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Management and conservation of the African Great Lakes

Lakes Victoria, Tanganyika and Malawi

Comparative and comprehensive study of Great Lakes

UNESCO/IHP-IV PROJECT M-5.1

RUUD C. M. CRUL

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Preface

Although a total amount of water on earth is generally assumed to have remained virtually constant, rapid population growth, together with the extension of irrigated agriculture and industrial development, are placing stress on the quality and quantity aspects of natural systems. Owing to the increasing problems, society has begun to realize that it can no longer follow a 'use and discard' philosophy – either with water resources or any other natural resource. As a result, the need for a consistent policy of rational management of water resources has become evident.

Rational water management should be founded upon a thorough understanding of water availability and movement. Thus, as a contribution to solving the world's water problems, UNESCO began in 1965 the first worldwide programme of studies of the hydrological cycle, the International Hydrological Decade (IHD). The research programme was complemented by a major effort in the field of hydrological education and training. The activities undertaken during the IHD proved to be of great interest and value to UNESCO's Member States. By the end of the Decade, a majority of Member States had formed IHD National Committees to carry out relevant national activities and participate in regional and international co-operation within the IHD programme. Knowledge of the world's water resources had substantially improved. Hydrology became widely recognized as an independent professional option and facilities for training hydrologists had been developed.

Conscious of the need to expand upon the efforts initiated during the International Hydrological Decade and further to the recommendations of its Member States, UNESCO launched a new long-term intergovernmental programme in 1975, the International Hydrological Programme (IHP).

Although the IHP is basically a scientific and educational programme, UNESCO has been aware from the outset of a need to direct its activities towards devising practical solutions to the world's very real problems concerning water resources. Accordingly, and in line with the recommendations of the 1977 United Nations Water Conference, the objectives of the IHP have been gradually expanded in order to cover not only hydrological processes considered in interrelationship with the environment and human activities, but also the scientific aspects of multi-purpose utilization and conservation of water resources to meet the needs of socio-economic development. Thus, while IHP's scientific concept has been maintained, its objectives have shifted perceptibly towards a multi-disciplinary approach to the assessment, planning and rational management of water resources.

The purpose of the on-going series, 'Studies and reports in hydrology', to which this volume belongs, is to present data collected and the main results of hydrological studies, as well as to provide information on hydrological research techniques. The proceedings of symposia are also sometimes included. It is hoped that these volumes will furnish material of both practical and theoretical interest to water resources scientists and to those involved in water resources assessment and planning for rational management.

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Foreword

This publication is one result of a project entitled 'Comprehensive and Comparative Study of Great Lakes (1992–1995)', part of the fourth phase (1990–1995) of the International Hydrological Programme run by UNESCO's Division of Water Sciences (UNESCO/IHP–IV Project M-5.1). The African Great Lakes Working Group of the International Limnological Society (SIL) collaborated with UNESCO on implementing the various project activities.

The project's overall objective was to bring together the knowledge gained over the past 15 years on the limnology and hydrology of the African Great Lakes Tanganyika, Malawi and Victoria, as a contribution to the overall aim of the UNESCO IHP–IV M-5 project of preparing material on hydrological, ecological and water management problems encountered in shared water bodies. A comprehensive, comparative study has been made in two earlier monographs on the individual lakes of Victoria (Crul, 1995), Tanganyika and Malawi (Crul, 1997), while the present publication focuses on the management and conservation of these same lakes.

The role of limnological and hydrological research in addressing the management and conservation of these major inland water bodies is highlighted in these three monographs. The comparative limnology and hydrology of the three lakes are discussed and an integrated approach is elaborated. Together with the workshop held in December 1995 in Entebbe, Uganda, on the Water Balance of East Africa, the three studies in this series may form the basis for a consensus on the hydrological and limnological descriptions of these international water systems. Consequently, it should be easier for the riparian countries to reach agreement on the use, development, planning and management of these lakes.

Acknowledgements

The author wishes to extend his thanks to all those who assisted in and facilitated the preparation of the present study. He thanks Bob Hecky, Andy Cohen and Sharon Nicholson for providing him with copies of their manuscripts for the Proceedings of the International Decade for the East African Lakes (IDEAL) Symposium, which were published in 1996.

Special thanks go to Frits Roest, Rosemary Lowe-McConnell, Bob Hecky and George Coulter of the African Great Lakes Group of SIL and to Habib Zebidi of UNESCO's Division of Water Sciences for their support, discussion and advice in the course of preparing this report.

Correspondence on the present report is to be addressed to:

R. C. M. Crul
Crul Consultancy
Muchterstraat 34
6511 TX Nijmegen
Netherlands
Tel. +31.24.3602405
Fax. +31.24.3606455
e-mail address: ruudcrul@dds.nl

1 Water as a renewable resource

Water is an absolute necessity not only for human beings, but also for the plants and animals on which they depend. Water provides people with food, in the form of fish, and with a means of transport; it is a key element of agriculture and energy production. In addition, adequate water resources are one of the necessary factors for economic development, as water plays an important role in various sectors of society.

Freshwater is a renewable resource made available by the constant flow of solar energy to the earth. Water evaporates from the oceans and the land and is redistributed around the world. There is a continuous flow of freshwater to the land because more water evaporates from the oceans than falls on them. Recent estimates of the flows of the global water cycle are given in Table 1.1. Of the total amount of precipitation on the land (119,000 km^3) about 40% (47,000 km^3) reaches the oceans as river discharge. Were this water supply to be evenly divided among all human beings on earth, each person would receive 8,000 m^3.yr^{-1}. Even this amount would not be sufficient to satisfy all domestic, industrial and agricultural demands.

Estimates of the world water stocks (which are only rough approximations of the actual values) by Shiklomanov (1993) show that the total volume of freshwater stocks amounts to 35 million km^3 or about 2.5% of the total stock of water on earth (1,385 million km^3). A large fraction of freshwater exists in the form of ice and snow in the Arctic and Antarctic regions (24 million km^3 or 68.7% of total freshwater reserves) and groundwater (10.5 million km^3 or 30% of total freshwater reserves).

Lakes and rivers contain only about 93,000 km^3 or 0.26% of total freshwater reserves. This water, however, forms the bulk of the usable supply, as hardly any freshwater reserves are easily accessible. Distribution of this usable water is concentrated in a number of large, deep lake basins, which account for approximately 85% of the volume and 40% of the water surface of all freshwater lakes. The creation of reservoirs has contributed to the use and storage of freshwater resources and the control of river flow. A list of the largest freshwater lakes and reservoirs in the world showing the main morphometric data is given in Table 1.2.

Table 1.1 Flows of the global water cycle (in km^3.yr^{-1})

	Berner and Berner, 1987	*World Resources Institute, 1988*	*Shiklomanov, 1993*
Evaporation from land	72,900	63,000 –73,000	72,000
Precipitation on land	110,300	99,000–119,000	119,000
Evaporation from the ocean	423,000	383,000–505,000	505,000
Precipitation on the ocean	385,700	320,000–485,000	485,000
Runoff from land to ocean	37,400	33,500–47,000	47,000

Table 1.2 Large lakes and reservoirs of the world

Lake/ Reservoir	*Countries*	*Surface area (km^2)*	*Volume (km^3)*	*Maximum depth (m)*	*Drainage[1] area (km^2)*	*Key sources*
Superior	Canada, USA	82,100–83,300	11,600–12,230	406	127,700	1
Victoria[1]	Uganda, United Republic of Tanzania, Kenya	68,800	2,700	84	263,000	2
Huron	Canada, USA	59,500–59,800	3,537–3,580	229	133,900	1
Michigan	USA	57,016–58,100	4,680–4,920	285	118,100	1
Tanganyika	Burundi, Zambia, United Republic of Tanzania, Democratic Republic of the Congo	32,600	18,800	1,470	249,000	3
Baikal	Russia	31,500	23,000	1,637	540,000	1
Great Bear	Canada	30,200–31,792	1,010–2,381	445	146,000	1
Malawi	Malawi, United Republic of Tanzania, Mozambique	28,800	8,400	700	97,700	4
Great Slave	Canada	27,200–28,570	1,070–2,088	614	971,000	1
Erie	Canada, USA	25,657–25,720	483–545	64	58,800	1
Bratsk [r]	Russia	5,100	169	–	–	1
Nasser/ Nubia [r] [2]	Egypt, Sudan	6,216	157	130	2,400,000	5
Kariba [r]	Zimbabwe, Zambia	5,364	156	120	823,200	6
Volta [r]	Ghana	8,270	165	74	394,000	7

1. The lake itself is not included.
2. All data are for 180 m.

[r] reservoir.

Sources: 1. Gleick, 1993*a* ; 2. Crul, 1995; 3. Crul, 1997; 4. Crul *et al.*, 1995; 5. Rashid, 1995; Vanden Bossche and Bernacsek, 1990*a* ; 6. Vanden Bossche and Bernacsek, 1990*a*; 7. Vanden Bossche and Bernacsek, 1990*b*.

The biggest lakes by surface area are the Laurentian Great Lakes in North America, of which Superior, Huron and Michigan are the largest, the African Great Lakes of Victoria, Tanganyika and Malawi, and Lake Baikal in Russia. Lakes Baikal, Tanganyika and Superior are by far the greatest in volume. Global runoff by rivers is unevenly distributed by continent, as more than half of it occurs in South America and Asia (56%). Runoff is also unevenly distributed throughout the year, as most of it occurs in the flood periods.

In recent decades, global water resources have been increasingly affected by man. Human population growth and economic activities have led to decreases in per-capita water availability and surface runoff, a decrease in water levels of interior, closed water bodies (e.g. the big drop in water level of the Aral Sea owing to extensive withdrawals of water for irrigation) and pollution of surface water in densely-populated regions of the world. Next to these anthropogenic factors, natural fluctuations in climate may also affect water resources and runoff, e.g. the decrease in the water level of Lake Chad caused by the severe drought in the early 1970s in the Sahel region. Analyses of the water supply in different regions of the world from 1950 to the present day have revealed that, in many regions, per capita water supply decreased sharply between 1950 and 1980 and it is anticipated that, by the end of the twenty-first century, the water supply will have shrunk farther in many regions of the world (Shiklomanov, 1993).

The shortage of water is already a serious problem in a number of the world's arid regions (e.g. Sahel, Central Asia and Kazakstan, North China and Mongolia), but it is the quality of water that may be the greatest cause for concern in most countries. The highest quality is required for drinking water, with water of progressively lesser quality being needed for recreational activities (like swimming), industrial use and agriculture (irrigation). Although some cases of anthropogenic pollution on a global scale do exist, most problems to do with the quality of natural water occur on a local and, increasingly, regional scale.

In developed countries, industrial and agricultural effluents contaminating surface waters are the main concern; they pose cumulative and chronic health risks to human beings and aquatic life. In developing countries, microbiologic contamination results in outbreaks of water-related diseases while, more recently, industrial and agricultural development has caused chemical pollution. The main challenge to water quality is rapid population growth and urbanization, resulting in the overloading of water and sanitation infrastructure and a deteriorating standard of living in fast-growing cities. Only part of the urban population has access to sewage and waste collection systems, and to adequate quantities of safe drinking

BOX 1.1: WATER AND POLLUTION: THE CASE OF THE BLACK SEA

Domestic, agricultural and industrial effluents of more than 16 countries enter the Black Sea via the two largest rivers in Europe, the Danube and the Djnepr, and some 300 smaller rivers. The water quality of these rivers has deteriorated in recent decades and the Black Sea has become a reservoir of wastewater, heavy metals, pesticides and other toxic and persistent chemicals originating from the 160 million people living in its drainage area. The Danube alone carries 60,000 tonnes of phosphorus, 1,000 tonnes of chrome, 900 tonnes of copper, 60 tonnes of mercury, 4,500 tonnes of lead, 6,000 tonnes of zinc and 50,000 tonnes of oil to the Black Sea. Water in the Djnepr contains pesticides and insecticides used in agriculture in its catchment. The inflow of nutrients into the Black Sea upsets the balance of the ecosystem. Invasions by non-endemic organisms have been coupled with a change in the composition of the fish fauna and the food web structure. The commercial fisheries of the Black Sea collapsed between 1986 and 1992, shrinking from 900,000 tonnes to approximately 100,000.

Data from Global Environment Facility (GEF) Black Sea Project.

water. Almost all domestic wastewater is discharged directly into receiving surface waters without treatment. Along with population growth, industrial development places pressure on scarce water resources in developing countries. Water quality is threatened by the rise in uncontrolled chemical contamination of surface waters through industrial effluents (see Box 1.1) and by a greater risk of accidents, as occurred in Bhopal, Chernobyl and Alaska. Water quality problems like sedimentation and eutrophication, caused by agricultural activities, will continue. In the future, problems will increasingly be related to contamination of surface and groundwater by chemicals and pesticides. The extremely toxic and persistent organochlorine pesticides, such as dichlorodiphenyltrichloroethane (DDT), aldrin and lindane, are still used in many developing countries despite their having been banned for decades in most industrialized countries. Large-scale changes in land use (e.g. deforestation and conversion of wetlands, grasslands and savannas) have contributed to greater erosion and sediment loading, eutrophication and pollution. Lastly, water supply and hydro-electric power generation projects may affect water quality (Ackermann *et al.*, 1973; Stanley and Alpers, 1975). Reservoirs and irrigation projects may contribute to greater eutrophication, an increase in water-borne diseases, loss of fish production and salinization of land and water (see also Box 1.2).

Today, agriculture accounts for two-thirds of global water use. Global food security depends mainly on the essential link between crops and water. In the twentieth century – during which the world population has more than doubled and the irrigated area has more than quadrupled from 50 million hectares to over 235 million hectares – irrigation has become of vital importance to global food security. One-third of the world's food production comes from an irrigated 16% of the world's cropland (Postel, 1993).

Since the late 1970s, the steady expansion in irrigated area has slowed markedly to the point where it has fallen behind population growth, resulting in a decreasing per-capita irrigated area. The slowdown was primarily caused by low commodity prices, high energy costs and the worldwide economic situation in the 1980s. Today, several factors are responsible for a more modest increase in irrigated area. Funds for irrigation contributed by international donors have declined over the past decade and the costs of adding irrigated area have been rising in many countries, the best sites for water development being exploited already.

In Africa, less than 5% of cropland is irrigated (Scudder, 1989). Developing a fresh irrigation capacity will be difficult and expensive in parts of Africa owing to the lack of roads and other infrastructure , the seasonality of river flows and the fact that agriculture is often practised on small parcels of land (Postel, 1993).

For the future, the contribution of irrigation should therefore come more from improving the existing systems than from new irrigation area. Irrigation performance and quality is generally low

BOX 1.2: WATER AND AGRICULTURE: THE CASE OF THE ARAL SEA

In 1954, the Aral Sea was sacrificed with the construction of the Kara Kum irrigation canal. This was the start of the destruction of a mighty inland sea. To grow cotton and other crops, the Kara Kum canal and other diversions built in the past 30 years tap almost 100% of the water from the two inflowing rivers, the Amu Dar'ya and the Syr Dar'ya. Coming down from the mountain ranges in the Southeast, these rivers used to feed the Aral Sea annually with 53 km^3 of water. Diverting the water has caused a drop in the level of the Aral Sea since 1960 of more than 15 m, reduced its surface area by 40% (from 68,000 km^2 to 40,000 km^2) and its volume by 65%. This has led to the economic collapse of the region and a myriad of health problems (caused by the uncontrolled use of pesticides, polluted drinking-water supplies and salt dust blowing off the dry seabed) affecting over 35 million people. What remained has become too saline to support any of the 24 endemic fish species that were once present in its water. Salinity has tripled since 1960 and the important commercial fisheries have collapsed completely. Winds dump annually 43 million tonnes of salt from the dry seabed on the surrounding cropland.

Sources: Micklin, 1988; Ellis, 1990.

because of lack of maintenance, poor water management and inequities of water distribution. Securing water and reducing overuse can be achieved by improving irrigation efficiency of current irrigation systems and further development of new systems as e.g. sprinkler and drip irrigation. Other measures may also contribute to secure water, as better management of the 84% of non-irrigated cropland, integration of modern water management with traditional agriculture, restoration of deforested watersheds and development of new strains of salt tolerant and drought-resistant crops (Postel, 1993).

Although irrigation has greatly expanded the world food output, it has had a profound impact on global water bodies and irrigated cropland. Negative environmental effects of irrigation include destruction of aquatic habitats, shrinking lakes and inland seas (see Box 1.2), contamination of land and water by salts and toxic metals, and disappearance of local crop and fish production systems.

Energy and water are closely connected. Water is required for energy production and use, while energy is used for water transportation and pumping, production (e.g. desalination) and purification. The amount of water needed to produce energy depends on the type of production facility and fuel characteristics: nuclear and fossil fuel power plants use large amounts of water for cooling, while such renewable energy sources as wind and solar energy production systems require only minimal amounts. Data on consumptive water use for energy and electricity production are given by Gleick (1993*b*). Hydroelectric power generation is an evident example of the use of water for energy production. Half of the global hydro-electric capacity is installed in North America and Western Europe, as compared to only 3% in Africa (Gleick 1993*b*). Hydroelectric facilities and reservoirs have a wide range of direct and indirect adverse effects on freshwater, terrestrial and marine ecosystems, both in temperate and tropical regions (Ackermann, *et al.*, 1973; Baxter, 1977; Petr, 1978; Beadle, 1981; White, 1988).

