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Aquatic Ecology Monitoring: Water quality, fish, fish catch, sanitation and disease vectors

Monitoring No. 5

Date: 6th – 9th October 2009

Monitoring carried out by:

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On behalf of :

Bujagali Energy Limited (BEL)

Date of Report : 25th February 2010

1.0 BACKGROUND

The survey covered by this report was undertaken between 6 th and 9th October 2009 as a follow-up on the during construction surveys of the Bujagali Hydropwer Project (BHPP). In addition to two pre-construction baseline surveys in April 2000 and April 2006, four monitoring surveys have so far been undertaken i.e. in September 2007, April 2008, April 2009 and the present one, in October 2009. The 2009 biannual monitoring surveys were conducted at an upstream and a downstream transect of the BHPP with emphasis on the following aspects:

1. water quality determinants
2. biology and ecology of fishes and food webs
3. fish stock and fish catch including economic aspects of catch and
4. sanitation/vector studies (bilharzias and river blindness)

2.0 GENERAL METHODOLOGY AND DATA COLLECTION

2.1. Materials and Methods

During this survey, Kalange-Makwanzi and Buyala- Kikubamutwe, upstream and downstream transects respectively were sampled for water quality, fish abundance, diversity and distribution, fish biology, fish catch, sanitation conditions, bilharzia and river blindness vectors.

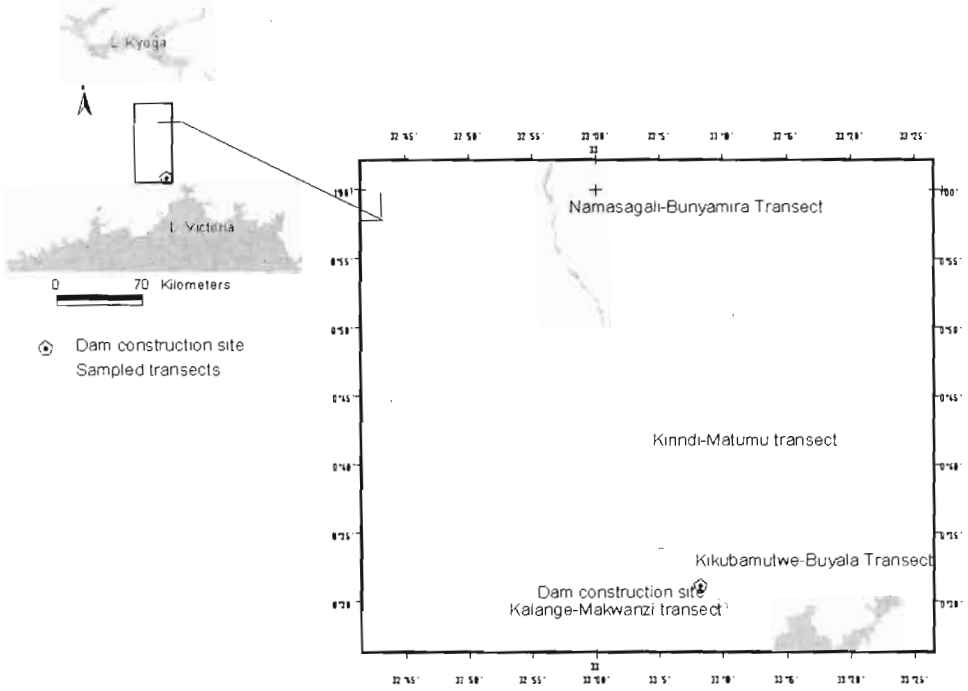

Figure 2.1a A map showing the Upper Victoria Nile where the BHPP is located and river segments where baseline as well as monitoring samples were taken

