Lake Victoria readily demonstrated changes in that lake since the earliest sample collections early in this century (Kling et al. 1999). In Malawi/Nyasa the earliest analyses of diatoms, a prominent member of the phytoplankton community predate the turn of the century (e.g. Muller 1895) and provide a long term period over which to evaluate floristic change. The earliest times for which quantitative analysis of phytoplankton change using identical methods begins in 1980 (Hecky and Kling 1987) with two other periods of observations over the past two decades (Bootsma 1993; Patterson and Kachinjika 1995).

The sediments and the sediment record of Lake Malawi/Nyasa are relatively well-known for such a great lake because of the continuing efforts Prof. T.C. Johnson and his collaborators and students over the last decade (Johnson and Davis 1989; Johnson and N'ganga 1990, Johnson et al. 1995, Kalindekafe et al. 1996). Sediment facies and thicknesses have been mapped (Johnson and Davis 1989) and long term (over thousands of years) sedimentation rates established (Finney and Johnson 1991; Finney et al. 1996) for most of the pelagic sediment facies (primarily by radiocarbon dating). However, the primary interest of most of these previous studies have been to detect evidence for geological and climatic change in southern Africa. Because such changes normally occur on the time scale of millenia to centuries, very recent changes in sedimentation (the last 100 years) have not been studied before now in Malawi/Nyasa. Such studies require special coring efforts and techniques to ensure recovery of the most recent years of sediment deposits which is technically challenging in sediments of high organic and water content such as the pelagic sediments of Malawi/Nyasa. We have used box cores made available by Prof. Johnson which were recovered in 1993 from depths of over 200 m to examine whether there have been changes in sedimentation over the past century. We have further recovered a more complete suite of cores in November 1997 and February 1998 which could be used to verify some of the conclusions from the present analysis which is restricted to just two cores. One of these cores (and large areas of pelagic sediment in Malawi/Nyasa see Johnson and Davis 1989) have laminated sediments which careful study has shown to be caused by seasonal variation in the sediment supply (Francois et al. 1996) and lack of sediment disturbance by biological organisms in the quiescent and permanently anoxic waters below 200 m (Piskaln and Johnson 1991; Johnson unpublished). The occurrence of annually laminated sediments allows very detailed reconstruction of the lake's history up to the present day and validates the use of chronologies established from radioisotopic techniques. Such detailed knowledge of sedimentation rates allow estimation of burial rates for elements such as P and Si which are critical plant nutrients. These burial rates are crucial components of nutrient budgets and water quality models which are also objectives of this Water Quality study. The reality of the deposition rates calculated from cores can be compared with settling fluxes collected by sediment traps deployed as part of the environmental monitoring programme of the LMBCP. This chapter will examine how well these different lines of evidence support one another and validate the use of the sediment record as a proxy indicator of ecosystem change in Malawi/Nyasa.

Methods

The floristic analysis was largely based on the published literature on the algal communities of Malawi/Nyasa, some of which predates the turn of the century. All relevant references are in the results and discussion below. Quantitative analysis begins in 1980 with the studies of Hecky and Kling (1987) and can be compared with other recent studies (Bootsma 1993; Patterson and Kachinjika 1995) using similar methods of preserving and counting samples using the sedimentation technique of Utermöhl.

The sedimentary analyses were conducted on two small box (SB) cores (25 cm x 25 cm) recovered in 1993. Core 93-SB2 was taken off the Songwe delta (9 deg. 48.9 min. S; 34 deg. 5.9 min. E) in 259 m water depth while Core 93-SB3 was raised from 264 m water depth off the Dwangwa delta (13 deg. 1.0 min. S; 34 deg. 35 min. E). Both cores are from below the depth of permanent anoxia (approx. 200 m) in the quiescent hypolimnion. The northern core is laminated, and the laminae have been confirmed to

be annual depositions (T.C. Johnson, unpublished data) as expected from the sediment trap observations in that area (Piskaln and Johnson 1991) because both biogenic sediment production (largely diatoms of *Aulacoseira* at the sediment trap and the core site) and detrital inwash from the mountainous rivers in the steep sided north basin are highly seasonal. The southern core was not visibly laminated likely because biogenic production is more continuous as is resuspension from shallower bottom sediments to the south of the core site. The southern portion of the Malawi/Nyasa basin is less steep sided than the north, and this is also true of the subaqueous bathymetry with the southern lake being shallower than the north. To make the most direct comparisons possible two cores from very similar water depths were analyzed with similar methods. Both cores recovered undisturbed surficial sediments and are ideal for examining recent trends in sedimentation in the lake. In November 1997 a more complete set of cores were recovered with a multi-corer which also recovers undisturbed surficial sediments. These cores should be analyzed to confirm the results and interpretations presented here on 93-SB2 and 93-SB3.

The chronology of the two cores and their sedimentation rates were determined by the application of ^{210}Pb dating techniques at the Radioisotope Dating Laboratory of the Freshwater Institute in Winnipeg. The radioisotope activity was measured on subsamples of the core taken at one centimeter intervals over the top 30 cm of the core. This isotope of Pb is produced in the earth's atmosphere at a nearly constant rate and is deposited to the earth's surface in precipitation and dry fall. It has a half-life of 22.7 years and can provide a detailed time scale in cores for the past century. Dating of previous cores from Lake Malawi has used primarily radiocarbon which has a much longer half-life (5,500 years) which provides good time resolution on millennial time scales but which cannot accurately date sediments deposited in the last century with the resolution that ^{210}Pb can achieve. The ^{210}Pb stratigraphy and sedimentation rates in core 93-2SB can be compared with an absolute chronology available in that core because the sediments contain annual laminations. The age assignments by the ^{210}Pb chronology agree extremely well (T.C. Johnson, unpublished data) which provides independent verification of the age assignments to sediment samples made by ^{210}Pb dating.

The ^{210}Pb activities in core 93-2SB can be fit well with a dating model which assumes that the isotope reaches the sediment surface at a constant rate (The Constant Rate of Sedimentation-CRS Model). This model was then applied to assign ages to core 93-3SB which was not visibly laminated. An advantage of the CRS model is that short term variations in dry weight sedimentation can be determined because it is assumed that the deposition of ^{210}Pb is constant while dry weight accumulation is allowed to vary in time.

The chemical composition of the sediment was also determined for total phosphorus (Stainton et al. 1974), bioavailable phosphorus (Williams et al. 1980), biogenic silica (DeMaster 1981) and loss on ignition (Bengtsson and Enell 1986) which is often well correlated with organic content. The concentrations of these parameters per gram dry weight of sediment were then multiplied by the dry weight sedimentation rates to determine the sedimentation rates of the various parameters to determine if the sedimentation rates of P, a critical plant nutrient, biogenic silica, produced by diatoms (an important phytoplankton component), or organic matter have changed. These cores also received a semi-quantitative (93-2SB) or qualitative (93-3SB) microfossil evaluation to see if there was evidence of change in the phytoplankton community over the recent past in waters overlying these two coring sites. One annual cycle of sedimentation was collected in sediment traps at the thermistor chain deployments (See Chapter 5, Hamblin et al.) near station 900 in the southern portion of Malawi and station 917 in the north. The collected materials were analyzed for total P, C, N, Si, total dry weight (by the methods of Stainton et al. 1974) as well as microfossil content.

Results and Discussion

Phytoplankton in Malawi-Nyasa--Then and now - The first surveys of African great lakes phytoplankton began around the turn of the century with the initial floristic works of Dickie (1879) and

Schmidle (1899). The African great lakes have received variable attention since the late 1940's up to the present day (van Meel 1954; Verbeke 1957; Talling 1965, 1966, 1969, and 1986; Hecky and Kling 1987). Lately there have been increasingly more studies of various aspects of the algae in the lakes. Cocquyt et al. (1993) have published a checklist of the algal flora of the East African Great lakes with special references to the synonyms of the algae listed. Five hundred and eight infrageneric taxa and 114 genera have been described for Malawi/Nyasa to date with the greatest number of species found in the diatoms (Cocquyt et al 1993). Part of the reason for the great number of taxa of diatoms is that the largest effort has been spent on this major taxonomic group which has paleoecological significance (e.g. Owen and Crossley 1990; Owen et al. 1992; Kilham et al 1986). There is a great deal more effort that needs to be expended on research into the taxonomy and ecology of taxa in the other eight major algal divisions which have great utility as indicators of current water quality conditions although they leave a poorer fossil record.