A substantial portion of accessible global freshwater resources is contained in international lakes and rivers. The use of these shared water bodies and associated drainage basins has often given rise to dispute between states. McCaffrey (1993) presented a number of controversies concerning international rivers. Currently, numerous treaties regulate the utilization of shared water resources, although international agreements are often inadequate or even completely lacking. An inventory of treaties concerning international water bodies and basins listed over 2,000 agreements, most of which were bilateral (FAO, 1978).

Multilateral agreements cover four European water bodies (the Rhine, Mosel and Danube Rivers and Lake Constance), two South American (La Plata Basin and Amazon River) and six African water bodies (Niger Basin, Lake Chad Basin, Kagera Basin, Zambezi River system and the Senegal and Gambia Rivers) (McCaffrey, 1993).

Most treaties on shared water resources reflect two basic principles: equitable utilization and the obligation not to cause harm to other riparian countries. Legislation to be developed (by international legal organizations) will play an important role in resolving existing and future conflicts over shared water resources. The key to peaceful resolution of water conflicts lies in communication between the countries concerned and in international commissions at a technical level preferably (McCaffrey, 1993).

Population growth will play an essential role in water issues in the future. In the fifty years to 2000, the world population will have climbed from 2.5 billion to over 6 billion. Over 90% of population growth in coming decades will occur in developing countries with rates above 3% in some parts of Africa, Asia and the Middle East. With fixed freshwater resources and a rapidly growing population, the amount of per-capita water available will drop continuously. By the end of this century, six countries in East Africa (Burundi, Ethiopia, Kenya, Rwanda, Somalia and the United Republic of Tanzania) will be experiencing water stress as annual supplies approach 2,000 m^3 per capita (Falkenmark, 1989). Egypt is almost entirely dependent on the Nile River for water. The Nile receives its water from headwaters in other East African countries. Increasing water demands in these countries will result in a diminished supply downstream in Egypt. In more than 30 of these countries lying upstream, the per-capita water availability will have fallen below 1,000 m^3 by 2025 because of population growth predominantly in Asia and Africa. In Africa, some of those countries are associated with the African Great Lakes: Burundi, Egypt, Kenya, Rwanda and the United Republic of Tanzania (Gleick, 1993*a*). In regions experiencing rapid population growth and urbanization, water shortages will spark competition between cities and farms. Global climatic changes will further complicate future water resources management.

To overcome anticipated problems of water availability and quality, new adaptive approaches to water management will have to be introduced. These will include, apart from the necessary political will to take action: collection and sharing of basic water resources data, especially at a regional level; proper evaluation of scarce resources like water; frameworks for flexible local, regional, national and international laws and customs on water use; more efficient water use; new sustainable water development; application of traditional water management experience and a reduction of the risk of water-related conflicts (Gleick, 1993*c*). Sustainable management of freshwater resources in the future will require an ecosystem approach that takes into account all interrelations among water, air and land, and all biota, including man.

2

The water resources of the African Great Lakes

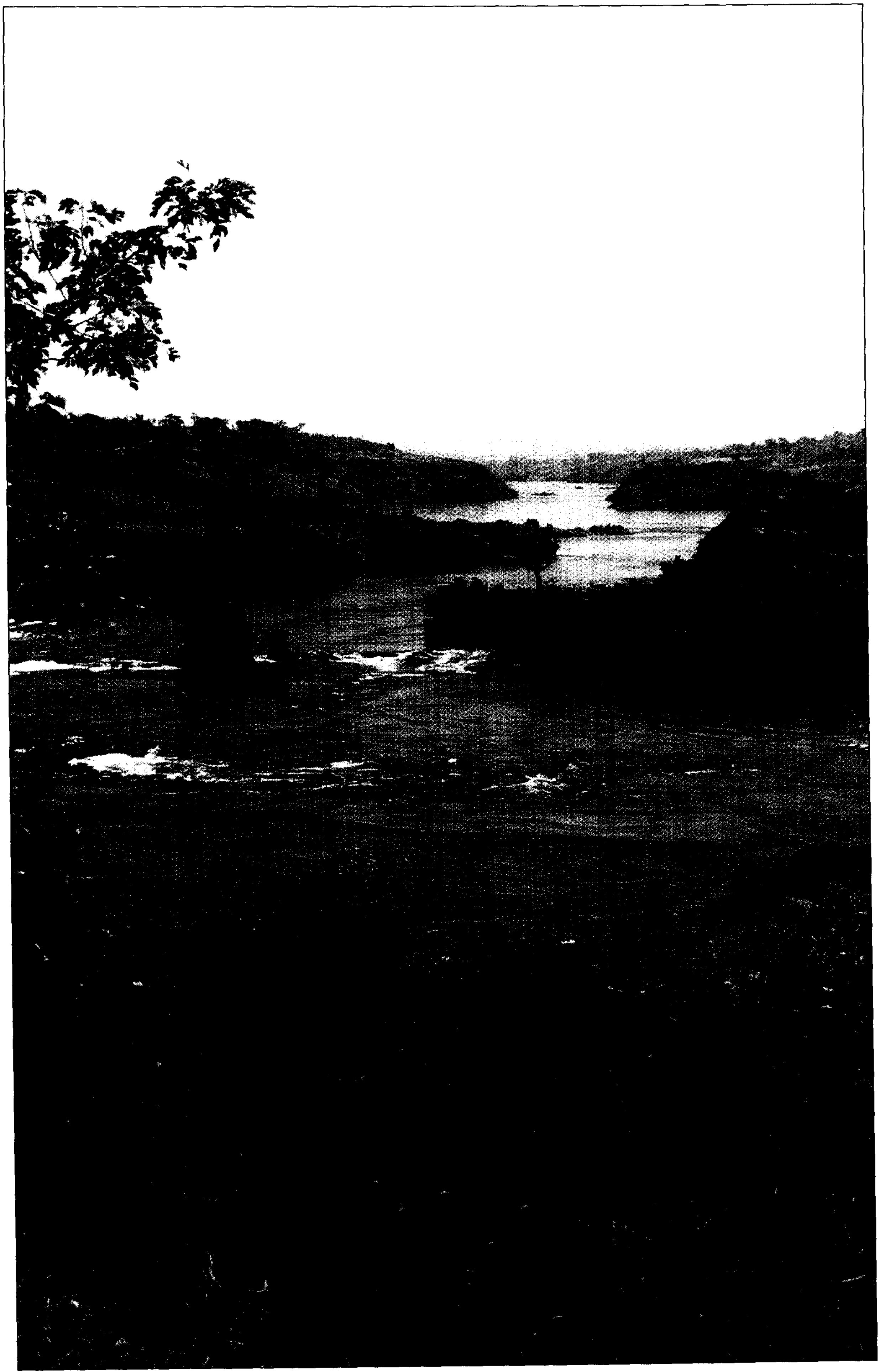
Lakes Tanganyika, Malawi and Victoria make up part of three large international river basins in sub-Saharan Africa. While Lake Victoria is the headwater of the Nile River, the Lake Tanganyika outlet flows into the Congo River and Lake Malawi feeds the Zambezi River. The main characteristics of these river basins and other river systems around the world are given in Table 2.1. Together with the Lake Chad and Niger-Benue River Basins, these river basins each have a catchment area larger than 1,000,000 km^2. The Nile and Congo River Basins are both shared by nine countries and the Zambezi River Basin by eight countries (Vanden Bossche and Bernacsek, 1990*a*).

Most large rivers in sub-Saharan Africa have some characteristics in common. Marked seasonal and annual fluctuations in rainfall predominantly concentrated in the mountainous upper reaches of the river systems cause wide variations in both seasonal and annual flows in the river systems. The main stretches and larger tributaries of these river systems are widely spaced, resulting in limitations on water use for domestic, agricultural and industrial purposes. In general, the water quality is high, salinity and pollution being low. The irrigation potential is relatively limited in relation to the size of the continent and opportunities for water resource development on the main stretches of the sub-Saharan rivers will require enormous investment, consensus and collaboration (Rangeley *et al.*, 1994).

2.1 THE NILE RIVER SYSTEM

Lake Victoria is one of the longest rivers in the world (Figure 2.1). It drains an area of more than 3,000,000 km^2 in nine countries (Table 2.1) and flows into the Mediterranean Sea. It is composed of the White and Blue Nile Rivers, which join in Khartoum, Sudan. The Nile River itself has one main tributary, the Atbara River, which has its source in Ethiopia. The Blue Nile (named Abay River in Ethiopia) has its source in a little spring called Gilgel Abay (Little Blue Nile), from which a small stream flows into Lake Tana in the Ethiopian mountains (Woube, 1994). The White Nile originates in the highlands of Burundi and Rwanda and flows as the Kagera River into Lake Victoria. The White Nile changes name several times in its course to the confluence with the Blue Nile. The first part between Lakes Victoria and Albert is known as the Victoria Nile; from Lake Albert to the border with Sudan, it is called the Albert Nile and in Sudan the White Nile or Bahr el Jebel (TECCONILE, 1995*a*). In Sudan, the White Nile flows through an extensive wetland, the Sudd Swamp, and has an important tributary, the Sobat River originating in and draining the Ethiopian highlands. The Sudd Swamp has a permanently inundated area ranging from between 3,000 km^2 and 16,500 km^2 and a seasonal floodplain ranging from between 11,000 km^2 and 15,500 km^2. The Sudd Swamp has two main inflowing rivers, the White Nile (Bahr el Jebel) and the Bahr el Ghazal (TECCONILE, 1995*a*).

The hydrology of the Nile is characterized by the two main sources of the Nile:



Photograph 2.1 The Victoria Nile to the north of Jinja, Uganda (photograph by R. C. M. Crul).

- the relatively steady flow of the White Nile buffered by Lakes Victoria and Albert and by the Sudd Swamps and augmented by the seasonal floods of the Sobat River in October–November; and
- the seasonal Nile floods of the Blue Nile and the Atbara River in July–August due to the rainfall in the Ethiopian mountains (Beadle, 1981).

About 85% of the annual discharge of the River Nile comes from the Blue Nile, Sobat and Atbara Rivers, the remainder originating from the East African headwaters of the White Nile (Woube, 1994). Buffering of the flows of the Nile River has been accomplished by a number of dams: the Roseires and Sennar reservoirs in the Blue Nile in Sudan, the Khashm el Girba Reservoir in the Atbara River in Sudan, the Jebel Aulyia reservoir in the White Nile and Nasser/Nubia Reservoir in the Nile River in Egypt/Sudan (Vanden Bossche and Bernacsek, 1991). The Sennar Reservoir has been constructed for irrigation purposes in an area south of Khartoum (Gezira Cotton Scheme) and the Roseires Reservoir for both irrigation (Gezira and Kenana Schemes) and power generation. The annual reservoir Jebel Aulyia has been constructed to regulate the flow of Nile water into Egypt by holding the water of the White Nile in July and August when the floods of the Blue Nile enter the Nile River (Beadle, 1981). Egypt and Sudan have been using water from the Nile for several millennia and this century both states started to create

Table 2.1 Main characteristics of the largest river basins in Africa and on other continents

Name of basin	*River length (km)*	*Catchment area (x 10^3 km^2)*	*Avg. discharge ($m^3.s^{-1}$)*	*Countries sharing catchment area*
AFRICA				
Congo	4,370–4,700	3,822–4,015	39,200–42,000	Democratic Republic of the Congo, Central African Republic, Angola, Zambia, United Republic of Tanzania, Cameroon, Congo, Burundi, Rwanda
Nile	6,484–6,670	2,881–3,000	1,584–2,830	Sudan, Ethiopia, Egypt, Kenya, United Republic of Tanzania, Uganda, Burundi, Democratic Republic of the Congo, Rwanda
Zambezi	2,650–3,500	1,295–1,340	2,500–7,100	Zambia, Angola, Zimbabwe, Mozambique, United Republic of Tanzania, Malawi, Botswana, Namibia
Niger-Benue	4,030–4,200	1,114–1,125	5,700–6,100	Mali, Nigeria, Niger, Algeria, Guinea, Chad, Cameroon, Benin, Côte d'Ivoire, Burkina Faso
Lake Chad basin[1]	1,400–1,450[2]	1,900–2,427		Chad, Cameroon, Niger, Central African Republic, Nigeria, Sudan (main inflowing river: Chari)
OTHER CONTINENTS				
Amazon	6,280–6,570	5,578–7,180	175,000–212,000	Brazil, Peru, Bolivia, Columbia, Ecuador, Venezuela, Guyana
La Plata	4,700–4,880	2,650[3]	19,500[3]	Brazil, Argentina, Paraguay, Bolivia, Uruguay
Mississippi	3,731–3,779	3,222–3,267	17,545–18,400	USA, Canada
Colorado	2,180–2,300	600–629	580[3]	USA, Mexico
Danube	2,850–2,860	805–817	6,200–6,450	Romania, Slovenia, Croatia, Serbia, Bosnia/Hercegovina, Hungary, Albania, Italy, Austria, Czech Republic, Slovakia, Germany, Ukraine, Poland, Bulgaria, Switzerland
Rhine	1,320–1,392	145–220	2,200[3]	Germany, Switzerland, France, Netherlands, Liechtenstein, Austria, Luxembourg, Belgium
Mekong	4,180–4,500	795–803	11,000–18,300	China, Laos, Myanmar, Thailand, Cambodia, Vietnam
Lena	4,270–4,400	2,430–2,490	16,300–16,400	Russia

1. Inland drainage basin.
2. length of the inflowing Chari River.
3. only one estimate available.

Note: The estimates of the above morphometric characteristics differ significantly due to different interpretations of where a river commences and different measurement locations, periods and/or methods. For example, a high estimate of discharge for the Nile River was measured prior to major irrigation schemes.

Sources: Gleick, 1993*a*; Vanden Bossche and Bernacsek, 1990*ab*; Horne and Goldman 1994; Rangeley *et al.*, 1994.

large reservoirs for irrigation and power generation purposes. To date, the states in the Upper Nile Basin have not significantly used the water resources of the Nile. There are no dams or hydro-electric power installations and almost no land under irrigation in the Blue Nile system in Ethiopia (Woube, 1994).

A number of agreements concerning the flow of the Nile River or various parts of the basin have been signed since 1891 (the most recent one in 1993), but none of them include all basin states or apply to the basin as a whole (McCaffrey, 1993), nor do any include Ethiopia (Woube, 1994). The most important agreements signed have been between Egypt and Sudan; the 1959 treaty allocated all water to Egypt and Sudan, excluding the remaining seven countries (McCaffrey, 1993).

As soon as the upper basin states start to develop their sections of the Nile River system, Egypt will have to share the allocated water resources of the Nile with them. Management of the water resources of the Nile clearly needs a joint commission with the participation of all basin states and negotiations will be necessary in the coming decades. Solutions to Egypt's future water problems will involve storage and projects in the other basin countries. The most important increase in water flow would come from the planned Jonglei Canal project. This canal would cut off a bend of the White Nile and bypass the Sudd Swamp, reducing the amount of water lost through evaporation. The proposed diversion has given rise to concern that the canal would destroy the livelihood of the native peoples of the Sudd. Further decreases in flow could result from irrigation projects in the upper basin states.

2.2 THE ZAMBEZI RIVER SYSTEM

The outlet of Lake Malawi, the Shire River, flows into the Lower Zambezi River some 150 km before it flows into the Indian Ocean. The Zambezi River crosses a number of plains which are flooded seasonally and has sections of rapids and falls of which the Victoria Falls on the border of Zambia and Zimbabwe are the most famous (Figure 2.1). The river has a great number of tributaries, of which the most important are the Cuando River, joining the upper Zambezi just upstream of the Victoria Falls, the Kafue and Luangwa Rivers flowing into the Middle Zambezi and the Shire River. The river drains an area of 1,300,000 km^2 in eight countries (Table 2.1). The Zambezi River floods occur in the period December–July with a maximum in March.

Several major reservoirs were created in the Zambezi River system: the Kariba Reservoir on the Zambezi River, 45% of which lies in Zambia and 55% in Zimbabwe; the Cahora Bassa Reservoir in Mozambique, also on the Zambezi river; and the Kafue Gorge and Itezhitezhi Reservoirs on the Kafue River in Zambia. All these reservoirs are used for power generation. On the Hunyani River, a tributary of the Middle Zambezi in Zimbabwe, the two small reservoirs of McIlwaine and Robertson (Darwendale) have been created to supply water to Harare, the capital (Vanden Bossche and Bernacsek, 1991).

Zambia and Zimbabwe have a bilateral river basin organization, the Zambezi River Authority, to operate, monitor and maintain the Kariba Dam complex and to study and construct new dams on the Zambezi River (Rangeley *et al.*, 1994).

2.3 THE CONGO RIVER SYSTEM

Lake Tanganyika's outflowing river, the Lukuga, flows into the Lualaba River, which changes its name to Congo River at Kisangani. The longest continuous stream is: Chambezi River, Lake Bangweulu, Luapula River, Lake Mweru, Luvua River, Lualaba River and Congo River, which flows into the Atlantic Ocean (Figure 2.1). The Congo River has a great number of tributaries covering a drainage area of over 4,000,000 km^2 in nine countries (Table 2.1). It has two flood periods, one in May and one in December. Within its drainage area lie a number of lakes, including Lakes Tanganyika, Mweru, Kivu, Bangweulu, Upemba, Tumba, Maji Ndombe and Pool Malebo and three floodplain areas, Luapula/Kifakula Depression, Lualaba/Kamalondo Depression and Mbandaka flooded forests. Only two relatively small reservoirs have been created in the Congo River system: Mwadingusha (Lufira) Reservoir on the Lufira River and Nzilo Reservoir on the Lualaba River. Both reservoirs are located in the extreme southern part of the drainage area (Figure 2.1).