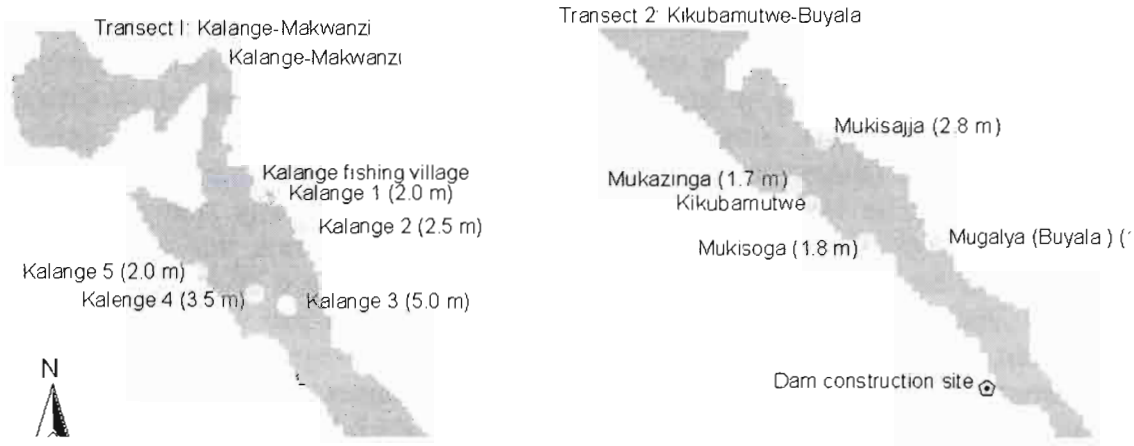

Figure 2.1b Detailed maps of the two sampled transects: Transect 1 = Kalange-Makwanzi and Transect 2 = Buyala-Kikubamutwe and associated locations on the Upper Victoria Nile.

Sampling, analytical procedures and techniques used in the previous surveys were followed (NaFIRRI, April 2006, September 2007, April 2008 and April 2009).

3.0 RESULTS

3.1 Status of Water Quality

3.1.1. Physico-chemical parameters

Table 3.1.1 Trends in mean values of water physico-chemical parameters at Kalange-Makwanzi and Buyala-Kikubamutwe

Parameter	Site	Monitoring Dates				
		Apr-06	Sept. 07	Apr-08	Apr-09	Oct-09
Dissolved Oxygen (mg/L)	u/s	4.2	7.2	5.6	4.5	5.9
	d/s	6.3	7.7	7	7.2	7.2
pH	u/s	7	7.3	8.2	6.7	7.6
	d/s	7.4	7.4	7.7	6.8	7.4
Temperature (°C)	u/s	26.7	26.1	26.2	26.4	25.7
	d/s	26.4	25.7	26.9	26.8	25
Conductivity (µS/cm)	u/s	103	112	81.1	95.5	96.9
	d/s	88.5	114	82.8	97.6	97.7
Secchi Visibility (m)	u/s	1.9	1.6	1.9	2.2	2.2
	d/s	1.7	1.8	1.8	2.3	1.9
Total Suspended Solids (mg/L)	u/s	2	2.7	4.2	7.9	3.7
	d/s	2	4.2	3.6	5.4	3.6
Oil & Grease (mg/L)	u/s	0.6	0.1	0.003	0.02	0.08
	d/s	0.9	0.8	0.002	0.06	0.52

Key:
Transect 1 (u/s): Kalange-Makwanzi
Transect 2 (d/s): Buyala-Kikubamutwe

The mean dissolved oxygen (DO) concentrations at Kalange-Makwanzi and Buyala-Kikubamutwe were comparable over the monitoring period, with the upstream transect consistently having lower dissolved oxygen compared to the downstream transect but showing concentrations of over 5 mg/L in both transects. Thus, the concentration of dissolved oxygen was consistently above the minimum (3 mg/L) that is required for survival of most aquatic biota especially fish. The mean pH at both transects was circumneutral and comparable to that of Lake Victoria and is within the NEMA prescrivbed range of 6 to 8. The slightly lower temperatures compared to the previous data were probably due to the cooling effect of the rainy season and was within the permissible NEMA range of 20 to 35°C. Other than conductivity, temperature and pH conditions were within ranges that have been recorded from Lake Victoria waters (NaFIRRI – IFMP 2007 and 2008), and conform to national effluent discharge standards set by the NEMA. Water clarity reduced at the downstream transect compared to the upstream one, but was comparable to previous readings. Less suspended solids were recorded in the waters at both transects compared to what was noted in April 2009, and were below the NEMA standard of 100 mg/L. Current observations showed a more than 6-fold concentration of oil and grease in the downstream compared to the upstream transect but , the concentration was still below the NEMA upper limit of 10 mg/L.