The first quantitative annual study of phytoplankton in Lake Malawi/Nyasa was that published by Hecky and Kling (1987). In 1980, the phytoplankton and protozoa in Lake Malawi were sampled over the entire year in conjunction with primary production studies off Nkhata Bay in 1979-80 (Degnbol and Mapila 1982). These samples were eventually sent to Canada for analysis. Other studies on Malawi/Nyasa algae focussing primarily on diatom ecology and sedimentation were conducted by Haberyan (1990), Klee, Shiefele and Hert (1990), Haberyan and Mhone (1991), Owen and Crossley (1992), and Klee and Casper (1992). Most recently, Bootsma (1993) and Patterson and Kachinjika (1995) beginning in 1990 conducted quantitative seasonal and lake wide surveys of the phytoplankton and protozoa of the lake covering one year or more, with methods which are comparable with those used in this study. In terms of algal abundance and biomass these recent studies (Hecky and Kling 1987; Bootsma 1993 and Patterson and Kachinjika 1995) were all comparable so that changes since 1980 can be assessed directly by comparing these data sets. Phytoplankton biomass levels of the 1990's studies ranged between minima of $<50 \mu\text{g l}^{-1}$ to maxima of near $600 \mu\text{g l}^{-1}$ and a mean of $< 100 \mu\text{g l}^{-1}$ for the whole lake. These maxima were slightly higher than those found in 1980. The low biomass of Lake Malawi in 1980 was similar to that for Lake Tanganyika during 1975 (Hecky and Kling 1981), but much lower than levels (200-1000 $\mu\text{g/l}$) found in 1983 for large but much more rapidly flushed Lake Kariba (Cronberg et al. 1988; Cronberg 1997) in nearby Zimbabwe. Although protozoan biomasses were not published in the 1980 study by Hecky and Kling (1987) they were enumerated. Protozoan biomasses in all three studies were very low but ratios to phytoplankton biomass were in the range 0-0.2, comparable to that found in temperate, oligotrophic lakes (unpublished data). There is no strong evidence of recent changes, i.e. since 1980, in the quantity of phytoplankton in Malawi/Nyasa from these studies.

Earlier reports on phytoplankton species can be found in the Northern Rhodesia, Joint Fisheries Research Organization annual reports 8, 9, 10, 11 from 1958, 1959, 1960 and 1961 where the majority of the samples were taken using net hauls. Such sampling techniques collect only the larger phytoplankton species and so cannot be compared quantitatively with the more recent studies in which numbers and biomass of phytoplankton are dominated by the alga $<20 \mu\text{m}$, but these early samples still contain valuable information. A few notes from those studies on the phytoplankton taken using nets indicate that the sizes were 180 mesh/inch in the 10 inch diameter fine mesh net (retaining phytoplankton on the order of $100 \mu\text{m}$) and 60 mesh/inch (approx. $300 \mu\text{m}$) in the 27.5 cm diameter zooplankton nets used in the 1950's. These mesh sizes will retain the larger diatoms and colonial phytoplankton.

The net hauls taken off Nkhata Bay during 1957/58/59 give an impression of the seasonality of the phytoplankton. During these years the dominant net plankters (identified by Mrs. T.D. Iles) were the diatoms *Nitzschia*, *Aulacoseira* and *Surirella* followed by the colonial cyanophyte *Microcystis*, and the chlorophytes *Botryococcus* and *Pediastrum*. These larger algal species were also common in Lake Victoria at that time (Talling 1966) but *Aulacoseira* and the chlorophytes are now rare in the open waters of Lake Victoria due to changes in that lake's water quality. In Lake Malawi/Nyasa in 1961, researchers reported a very large bloom of *Aulacoseira* in the southeast arm. This was caught in the 60 mesh/in zooplankton nets and estimates of abundance were only reported as occasional, rare, common or abundant in comparison to the zooplankton. The actual abundance cannot be estimated from these data.

This *Aulacoseira* bloom of 1961 and a smaller bloom in 1958 occurred in the months of July - August. This timing of the diatom blooms was similar to the time of occurrence of *Aulacoseira* in the plankton reported by Patterson and Kachinjika (1995) for the years 1992-1994. However, during 1992-94 an *Aulacoseira* peak occurred only in the month of May at Nkhotakota station and at two northerly stations during July and September-October. From these studies maximum diatom biomass seems quite variable from year to year and the timing of the diatom peaks seems also variable around the lake.

Aulacoseira in 1991 occurred in surface plankton samples in the months of October - November when the wind speeds were high (Bootsma 1993). He points out that usually *Aulacoseira* was found to be most abundant under turbulent conditions, but that it was difficult to access whether this was from resuspension or redistribution of slow growing cells or higher growth rates. He concluded that much of what he found had to be redistribution of a benthic population as production rates were not especially high, and the total biomass excluding *Aulacoseira* was only $54 \mu\text{g l}^{-1}$, much lower than the annual mean for phytoplankton biomass in that study. It was notable from Bootsma's data that the *Aulacoseira* only became dominant in the southern end of the lake. However, during his study species of the *Nitzschia* complex also became particularly abundant in the southern end of the lake during November-December. *Cyclotella*/*Stephanodiscus* were the major contributors to the diatom biomass throughout the rest of the lake, and large *Surirella* also occasionally made a significant contribution to this biomass.

Analysis of a recent plankton survey (September 1996) near the end of the period of dry season mixing found that the maximum biomass of approximately $210 \mu\text{g l}^{-1}$ occurred at the south end (St. 901) of the lake and was dominated by diatoms (*Nitzschia* and to a lesser extent *Aulacoseira*) and dinoflagellates (*Peridinium cf africanum* Lemm., *P. perardii* (Lemm.) Bourr., and *Glenodinium* spp.) *Aulacoseira nyassensis*, a common component of the sediments, was rare in the plankton compared to *Nitzschia* and only present in the samples from the south end of the lake, disappearing from the plankton at stations away from the southeast arm. According to Bootsma the weather had been unusually windy and cold prior to and during the September 1996 survey. These conditions would normally favor an *Aulacoseira* bloom. Total biomass concentrations decreased rapidly northward to near $50 \mu\text{g l}^{-1}$ in the rest of the lake where diatoms were rare. The major centric diatoms present were *Stephanodiscus mulleri* Klee and Casper and *Cyclotella malawiensis* Casper and Klee. Both diatoms were present in low numbers and much more abundant at the south end of the lake with *S. mulleri* being the more heavily silicified and more abundant of the two taxa. All stations, except for the southern most two (901 and 902) which had a high abundance of dinoflagellates, were dominated by cyanophytes and chlorophytes as was typically found in previous years by the other authors. This most recent September cruise reinforces the conclusions in Hecky and Kling (1987), Bootsma (1993) and Patterson and Kachinjika (1995) that *Aulacoseira* is less abundant or more restricted in its distribution than it used to be or that earlier sampling techniques overestimated its abundance relative to other taxa in the mixed layer.

A study by Haberyan (1990) comparing shallow, inshore sediment trap samples to the surface sediments in Lake Malawi provided evidence that several key indicator taxa may be over (e.g. *Aulacoseira*) and under (e.g. *Nitzschia*) represented in the sediment record. According to Owen and Crossley (1992) the surface sediments can be divided into four regions based on a predominance of *Aulacoseira*, *Stephanodiscus*, *Cyclotella* and *Nitzschia* in the surface sediment samples. Patterson and Kachinjika (ibid.) found that *Cyclotella*/*Stephanodiscus* on an annual basis dominated the plankton diatom biovolume of all four of these regions while *Nitzschia* spp. were important in the southern portion of the lake during the November-December cruise (as in Bootsma's study) and *Aulacoseira nyassensis* (O. Mull.) Sim. was seldom a significant contributor to the plankton with the exception of two northerly stations during their July and September surveys. Reconciling the observations of Owen and Crossley (1992) with direct observations of the plankton requires assuming that either there have been changes in the recent phytoplankton assemblages in the lake from those which used to occur (which are now found only in the sediments) or that sedimentation and diagenetic processes sort diatom frustules into different sedimentary facies and generally causes overrepresentation of *Aulacoseira* in the sediment record.