2.4 THE AFRICAN GREAT LAKES

Lakes Victoria, Tanganyika and Malawi are important freshwater reservoirs in their respective river systems. The lakes are by far the greatest in Africa and are shared between different countries: Lake Victoria lies between Uganda, Kenya and the United Republic of Tanzania; Lake Tanganyika between the Democratic Republic of the Congo, the United Republic of Tanzania, Zambia and Burundi; and Lake Malawi between Malawi, Mozambique and the United Republic of Tanzania. The United Republic of Tanzania is therefore the only country which borders all three lakes. Lakes Tanganyika and Malawi are both situated in the Western Rift Valley, while Lake Victoria occupies a shallow basin between the Eastern and Western Rift Valleys. Key characteristics of the lakes are given in Table 2.2. More detailed information can be found in the individual monographs (Crul, 1995; 1997; Crul *et al.*, 1995).

In addition to their scientific and aesthetic value, the lakes are important sources of food and income for the populations of the riparian countries; they are used for: (1) supplying water for domestic, industrial and agricultural purposes, (2) supplying energy; (3) transportation, (4) fisheries and (5) tourism.

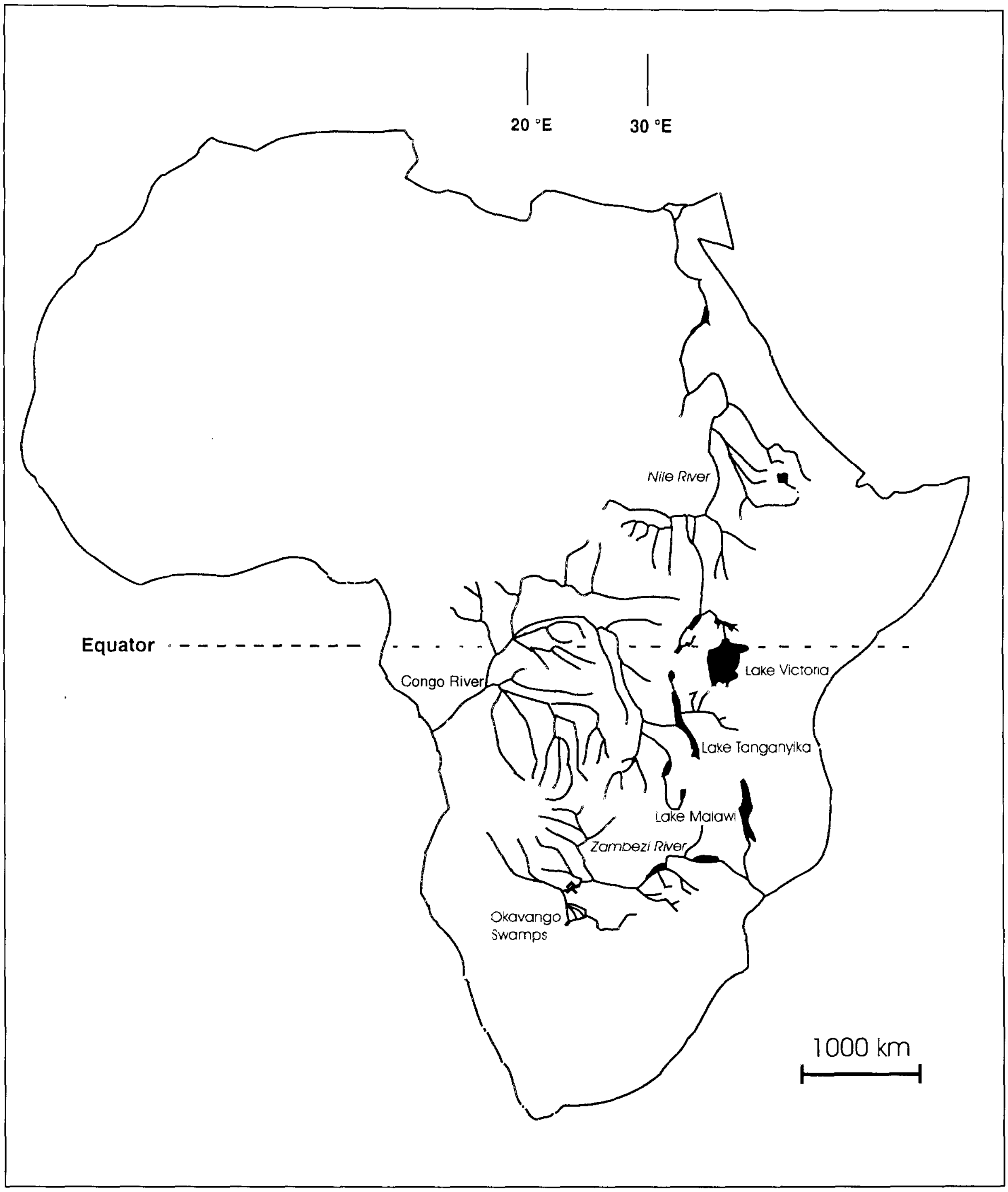


Figure 2.1 Map of Africa showing the three river systems associated with the African Great Lakes.

Table 2.2 Main characteristics of Lakes Victoria, Tanganyika and Malawi

	Lake Victoria	*Lake Tanganyika*	*Lake Malawi*
Surface area (km2)	68,800	32,600	28,800
Catchment area (km2)	194,200	249,000	97,700
Volume (km3)	2,760	18,800	8,400
Shared by	Kenya, Uganda, United Republic of Tanzania	Burundi, Democratic Republic of the Congo, United Republic of Tanzania, Zambia	Malawi Mozambique, United Republic of Tanzania
Population in lake basin (millions in mid-1990s)	27.7	6.2	5.5
Urban population (as % of total)	7	12	7

Sources: Crul, 1995; 1997; Crul *et al.*, 1995; data on population from Cohen *et al.*, 1996.

2.4.1 Water supply

All three lakes are important resources of freshwater for those living in the vicinity of the lake. Together with Lakes Kyoga and Albert, Lake Victoria forms an estimated reservoir of 3,200 km^3 of freshwater (Kite, 1981). Lake Victoria's sole outlet is the Nile River, which leaves the lake near Jinja (Uganda), flows through Lakes Kyoga and Albert, and contributes on average 14% of flow in the combined White and Blue Niles as measured at Aswan (Hurst, 1952). The Nile River is of great importance for the water supply of Sudan and Egypt. Lakes Tanganyika and Malawi are important sources of drinking water for their riparian population. Water from Lake Victoria is used for irrigation in all three riparian countries. For irrigation purposes, water is diverted from major affluents of Lake Malawi, such as the Dwangwa and Bua Rivers (Tweddle, 1992).

2.4.2 Energy supply

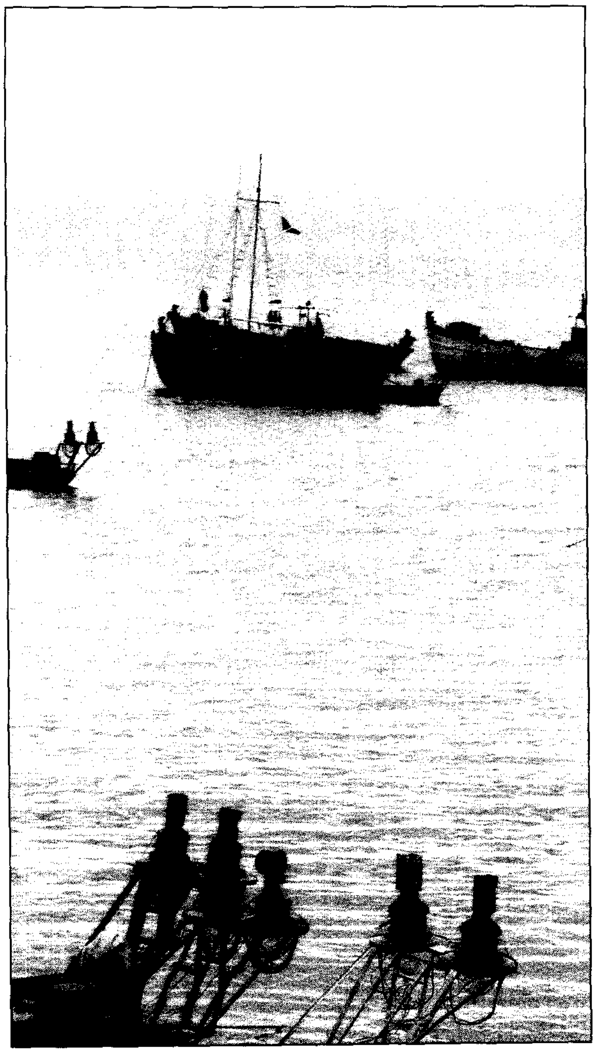
Since 1954, hydro-electric power has been produced at the Owen Falls Dam at the outlet of Lake Victoria near Jinja. With a capacity of 150,000 kW, the station works on the run of the river principle (Kite, 1981). One minor power installation is the Kikagati plant on the Kagera River, the largest tributary of Lake Victoria. In Malawi, hydro-electric power stations on the Shire River are used for electricity generation.

2.4.3 Transportation

The lakes constitute important avenues of transportation for the riparian countries, especially Lake Tanganyika where most roads in the lake region are tangential to the lake. Lake Victoria serves as a link between the northern railway network in Kenya and Uganda and the southern one in Tanzania.

2.4.4 Fisheries

Artisanal fisheries and post-harvest activities are important in and around all three lakes. Lakes Victoria, Tanganyika and Malawi produce 400,000 tonnes, 160,000 tonnes and 40,000 tonnes respectively. Industrial fisheries exist only on Lake Tanganyika. The traditional fisheries of Lake Victoria witnessed a rise in production of table fish from 44,000 tonnes to 405,000 tonnes between 1975 and 1989, owing to the introduction of the exotic tilapias and Nile perch. In Kenya, a new industrial, large-scale fishing trade with the export of fillets to overseas markets has developed in the last decade and complements the traditional local, small-scale fishing trade; similar developments are under way in Uganda and Tanzania. Fish from Lake Tanganyika constitute a very important source of food for inhabitants of the 'copperbelt' in Zambia and the Democratic Republic of the Congo, some 1,000 km distant from the lake.



Photograph 2.2 Industrial fishing boats (purse seiners) along the Burundian shore of Lake Tanganyika (photograph by R. C. M. Crul).

2.4.5 Tourism

The African Great Lakes have a considerable potential for tourism. The rift lakes boast beautiful beaches and scenery, while the clear water provides excellent opportunities for snorkelling and scuba diving.

All lakeshores are rich in bird species and other wildlife. Several national parks are located in the vicinity of the lakes. Some of these include parts of the lake(shore): the Lake Malawi National Park located near the southern end of the lake (Bootsma, 1992) and the four existing national parks along the shores of Lake Tanganyika: the Ruzizi River National Park in Burundi, the Gombe Stream National Park and Mahale Mountains National Park in the United Republic of Tanzania and the Nsumbu National Park in Zambia (Coulter and Mubamba, 1993). These existing national parks and any new ones near the lakes may attract tourists. The lakes provide opportunities for angling, especially Lakes Victoria and Tanganyika with their Nile perches. Visits to the African Great Lakes can be incorporated into existing tours to the well-known game reserves in the countries bordering the lakes.

2.4.6 Scientific value

In addition to the above-mentioned economic benefits, the African Great Lakes are of high scientific value, especially to evolutionary research. The lakes' biodiversity is exceptional with remarkable endemism, even though Lake Victoria's biodiversity has been severely reduced.

2.5 THE LAURENTIAN GREAT LAKES

The Great Lakes in Africa are not the only group of large freshwater lakes in the world; there are also the Laurentian Great Lakes in North America (Figure 2.2). These five North American Lakes collectively form the largest continuous body of freshwater in the world, with a surface area of more than 245,000 km^2.

The basins of the Laurentian Great Lakes were formed by glacial action in contrast to the tectonic basins of the African Great Lakes. Successive retreats and advances of the Wisconsin Ice Sheet beginning some 15,000 years ago formed the basins of the five lakes while, after the retreat of the ice sheet, upwarping of the earth's crust contributed to their present shapes. Water flows from west to east from the highest lake, Superior, into Lake Huron. The waters from Lakes Huron and Michigan flow into Lake Erie and, via Niagara Falls, into Lake Ontario, the lowest lake in the chain. The outflow from Lake Ontario, the Saint Lawrence River, flows into the Atlantic Ocean.

2.6 LAKE BAIKAL

With a maximum depth of 1,637 m (Martin, 1994), Lake Baikal is the deepest lake in the world and contains the world's largest volume (23,000 km^3) of freshwater, which represents approximately 20% of the earth's unfrozen fresh surface water. The crescent-shaped lake has a surface area of 31,468 km^2 and about 1,963 km of shoreline. In terms of surface area, it is the largest freshwater lake on the Eurasian continent and the seventh-largest in the world. The lake is about 636 km long and varies in width from about 25 km to 80 km (Figure 2.3).

Lake Baikal is fed by the Selenga, Barguzin and Angara Rivers and by more than 300 mountain streams. From its catchment (540,000 km^2), annually 60 km^3 of water flows into the lake. The only outlet is the Lower Angara River, which flows west from Lake Baikal into the Yenisey River. The Baykal, Barguzin and other mountain ranges surround the lake, rising on all shores except the southeastern Selenga Delta. Lake Baikal has several islands, the largest of which is Olkhon Island.

Lake Baikal is known for the remarkable clarity of its waters and for the great diversity of its plant and animal life; the majority of species found in the lake are endemic. The sturgeon, salmon and freshwater-seal fisheries of the lake are valuable and large quantities of other fish are also caught. Petroleum wells and both mineral and hot springs are found in the vicinity. The southern shores of the lake are inhabited by the Buryats. Since its discovery by the

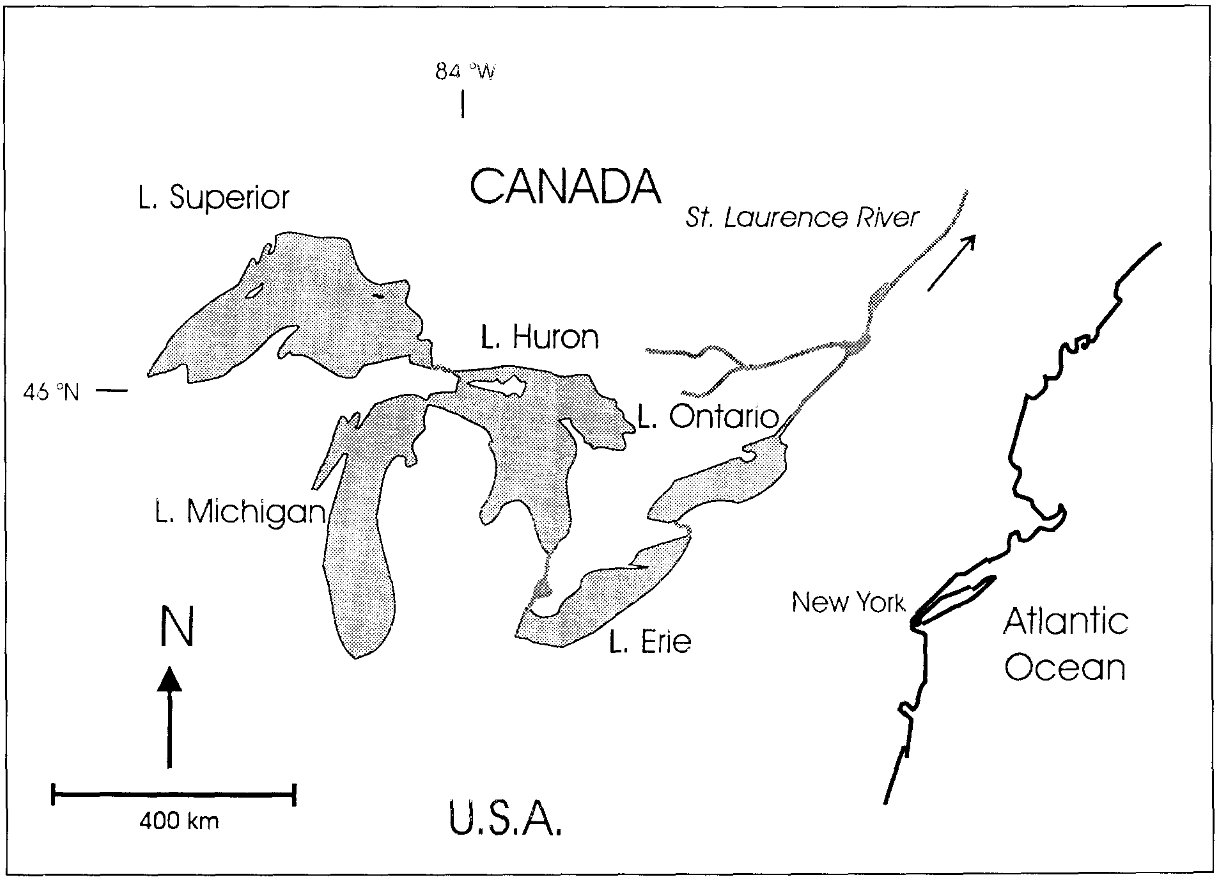


Figure 2.2 The Laurentian Great Lakes of North America.