3.1.2 Nutrient (nitrogen, phosphorus and silica) concentrations in water

Table 3.1.2 Trends in mean concentrations of nutrients in water at Kalange-Makwanzi and Buyala-Kikubamutwe

Parameter	Site	Monitoring Dates				
		Apr-06	Sept. 07	Apr-08	Apr-09	Oct-09
Ammonium Nitrogen, NH_4-N (μ g/L)	u/s	42.3	20.2	79.4	88	186.1
	d/s	29.5	24	97.9	79.4	136.6
Nitrite-Nitrogen, NO_2-N (μ g/L)	u/s	8.7	9.5	4	3.1	2.9
	d/s	8.7	2.8	6.1	2.6	3.9
Nitrate-Nitrogen, NO_3-N (μ g/L)	u/s	12.5	36	146.3	26.4	114.2
	d/s	12.6	94	182.5	35	75.9
Total-Nitrogen, TN (μ g/L)	u/s	1174	2093.5	1925	306.7	2361.7
	d/s	1192.5	2138.8	2492.3	216.7	2420.5
Total Phosphorus, TP (μ g/L)	u/s	108.6	54.5	58.5	60.3	35.9
	d/s	100.8	48.7	76.3	47.3	44.7
Soluble Reactive Phosphorus, SRP (μ g/L)	u/s	19	24.2	11.7	6.9	27.3
	d/s	19.2	27.7	18.9	16.6	32.4
Soluble Reactive Silica, SRSi (μ g/L)	u/s	319.9	539.7	238.4	501.2	858.5
	d/s	309.4	530.7	282.8	496.7	846.9
Chlorophyll-a, Chl-a (μ g/L)	u/s	3.7	5.7	7	ND	ND
	d/s	4	5.3	4.4	ND	ND

Key:
Transect 1 (u/s): Kalange-Makwanzi
Transect 2 (d/s): Buyala-Kikubamutwe

Higher concentrations of ammonium-nitrogen (NH_4-N) were noted compared to previous surveys while nitrite nitrogen (NO_2-N) was comparable to that recorded in April 2009. Despite the increasing trend of NH_4-N at both transects, the concentrations were less than 50-fold the permissible NEMA upper limit of 10,000 μg/L (or 10 mg/L). Additionally, the concentration of nitrate-nitrogen (NO_3-N) was more than double that recorded in

April 2009, but was less than 175-fold the permissible NEMA upper limit of 20,000 μg/L (20 mg/L). Though total-nitrogen (TN) concentration was more than seven-fold the concentration noted during April 2009, it was comparable with other previous readings and was also below the permissible NEMA upper limit of 10,000 μg/L (or 10 mg/L). Like in previous surveys, soluble reactive phosphorus (SRP) was higher at Buyala-Kikubamutwe than at Kalange-Makwanzi, implying that there could be sources of this nutrient around Transect 2, thus contributing to its elevation in the waters. Despite this possibility, the range of SRP was consistently below the permissible NEMA upper limit of 5,000 μg/L (or 5 mg/L). Additionally, the concentration of Total phosphorus (TP) was far below the permissible NEMA upper limit of 10,000 μg/L (or 10 mg/L). Both Total Phosphorus and SRP concentrations at Transect 2 were higher during the present survey than in the previous. The concentration of SRSi at both transects was by far higher than any previous concentrations, but with similar concentrations at both transects.

3.2 FISH SPECIES COMPOSITION AND RELATIVE ABUNDANCE

3.2.1 Catch composition

A total of nine fish species (haplochromines were taken as a single taxon group) were recorded at the two transects compared to 13 in April 2009 and 10 in April 2008 (Table 3.2.1). Two haplochromine species (*Lipochromis microdon* and *Paralabidochromis "rock kribensis"* were added to the list of fishes so far recovered from the study transects (Table 3.2.2). Thus 62 fish species of which 42 are haplochromines have so far been recovered from the two transects.

Among the recognised keystone species (only *Barbus altianalis*) was not caught, *Lates niloticus, Mormyrus kannume, Oreochromis niloticus* and the haplochromines were still recovered from each transect.

Quantities of *O. niloticus* still declined probably as a result of fishing pressure. The native tilapiine *Oreochromis variabilis* has persisted especially at Kalange, the upstream transect. As in the previous surveys, Kalange recorded higher fish densities than Buyala. This could be as a result of the presence of larger bays with calmer waters preferred by many fish species compared to mostly fast-flowing waters downstream at Buyala. Just like in the previous surveys, haplochromines continued to feature prominently. In Lakes Victoria and Kyoga the water bodies at the two ends of Upper Victoria Nile, a recovery of haplochromines has also been observed (IFMP reports 2005, NAFIRRI Report 2006). Eleven fish species were caught in gillnets while the beach seine recovered only four species. From all gears, 9 (10, 10, 10) species were recorded at Kalange (Transect 1) and 6 (12, 8, 11) at Buyala (Transect 2) (Numbers in brackets are for the number of species caught during the April 2009, April 2008 and September 2007 surveys respectively). *Bagrus docmak, Oreochromis variabiliss,* and *Synodontis victoriae* were the only species that were caught in Kalange but not in Buyala. Haplochromines, *L. niloticus* and *Synodontis afrofischeri* dominated catches both by numbers and weight.