During this study from February 1997 to May 1998 (and still continuing), we have made continuous sediment trap collections at a northern (Station 917; trap depth 180 m) and a southern location (Station

900; trap depth 140 m). These sediment traps indicated that *Nitzschia* predominated at the southern station during the May-September season (50% of the fossils by number) and *Aulacoseira* never exceeded 10% at either station while *Cyclotella malawiensis* dominated fossil numbers at the southern station with >60% during September-December. *Stephanodiscus* did not exceed more than 35% of fossil numbers at any station and reached their maximum contribution in September-December. Diatoms were least important during December-May when bluegreens numerically dominated the traps at both stations. Zooplankton remains in the traps were also greatest during this time at both stations.

Bootsma noted that the timing of the peaks (1991/92) in diatoms was similar to that observed by several other researchers (Schmidle 1902, Jackson et al 1963 and Hecky and Kling, 1987) but that relative abundances were lower and *Aulacoseira* was not as wide spread as previously suggested. He notes that in 1990/91 wind speeds were significantly lower than in 1980/81 as were photosynthetic rates (Bootsma 1993) and attributes this to the fact that photosynthetic rates are a function of nutrient availability as determined by the mixing conditions. He used this comparison to provide circumstantial evidence that, at least in Lake Malawi, diatom abundance is strongly related to the mixing regime and that *Aulacoseira* in particular requires quite turbulent conditions to persist in nutrient poor surface waters. Kilham et al. (1986) concluded that *Aulacoseira* (formerly *Melosira*) *nyassensis* is adapted to low light conditions and consequently deep blooms (50-100) of this diatom may occur. This creates the possibility that *Aulacoseira* may have been undersampled in previous studies which concentrated on phytoplankton sampling in the upper 50 m which should exceed the maximum depth of the euphotic zone (depth of penetration of 1% of surface irradiance) in Lake Malawi. The limited abundance of *Aulacoseira* in our deep sediment traps in 1997 suggests that deep blooms which might escape routine sampling did not occur in that year. *Aulacoseira* did dominate sediment trap collection in the northern part of the lake in the early 1990's (François et al 1996) as well as the light colored laminations in sediment cores from the same area (Piskaln and Johnson 1991). These trap collections would have been contemporaneous in time with the studies of Bootsma and Patterson and Kachinjika, and do suggest that deep, undersampled, *Aulacoseira* blooms, likely of short duration, can occur in Malawi/Nyasa. *Aulacoseira* can be a key indicator of eutrophication as it has a high silica requirement and cannot achieve growth rates sufficiently high to allow it to persist in Lake Victoria since eutrophication has lowered the dissolved silica concentrations by an order of magnitude. Because the *Aulacoseira* blooms may not be expressed in surface waters except under very windy conditions and because they may be short lived, the sediment traps being operated in Malawi/Nyasa at present are the best way to determine if the abundance of this critical and indicative phytoplankton is decreasing or not.

Chlorophytes have been a major component of the plankton of the lake since quantitative studies began. The most abundant species are small chlorococcales, the desmids *Closterium* and *Staurastrum* and a filamentous taxa cf. *Mougeotia/Oedogonium* complex. There was no mention of this *Mougeotia/Oedogonium* complex in the net haul studies of the late 50's, although it would be expected to be retained by the nets; but it was noted as important by Hecky and Kling 1987, Talling 1969 and Bootsma 1993). It is an obvious algal form when present and is unlikely to be overlooked by phytoplankton enumerators. Examination of the historic samples could give more information if they could be located, and it is for this reason that it is recommended that current collections be archived for future reference. Currently these collections are held at the Freshwater Institute in Winnipeg, but they could be transferred to Malawi/Nyasa if a trained person were available to maintain them.

The filaments of *Mougeotia/Oedogonium* are often in excess of 500 µm in length, and it may be a recent addition to the lake plankton. With the exception of this filamentous green, the large sized taxa were usually present over most of the lake but in very low numbers. The small chlorococcal taxa were very abundant numerically but, due to their small size, didn't contribute much to the biomass. Many of the small greens were in the size range of 1-3 µm and would be classified as picoplankton. This small size fraction is very difficult to identify and enumerate using the Utermohl method and perhaps should be analysed using a method designed for bacteria and picoplankton to get more accurate measurements of the overall contribution of this small size fraction to the biomass. Guildford et al. in Chapter 6 of this report found that cells <2 µm accounted for 30-50% of the chlorophyll in their samples indicating the quantitative importance of these small cells in aggregate to the phytoplankton biomass.

A maximum in abundance of cyanoprokaryotes in November-December, following the period of deep mixing and the diatom maximum seems to be a standard pattern in Malawi/Nyasa, and this was also the case in the earlier years (Northern Rhodesian Fisheries reports 1959-1961, Hecky and Kling 1987). In the earlier years the major blue greens recorded were either *Microcystis* or *Anabaena*. The very small blue green taxa such as *Aphanocapsa*, *Synechococcus*, and *Chroococcus* recorded by Hecky and Kling (1987), Bootsma (1993) and Patterson and Kachinjika (1995) may have been missed due to the use of large mesh nets. *Lyngbya* (now *Planktolyngbya*) mainly *Pl. nyassensis* has only been recorded in the lake since 1980 although it might be caught in nets and should have been reported earlier. The documentation of the occurrence of the genus *Cylindrospermopsis* by Patterson and Kachinjika (1995) is of major concern. Species of this genus have become the dominant blue greens in Lake Victoria since the late 1980's along with the planktic diatom *Nitzschia acicularis* (Kutz.) W. Smith. These taxa seem to be adapted to high nutrient, high temperature and low light situations. According to Australian studies, *Cylindrospermopsis raciborskii* (Wolosyn) Seenayya et Subba (most commonly occurring species of the genus) is very efficient in growth at temp >23 C, light below 25 $\mu\text{Ein s}^{-1}$, increasing P and as a fixer of diazotropic nitrogen can fix its own nitrogen (Fabbro pers. comm.). It has recently become a major problem in reservoirs and rivers in Australia, Brazil, Florida, and south central Europe. Other species of this genus have become a dominant blue green in Lake Victoria (Komarek and Kling 1991). *C. raciborskii* produces a very potent hepatotoxin which has been shown to kill animals and people that drink the water in which it is growing. It has recently been found also to produce an unknown neurotoxin similar to anatoxin produced by other blue greens (Fabbro, pers. comm.). In warm eutrophic N deficient waters characteristic of Malawi/Nyasa (see Chapter 6), *C. raciborskii* can be a climax species and thus increases in P loading to warm light limited tropical waters are of utmost concern. *C. raciborskii* is present in this region of Africa and has been recorded as a dominant from October to April in Lake Kariba, Zimbabwe during 1984-1986 (Ramberg 1984, Cronberg et al 1988, Cronberg 1997) so the reported occurrence in Malawi/Nyasa by Patterson and Kachinjika is highly probable. These examples of toxic algae in other systems must alert us to the dangers incumbent in shifts in algal populations in response to water quality changes and illustrate the need to identify such risks as soon as they occur in order to institute lake management which will prevent the occurrence of these toxic species.

The analysis of the sediment trap samples and plankton during the period from December 1996-May 1998 revealed an exceptional predominance of green algae as well as bluegreen algae, (*Microcystis*, *Synechococcus* and *Planktolyngbya*). Most noticeable was the dramatic difference in species composition between the south basin station 900 and station 917 farther north. Station 900 (THRM2) was dominated by green algae of the genera *Choricystis* and *Chlorella* with bluegreen filaments of *Planktolyngbya tallingii* Kom. & Kling (these filaments are very close to the range of *Pl. capillaris* although the coiling of the trichomes and elongate cells appears to fit with *P. tallingii*). At station 917 during this same period, there was a predominance of *Microcystis* cells (size range 2.8-4.2 μm), *Synechococcus cf linearis* cells and short filaments as well as a small percent of *Pl. tallingii*. There were a few *Anabaena* cells and heterocysts that had not yet decomposed at both stations. The *Anabaena* cells do not preserve well and in the tropics very few akinetes (resting spores which preserve well in temperate sediments) are produced. The appearance of the *Planktolyngbya tallingii* in such abundance in the south basin is disturbing due to the fact that it is a low light, high nutrient species and was not present in noticeable quantities in the earlier studies. The typical open water, low nutrient species *Planktolyngbya nyassensis* (*Lyngbya nyassensis*) is still common in the north basin and as well as being present in the south.