Russians in 1643, the lake has been an important link in the trade route between Russia and China, connecting Listvyanka with points east of the Mongolian frontier via the Selenga River. Nizhneangarsk and Listvyanka are the main ports on the lake.

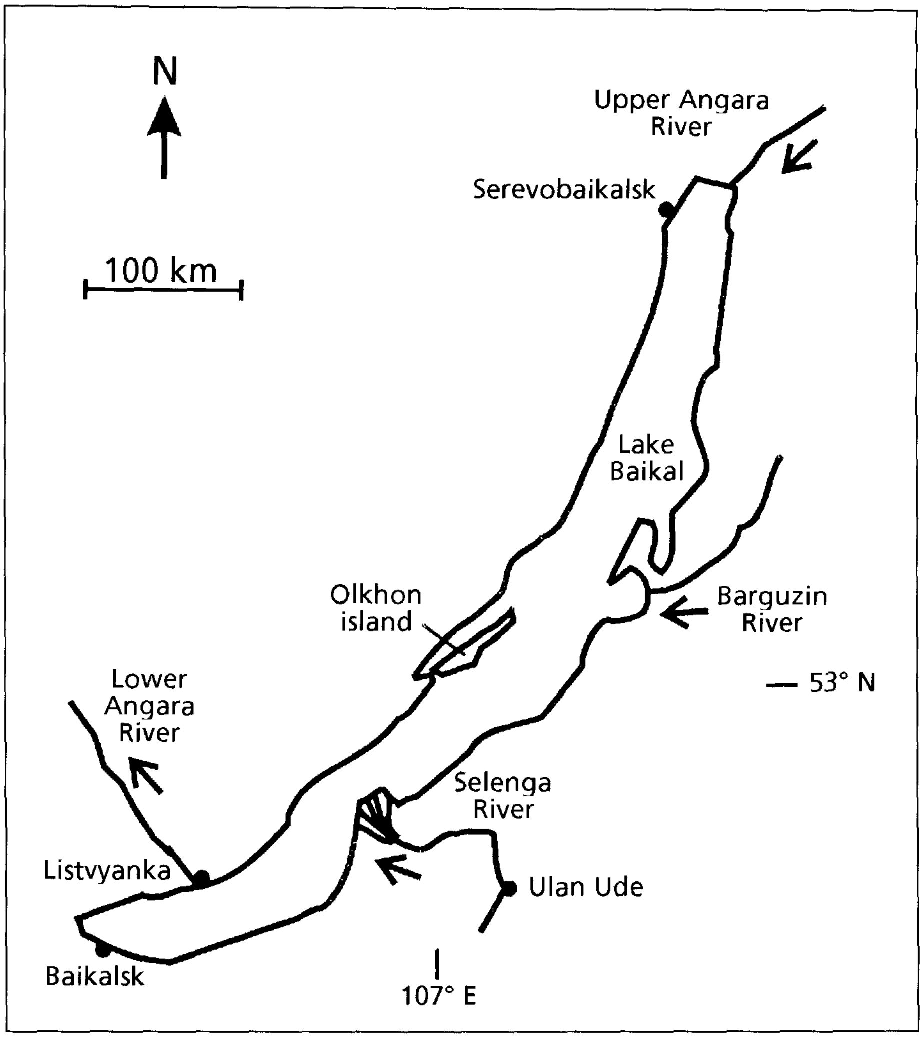


Figure 2.3 Lake Baikal.

3 The human impact on the African Great Lakes

Everywhere on earth, aquatic ecosystems are under stress. Large lakes, rivers and wetlands have been affected, altered and contaminated by anthropogenic activities in the water bodies themselves and in their catchments and drainage areas; these include the Laurentian Great Lakes and associated wetlands in North America, the Aral Sea and the Danube and Rhine Rivers. The African Great Lakes have long remained unspoiled and pristine, but in recent decades this situation has changed dramatically. The rapidly expanding human populations in the catchments and on the lakeshores are now threatening the lakes, as more intensive exploitation of the resources of the lakes and catchments becomes inevitable. Catchment development and alterations, urbanization, water use, agriculture, fisheries and industrial development are increasing in tandem with the rapidly growing populations.

The threats to the lakes are diverse; these include eutrophication and pollution caused by domestic, industrial and agricultural effluents, oil exploration and exploitation, transport and recreational activities; reduction of fish stocks owing to overfishing and/or introduction of exotic fish species; and lake level changes and siltation due to deforestation of the watersheds in combination with climatic changes. Some of these threats are already cause for growing concern because they bring about local or even lakewide problems (Table 3.1).

Pollution is increasing in tandem with the rapidly growing populations in the lake catchments, leading to deterioration of the water quality near the major urban settlements and inflowing rivers. Riparian populations in these areas may experience health problems, a rise in water-related diseases or drop in benefits from fishing in the lake and rivers. Lake Victoria has undergone profound changes owing to the combined effect of eutrophication and the introduction of the Nile perch, while Lakes Tanganyika and Malawi remain relatively unspoiled. Their long retention times make the three lakes potential depositories for waste and the experience of the Laurentian Great Lakes (see Box 3.1) bears witness to the fact that the size of a lake does not protect it from anthropogenic influences.

Both Lakes Victoria and Tanganyika have urban settlements on their shores from which partly treated or completely untreated domestic and industrial effluent enters the lakes. In Kenya, pollution derives both from urban centres in the catchment of Lake Victoria and from extensive agricultural activities and agro-based industries. Contamination of the sediments by toxic waste entering the Nyanza Gulf may become an important environmental issue in the near future. The Entebbe and Kampala areas in Uganda and the Mwanza, Bukoba and Musoma areas in the United Republic of Tanzania have also been identified as areas with serious pollution problems caused by domestic, agricultural and industrial sewage effluents (Bugenyi and Balirwa, 1989; World Bank, 1992).

In the United Republic of Tanzania, gold mining near Musoma and Mwanza resulted in settlements of up to 6,000 people and mercury pollution by runoff water and rivers flowing into the lake (World Bank, 1992). Scheren *et al.* (1994) identified domestic, and

Table 3.1 Main threats to the African Great Lakes

Environmental problem	*caused by:*	*Current status Victoria Tanganyika Malawi*	*Key sources*
POLLUTION			
Eutrophication	excessive (atmospheric and runoff) nutrients input	■ + +	Hecky, 1993; Bootsma and Hecky, 1993
Chemical pollution	industrial/agricultural/mining effluents near major towns	❒ ❒ ❒	Dejoux, 1988; Scheren, 1995; Scheren *et al*, 1994; Cohen *et al.*, 1996
Oil pollution and oil spill risks	oil exploration and exploitation; oil transport	+ + +	Baker, 1992
Contaminated sediments	industrial/agricultural effluents	❒ + +	Dejoux, 1988
Sedimentation	deforestation in catchment	❒ ■ ❒	Cohen *et al.*, 1993; 1996; Bootsma, 1992
Microbial contamination	domestic effluents with faecal matter	❒ ❒ ❒	Nash, 1993
Water-related diseases	no access to safe water, lacking sanitation, inefficient vector control	❒ ❒ ❒	Nash, 1993; Cohen *et al.*, 1996
Biological pollution	introduction of exotic species	■ + +	Witte *et al.*, 1995; Craig, 1992
REDUCTION OF FISH STOCKS			
Overexploitation of commercial fish species	inadequate management of fisheries/ law enforcement; illegal fishing activities	❒ ❒ ❒	Ogutu-Ohway, 1992 Roest, 1992; Tweddle, 1992
Reduction/extinction of endemic species by competition and predation	introduction of exotic species (intentional and accidental)	■ + +	Witte *et al.*, 1995; Craig, 1992; Cohen *et al.*, 1996
Overexploitation of ornamental fish species	uncontrolled and illegal fishing; commercial fishing activities	+ + +	Reinthal, 1993
CHANGES IN PHYSICAL ENVIRONMENT			
Habitat destruction, alteration and fragmentation	wetland destruction, shore and catchment development;	❒ ❒ ❒	UNEP, 1989; Cohen *et al.*, 1996
Lake level changes	water use for irrigation; hydro-electricity generation; deforestation of catchment area; climate change	+ + +	Kite, 1981; Eccles, 1984; Lema, 1990; Sene and Plinston, 1994; Cohen *et al.*, 1996
CHANGES IN ECOSYSTEM STRUCTURE AND PROCESSES			
Loss of biodiversity; food web changes; algal blooms; conditions of hypoxia and anoxia; instability	pollution; overexploitation; habitat alteration; introduction of exotic floral and faunal species; climate change	■ ❒ ❒	Kaufman and Cohen, 1993; Kaufman, 1992; Ochumba and Kibaara, 1989; Hecky *et al.*, 1994; Cohen *et al.*, 1996

■ = lakewide problem; ❒ = local problem; + = threat

BOX 3.1 EUTROPHICATION OF THE LAURENTIAN GREAT LAKES OF NORTH AMERICA

Events involving the Laurentian Great Lakes over the past century have demonstrated that the size of a lake does not prevent it from being affected by nutrient enrichment and chemical pollution. All five lakes: Superior, Huron, Michigan, Erie and Ontario, have received domestic, agricultural and industrial waste from their catchments. The two largest lakes, Superior and Huron, count few big cities on their shores. Their catchments mainly consist of Pre-Cambrian rock covered with coniferous forests and the climate is too cold for intensive agriculture. To date, they are less polluted than the other three lakes and the environmental problem areas have been localized. Lakes Superior and Huron are still oligotrophic as they would be in their natural state. Lakes Michigan, Erie and Ontario, on the other hand, play host to a number of industrial cities on their shores and their catchments consist of more fertile sedimentary rock, which sustains extensive agriculture. Lakes Erie and Ontario have responded more rapidly to nutrient pollution than the larger Lake Michigan. The most serious problems have occurred in Lake Erie, mainly because of its small size, its relatively shallow mean depth (19 m) and short retention time (3 years). Domestic sewage from such cities as Detroit and Cleveland on the western side of the lake and effluents from industry used to be discharged directly into the lake or its inflows, which caused severe eutrophication. The worst effects, dense algal blooms and severe deoxygenation of the hypolimnion, used to be visible close to the cities. The phosphorous restoration programme has achieved a decrease in the phosphorus loading resulting in lesser eutrophication. Today, chemical pollution with polychlorinated biphenyls (PCBs), pesticides and heavy metals is Lake Erie's main problem.

to a lesser extent industrial, sources of organic and microbiologic pollution of water courses in the Lake Victoria catchment in the United Republic of Tanzania. Agriculture is the main source of nutrients, primarily from manure. To date, the use of agrochemicals by small farmers is heavily restricted in the lake's catchment in the United Republic of Tanzania because of high commercial prices. Chemical pollution by industrial effluents consists mainly of chromium (800 kg. yr^{-1}) from the leather tanning industry in Mwanza and mercury (300 kg. yr^{-1}) from gold mining.

In Lake Tanganyika, sources of pollution are concentrated at the northern end of the lake near Bujumbura (Caljon, 1992) and near the other harbours, Kalemie in the Democratic Republic of the Congo, Kigoma in the United Republic of Tanzania and Mpulungu in Zambia. Lake Malawi differs from Lakes Victoria and Tanganyika in that it has no urban settlements on its shore. Pollution by sewage effluents from cities in the catchment area, Lilongwe and Mzuzu, is negligible, because the cities are situated well inland and possess treatment plants (Tweddle, 1992).

Untreated domestic effluents from urban settlements also contribute to human health problems. Use of lake water for consumption and other domestic purposes in combination with unsanitary conditions and the absence of safe drinking water increase the occurrence of water-borne enteric and diarrheal diseases. In some rural areas along the shores of Lake Victoria, the water-based disease schistosomiasis affects entire populations in the absence of proper sanitation. Potential sources of pollution include oil spillage during exploration, extraction, storage and/or lake transport in or near the African Great Lakes (Baker, 1992) and uncontrolled urbanization and industrialization on the lakeshores.

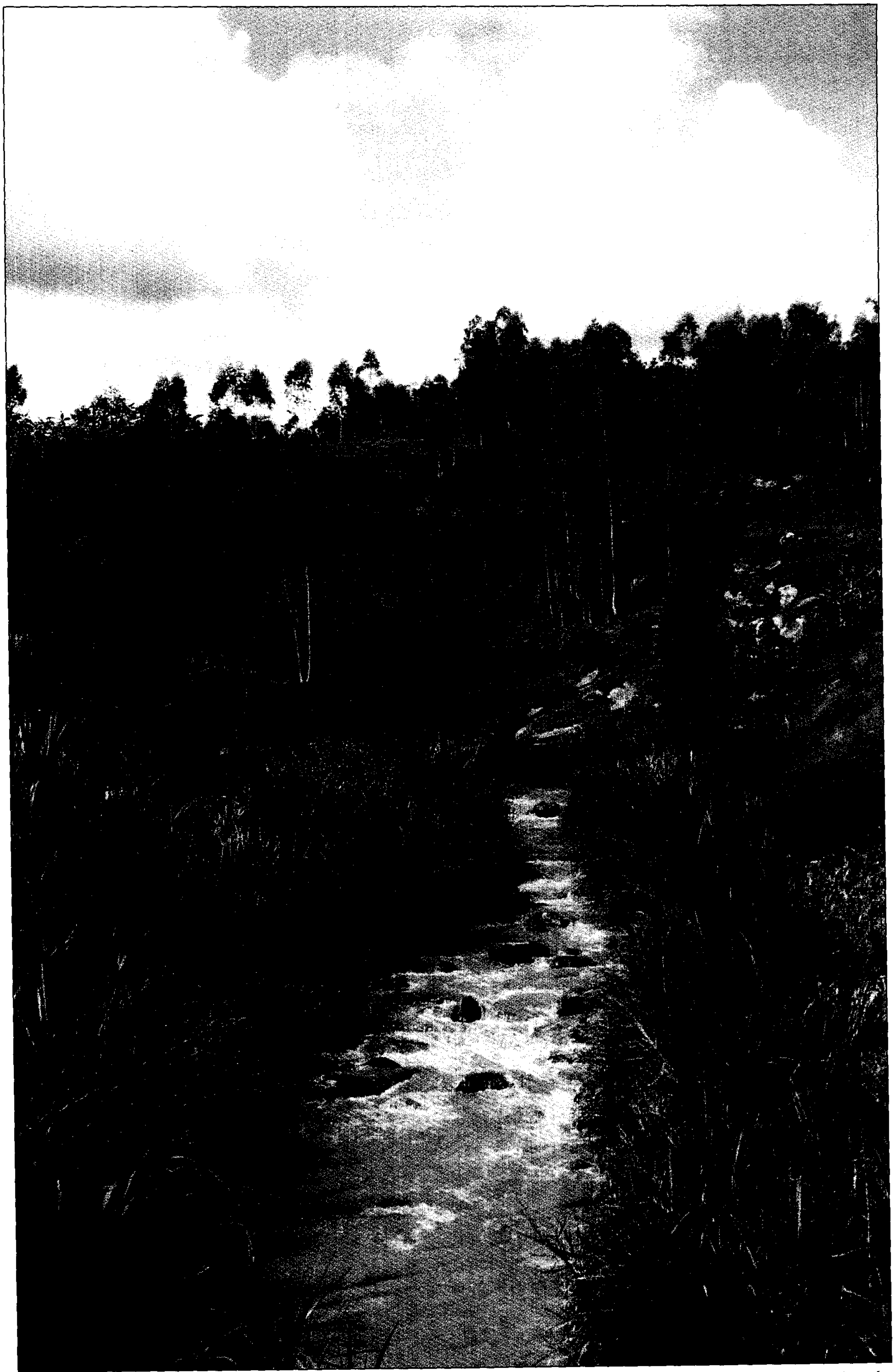
In recent decades, evidence has accumulated that dry and wet atmospheric deposition can be important sources of non-point nutrient loading and chemical pollution next to river inflow, runoff and groundwater seepage. Acidification of lakes in Europe and North America has resulted from acid deposition of industrial wastes from the air. Lake Superior receives four-fifths of its toxics from the air and Lake Michigan half, these originating from inside and outside the airsheds of the lakes (Cobb, 1987). Atmospheric deposition is also an important pathway to the cultural eutrophication of Lake Tahoe in North America (see Box 3.2) (Horne and Goldman, 1994).

Land use in the catchment and riparian zone of the lakes also plays a major role in the pollution process. Increased pressure on land in the riparian countries has led to high rates of deforestation, resulting in increased soil erosion and high loads of silt and nutrients being washed into the lakes, thereby contributing to eutrophication and siltation.