Status of Water Quality and its Implication on Fishery Production

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SUMMARY

Within the past five decades, it has been realized that people significantly influence the water quality, which, in turn, affects the fisheries. Since the 1960s, Lake Victoria and its basin have come under increasing and substantial pressure from a variety of human activities. These include deforestation, over-fishing, intense cultivation, animal husbandry and introduction of exotic fish species. Human activities have disrupted biogeochemical cycles with have consequences for the water quality and fisheries of Lake Victoria. Measurements and theoretical analyses have clearly connected observed changes in the watershed and water quality and conclusions have been drawn that aquatic biota including fisheries are strongly influenced by disturbances around and within Lake Victoria

The Lake Victoria basin has clearly shown signs of population pressure and associated land use changes to and within the lake. Nutrient enrichment in the water column, sediment and in rainfall over Lake Victoria accelerated after the 1960s. Phosphorus concentrations have risen by a factor of 2 to 3. Atmospheric loads of nutrients, especially of nitrogen (N) and phosphorus (P) have increased due to biomass burning and deforestation in the catchment. These high nutrient concentrations support elevated algal primary production and algal biomass that have risen by factors of 2, and 6 to 8 respectively. Algal and invertebrates species composition have responded to changes in water quality. Algae are now dominated by the blue-greens with types that are potentially toxic. Elevated algal production probably supports the 4 to 5-fold rise in fish production in the lake since the 1950s.

Increased fish production is good as more local people have turned to the lake for their livelihood and fish exports to international markets earn foreign exchange for the riparian states. But problems associated with nutrient enrichment (eutrophication) impacts of elevated algal biomasses and proliferation of the obnoxious water hyacinth (Eichhornia crassipes) threatens continued beneficial use of the lake resources. High algal biomass and increased sediment have contributed to a 4-fold reduction in the lake transparency since the 1960s. Reduced lake transparency is believed to have accelerated hybridization of some cichlids that are picky in choosing mates and use visual cues of bright male coloration to identify suitors of their own species.

Deoxygenation of deep waters is another undesirable change that has precluded a stable demersal fishery. Seasonal bottom oxygen deficiency created by decomposition of algal biomass and aggravated by stronger thermal stability directly affects the distribution of organisms including invertebrates and fish. Low oxygen has led to loss of approximately 50% of aerated fish habitat since the 1960s, and also lowers potential fish production. Among the invertebrates, Caridina nilotica has become a keystone species as it is resilient to low oxygen conditions. Low oxygen conditions (anoxia) and algal blooms are often associated with fish kills in Lake Victoria. Overall,

the length of the food chain from algae to invertebrates and leading to the Nile Perch is short consisting of two trophic levels.

BACKGROUND

Until about five decades ago, few scientists had the insight to recognize that human activities could lead to environmental change on the scale that would impact a large water body such as Lake Victoria. Increasing human population and corresponding settlements within the Lake Victoria basin have impacted water quality. Worldwide, management of the fisheries has become controversial as several factors constraining fish production and health occur contemporaneously. These factors include over-fishing, changes in the trophic dynamics, and water quality. Carignan and Steedman (2000) reported on disruptions of biogeochemical cycles in temperate lakes following watershed deforestation and wildfire. It was concluded that water quality and aquatic biota are strongly influenced by disturbances in the watershed (Carignan *et al.*, (2000).