During the course of our studies blooms of *Anabaena* occurred in the southern part of the lake in March-April. In March 1997 a dense surface bloom was found off the Maleri Islands. This algal bloom was very near a pure assemblage of *Anabaena cf aptekariana*. In March 1998 a similar bloom was observed in the southern region which was *Anabaena* with *Peridinium africanum* as a co-dominant. Dinoflagellate blooms have been linked to fish kills in the ocean and more recently to toxicity problems involving humans, livestock as well as fish in fresh to brackish river water of the south eastern United States. These toxicity problems have been attributed to increase pollution accompanied by warmer than usual water conditions. Blooms of either of these taxa may produce a potential toxicity problem. March

to May occurrences of *Anabaena* blooms have not been previously reported in Malawi-Nyasa and may be resulting from extreme enrichment especially in phosphorus brought in by the Linthipe River (Chapter 2) in the December to April rains. This area of the lake should receive special monitoring attention to determine if these blooms are recurring and predictable.

Recent sedimentation in Malawi/Nyasa - Basin-scale sedimentation in Malawi/Nyasa has been exceptionally well studied for an African Great Lake. These studies have been primarily driven by interest in reconstructing the climatic history of the lake in view of its great age and position at the southern extreme of the western rift valley of Africa (Johnson 1996). To date such historical reconstructions, have been limited mostly to the last 10,000 years but sediments up to >40,000 years old have been recovered. The sediments have proven to be information-rich with interpretable microfossil and mineralogical compositions. The presence of several million years accumulation of fine grained sediments in Malawi/Nyasa continues to spur interest in recovering long sections from the lake, and substantial progress on such deep coring may be expected within the next five years through the U.S. National Science Foundation's programme on the International Decade for the East African Lakes (IDEAL). To date studies have indicated that the lake has had a different climatic history than more northern African lakes (Finney and Johnson 1991; Finney et al. 1996) but there is apparent synchrony with some global scale climate changes such as El Niños and the Little Ice Age (T.C. Johnson unpublished data). Johnson et al. 1995 discuss deltaic sedimentation and estimated that up to 90% of the suspended sediment load carried by rivers is deposited. The remaining 10% of very fine-grained sediments and all the dissolved load of the rivers can be widely distributed by currents within the lake and affect sedimentation rates lake-wide. These fine grained sediments carry a disproportionate amount of the available phosphorus and contaminants into lakes (Stone et al. 1995). The fine-grained sediment facies of the lake have been mapped in some detail (Johnson and Davis 1989), and the clay mineral assemblages in these facies have been established (Kalindekafe et al. 1996). The clay minerals reflect geological provenance and climatic gradients within the basin. Rhythmic seasonal patterns of sedimentation in at least the northern portion of the lake (Francois et al. 1996) are preserved as annual sediment laminations which can be recovered in sediment cores (Piskaln and Johnson 1991). These laminated sediments have been proven to be annual in nature by comparison with radiochronology using the isotope ^{210}Pb (T.C. Johnson, unpublished data), and these can provide absolute chronology for sedimentation on millennial time scales.

Lake level fluctuations have been interpreted from sediment cores representing the past 40,000 years (Finney et al 1996) while Owen et al (1990) conclude that lowerings of hundreds of meters may have occurred within the past 500 years. The modern observations on lake level substantiate this fine sensitivity to climate (Calder et al. 1995), and now deforestation, with the lake falling below its outlet between 1914 and 1937 and almost to its outlet as recently as 1997. Interest in the climatic history and the lake's sensitivity to climatic events has recently been heightened by evidence that El Niño events may be preserved in the laminated sediments of the lake (T.C. Johnson, unpublished data). Better understanding how this great lake has responded to past El Niño events will improve future predictions about regional effects of strong El Niño years like 1997.

Detrital dominance of recent sedimentation in northern Lake Malawi/Nyasa - Small box core 93-SB2 is from outer slopes of the Songwe delta in the northernmost portion of the lake. It has a mean sedimentation rate of $43 \text{ mg cm}^{-2} \text{ y}^{-1}$ since approximately 1850 A.D. by the constant rate of sedimentation of Pb-210 model. There is an excellent agreement (T.C. Johnson unpublished data) between age assignments by counting laminae (assuming one couplet per year) and the ^{210}Pb assignments by the CRS model which independently validates the use of the CRS model for this core. Using the model to assign ages estimating the dry weight of sediment accumulated for each dated interval reveals that sedimentation rates since 1950 are lower than in the previous decades (Figure 7.2) with highest sedimentation rates occurring in the 1920's and early 1930's a period of rising lake levels from the lows of 1915 (Calder et al 1995). The lake was below the Shire River outflow from 1914 until 1937 when the higher rainfall of the 1920's and 30's eventually reopened the outflow. This period

of higher rainfall should have resulted in higher river discharges and sediment transport which appears to be reflected in the higher sedimentation rates at the SB2 site. In contrast lower rainfall since 1970 (Calder et al 1995) has apparently led to lower sedimentation rates recorded at SB2 (Figure 7.2). In fact the lowest rates of this century occur in the most recent sediments since 1970. The good agreement between the annual sedimentation rates at SB2 and the known rainfall and lake level records suggests that river transport of terrigenous material is an important determinant of sedimentation at this site.

The concentrations of the biologically important elements phosphorus and silicon (essential for diatom growth) per gram sediment dry weight differ in their recent trends in SB2. Total sedimentary phosphorus shows a steady increase beginning in sediments assigned an age of 1940 but silica and organic matter (measured as loss on ignition) show no trend over this same period (Figure 7.3) although they do show a slight rise since 1970. However, when the concentrations of these biophilic elements per gram dry weight are multiplied by the dry weight sedimentation rates of Figure 7.2 there is no clear trend apparent in P, silica or organic matter sedimentation at SB2 over the sampled time interval (Figure 7.4).

Increased biogenic sedimentation in southern Malawi/Nyasa - The long term mean (post 1850 A.D.) sedimentation rate established from the Pb-210 chronology at site SB3 was $33 \text{ mg cm}^{-2} \text{ y}^{-1}$, which is 25% lower than at SB2 over the same time period. This core was not laminated so it is not possible to validate independently the age assignments using laminar counts, but the same CRS model was applied to evaluate the variation in annual rates of sedimentation since 1900 as was done for core SB2 (Figure 7.2). The record of sedimentation does not demonstrate such a strong increase in the 1920's as does the SB3 site although the highest rates of the first half of the century at SB3 do occur at that time.

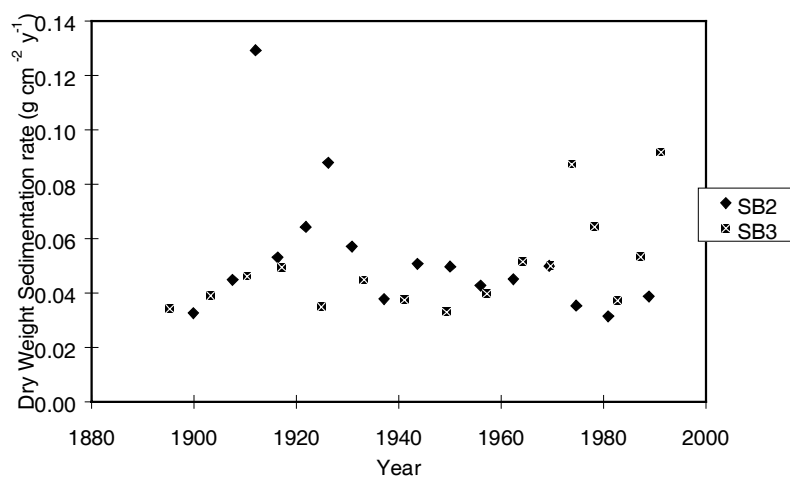


Figure 7.2. Variation in dry weight sedimentation at coring sites SB2 off the Songwe delta and SB3 off the Dwangwa delta since the turn of the century. Note difference in post-1960 rates of sedimentation at the southern site.