In Lake Tanganyika, sediment pollution has been identified as a major problem in the northern and

BOX 3.2 EUTROPHICATION OF LAKE TAHOE

Lake Tahoe is an oligotrophic lake in the Sierra Nevada on the border between California and Nevada. It has a relatively small catchment area of 800 km^2 compared to its surface area of 499 km^2. The nutrient-poor soils of the catchment area have been responsible for the natural ultra-oligotrophic status of the lake and the extremely slow rate of eutrophication. However, over the past three decades, the rate of eutrophication has accelerated on account of the anthropogenic activities within its catchment, such as sewage disposal and land disturbance caused by large-scale tourism development and recreational activities (Loeb, 1993). Pathways for nutrients into the lake include atmospheric deposition, stream inflows and groundwater seepage. Atmospheric input of nutrients originates from air pollution, such as car emissions, wood-burning stoves and possibly forest fires (Goldman *et al.*, 1990). Signs of eutrophication are decreasing water clarity and increasing algal growth (Goldman, 1988).



Photograph 3.1 Land-use practices in the Burundian catchment of Lake Tanganyika causing high silt loads in rivers flowing into the lake (photograph by R. C. M. Crul).

southern parts of the lake where relatively large drainage basins exist (Cohen *et al.*, 1993). In the Lake Malawi National Park situated in the southern part of the lake, siltation has been observed in the lake as a result of deforestation (Bootsma, 1992). Increased nutrient loading into Lake Victoria has led to eutrophication of the lake, resulting in higher algal biomass and productivity, a more frequent occurrence of algal blooms and prolonged deoxygenation of the hypolimnion (Ochumba and Kibaara, 1989; Kaufman, 1992; Hecky, 1993; Mugidde, 1993; Hecky *et al.*, 1994).

Changes in the physical environment of lakes and their catchments may have severe consequences for the lakes, especially shore development involving associated wetlands. Wetlands bordering Lake Victoria have gradually been converted into agricultural land or into sites for industrial use and are, therefore, increasingly unable to regulate and conserve water, to act as sediment and nutrient traps, to provide breeding and nursery grounds for fish species and to sustain a variety of bird species and other wildlife. Furthermore, destruction of wetlands will limit the availability of renewable resources, such as grass for cattle fodder, reeds and papyrus for domestic use and clay for brickmaking (UNEP, 1989). Industrial plants along the lakeshores pose a threat to the lakes when effluents are dumped into them untreated, as was the case with a pulp mill on the shore of Lake Baikal (see Box 3.3).

A drop in fish stocks caused by overfishing and the introduction of exotic species poses a major threat to all three Great African Lakes. In Lake Victoria, overexploitation of endemic tilapia started as far back as the 1920s (Graham, 1929) and resulted in a sharp reduction in the catches in the inshore areas in the 1950s (Fryer and Iles, 1972). The high demand for fish led to the introduction of exotic tilapias from Lake Albert (*Oreochromis niloticus, O. leucostictus, Tilapia zillii* and *T. rendalli* 'melanopleura') into the lake during the 1950s and 1960s, which eventually replaced the endemic tilapia (Craig, 1992). In the 1950s, the Nile perch found its way into Lake Victoria. The introduced Nile perch resulted in bigger commercial catches estimated at 500,000 tonnes in the early 1990s, but also caused a severe decline in numbers – and in some cases the total disappearance – of endemic cichlids (Ogutu-Ohwayo, 1992). Current causes for concern are overfishing in some inshore areas and the use of small-meshed nets (Lowe-McConnell *et al.*, 1994). In the heavily fished southeastern arm of Lake Malawi, recent severe declines in tilapia and other fish stocks were caused by overfishing, aggravated in some cases by the use of small meshed seines and trawls, which destroy immature fish (FAO, 1992).

Box 3.3 POLLUTION IN LAKE BAIKAL

Until recently, pollution levels in Lake Baikal had been low compared to some of the Laurentian Great Lakes for example. Today, the lake is threatened by industry and agriculture. Main sources of pollution are the inflowing Selenga River bearing pollutants and nutrients from industrial plants in Ulan Ude, a cellulose plant in Baikalsk on the southern shore of the lake, and from the area around Severobaikalsk at the northern end of the lake where the recent construction of a railway is causing erosion and the town itself delivers air pollutants. In the 1950s and 1960s, much of the unique plant and animal life near the pulp mill in Baikalsk was affected by waste material – including chlorinated organic compounds – from this complex. Since the 1970s, efforts have been made to purify effluents and reduce pollution from the plant, but in 1989 it still discharged 26,000 tonnes of minerals, 200 tonnes of suspended substances and 2,500 tonnes of organic compounds into Lake Baikal.

Sources: Belt, 1992; Flower, 1994; Martin, 1994.

In Lake Tanganyika overexploitation of the pelagic fish stocks poses a threat, especially in heavily fished areas in the northern part of the lake where population density is highest and in the southern-most part near Mpulungu (Roest, 1992). Annual production in Lake Tanganyika was estimated at 120,000 tonnes in 1988 (Gréboval and Fryd, 1993). Overall catches have declined since 1985 and in recent years traditional small-scale fisheries have developed excessively in the northern part of the lake (Lowe-McConnell *et al.*, 1994). Introduction of exotic species poses a threat to Lakes Tanganyika and Malawi, as the introduced species may affect the lakes' spectacular flocks of endemic cichlids. Two exotic species, *Oreochromis leucostictus* and *Cyprinus carpio,* are already present in the catchment area of Lake Tanganyika, respectively in the Ruzizi estuary and associated swamps, and in rice fields in the Ruzizi drainage basin (Lowe-McConnell *et al.*, 1994).

The recent infestation by the water hyacinth of Lake Victoria is a cause for serious concern, especially in the Ugandan part of the lake. The weed hampers fishing and transport activities on the lake and threatens both hydro-electric power generation and the domestic and industrial water supply.

The African Great Lakes are known for their biodiversity and form some of the most spectacular examples of adaptive radiation of fishes in the world (Lowe-McConnell, 1993). They hold the highest biodiversity of all existing lakes, together with Lake Baikal (Worthington and Lowe-McConnell, 1994). The recent events in Lake Victoria, however, show that anthropogenic activities may have dramatic implications for their biodiversity. The introduction of exotic tilapia and the large predatory Nile perch has decimated the endemic flock of haplochromine fishes (Witte *et al.*, 1995; Ogutu-Ohwayo, 1992) and caused a loss in the lake's fish diversity. The other two lakes still hold their immense biodiversity. Lake Tanganyika has a very rich flora and fauna with preliminary species totals of 840 floral and 1,248 faunal species, while much of the lake remains biologically unexplored. More than 35% of the faunal species described and more than 70% of the fish fauna are endemic (Coulter, 1991). Lake Malawi has the richest

Photograph 3.2 Water hyacinth mats at the Owen Falls Dam near Jinja (photograph by M. van der Knaap).

diversity of fish species of any lake in the world with up to 1,000 species (Fryer and Iles, 1972; Lowe-McConnell, 1987; Eccles and Trewavas, 1989). The endemic fauna of Lake Victoria has been decimated in recent years, but it is the other two lakes that are in need of priority protection from the introduction of exotic species (Lowe-McConnell, 1993). An important step towards conserving the endemic fish fauna has been made by the Government of Malawi in establishing the Lake Malawi National Park (Bootsma, 1992). Conservation strategies have been suggested with special reference to underwater parks in Lake Tanganyika (Coulter and Mubamba, 1993).

The impact of anthropogenic activities on the African Great Lakes depends upon their hydrological characteristics. The lakes have long retention times owing to their large volume and relatively small outflow. The residence time of water in Lake Victoria is shortest (23 years), while the deep Lakes Tanganyika and Malawi both have longer residence times, 440 and 140 years respectively (Hecky, 1993; Hecky *et al.*, 1994).

In addition to the risks posed by activities of the rapidly growing populations in the catchment areas, the lakes are threatened by climatic change, which may result in large variations in lake level, as occurred in Lake Malawi between 500 and 125 years ago when the lake receded more than 100 m below its present level in response to a prolonged drop in rainfall (Owen *et al.*, 1989). The riparian countries depend on stable lake levels, as considerable investments have been made to develop lakeshore infrastructure (e.g. water supply, electricity generation, irrigation and harbour facilities). Changes in the water balance of these lakes will have implications for the flow regimes of the outflowing rivers and, in the case of Lake Victoria, also for the regime of the Nile River. The Nile is of major importance to Sudan and above all to Egypt, which is totally dependent on the continuous flow of the Nile for drinking water, irrigation and power generation. Significant increases in flow of the Nile River in the 1960s and late 1970s were related to higher water levels in Lake Victoria (Kite, 1981).

In the past, population density and agricultural, industrial activities and fisheries were at levels that allowed the lakes to maintain their natural conditions. The environmental stress that the ecosystems of the African Great Lakes are currently experiencing is endangering their proper functioning. Lake Victoria has undergone great changes in its chemistry and biology in recent decades brought about by eutrophication, the introduction of exotic species and possibly climatic change (Hecky, 1993; Witte *et al.*, 1995; Hecky *et al.*, 1994). The same fate could befall Lakes Malawi and Tanganyika.

4 Limnological research

Scientific research and monitoring of water quantity and quality are important for the development of proper management schemes for the African Great Lakes. With rapidly growing populations in their watersheds, it is necessary to guarantee that these lake ecosystems remain healthy and continue to serve as renewable sources of freshwater and food. This requires sustainable development involving resources management and conservation of the lake ecosystems. Prerequisite to rational management and conservation of these shared water bodies is an understanding of how these large ecosystems function and how they respond to perturbations caused by anthropogenic activities. Comprehensive research programmes will provide the riparian states with the necessary background to take all measures to conserve their lakes. Mutual consultation and co-ordinated action between the lacustrine states, together with adequate support from the international community, are additional preconditions.

BOX 4.1 THE IMPORTANCE OF LONG-TERM LIMNOLOGICAL AND HYDROLOGICAL RESEARCH

Long-term physical, chemical and biological data sets are a powerful analytical tool that is essential for lake management. The Laurentian Great Lakes and Lake Tahoe have been subject to intensive, continual research for more than 30 years. Policies, (legislative) strategies, regulations and action plans have been developed based on the long-term scientific investigations and monitoring of these lakes.

In the case of Lake Tahoe, biological assays on nutrient limitation and input, investigations into nutrient cycling within the drainage area and the lake, and studies on periphyton productivity formed the basis of a legislative strategy devised by the Tahoe Regional Planning Agency (TRPA) to address the declining water quality of the lake and to reverse the rate of eutrophication (Loeb, 1993).

Limnologists also played an important role in water-quality issues involving the Laurentian Great Lakes in the 1960s. Their studies on eutrophication led to the USA–Canada Great Lakes Water Quality Agreements of 1972 and 1978. These plans foresaw nutrient reductions of municipal and industrial origin and phosphorus limitations in detergents. Analysis of long-term trends has shown a sharp decrease in phosporus loadings and total phosphorus concentrations in the lakes. The long-term data set on phytoplankton biomass also shows a significant decrease, especially in near-shore areas where eutrophication has been more advanced (Barica, 1990).

Another example of the importance of long-term data sets is the case of Lake Washington. The lake underwent two phases of eutrophication in the 1920s and 1950s. A sewage diversion scheme started up in the late 1950s reversed eutrophication. Limnological studies and advice played a crucial role in setting up this scheme; monitoring of the conditions in the lake during the diversion of the sewage in the 1960s clearly indicated that the lake had responded immediately after the diversion scheme started and that by the early 1970s the lake had returned to pre-1950 conditions (Edmondson, 1972).

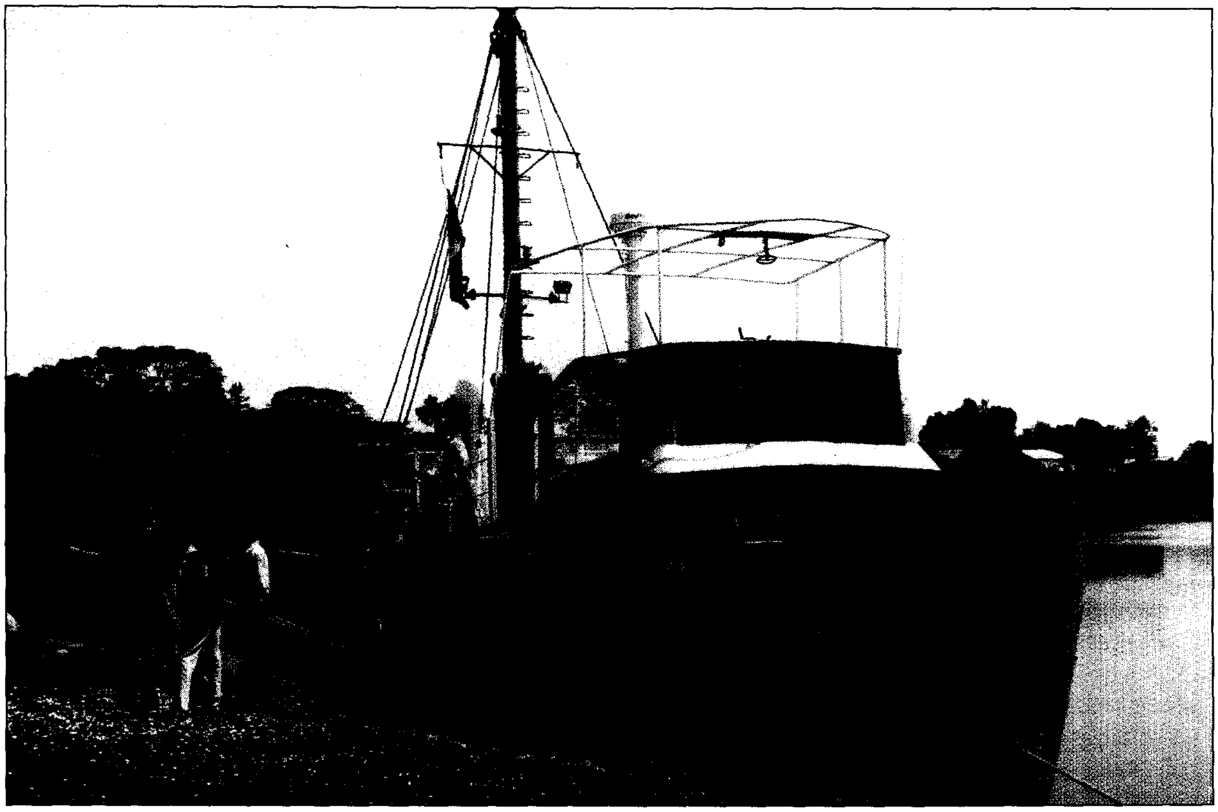
Limnological and hydrological research provides information on the main physical, chemical and biological events occurring in the lakes. The ecosystem of Lake Victoria is still changing owing to recent anthropogenic activities. The other two lakes remain relatively unchanged. Further research is needed to broaden the knowledge base of all three lakes on such ecosystem aspects as hydrological regimes, nutrient loading, mixing rates and nutrient dynamics. Long-term environmental data on the lakes provide a powerful analytical tool for monitoring changes in ecosystem structure and processes. Long-term limnological research has proven invaluable in conserving fragile lake ecosystems like Lake Tahoe and in reversing a trend towards eutrophication in the Laurentian Great Lakes (see Box 4.1). Furthermore, limnological and hydrological research has direct applications not only to the control of pollution and health, but also to fisheries and lake management.

The sheer size of the large African Great Lakes poses enormous financial and logistical problems to the riparian states. The general advancement of technology is bringing remote sensing within reach of research institutes and projects on large lakes as it is a relatively inexpensive method of collecting lakewide data (see Box 4.2). Remote-sensing techniques and Geographical Information Systems (GIS) technology have been applied to two recent fisheries research projects on Lakes Tanganyika and Malawi (Patterson *et al.*, 1995; Parkkinen *et al.*, 1995) and to the ongoing regional FAO Project 'Information System for Water Resources Monitoring and Planning in the Lake Victoria Region' (FAO, 1995).

BOX 4.2 SATELLITE REMOTE SENSING AND GIS IN RESEARCH ON LARGE AQUATIC ECOSYSTEMS

Remote-sensing techniques have been successfully applied to ocean research and fisheries management in the past decade and may become increasingly useful in research and management of large freshwater ecosystems such as the African Great Lakes. Parameters that can be derived from satellite images are: surface temperatures, water colour, suspended matter and phytoplankton concentrations near the surface and aquatic macrophytes. Certain pollutants may even be detected (Meaden and Kapetsky, 1991; Nakayama, 1994). The spatial pattern of water transparency (Secchi depth) may even be determined from satellite images, as was done in a large reservoir in the USA, Lake Mead (Horne and Goldman, 1994). In combination with GIS, remote sensing may provide spatial and temporal information on water quality in large lakes at relatively little cost.

Since long-term sets of basic physical and chemical parameters are not available for the African Great Lakes, one alternative means of gathering information about long-term trends in these tropical lakes is the study of sediment cores. As a multidisciplinary science using physical, chemical and biological information preserved in sediments, paleolimnology may yet become an important tool for lake management and offers great potential for the African Great Lakes. Tanganyika and Malawi are among the oldest lakes on earth and have sediments up to 2–6 km thick; even young Lake Victoria has



Photograph 4.1 The research vessel 'Ibis' operating on Lake Victoria (photograph by R. C. M. Crul).

Photograph 4.2 Fisheries Research Institute in Jinja, Uganda, formerly EAFRO headquarters (photograph by R. C. M. Crul).

relatively thick fossil-rich, organic sediments. The sediments provide important information on the lakes' climatic history (Johnson, 1993). Sedimentation rates of between 0.2 mm.yr^{-1} and 5 mm.yr^{-1} for these lakes imply that the sediment records are resolvable to decades or more (Johnson *et al.*, 1990).