In extensive reviews addressing the impact of water quality and ecosystem health on influencing fish production in tropical aquatic ecosystems, Downing *et al.*, (1999) and Hecky *et al.*, 2003 assert that disturbances in the catchment will lead to increased primary production in freshwaters and potentially large changes in tropical freshwater communities. These changes have already happened in Lake Victoria. Water quality and ecosystem changes have become more central in fisheries stock assessment and management as the lake has experienced seasonal peaks and declines in fish availability since the late 1990s. Domestic and commercial fish operations are directly exposed to the fish changes in Lake Victoria (Bugenyi & Balirwa, 1989). However, counter arguments refer to changes in the fish habitat and fish food as affecting a bountiful fish resource of Lake Victoria (Ogutu-Ohwayo, 1990). Several authors have debated the potential effects of the stressed and altered physical and chemical environment that has changed the fish habitat (Hecky and Bugenyi 1992; Hecky, 1993; Hecky *et al.*, 1994, 1996; Lehman *et al.*, 1998; Mugidde, 2001).

Major Physical Changes and Potential Impacts on Fishery

Changes in the physical and chemical properties in Lake Victoria are some of the factors responsible for seasonal changes in biological productivity including fish production and distribution. In Lake Victoria, thermal stratification has direct physical impact on the depth of the mixed layer, which in turn affects the vertical distribution of nutrients including oxygen and biota (Talling, 1965; Hecky *et al.*, 1996; Mugidde, 2001). In the deep offshore waters of Lake Victoria, the strength and frequency of mixing governs the movement of nutrients from deeper waters into the euphotic zone as well as the development of anoxia and the distribution of plankton and fishes.

Thermal Stratification and Mixing

Lake Victoria experiences three phases of stratification. Moderate thermal stratification occurs between September and December, stable thermal stratification in January to March/April, and deeper and strong mixing occurs around June- July (Talling, 1965, 1966,1969; Mugidde, 2001). Thermal stratification regulates exchange of dissolved oxygen and nutrients from deeper depths into the surface as well as development of low oxygen conditions (anoxia) and distribution of plankton including fish. The lake rapidly warms in September throughout to March/April. A stable thermocline extends throughout the water column and limits exchange and supply of nutrients from the bottom into the surface waters resulting in a build up of regenerated nutrients in bottom waters.

Lake Victoria water is now warmer and thermal stratification is more stable than in the 1960s. Overall minimum water temperatures during the mixing period in June-July are 0.5 °C warmer in the 1990s than it

used to be in the 1960s (Mugidde, 2001). These elevated water temperatures accelerate temperature-dependent chemical reactions and microbial processes such as denitrification-nitrification, thus affecting nutrient cycling and availability as well as algal biomass development. Low oxygen conditions allow return of P from bottom to surface waters, but not nitrogen (Hecky *et al.*, 1996, Hecky, 2000, Mugidde, 2001). Continuous N loss to denitrification during persistent thermal stratification leads to high N demand and favors growth of blue-green including N-fixers as light in the euphotic zone is often adequate during this time of the year.

More stable thermal stratification makes the lake less able to mix effectively and promotes low oxygen conditions in deep waters during the stratified period between September and April (Tables 1 & 2). Decomposing organic matter that includes high algal biomass consumes oxygen leading to oxygen-depletion (anoxia) of deep waters when the lake is thermally stratified. Anoxia has spread horizontally into the inshore shallow bays and gulfs such as Napoleon Gulf, and vertically into the water column to as high as 30 m to 40 m deep from the bottom in offshore waters. Low oxygen conditions affect nutrient distribution, and distribution of organisms including fish in Lake Victoria. There has been loss of about 50% of the oxygenated water volume in Lake Victoria since the 1960s, which reduces fish habitat, and subsequently lowers the potential fish production. Seasonal low bottom water oxygen conditions are thought to have forced haplochromine species into the surface waters where they were exposed to heavy predation by the Nile perch.

Table. 1. Temporal variation of temperatures and dissolved oxygen from inshore waters (Napoleon Gulf) of Lake Victoria.

Month	Temperature (°C)		Dissolved oxygen (mg L^{-1})		Mixing depth
	Surface	Bottom	Surface	Bottom	Z_{mix} (m)
January	27.4	26.4	8.3	2.1	12.0
March	28.1	26.9	9.7	4.4	8.0
July	25.3	24.3	10.6	6.2	20.0
August	25.9	25.3	6.6	0.04	10.0
October	25.6	25.4	5.8	1.3	6.0
November	27.7	25.8	9.8	0.5	6.0
December	26.8	23.9	7.0	0.6	8.0

Table 2. Temperature and dissolved oxygen from offshore (70 m) waters of Lake Victoria