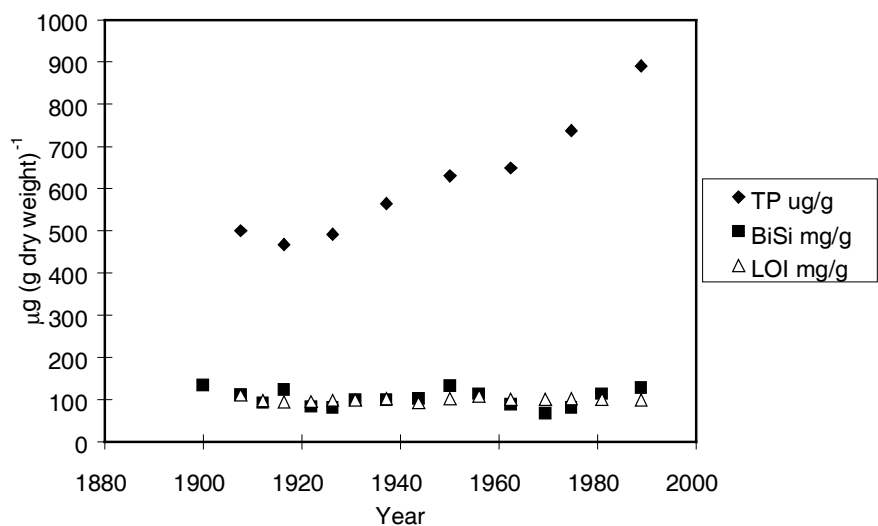


Figure 7.3. Concentrations of total phosphorus, biogenic silica, and organic matter (as loss on ignition) versus sediment age in core SB2 off the Songwe delta.

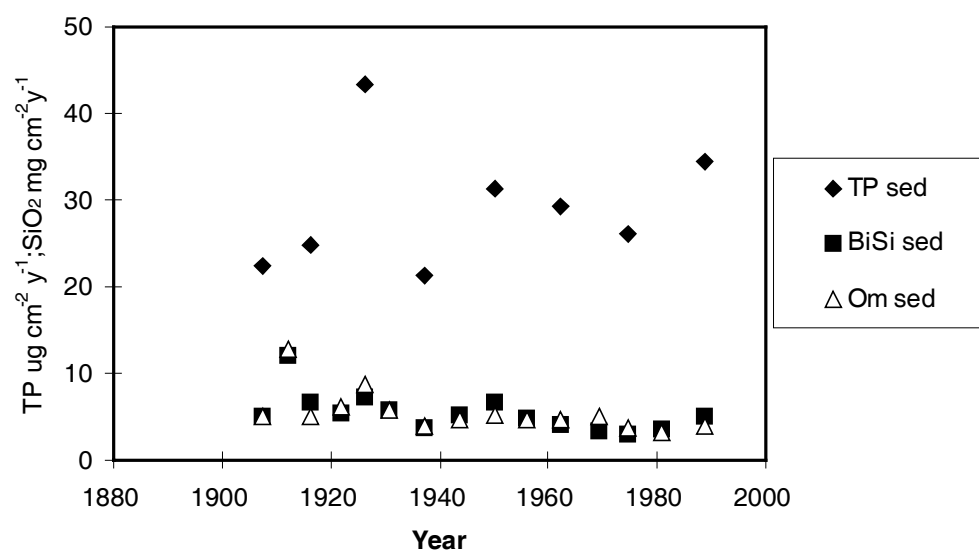


Figure 7.4. Variation in sedimentation rates of the biogenic components total P, biogenic silica, and organic matter over time at the northern site SB2 off the Songwe delta.

Higher sediment yields from the northern catchments and stronger responses to increased rainfall would be expected from the higher relief in the northern Malawi/Nyasa basin because maximum elevation in a catchment is a strong determinant of sediment yield (Milliman and Syvitski 1992). However, sedimentation at site SB3 has increased substantially since 1960 (Figure 7.2) while SB2 rates were falling indicating differential responses to a common influence or different recent determinants of sedimentation rates.

Concentrations of the biologically important elements Si and P have also risen in sediments deposited since 1950 at SB3 (Figure 7.5). Whereas at SB2 lower sedimentation rates accompanied a rise in the concentrations of total P, biologically available P, biogenic silica and organic matter (LOI), i.e. sedimentation rate was inversely correlated with these biogenic sedimentary concentrations, biogenic silica and LOI were positively correlated with the increase in mass sedimentation rate at SB3 (Table 7.1). The phosphorus fractions remain negatively correlated in SB3 (although much weaker in the case of TP) indicating that there is a dilution effect of increased sedimentation on P concentrations and especially bioavailable P. The difference between the P response and the LOI and biogenic silica response is related to their different contributions to the sedimenting mass. P is contributed at $\mu\text{g g}^{-1}$ concentrations while silica and organic matter are contributed at mg g^{-1} . In fact, the increase in silica and organic matter sedimentation after 1960 at SB3 (Figure 7.6) can account for 75% of the approximately $20 \text{ mg cm}^{-2} \text{ y}^{-1}$ increase in mass accumulation rates (Table 7.2) while the contribution of increased P sedimentation would have a negligible direct effect on dry weight sedimentation. The remaining 25% increase in dry mass sedimentation can be accounted for by clays and other mineral sedimentation (Kalindekafu et al. 1996). Phosphorus, biogenic silica and organic matter sedimentation rates all increase after 1960 at SB3 in contrast to the sedimentation of these same parameters at SB2 (Figures 7.7, 7.8, 7.9).

Table 7.1. Correlation coefficients between dry sedimentation rates and concentrations in 93-SB2 and 93-SB3, where n is sample size, SR is dry weight sedimentation rate, TP is total P, BAP is bio-available P, BiSi is biogenic silica, and LOI is loss on ignition (proxy for organic matter).

	93-SB2	n	93-SB3	n
SR:TP	-0.53	8	-0.20	8
SR:BAP	-0.49	8	-0.54	8
SR:BiSi	-0.51	19	0.65	16
SR:LOI	-0.34	15	0.69	16
TP:BiSi	0.14	8	0.26	8
BAP:BiSi	0.11	8	-0.41	8
TP:LOI	-0.04	8	0.10	8
BAP:LOI	-0.06	8	-0.20	8
TP:BAP	0.88	8	0.55	8
BiSi:LOI	0.16	15	0.82	16

Microfossil analyses of Core SB2 and SB3 - Diatoms leave readily identified remains; and, assuming that the preserved assemblages are not too distorted by differential preservation, the assemblages can be used to determine trends in past community structure. Differential preservation is a concern in Malawi/Nyasa (Haberyan 1990), and its possible effects must be recalled when interpreting diatom assemblages from sediments. The large, heavily silicified *Aulacoseira nyassensis* will generally persist better than thinly silicified *Nitzschia* species and small *Stephanodiscus* and *Cyclotella*. For example *Aulacoseira* never accounted for more than 7% of all diatom remains in our sediment traps but it is always prominent in sediments (Figures 7.10 and 7.11). In contrast *Nitzschia* species, which can account for up to 20% of all diatoms in the southern trap, scarcely appear in our sediment

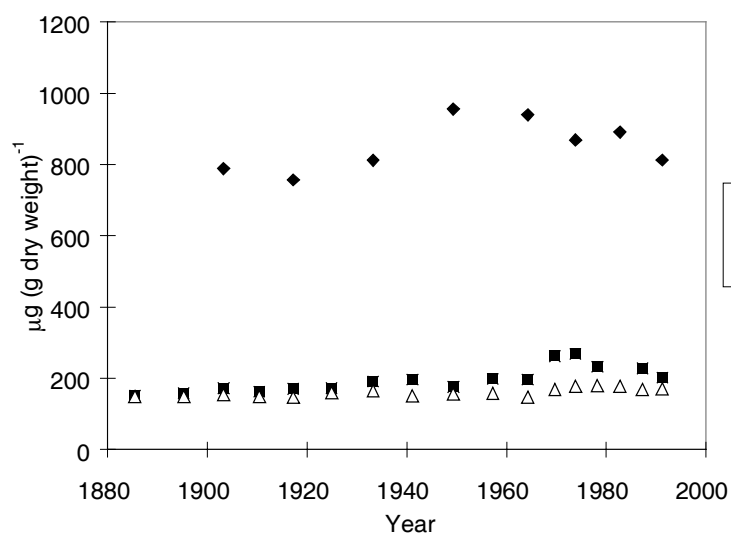


Figure 7.5. Concentrations of total phosphorus, biogenic silica, and organic matter (as loss on ignition) versus sediment age in core SB3 off the Dwangwa delta.