Another interesting research area offering good prospects is the comparative limnology of Lakes Tanganyika, Malawi and Victoria, other lakes in East Africa (e.g. Lakes Edward, Kivu, Albert, George and Mweru and the Kariba Reservoir) and similar lakes in other regions, such as the Laurentian Great Lakes, Lake Tahoe and Lake Baikal.

Limnological investigations of the African Great Lakes have gradually evolved from short-term investigations and taxonomic studies in the late 1850s to more regular research after the founding of research institutes in the riparian countries. Most of the research on the lakes has been carried out for logistical reasons in the vicinity of the lakeshore population centres using laboratory and port facilities. Research on Lake Victoria has been conducted from stations based at Jinja and Kampala (Uganda), Kisumu (Kenya) and Mwanza (United Republic of Tanzania); research on Lake Tanganyika from stations at Bujumbura (Burundi), Kigoma and Kipili (United Republic of Tanzania), Mpulungu (Zambia) and Uvira (Democratic Republic of the Congo); and research on Lake Malawi from stations at Nhkata Bay, Monkey Bay and Senga Bay in Malawi. Lakewide limnological surveys have occasionally been done in connection with fisheries surveys and projects when research vessels were operational.

The Freshwater Biological Association (FBA) has contributed considerably to the limnology of the African Great Lakes and African limnology in general (Fryer and Talling, 1986). In the first half of the twentieth century, the FBA supported expeditions, surveys and short-term studies on the three lakes. In the late 1930s, Beauchamp (1939; 1940; 1946; 1953) carried out limnological studies on Lakes Tanganyika and Malawi, while Ricardo-Bertram *et al.* (1942) made the first fisheries survey on Lake Malawi. In the 1940s, studies on Tilapia ('Chambo') fisheries along the southeast arm of Lake Malawi were conducted by Lowe (1952). In the late 1940s, extensive limnological research was conducted on Lake Tanganyika during a major Belgian hydrobiological expedition to the lake (Leloup, 1949; Capart, 1949).

Around 1950, research organizations were set up in East Africa and with them the first permanent laboratories on the shores of the African Great Lakes: in 1947, the East African Fisheries Research Organisation (EAFRO) at Jinja on Lake Victoria; in 1951, the Joint Fisheries Research Organisation (JFRO) with stations at Nkhata Bay on Lake Malawi and later at Mpulungu on Lake Tanganyika and in the *Institut pour la recherche scientifique en Afrique centrale* (IRSAC) at Uvira on Lake Tanganyika. The EAFRO and JFRO research stations were mainly staffed by FBA scientists and the IRSAC station by scientists from Belgium. The EAFRO was to make a major contribution to knowledge on Lake Victoria and other East African inland waters and their fisheries.

The former EAFRO headquarters in Jinja and the EAFRO's sub-stations at Kisumu and Mwanza have

Photograph 4.3 'Tanganyika Explorer', research vessel of the FAO/FINNIDA Fisheries Research Project (photograph by F. C. Roest).

remained centres of lake research as laboratories of the Kenya Marine and Fisheries Research Institute (KMFRI), the Fisheries Research Institute in Uganda (FIRI) and the Tanzanian Fisheries Research Institute (TAFIRI). JFRO scientists carried out limnological research on Lakes Malawi and Tanganyika in the 1950s and 1960s. A research station was first established at Nkhata Bay at the northern end of Lake Malawi and, later in 1959, at Mpulungu at the southern end of Lake Tanganyika. A fisheries survey with a limnological component was conducted in the northern part of Lake Malawi in 1954–1955 by JFRO scientists (Jackson *et al.*, 1963) and limnological research continued in the vicinity of Nkhata Bay until 1962 when the focus of JFRO research on Lake Malawi shifted to the southern part of the lake with the establishment of new laboratories at Monkey Bay (JFRO, 1960; 1962; 1964). The IRSAC at Uvira carried out limnological research in the northern part of Lake Tanganyika (Symoens, 1956).

After gaining independence in the 1960s, the young riparian states took over responsibility for fisheries research. International donor organizations, universities and research institutes from Europe, Japan and North America have supported the work of these national fisheries research stations and universities in Burundi, Kenya, Malawi, Uganda and the United Republic of Tanzania through the funding of, and participation in, research projects and studies. Limnological research on the lakes has always been a component of the different fisheries research projects on the lakes of the Food and Agriculture Organization (FAO) (Crul, 1995; 1997; Crul *et al.*, 1995).

Until the late 1980s, limnological research was focused on inland fisheries, but events in Lake Victoria have shifted attention to the conservation of the lakes and sustainable exploitation of their natural resources (Lowe-McConnell *et al.*, 1992). Recent limnological research on Lake Victoria has focused on eutrophication and changes in the lake ecosystem (Ochumba and Kibaara, 1989; Hecky and Bugenyi, 1992; Kaufman, 1992; Hecky, 1993; Hecky *et al.*, 1994; Gophen *et al.*, 1995). Limnological research on Lakes Tanganyika and Malawi is still mainly linked with fisheries research, focusing on productivity and distribution of pelagic fish stocks (Lindqvist and Mikkola, 1989; Hanek and Coenen, 1994; Mölsä, 1995; Menz, 1995).

Research on pollution of the African Great Lakes and their catchments is to date restricted to a handful of studies in Burundi, Kenya, Uganda and the United Republic of Tanzania. These studies will become increasingly important as the impact on the catchments and lakeshores of the rapidly growing populations' activities makes itself felt. Bibliographies on the limnology, fisheries and related fields of the three lakes have recently been published (Tweddle and Mkoko, 1996; Tweddle, 1991; Coulter and Coulter 1991; Crul *et al.*, 1995) and overviews on the limnology of the lakes have been given by Coulter (1991), Crul (1995; 1997), Crul *et al.* (1995) and Menz (1995). Several international symposia have been held on resource use, conservation, biodiversity and climatic change with reference to the African Great Lakes (Lowe-McConnell *et al.*, 1992; Cohen, 1991; Kaufman, 1992; Martens *et al.*, 1994; Johnson and Odada, 1996).

Global Environment Facility (GEF) projects have recently started on the three lakes. The programme on Lake Victoria will focus on the environmental management of the lake with emphasis on fisheries and water quality, while the two programmes on Lakes Tanganyika and Malawi will be directed more towards protecting biodiversity.

Hydrological information on the three lakes is essential to all riparian countries for rational economic development. The lakes are (potentially) important for hydro-power generation, irrigation, flood control, inland navigation, fisheries, recreation and tourism. Data on water availability and water demands are necessary for sustainable management of the lakes' water resources. Water levels have been monitored in all three lakes since the beginning of this century. Hydrological research on Lake Victoria has focused mainly on assessing the different components of the water balance in order to predict changes in water level and the flow of the Nile (WMO, 1974; 1981; Kite, 1981; 1982; 1984; Piper *et al.*, 1986; Sene and Plinston, 1994; TECCONILE, 1995*a*). The hydrology of Lakes Tanganyika and Malawi has been studied in connection with lake-level fluctuations (Devroey, 1949), their implications for water availability (Kidd, 1983) and speciation of its cichlid fauna (Owen *et al.*, 1990). Rough estimates of the water balance components of Lake Victoria are given by Kite (1981), Piper *et al.* (1986) and by Sene and Plinston (1994), by Owen *et al.* (1990) for Lake Malawi, by Coulter and Spigel (1991) and Edmond *et al.* (1993) for Lake Tanganyika.

It has gradually become apparent that there is an urgent need for more fundamental research on the ecosystems of large lakes and for applied research on water quality. This research must include the watershed and airshed of the lakes, paying special attention to the fringing wetlands. A recent workshop on the 'Importance of external perturbations for short-term and long-term changes in large lakes ecosystems' in 1991 assessed current understanding of the most important ecosystem processes in large lakes and identified the most urgent research priorities (Tilzer and Bossard, 1992) (see also Appendix I).

Knowledge of tropical waters remains limited compared to that of waters in the temperate zone. The reasons for this are obvious. In the temperate region, more funds have been available for research and information transfer there has functioned far better than in tropical countries. There is an urgent need to correct the 'limnological imbalance' and to improve the status of tropical limnology (Williams, 1988; 1994). An understanding of tropical aquatic ecosystems is essential for their proper management and conservation, as most of them are presently under stress. The utmost caution should be exercised when applying to lakes in the tropics any ideas on management and conservation that are based upon research on temperate lakes. Tropical lakes possess unique features that by definition differentiate them from temperate lakes (Kilham and Kilham, 1990). Although the International Limnological Society (SIL) made recommendations to improve the status of limnology in developing countries as far back as 1980 (Mori and Ikusima, 1980), none of these would seem to have been implemented so far (Williams, 1994).

5 Comparative limnology and hydrology of the African Great Lakes

5.1 INTRODUCTION

The present chapter compares the limnology and hydrology of Lakes Victoria, Tanganyika and Malawi on the basis of available information as reviewed by Crul (1995; 1997) and by Crul *et al.* (1995). The two rift lakes, Tanganyika and Malawi, clearly share a number of characteristics, but also show several striking differences. Shallow Lake Victoria has undergone great change in its ecosystem in recent decades and it is therefore interesting to compare the situation in the 1960s with the present state of the lake. The three lakes will also be compared with other lakes in East Africa and with large lakes in other regions in the world (e.g. Lakes Kivu and Mweru, the Laurentian Great Lakes and Lakes Tahoe and Baikal).

Until recently, papers on the comparative limnology and hydrology of the African Great Lakes were scarce (Talling, 1965; 1966; 1969; 1987; Talling and Talling, 1965; Beadle, 1974; 1981; Hecky, 1984; Livingstone and Melack, 1984; Coulter *et al.*, 1986; Payne, 1986; Eccles, 1988). The dramatic events experienced by Lake Victoria and the threats hanging over all three lakes have focused greater attention on the conservation and biodiversity of the African Great Lakes (Lowe McConnell *et al.*, 1992; 1994; Cohen, 1991; Kaufman, 1992; Kaufman and Cohen, 1993; Martens *et al.*, 1994; Worthington and Lowe-McConnell, 1994) and their limnology (Coulter, 1991; Hecky and Bugenyi, 1992; Talling, 1992; Hecky, 1993; Bootsma and Hecky, 1993; Edmond *et al.*, 1993; Hecky *et al.*, 1994; Menz, 1995; Gophen *et al.*, 1995; Johnson and Odada, 1996; Hecky *et al.*, 1996).

Information on the water quantity and quality of the African Great Lakes remains somewhat limited, but it is essential that what information on the lakes is available be used to establish an information and documentation base. This will contribute to reaching consensus on the joint development, management and utilization of these international water bodies. In addition, summarizing research findings will facilitate the identification of gaps in knowledge and the setting of priorities for future limnological and hydrological research.

5.2 FEATURES OF THE AFRICAN GREAT LAKES

5.2.1 Morphometry

As stated earlier, the African Great Lakes of Victoria, Tanganyika and Malawi are among the largest lakes in the world. Together with a number of others, these lakes dominate the landscape in East Africa in much the same way the Laurentian Great Lakes do in North America. The basins of the three lakes have formed gradually during their long geological histories. The two rift lakes, Tanganyika and Malawi, are by far the oldest in Africa. They have probably conserved roughly their present forms for approximately 6 million and 2 million years respectively, while Lake Tanganyika originated in one form or another up to 20 million years ago (Coulter, 1994; Ribbink, 1994). Equatorial Lake Victoria is relatively young with an age of 750,000

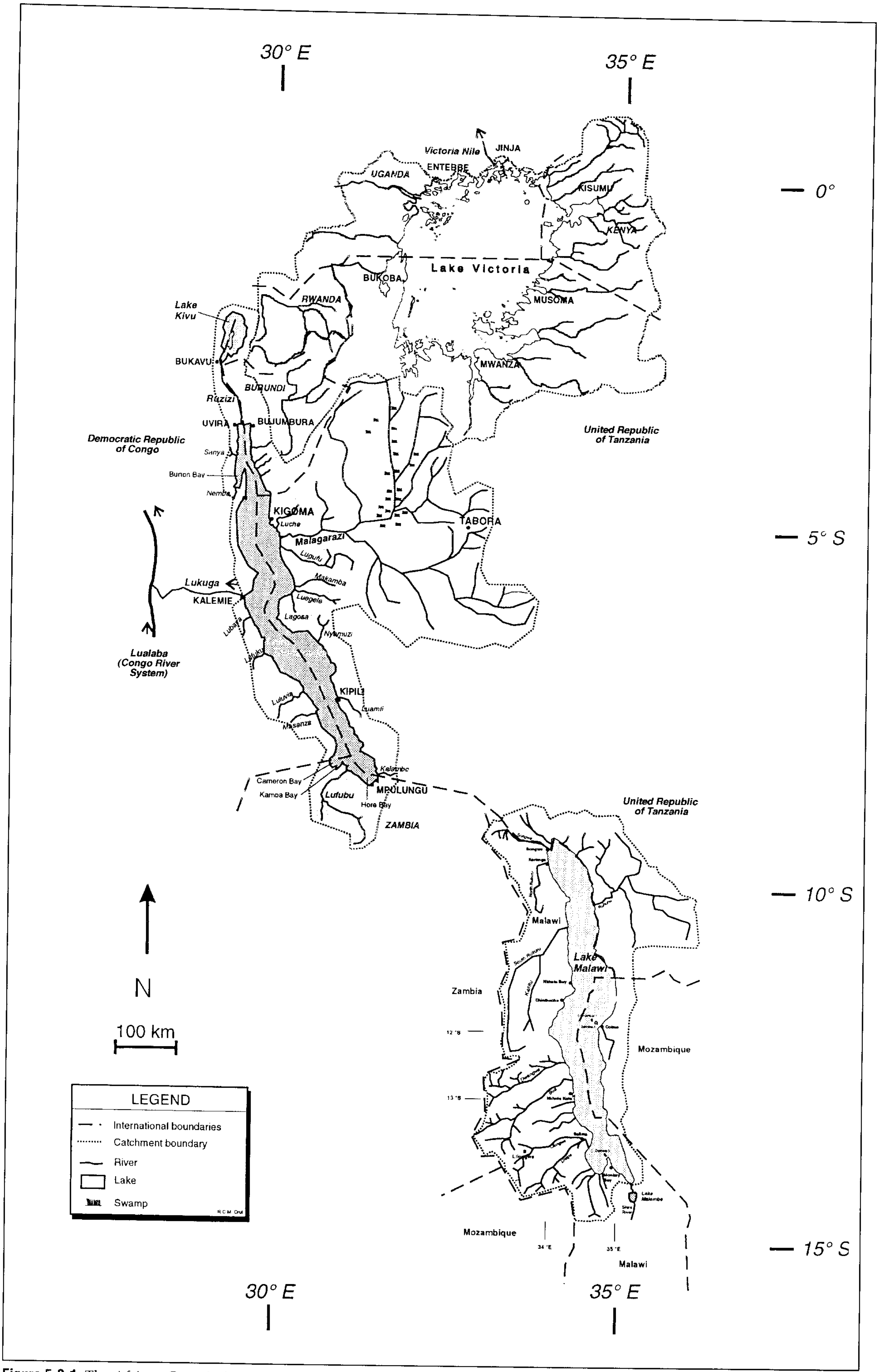


Figure 5.2.1 The African Great Lakes and their catchment areas.

Table 5.2.1 Morphometric and geographical information for the African Great Lakes

	Lake Victoria	*Lake Tanganyika*	*Lake Malawi*
Position: Latitude	0° 20′ -3° 00′ S	3° 20′ -8° 45′ S	9° 30′ -14°30′ S
Longitude	31° 39′-34°53′ E	29° 05′-31°15′ E	33° 50′ -35°20′ E
Altitude (m above sea level)	1,134	773	471
Catchment area (km^2)[1]	194,200	249,000	97,700
Lake basin area (km^2)	68,800	32,600	28,800
Lake area as % total catchment	26	12	23
Max. length (km)	400	650	560
Max. width (km)		240	8775
Mean width (km)	172	50	51
Max. depth (m)	84	1,470	700
Mean depth (m)	40	570	292
Volume (km^3)	2,760	18,880	8,400
Shore line (km)	3,440[2]	1,838	1,500
Oxygenated bottom area (%)[3]	100	25	50

1. The lake itself is not included.
2. The islands are excluded.
3. Hecky *et al.* (1994), at time of deepest annual mixing (July–August).

Sources: Crul 1995; Crul 1997; Crul *et al.*, 1995.

years, although some 14,000 years ago it may have dried up completely or its water level would have been at least some 60 m below the present level (Greenwood, 1994).

The three lakes lie in the southern hemisphere, with Lake Victoria lying closest to the equator between 0° S and 3° S, Lake Tanganyika being situated between 3° S and 9° S and Lake Malawi between 9° S and 15° S, at altitudes of 1,134 m, 773 m and 471 m respectively. Morphometric and geographical information on the lakes is given in Table 5.2.1. The basins of Lakes Victoria and Malawi constitute a relatively large proportion of their catchment areas at 26% and 23% respectively, while the lake area of Lake Tanganyika represents only 12% of its catchment area (Figure 5.2.1). Lake Tanganyika's catchment is the largest of the three lakes.