Month	Temperature (°C)		Dissolved Oxygen (Mg L^{-1})		Mixing Depth (M)
	Surface	Bottom	Surface	Bottom	
March	26.7	24.4	8.2	0.4	25.0
May	26.6	25.7	7.7	5.6	40.0
July	25.4	25.1	6.1	6.0	65.0
September	26.6	24.4	9.0	4.7	40.0
November	27.7	25.8	11.0	2.2	30.0
December	25.2	24.7	7.4	2.4	30.0

Deeper and Stronger Mixing Season

Complete mixing of the lake occurs around June-July. This results in almost uniform distribution of dissolved oxygen and nutrients in the water column. Complete mixing allows oxygen-rich surface waters to reach the bottom of the lake. Well-oxygenated water allows fish and other aerobic organism to occupy deeper zones. Thus, Lake Victoria tends to have low fish densities during the mixing as fish are well distributed throughout the water unlike during stratification when it is restricted to the surface water and shallow inshore regions of the lake. Because of light-dependence, algal biomass and primary production in Lake Victoria varies with season. Lower light availability combined with deeper mixed layers precludes development of high standing algal crops offshore during July and August.

Nutrient Status

Increasing nutrient concentrations is a major factor that controls seasonal changes in biological productivity including fish production. Lake Victoria has high nutrient concentrations (Table 3) and is eutrophic (Hecky, 1993). Elevated nutrient levels are a key environmental concern as they are responsible for increased phytoplankton production, proliferation of macrophytes including water hyacinth, increased incidences of noxious and toxic blooms of algae, lack of oxygen (hypoxia and anoxia) and fish kills (Ochumba & Kibaara, 1989). Data collected from inshore shallow bays and gulfs and deep open waters of the lake since the 1990s compared to historic records of the 1930s and 1950 -1960s show that phosphorus concentrations are 2 to 3 times higher today. In the 1990s to 2000s total phosphorus concentrations were in a range from 1.0 μM to 12.0 μM, with average value of 2.7 μM (Table 3). The total nitrogen concentrations vary from 20 μM to 250 μM, with average values increasing from 37.1μM in offshore to 106.4 μM in inshore.

Table 3. Average chlorophyll-a, nutrients, light and their standard deviation in Lake Victoria.

Parameter	Inshore	Offshore
Chlorophyll-a (mg L^{-1})	70.0 ±100.4	13.5 ± 5.8
Particulate N (μM)	48.8 ±7.1	10.6 ± 4.4
Total N (μM)	106.4 ±28.2	37.1 ±18.7
Total P (μM)	2.7 ±2.1	3.1 ± 0.9
N-fixation (g N m^{-2} y^{-1})	14.0 ±4.2	7.3 ± 3.7
Euphotic depth (m)	4.7 ±1.2	9.2 ± 2.0
Mixing depth (m)	7.1 ±2.6	35.0 ± 2.6

The increase in nitrogen has not marched the increase in phosphorus as indicated by the total nitrogen (TN) to total phosphorus (TP) ratios in the range 8.0 to 42.0, average 15.7. Average TN:TP ratios are almost double in inshore (14.5) than offshore (8.1) indicating that P was in excess relative to N in offshore than inshore Lake Victoria. The deficit in nitrogen concentrations have stimulated growth of nitrogen fixing algae that fix and bring in approximately 480 kilo tonnes a year of atmospheric nitrogen. The average Silica concentrations (17.3±13.6 μM) have decreased by a factor of 10 since the 1960s, due to increased phosphorus loading in the water column and burial in the sediment. The long water residence time (23 years) and the long (3440 km) and highly indented shoreline that include numerous bays exacerbate nutrient enrichment/pollution effects in Lake Victoria.

Evidence from the sediments indicates that phosphorus loads into Lake Victoria begun in the 1920s and increased rapidly after the 1960s (Lipiatou *et. al.*, 1996). Phosphorus comes from the watershed and the airshed and contributes approximately 14.6 Kilo tonnes a year (Mugidde, 2001). Given that Lake Victoria is enriched with both phosphorus and nitrogen, water degradation will continue unless nutrient loads, in particular P loads, are reduced through watershed management including management of the wetlands. Phosphorus reduction is the most feasible way of controlling eutrophication. At present, there is a pollution control legislation embodied in the NEMA that deals with water quality standards of effluent. However,

there is no single polluter to prosecute or blame for non-point pollutants into the lake and this will need new regional legislation.