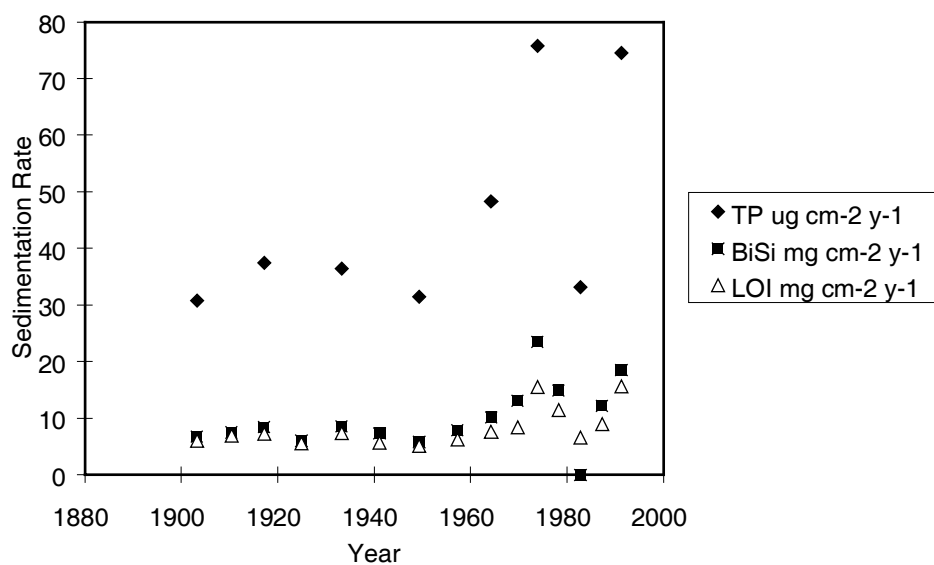


Figure 7.6. Variation in sedimentation rates of the biogenic components total P, biogenic silica, and organic matter (measured as loss on ignition) over time at the southern site SB3 off the Dwangwa delta.

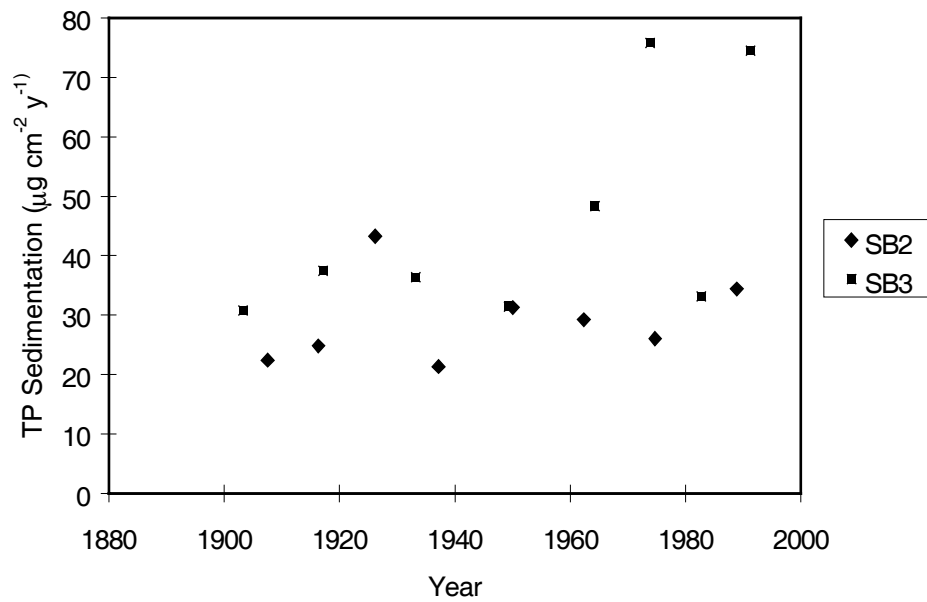


Figure 7.7. Comparison of changes in total P sedimentation at the northern (SB2) and southern (SB3) coring sites.

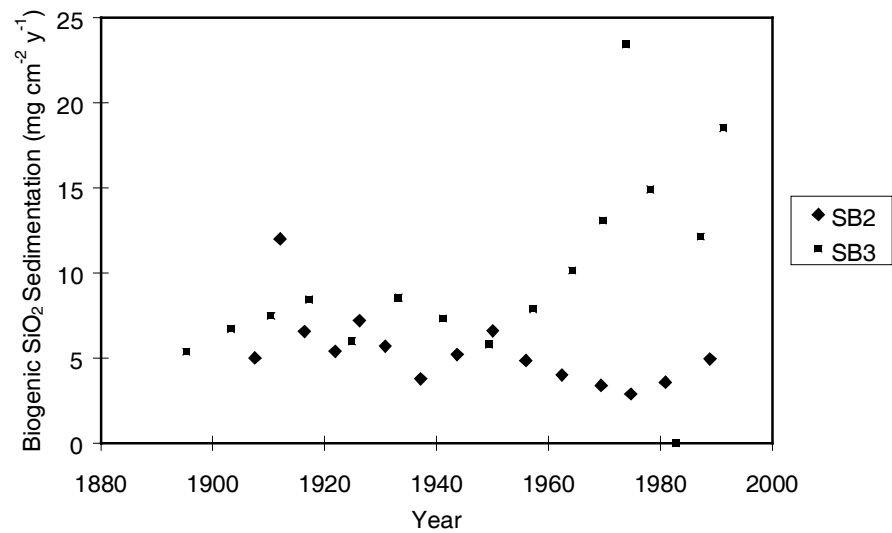


Figure 7.8. Comparison of changes in biogenic silica sedimentation at the northern (SB2) and southern (SB3) coring sites.

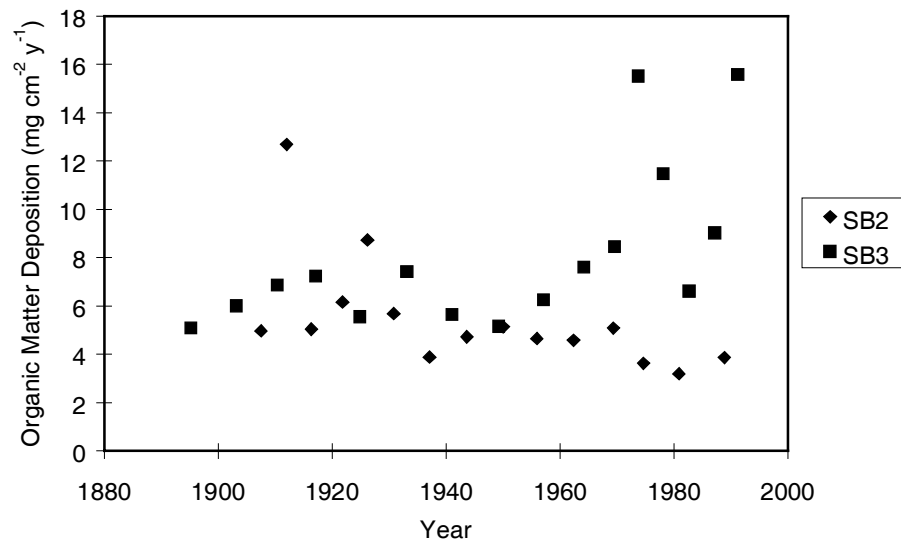


Figure 7.9. Comparison of changes in organic matter sedimentation at the northern (SB2) and southern (SB3) coring sites.