The saucer-shaped basin of Lake Victoria is situated on a plateau between the Western and Eastern Rift Valleys, while Lakes Tanganyika and Malawi lie in the Western Rift Valley. Both rift lakes are steep-sided *'graben'* lakes formed between two parallel faults. Many of the deepest lakes in the world are graben lakes (e.g. Lakes Baikal and Tahoe). With a depth of 1,470 m, Lake Tanganyika is the second-deepest lake in the world after Lake Baikal; Lake Malawi is the fourth-deepest, with a depth of just over 700 m. In sharp contrast to the two deep rift lakes, shallow Lake Victoria, with a maximum depth of some 80 m and numerous islands, has a long indented shoreline.

Bathymetric maps of the African Great Lakes show the shape of the bottom of the lake basins (Fig 5.2.2). The hypsographic (depth-area) curves of the lakes show how shallow Lake Victoria is compared with the steep-sided, deep lakes of Tanganyika and Malawi (Figure 5.2.3). Lake Victoria consists of a single basin with a maximum depth of about 80 m in the northeastern part of the lake. The western part of the lake is relatively shallow, with a depth of less than 50 m. Lake Malawi also consists of a single basin. The lake is deepest in the northern part with a maximum depth of approximately 700 m and a depth of over 200 m close to the shore. The southern part of Lake Malawi is relatively shallow with a depth of less than 200 m some 110 km from the south end. There, the lake forks and is less than 100 m deep. Lake Tanganyika consists of two main basins with a number of sub-basins and a minor basin inbetween. The northern basin has a maximum depth – the 'Baron Dhanis Deep' – of 1,310 m, while the 'Alexander Delcommune Deep' in the southern basin is 1,470 m deep.

5.2.2 Light

The African Great Lakes have different light regimes. The water in Lake Victoria is relatively turbid in comparison with the transparent waters of Lakes Tanganyika and Malawi. In Lake Victoria, the euphotic depth decreased from 15–20 m offshore in the 1960s (Talling, 1966) to 7.8–29.2 m (with a mean of 13.5 m) in the early 1990s (Mugidde, 1993). In the inshore water of Pilkington Bay, the euphotic zone ranged in the early 1990s from between 3.7 m and 6.7 m (Mugidde, 1993). Crul (1995; *Table 8.2*) gives an overview of the Secchi depths of several inshore and offshore waters of Lake Victoria. Along with the reduction in euphotic depth, Secchi depths have also decreased over the past 30 years. Several factors may affect water transparency in Lake Victoria: seasonal algal blooms, stirring-up of sediments during periods of mixing and the silt load of inflowing rivers (Ochumba and Kibaara, 1989), and the lake-bottom type and depth (de Beer, 1989).

Lake Tanganyika is quite transparent owing to its large volume and steep basin slopes. The mean depth of the euphotic zone was estimated at 28 m in the

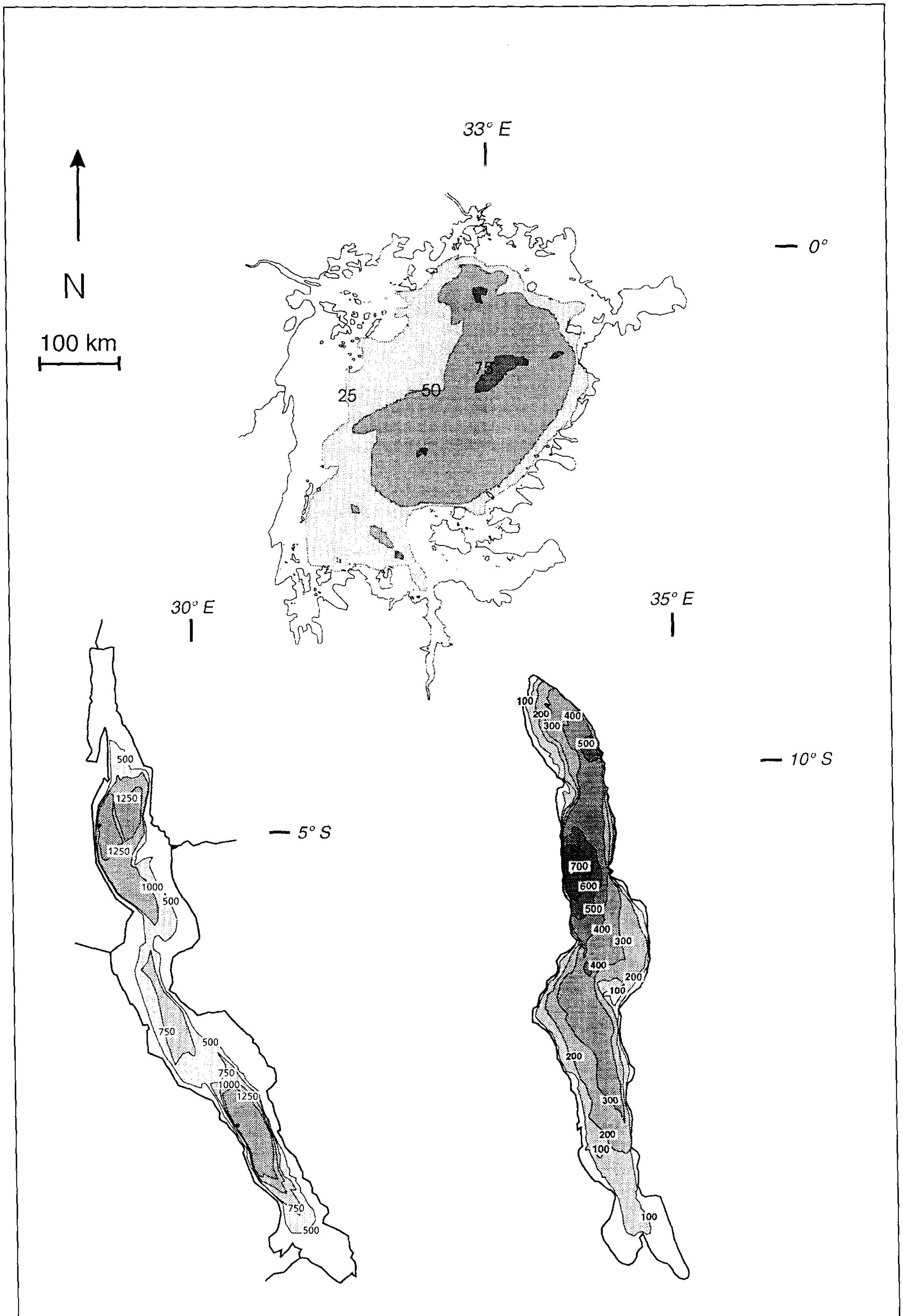


Figure 5.2.2 Bathymetric maps of the African Great Lakes.

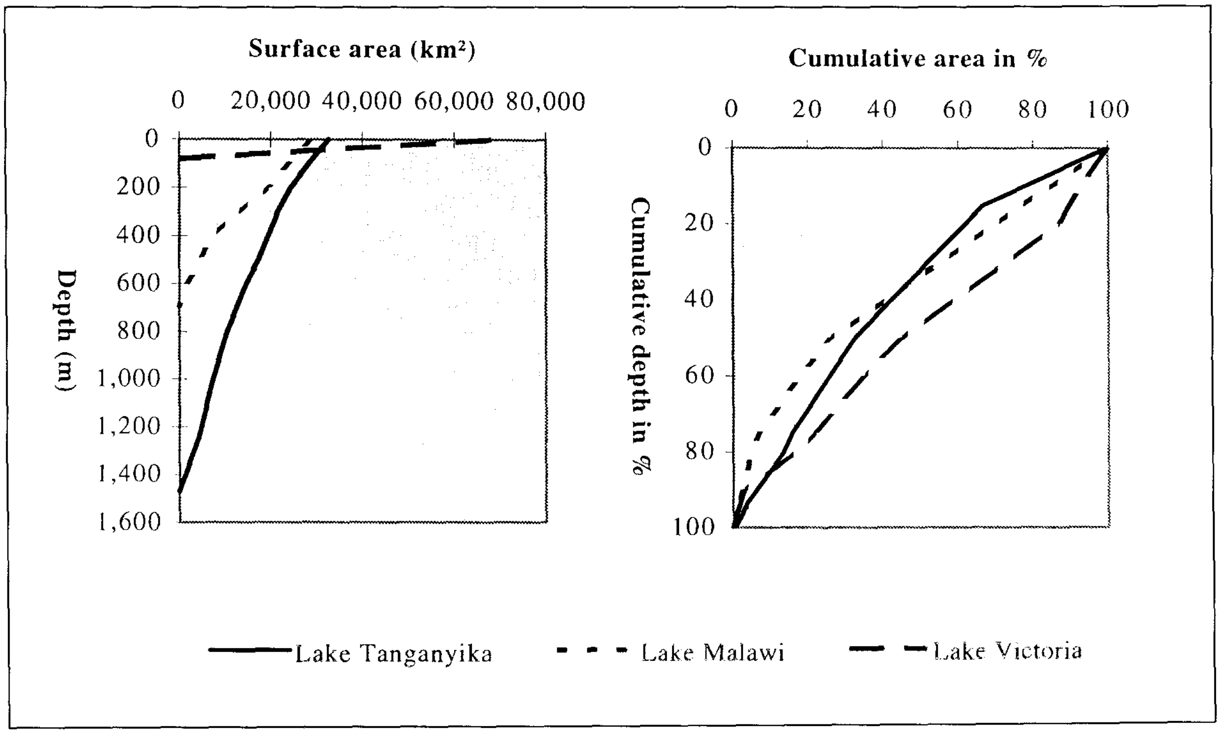


Figure 5.2.3 Hypsographic curves of the African Great Lakes.

pelagic zone in 1975 (Hecky, 1991). The Secchi depth ranged between 5 m and 17.5 m at an offshore station at the south end of the lake. In 1994, a transparency of 23.5 m was measured off Kigoma (Kurki and Vuorinen, 1994). Observed fluctuations in transparency were associated with changes in phytoplankton abundance (Coulter, 1968*ab*; Hecky and Kling, 1981). Lake Malawi is even more transparent than Lake Tanganyika: the euphotic zone in Lake Malawi may reach down to 50 m (Hecky and Kling, 1987; Patterson and Kachinjika, 1995).

As the African Great Lakes are situated in the tropics, solar radiation – ranging from between 400 cal.cm^{-2}. day^{-1} and 600 cal.cm^{-2}. day^{-1} – seems adequate for photosynthetic growth all year round. Light may, however, be limiting in all three lakes when deep mixing carries the phytoplankton below the euphotic zone (Hecky *et al.*, 1991; Patterson and Kachinjika, 1995). There is evidence to suggest that photosynthesis in Lake Victoria is now light-limited, owing to the higher phytoplankton concentrations (Mugidde, 1993).

Box 5.2.1 Light in lakes

When light reaches the surface of a lake, some of it is refracted at the air–water surface or scattered and absorbed in the upper water layers, leaving only a fraction to be transmitted. Light intensity decreases exponentially with depth. Transmission of light will depend on the colour and turbidity of the water. Approximately 50% of the underwater spectrum of wavelengths of transmitted light can be used by phytoplankton for photosynthesis. This fraction is called Photosynthetically Active Radiation (PAR). Photosynthesis in lakes is restricted to the euphotic zone (z_{eu}). The lower limit of the euphotic zone is the depth at which 1% of the surface light occurs. Underwater, light is usually measured with photocells. The transparency of water can be estimated by means of a black and white disk 20–30 cm in diameter, the Secchi disk. The Secchi depth is that at which the disk is no longer visible. In comparison to measurements with underwater photometers, the Secchi depth typically varies between 10% and 15% transmission (Wetzel and Likens, 1991).

5.3 HYDROLOGY OF THE AFRICAN GREAT LAKES

5.3.1 Hydrology

Key hydrological characteristics of the African Great Lakes are given in Table 5.3.1. The hydrology of the three lakes is still largely unknown. Of the three, Lake Victoria is the most intensely studied because of its importance as a source of the Nile. Since construction of the Owen Falls Dam in 1954, the outflow from Lake Victoria has been controlled by an agreed curve relating lake levels to pre-construction discharge measurements. Studies show that Owen Falls Dam had only a minor effect on the level of Lake Victoria over the period 1957–1980 (Kite, 1981). The Kagera River is the largest tributary, contributing 30% of the total river inflow to the lake (Sene and Plinston, 1994). A large number of relatively small rivers and streams flow into the lake (Table 5.3.2). Annual river discharges of these smaller rivers may vary considerably from year to year (WMO, 1974). Groundwater flow into or out of the lake is negligible (Krishnamurthy and Ibrahim, 1973). The outlet of

Table 5.3.1 Main hydrological data for the African Great Lakes[1]

	L. Victoria	*L. Tanganyika*	*L. Malawi*
Lake area (km^2) (A)	68,800	32,600	28,800
Volume (km^3) (V)	2,760	18,880	8,400
Annual lake level fluctuations (m)	0.4–1.5	0.3–1.8	0.3–1.8
Maximum rise in water level (m)	2.4[2]	1.8	1.5
Flushing time (years) (V/O)	140	7,000	750
Residence time (years) (V/P+I)	23	440	140

1. see Table 5.3.3 for water balance components.
2. 1961–1964.

Sources: Crul 1995; 1997; Crul *et al.*, 1995.

Lake Malawi, the Shire River, leaves the lake at its southernmost point and discharges into the Zambezi River. There are several inflowing rivers (see Table 5.3.2), of which the largest are the North and South Rukuru, Bua and Lilongwe Rivers in Malawi, the Songwe River on the border of Malawi and the United Republic of Tanzania and the Ruhuhu River within the United Republic of Tanzania. In Mozambique, only short coastal streams flow into the lake. Lake Tanganyika has as its unique outlet the Lukuga River, halfway along the western shore. A rock sill at the mouth of the Lukuga River plays an important role in the lake's hydrology, although outflow only represents 6% of the lake's total water input (Coulter and Spigel, 1991). There are two main inflowing rivers: the Ruzizi and Malagarazi Rivers, both entering the lake in the northern basin. A large number of smaller rivers flow into the lake, of which the Lufubu River in the south is the most important.

Lakes Victoria, Tanganyika and Malawi are nearly closed basins. In the course of their history, the lakes have exhibited considerable long-term water-level fluctuations between open-basin and closed-basin status (Kendall, 1969; Haberyan and Hecky, 1987; Scholz and Rosendahl, 1988; Owen *et al.*, 1990; Coulter, 1994). Recent times in East Africa have been characterized by relative tectonic stability with lake-level fluctuations in the African Great Lakes being exclusively caused by changes in climate (Nicholson, 1980; 1981; 1996; Nicholson and Flohn, 1980; Lema, 1990; Owen *et al.*, 1992; Greenwood, 1994) (see also section 5.7). The catchment areas of the three lakes are shown in Figure 5.2.1.

The long flushing times of the three lakes have great implications for nutrient dynamics (see section 5.4), as well as for eutrophication processes and pollution e.g. from oil spills (Hecky, 1993; Baker, 1992). Lake Victoria has the shortest flushing

Table 5.3.2 Outflowing and main inflowing rivers of Lakes Victoria, Tanganyika and Malawi

Lake Victoria		
Major inflowing rivers in	United Republic of Tanzania:	Kagera (main inflow), Mori, Mara
	Kenya:	Nzoia, Sio, Yala, Kibos, Nyando, Sondu, Mongusi, Kuja, Awach Kaboun
	Uganda:	Kibali, Katonga, Sio
Seasonal inflowing rivers in	United Republic of Tanzania:	Ruwana, Gurumeti, Mbalageti, Bariadi, Isanga
Outflowing river in	Uganda:	Victoria Nile
Lake Tanganyika		
Main inflowing rivers in	Burundi:	Ruzizi (main inflow), Mpanda, Ntahangwa, Mugesa, Ruzibazi, Dama, Murembwe, Nyangwe
	United Republic of Tanzania:	Malagarazi (main inflow), Lugufu, Luega, Kampisia, Ifume, Kalambo
	Zambia:	Lufubu
	Democratic Republic of the Congo:	Lunangwa, Lufuko, Lubaye, Lemba
Outflowing river in	Democratic Republic of the Congo:	Lukuga
Lake Malawi		
Major inflowing rivers in	Malawi:	Songwe (International), Lufira, North Rukuru, South Rukuru, Dwangwa, Bua, Lilongwe
	United Republic of Tanzania:	Songwe, Ruhuhu (main inflow)
	Mozambique:	Cobue, Lunho, Luaice, Luangua
Outflowing river in	Malawi:	Shire

Source: Crul, 1995; 1997.

time of the three lakes at 140 years, which is only comparable to that of very large temperate lakes, such as Baikal and Superior. The other two, Lake Malawi and Lake Tanganyika, have much longer flushing times: 700 and 7,000 years respectively (Hecky and Bugenyi, 1992).