Status of Phytoplankton Primary Production

Rates of algal primary productivity in near shallow waters to the north in Lake Victoria are two times the rates at the deeper open regions of the lake. Algal photosynthesis occurs in a shrunken euphotic depth of 4 m to 10 m. Phytoplankton primary productivity was in the range 8 to 50 g O_2 m^{-2} d^{-1}, with are average of 18.3 g O_2 m^{-2} d^{-1} that was twice higher than the values recorded in the 1960s (Mugidde 1992, 1993). Overall, the algal photosynthetic efficiency is now lower as indicated by average productivity per unit biomass of 18.1 mg O_2 mg $chl^{-1}h^{-1}$ in the 1990s compared to 25 mg O_2 mg $chl^{-1}h^{-1}$ in the 1960s. The current Lake Victoria is inefficient in using nutrients, as algal primary productivity is light limited most of the time. However, algal primary productivity supports remarkable levels of secondary production including fish production in Lake Victoria.

Algal Biomass

The higher primary productivity throughout the year has been accompanied by elevated algal biomasses evaluated as chlorophyll-a and wet-biomass. Chlorophyll-a concentrations are in the range 3.0 to 656.0 mg L^{-1}, average 45.7 mg L^{-1} (Table 3) that is five times higher than values of the 1960s. The high algal biomass has reduced lake transparency by a factor of four. Lake transparency as a measure of light availability is in the range of 0.5 m to 7.0 m but usually less than 1.0 m inshore water and about 2.0 m offshore waters.

In both inshore and offshore zones of the lake, the lowest algal biomass occurs during periods of low light conditions around July when the lake is most deeply mixing (Tables 1 & 2). During this period, light restricts algal standing crops to levels below the potential provided by the available nutrients during the mixing period. Light limitation constrains algal biomass in the offshore compared to the shallower and more protected inshore surface waters. As a result, phytoplankton biomass and productivity are always higher in the shallow regions than offshore due to better light conditions inshore. Algae contribute to suspended nutrient concentrations (carbon, nitrogen and phosphorus) which are 2 to 5-fold higher inshore than offshore (Table 3). The consequences of high suspended nutrient concentrations and loading depend on the degree to which the phytoplankton are light limited.

Status of algal Species Composition

The very fertile conditions favour dominance of blue-green algae dominated by *Cylindrospermopsis*, *Anabaena* and *Microcystis*. Overall, there is seasonal succession in species composition of algae with increasing dominance of N-fixing blue-green algae during the early stratified period followed by non-fixers later in the stratified period and during the deepest mixing period in June-July. Some of the blue-green algae produce toxins that can be dangerous to aquatic life and land-based animals that use the water. Large green algae such as *Pediastrum* are rare to absent. There has been a 10 -fold reduction in soluble reactive silica, which has been accompanied by a shift in diatom dominance from *Aulacosiera* (*Melosira*) to *Nitszchia*. *Aulacosiera* formed the main food of the native commercially important tilapiine *Oreochromis esculentus* and its reduction might have affected stocks of this species as dominance of cyanobacteria including toxic forms, could have led to reduction of preferred food for the native fish species. Besides, cyanobacteria are less digestible and provide poor quality food that may have contributed to the reduction or loss of planktivorous haplochromines and tilapiines that once flourished in Lake Victoria. It is therefore reasonable to conclude that changes in the fishery may have resulted in part, from dramatic shifts in phytoplankton species composition in Lake Victoria.

Changes in phytoplankton biomass and species composition have been attributed to general increases in P and N loading, changes in fish communities and climate change in Lake Victoria (Lehman *et al.*, 1998). In Lake Victoria, P loads are dominated by external sources that include rainfall, dry-fall, rivers, industrial and municipal inputs. However, in situ biological nitrogen fixation is an extremely important source of nitrogen

as it contributes over 60 % of the total N budget of Lake Victoria and is higher inshore than offshore (Table 3). The undesirable algal blooms and excess biomasses in Lake Victoria will persist if increased nutrient loads in particular P loads and conditions of anoxia and high rates of denitrification continue. Management strategies to protect water quality of the lake should, therefore, give high priority to actions that control nutrient loads that stimulate growth of algal blooms and other aquatic plants. Effective watershed management should involve educational programs aimed at sensitizing the local people as to how their activities including intense subsistence crop farming, animal husbandry, mining and releasing of waste products, change the atmospheric and river chemistry, which in turn impact the water quality and aquatic biota. Unless local people recognize the adverse impacts of their uncontrolled soil erosion and generation of waste products and take action to reduce the nutrient emissions, control of excess algal biomass and blooms will be difficult to achieve. Reductions of nutrient loads, in particular phosphorus into the lake, will lead to decreases in blue-green algae biomass in inshore areas and, in particular, biomass of heterocystous N_2-fixers including toxic species such as *Cyclindrospermopsis* and *Anabaena*. This should relax some of the negative consequences of high algal biomass such as excess oxygen demand and nutrient and light-limited algal growth. Reductions in algal biomass will improve the light environment which will led to improved algal productivity and ecological efficiency in the transfer of energy to higher levels in the food-web and sustaining high levels of fish production in Lake Victoria.