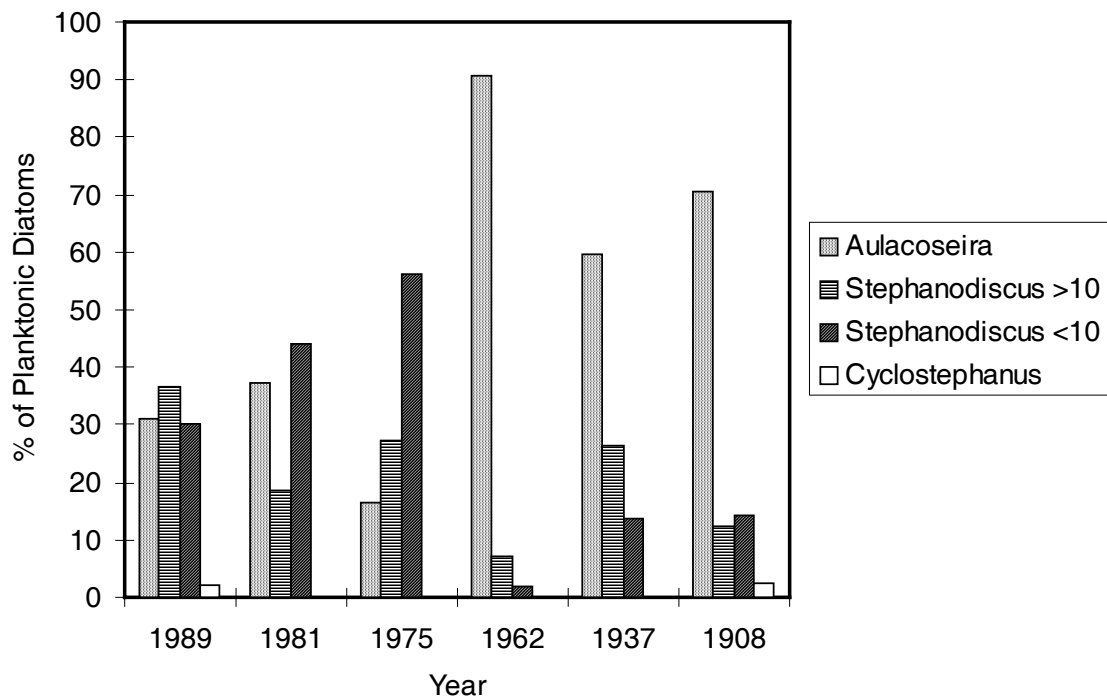


Figure 7.10. Changes in relative abundance of dominant diatom microfossils at the northern coring site (SB2). Note the decline in *Aulacoseira* over time.

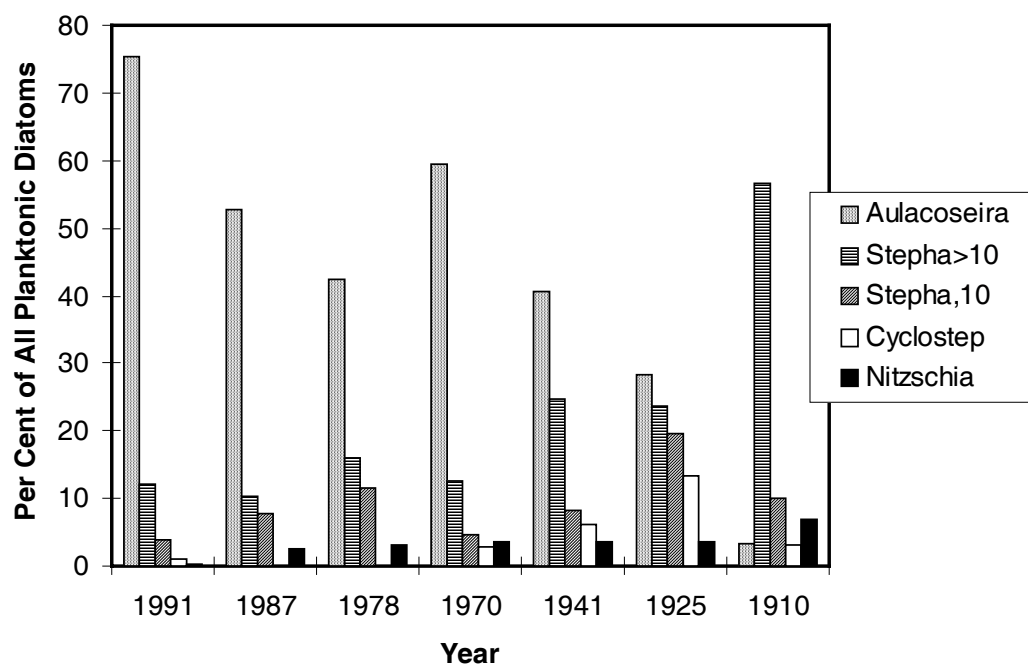


Figure 7.11. Changes in relative abundance of dominant diatom microfossils at the southern coring site.

cores. However, if the factors controlling differential delivery to and preservation within the sediment column are assumed to remain relatively unchanged over time then the diatom assemblages in cores can be used to infer past changes in Malawi/Nyasa.

The two cores record quite different recent trends. In the north at SB2 *Aulacoseira* dominates up to at least 1960 when its relative abundance drops markedly in the most recent sediments (Fig. 7.10). In contrast in the south at SB3 *Aulacoseira* relative abundance increases since the turn of the century account for approximately 50% of all diatom remains (Fig. 7.11). The ecology of *Aulacoseira* suggests that it competes well at low light, when nutrients, especially SiO_2 , and turbulence (e.g. upwelling conditions) are relatively high (Kilham et al. 1986). The recent reduction of *Aulacoseira* abundance in the north may be the result of stronger stratification in recent years which would reduce vertical turbulence and nutrient loading to the mixed layer in the north (Bootsma 1993; Patterson and Kachinjika 1995). The southern trend to higher *Aulacoseira* is consistent with a general enrichment of the south as indicated in the increased loading of nutrients and sediments (Chapter 2) to reduce light transparency. Because the lake seasonally is mixed to the bottom over much of the southern half increased stratification will not have as strong an effect on productivity in this region as in the deep northern region, and the southern region has received increased inputs of nutrients. The most secure interpretation of the diatom assemblages in these two cores is that recent events have led to a differentiation of their sediment records both in regards to sedimentation of nutrients but also the preserved diatom assemblages.

Sedimentation and the changing environment - If the two cores examined in detail here are representative of recent sedimentation in Malawi/Nyasa, then there is reason for concern about how watersheds may be changing in the southern half of the lake. Prior to 1960, sites SB2 and SB3 had

Table 7.2. Sedimentation rates for total P, bio-available P, biogenic silica and organic matter at SB2 and SB3. Mean of similar rates at the two sites prior to 1960 is taken as best estimate of long term pelagic sedimentation rate for Lake Malawi/Nyasa.

	TP	BAP	BiSi	OM	DW Sed.
	ug cm ⁻² y ⁻¹		mg cm ⁻² y ⁻¹		
SB3 post -1960	57.94	32.22	15.38	10.60	62.1
SB3 pre-1960	34.00	20.59	6.76	5.91	40.5
SB2 post-1900	29.11	18.13	5.41	5.47	53.1
Lake pre -1960	31.55	19.36	6.08	5.69	46.8

similar rates of sedimentation of bioavailable (BAP) and total phosphorus (TP), biogenic silica (BiSi) and organic matter (OM) measured as loss on ignition (Table 7.2) as well as diatom assemblages with a predominance of *Aulacoseira*. Finney and Johnson (1991) have previously observed that long term, offshore sedimentation rates, determined primarily by radiocarbon dating, were similar all over Malawi/Nyasa at 1 mm y⁻¹. Before 1960, both sites had their highest rates of mass sedimentation between 1910 and 1935 when lake levels were rising (Calder et al 1995) while the lake was closed with the northern site having some very high rates. Under natural conditions, sediment yield is primarily determined by elevation and rainfall (Milliman and Syvitski 1992) and the stronger sedimentation response in the more mountainous and wetter north (Figure 7.2) and the higher long term sedimentation rate at SB2 (430 g m⁻² y⁻¹) compared to SB3 (330 g m⁻² y⁻¹) would be expected. However, since 1960 the southern portion of the lake as represented by sedimentation at SB3 has increased substantially (Figure 7.2) and that increase has occurred primarily in the biogenic sediments represented by silica and organic matter (Table 7.2). In contrast mineral sedimentation rates have fallen at the northern site (Figure 7.2), and biogenic Si and organic matter sedimentation has remained unchanged (Table 7.2).

Declining detrital sedimentation rates would be expected all over the lake, at least since the 1970's because of below average rainfall (Calder et al 1995). The increase in sedimentation at SB3 must have another cause. That cause is most likely changing patterns of land use resulting from forest clearance (Calder et al 1995) for agriculture to sustain the growing population in the southern catchments. Milliman and Syvitski (1992) in a global survey of factors affecting sediment yield noted that heavily populated, mountainous regions in intensive agriculture gave by far the highest sediment yields. The effect of land use on sediment yield to great lakes has also been established in North America (Stone and Saunderson 1996). Calder et al (1995) estimated that forest cover in Malawi has likely declined from 64% to 51% since 1967, lake-wide, and a disproportionate amount of that clearance has likely been in the south. This clearance has led to increased runoff (Calder et al 1995) and has likely resulted in increased sediment yield (Kingdon et al Chapter 2 of this report). Ongoing remote sensing classification and GIS modelling of land use may substantiate our inference of greater land use change and more intensive land use in the southern catchments. The current pattern of sedimentation in the northern and southern cores is substantiated by sediment trap collections during 1997-98 (Table 7.3). The more southerly trap measured higher fluxes of total P, biogenic silica and total solids than the northernmost trap. The southern trap is near site SB3 but the northernmost trap is off Nkhata Bay and still far south of SB2. Still the pattern and the even the rates of sedimentation to the traps are similar to those inferred from the cores. Further supporting the inference of recent change at SB3 are the conclusions of Kingdon et al (Chapter 2) which found evidence that southern rivers were giving higher than expected yields of sediment and nutrients although there is no historical data to allow a detailed comparison of river chemistries.

Table 7.3. Daily sedimentation rates for carbon, nitrogen, phosphorus, biogenic silica, and total dry sediment for three periods beginning 14-15 May 1997. THRM2 is the more southerly trap. Traps are mid-water with the depth indicated being from the surface. n.a.=not available.

Sampled	Station	Depth(m)	C	N	P	Si	Sediment
			mmol m ⁻² d ⁻¹				mg m ⁻² d ⁻¹
Sep 8/97	THRM2	140	3.34	0.31	0.026	3.81	629
Dec 15/97	THRM2	140	4.21	0.30	0.034	4.15	717
May 8/98	THRM2	140	7.06	0.67	0.042	n.a.	959
Sep 14/97	917	180	3.92	0.34	0.027	0.81	601
Dec 16/97	917	180	4.45	0.44	0.023	2.29	376
May 7/98	917	180	4.73	0.51	0.028	n.a.	433

The conclusion that increasing sedimentation rates in the southern region of Lake Malawi/Nyasa are driven by more intensive and extensive land use is important to the future of the lake. The conclusions presented here are consistent with all the evidence which can currently be brought to bear on this issue, but must still be considered preliminary until further substantiated by examining more cores especially those recovered in November 1997 to see if cores SB2 and SB3 are truly representative of the different regions of the lake. Similarly the trends in contaminant inputs could also be determined by analyses of these cores. Given the significance of increasing sedimentation, increased nutrient loading (Chapter 8 and Chapter 6) and possibly increasing contaminant loading (Chapter 9), the analyses of more sediment cores deserve the highest priority for future research funding.

Conclusions

Until now changes in qualitative phytoplankton flora of Malawi/Nyasa have been few, but the ones which have been recorded create concern. The filamentous chlorophytes of the *Mougoetia/Oedogonium* complex is an example of a large new species occurring since the 1960's which had not been reported earlier in this century. The prominence of *Planktolyngbya tallingi* in southern region of the lake, where it has replaced the previously dominant *Planktolyngbya nyassensis*, is indicative of increasing nutrient availability and poorer light conditions. The reported occurrence of *Cylindrospermopsis raciborski*, a filamentous bluegreen, which is often a climax species in highly eutrophic situations and which has toxic forms is also cause for concern. In recent years *Anabaena* blooms have become a repetitive occurrence especially inshore in the vicinity of the Linthipe River in March-April at the end of the rainy season and has provided visible evidence (which would have been difficult to overlook in earlier years) of possible nutrient enrichment. Although *Anabaena* blooms are reported in the earlier literature, they then occurred only in October-November. The co-occurrence of the dinoflagellate *Peridinium* with the *Anabaena* bloom in at least one bloom is also worrisome as both taxa have forms which can produce phycotoxins.

Although changes in the phytoplankton community composition may yet appear minor, they are indications that greater changes may follow. Interpretation of such changes is now greatly hampered by the qualitative, fragmentary and discontinuous availability of earlier studies. In Lake Victoria quantitative analysis of the phytoplankton did not occur until after dramatic changes had occurred in which the phytoplankton community which had been dominant for centuries changed within decades to a eutrophic assemblage dominated by potentially toxic blue-green algal species (Hecky 1993; Mugidde 1992). *At minimum, these recorded changes in Malawi relative to earlier observations and the evidence of the quantitative changes in the algal community recorded in the sediments require the installation of an algal monitoring programme as part of an integrated ecosystem monitoring initiative.* Not only will such a programme identify undesirable trends in water quality from indicator species, but it will also warn of toxic algal blooms which could be linked to consumption advisories. Such programmes are now routine in the Baltic and in the Laurentian Great Lakes. Taxonomy and biodiversity studies should be applied to all elements of the food chain not only to fish which are dependent on healthy and productive algal communities. It is essential that attention is paid to the changes that are occurring at the bottom of food chain (where changes can occur rapidly because of the high rates of population turnover) in order to protect and manage the top. A programme of algal study and monitoring can refer to the early few records which are an invaluable asset as reference checks against which recent and future data comparisons can be made. Such a programme should be extended to sediment trap collections which are an efficient method to detect changes from year to year. The sediment record is also a valuable archive, containing the historic record of biological, chemical and physical change in the lake and catchment area which must receive further study. The greatest void in biodiversity data in Lake Malawi is in studies of the micro- benthic community of the littoral zone. According to Bootsma (1993) a significant portion of the lakes productivity occurs in this region, and the algal community in these littoral environments can also be indicative of environmental change if they are included in a monitoring programme.

Other studies in this Water Quality Report (eg. Chapter 2) indicate that the southern catchments of the Malawi/Nyasa basin are changing and yielding heavier loads of sediment and nutrients than would have been expected under natural conditions. This inference has been substantiated by the direct measurements of sedimentation in sediment traps in the lake where the most southerly trap records higher rates of dry weight and nutrient sedimentation than the trap farther north. But most indicative are the results of sediment core analyses from the northern and southern regions of the lake. The northern site has experienced somewhat reduced mass sedimentation in the the last three decades while the southern site records increased sedimentation by as much as 50%. At the northern site, dry weight sedimentation rates are dominated by terrigenous, detrital material, and therefore rates change in response to natural variation in runoff from the catchments. In the south, the recent increase in sedimentation is largely accounted for by biogenic sedimentation especially of diatoms and organic matter. These results are consistent with greater catchment disturbance through land clearance and more extensive agriculture in the south. These interpretations are based on a minimum of cores and more of

the cores collected during this study should be analyzed to confirm these serious conclusions about land use and sedimentation in Lake Malawi. Ongoing studies by the Centre for Earth Observation Studies will analyze and quantify the relationship of these changes in river quality and sedimentation to land use in the southern catchments. *Therefore, it is recommended that at least five more sediment cores be analyzed to confirm the conclusions about increased sedimentation and for trends in contaminants entering the lake. A water quality monitoring programme should also be established directed primarily at sediment loads carried by the rivers in order to provide early warning of catchment degradation and soil loss.* Completion of the CEOS land use and basin characteristics database is an essential requirement to complete the chain of evidence linking increased sediment and contaminant input with land use and will be a useful management tool to guide corrective or preventative action. The development of GIS models relating land use and human activities to water quality characteristics will allow assessment and forecasting of consequences of different catchment development scenarios.

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