The Status and Changes in Invertebrate Communities

All young (larvae) fish utilize invertebrates as the first external food, and the commercially important fish *Rastrineobola argentea* depends entirely on invertebrates throughout their life. Juveniles and sub-adults of the Nile perch depend heavily on invertebrates especially *Caridina nilotica*. Invertebrates are also important as indicators of water quality. Changes in the composition, abundance and size structure of zooplankton and macro-invertebrate communities of Lake Victoria are correlated with predation impacts by pelagic fish communities but also with increasing eutrophication and pollution. Species composition, size structure, distribution and relative abundance of invertebrates have been examined since 1990 and results compared with historical data on collections made between the 1930s and 1960s.
Invertebrates are widely distributed in the lakes with exception of rotifers, which are more abundant in near shore areas. Copepods, their larval phase (nauplii) and dipteran larvae dominate the invertebrate communities. Historical changes have occurred involving increase in proportion of cyclopoids and decline in calanoids and cladocerans. Areal densities increase in a nearshore-offshore gradient with >4 million indiv. m^{-2} recorded offshore. Seasonal variation of abundance indicates attainment of maximum density in May-August coinciding with the annual complete mixing of the lake. Size structure of zooplankton indicates suppression of large-bodied zooplankters around nearshore areas where high pelagic fish densities occur. The population of the prawn, *Caridina nilotica* has increased tremendously in the last four decades probably in response to eutrophication of the lake and changes in fish fauna. Average net production of *C. nilotica* (11.4mgC m^{-2} g^{-1}) is an order of magnitude greater than the fishery yield, making the prawns quantitatively significant as a forage item for fishes especially the Nile perch.

Long-term changes in relative abundance of key fish food items such as calanoid and cyclopoid copepods, Cladocera, rotifers and *C. nilotica* and the occurrence of low-oxygen tolerant forms indicate deterioration of the water quality and changes in food-web dynamics. Increased relative abundance of forage items such as cyclopoid copepods and *C. nilotica* are important for sustenance of commercially important fish species, such as *Lates niloticus* and *Rastrineobola argentea*. Action must be taken to enforce existing regulations on pollution and eutrophication of water bodies so as to protect the ecologically valuable invertebrate and fishery resources.

CONCLUSIONS AND RECOMMENDATIONS

Human settlements in the numerous urban and rural centers along the shoreline enhance pollution in the inshore regions, where nutrient loads from municipal and agricultural effluents are high. In light of these observations we recommend that an effective water quality monitoring system and research be facilitated to ensure collection of accurate data and information for informed decision-making. There is need for reduction of nutrient loads and pollutant input into the nearshore areas through treatment of municipal and industrial effluents. We further recommend reduction of waste into the lake through promotion of cleaner production practices, promotion of good land-use practices in the catchment area, and conservation of the natural wetlands as well as promotion of constructed wetlands (CWs) as tertiary treatment systems for industrial and municipal effluents to include management of sources of nutrients contributing to atmospheric deposition. The communities should be sensitized with regard to benefits of sound environmental management and harmonization of policies and laws on environmental protection and management. There is need for enhancement of analytical capability necessary to address emerging issues such as algal toxins, monitoring atmospheric deposition particularly phosphorus to establish amount that originate outside the basin boundaries, monitoring atmospheric and riverine loadings of potential toxic contaminants particularly mercury which may originate from small-scale gold mining areas of Mwanza and Mara regions. There is further need for improvement of sanitary conditions in shoreline settlements and capacity for water quality management with the aim to enhance co-management of the lake waters. Finally, management should include setting water quality objectives primarily focusing on drinkability, fishability and minimization of water-borne and other water related diseases as well as harmonization of environmental policies and laws among the Lake Victoria riparian states.

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