The hydrology of the lakes is controlled by rainfall, winds and temperature in the catchment areas. Rainfall in East Africa is associated with the movement of the Intertropical Convergence Zone (ITCZ). In the catchment areas of Lake Victoria and Lake Tanganyika, situated near the equator, the rains are concentrated in two periods, March-May (main rainy season) and November–December ('short rains'). Most of the catchment of Lake Malawi lies far enough from the equator to experience only one rainy season between November and May. Rainfall varies randomly with sudden shifts in mean conditions and quasi-periodic oscillations. In general the main rains are less variable and interannual variability is related primarily to fluctuations in the short rains. Fluctuations in rainfall show strong links to fluctuations in sea temperatures in the tropical Atlantic and Indian Oceans which are loosely coupled with the El Niño–Southern Oscillation phenomenon (Nicholson, 1993).

5.3.2 Lake levels

Lake levels are influenced by seasonal fluctuations in rainfall and evaporation. In East Africa, higher evaporation co-incides with southerly winds. Lake levels in Lake Victoria generally show two peaks – a maximum in May–June and secondary peak in December following the two rainy seasons – and a minimum in October. Lakes Tanganyika and Malawi both experience only one high-water level in April–June and a low-water level in October–November. The average difference between the high-water and low-water level in all three lakes is approximately 1 m.

The lake level in Lake Victoria usually declines by between 20 cm and 40 cm with a maximum of 70 cm. The rise in water level can be somewhat more – a maximum of 90 cm was recorded for the period 1899–1960. During the period October–December 1960, an exceptional rise of 105 cm was recorded and, by June 1961, the water level had risen another 61 cm. (Krishnamurthy and Ibrahim, 1973). A significant increase in rainfall was observed in East Africa in September, October and November of 1961–1990 as compared to the period 1931–1960 (Hulme, 1992).

Lake Malawi usually reaches its seasonal low-water level at the end of November. The lake rises during the rainy season (November–April), reaching a maximum after the rains in the south of the catchment come to an end, usually in May. In the period 1948–1982, seasonal lake-level fluctuations ranged between 0.25 m in 1948–49 and 1.83 m in 1978–79 with an average fluctuation in lake level of approximately 1 m (Eccles, 1984).

Lake Tanganyika's water level fluctuates annually by about 80 cm from the seasonal low water level in October to the high water level in the period from April to June (Devroey, 1949). Lake Mweru, a shallow lake situated southwest of Lake Tanganyika, shows the same annual pattern of rise and fall as Lakes Tanganyika and Malawi. It reaches a minimum water level in December and a maximum in May. In the period 1955–1976, the lake showed an average seasonal fluctuation in water level of between 70 m and 260 m, with the exception of the 457 cm rise in water level in 1962 (Bos, 1995). In 1993, gauge recordings exhibited a fall of 150 cm and a rise of 72.5 cm (Bos, 1995).

Information on historical lake levels has become available through paleolimnological studies on strandlines, beaches lying above the present lake levels and lake sediments (see section 5.7).

In the nineteenth century, East African lakes exhibited large fluctuations in water level. Most lakes in East Africa, including Victoria, Tanganyika and Malawi, reached high levels in the period 1870–1895 as a result of above-average rainfall (Nicholson, 1981). After this period, a drop in their water levels of several metres was brought about by significantly drier conditions that lasted until 1920.

Lake Victoria showed a relatively stable water level in the period 1900–1960 with long-term fluctuations: ten- or eleven-year cycles of water level maxima prior to 1927 and a five-year cycle since 1927 (Graham, 1929; Temple, 1964).

Lake Malawi showed a progressive fall in lake level from 1900 to a minimum in 1915 when the outflow via the Shire River ceased. The water level would then rise more than 5 m to a maximum in 1937. It took until 1935 for the water level to be high enough to wash away the obstructions at the outlet. Until 1964, the water level of Lake Malawi remained below the maximum level of 1937.

After dropping to its minimum level in 1929, the water level of Lake Tanganyika rose for a period of ten years, dropping steadily after 1939 until it had sunk to a minimum in 1950 (Devroey, 1949).

In the early 1960s, Lakes Victoria, Tanganyika and Malawi, together with other Lakes in East Africa (e.g. Albert, Turkana, Naivasha and Mweru), showed a considerable rise in water level (Kite, 1981; Lema, 1990, Bos, 1995). In late 1961, the water level of Lake Victoria rose more than 1 m in a few months and in 1964 reached its maximum of more than 2 m above the 1961 level (Kite, 1981). The level of Lake Malawi in 1964 exceeded the former maximum level of 1937 by 0.08 m. Lake Tanganyika rose more than 2.5 m over a three-year period to its maximum level in 1965. Lake Mweru reached its maximum level in 1962 after a rise of more than 4.5 m in a few months (Bos, 1995).

From historical evidence collated over a longer period, it is clear that the 1961–1964 rise was not unique and that similar fluctuations have occurred in the past, notably in 1878 (Nicholson, 1981). The rise of Lake Victoria was linked to unusually heavy

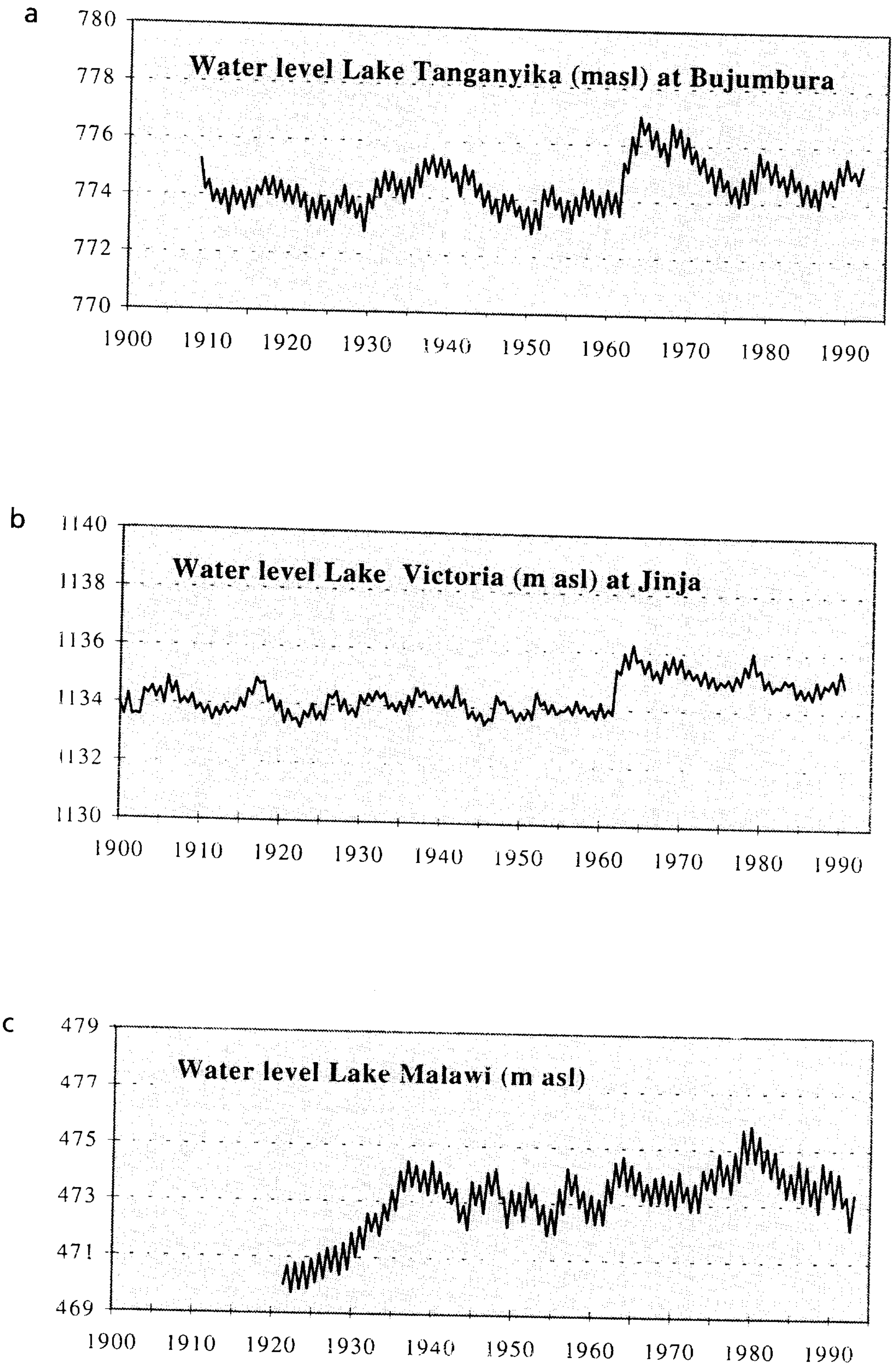


Figure 5.3.1 Lake levels of the African Great Lakes from 1900 to 1995 [a] Lake Tanganyika (Data from National Centre of Hydrometrology, Bujumbura, Burundi), [b] Lake Victoria (Data from Dept of Water Resources, Entebbe, Uganda) [c] Lake Malawi (Data from Dept of Water Affairs, Malawi).

rainfall in East Africa in late 1961 and early 1962 (Piper *et al.*, 1986). In the following years, the water level of the lakes gradually decreased, but remained somewhat higher than pre-1960 levels. In the case of Lake Victoria, this was most probably caused by the several percentage point increase in rainfall in the lake basin since the early 1960s (Kite, 1981; Piper *et al.*, 1986). The lakes were to show rises in water level again in the late 1970s, but in the case of Lake Malawi, the rise was to be disproportionately greater than in the other lakes (Eccles, 1984).

5.3.3 Water balance

Due to their large surface areas, the main factors affecting the water balance of the African Great Lakes are precipitation on the water surface and evaporation from it. The lakes are highly sensitive to changes in the rainfall–evaporation ratio.

A general equation for the water balance of a lake can be described as:

$$I_r + P_l + I_{Gr} = O_r + EV + O_{Gr} \pm S$$

where I_r = river inflow and runoff; P_l = direct precipitation over the lake; I_{gr} = inflow from groundwater; O_r = outflow through river; EV = loss through evaporation; O_g = outflow through groundwater; S = change in storage.

In the case of Lakes Victoria and Tanganyika, groundwater inflow and outflow are considered to be insignificant. Groundwater inflow into Lake Malawi has been estimated at between 7 mm and 19 mm over the lake area (between 0.2 $km^3.yr^{-1}$ and 0.6 $km^3.yr^{-1}$) (Owen *et al.*, 1990). The components of Lake Malawi's water balance are, in order of decreasing importance, rainfall over the lake, evaporation from the lake surface, and outflow and inflow from the surrounding land areas. Rough estimates of the three lakes' water balances are given in Table 5.3.3.

Rainfall appears to be the most variable component of the water balance. Estimations of total inflow and outflow from Lake Victoria are more

Table 5.3.3 Mean annual water balances of the African Great Lakes

Water balance components	*Lake Victoria*[1]				*Lake Malawi*[2]		*Lake Tanganyika*[3]			
	Krishnamurty and Ibrahim (1973)		Sene and Plinston (1994) for 1925 and 1990		Owen *et al.* (1990) for 1954–1980		Coulter and Spigel (1991)		Edmond *et al.* (1993)	
	mm	$km^3.yr^{-1}$	mm	$km^3.yr^{-1}$	mm	$km^3.yr^{-1}$	mm	$km^3.yr^{-1}$	mm	$km^3.yr^{-1}$
River inflow	262	18	300	21	1,000	29	430	14	560	18.2
Rainfall over lake	1,450	100	1,780	122	1,414	41	900	29	900	29
River outflow	340	23.4	450	31	418	12	80	2.7	130	4.2
Evaporation	1,450	100	1,600	110	1,872	54	1,350	44	1,320	43
Groundwater inflow					12	0.3				
Increase in storage					112	3				

1. surface area of Lake Victoria: 68,800 km^2
2. surface area of Lake Malawi: 28,750 km^2
3. surface area of Lake Tanganyika: 32,600 km^2

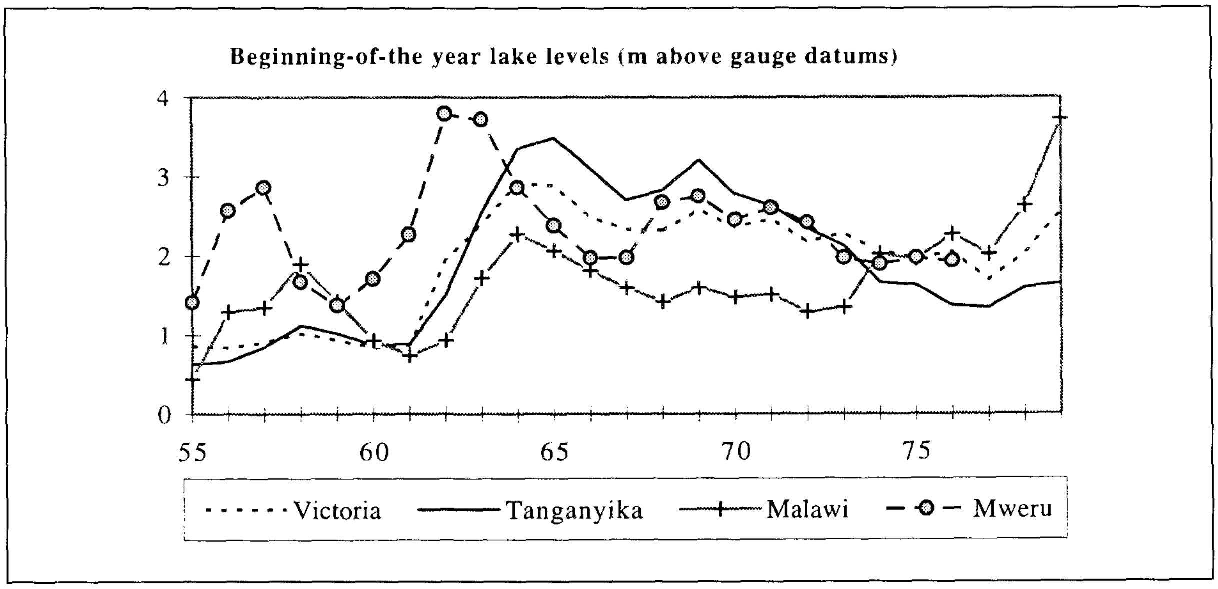


Figure 5.3.2 Exceptional lake levels of the African Great Lakes in the early 1960s and late 1970s.

accurate than those of lake rainfall and evaporation from the lake. An error of 5% in the inflow and outflow estimates and of 10% in rainfall and evaporation already results in an error in the water balance equation of 14 billion m^3 (Kite, 1981). Estimated rainfall over the lake is based on rainfall measured at a small number of lakeshore stations. Satellite images and rainfall records from islands in Lake Victoria suggest that rainfall is significantly higher over the lake than at the lakeshore and atmospheric circulation models suggest average rainfall over the lake of 3 $m.yr^{-1}$ (Sene and Plinston, 1994). Kite (1981) was only able to simulate the rise in lake levels in the early 1960s by increasing the observed lake rainfall data by 25%. Piper *et al.* (1986) were able to explain the water balance and lake-level variations in terms of natural variations in rainfall over lake and catchment. Recently, Sene and Plinston (1994) confirmed the results of Piper *et al.* (1986) with an improved monthly water balance model and an annual model.

A mean annual water balance for Lake Malawi was determined by Owen *et al.* (1990). They used mean hydrological data from the period 1954–1980. Evaporation was estimated using the annual lake-level recessions in the dry season and correcting for river inflow and outflow and for lake rainfall, assuming no groundwater inflow (Harrison *et al.*, 1976) and using lakeshore Penman evaporation data from Kidd (1983). This resulted in annual evaporation of 1,872 mm. Groundwater inflow into Lake Malawi appears to be low at an estimated 12 $mm.yr^{-1}$.

The first estimate of the annual water balance of Lake Tanganyika in Table 5.3.3 given by Coulter and Spigel (1991) is based on the work of Gillman (1933). Edmond *et al.* (1993) presented different data, which are given as the second estimate in Table 5.3. The second estimate is based on the same work by Gillman (1933) and that by Degens *et al.* (1973). The average inflow from the Ruzizi River was estimated as 3.2 $km^3.yr^{-1}$ based on the outflow from Lake Kivu at the dam in Bukavu (Democratic Republic of the Congo). The average inflow of the Malagarazi River and the lake's other tributaries were estimated at 6.9 $km^3.yr^{-1}$ and 8.1 $km^3.yr^{-1}$ respectively (Gillman, 1933). This produces a total inflow of 18.2 $km^3.yr^1$. Precipitation and evaporation were estimated at 43 $km^3.yr^{-1}$ and 29 $km^3.yr^{-1}$ respectively, while outflow from the Lukuga River averaged 4.2 $km^3.yr^{-1}$ (Edmond *et al.*, 1993). Data on a currently higher annual inflow from the Ruzizi River (Ntakimazi, personal communication) and recent estimates of the different components of the water balance by the FAO/FINNIDA project (Verburg, personal communication) suggest that the above estimates of the water balance of Lake Tanganyika, partly based on hydrological data collected in the 1930s, are in need of updating.

Owing to the large surface area of the three lakes, rainfall over each one and evaporation dominate their water balances. Evaporation accounts for 75–90% of the lakes' water loss, while direct precipitation on the lakes accounts for 60–90% of water input. Records of open lake rainfall and evaporation are not available. Modelling suggests that lakeshore data are probably underestimating rainfall and evaporation of the open water (Kite, 1981; Piper *et al.*, 1986; Sene and Plinston, 1994).

A more precise determination of lake rainfall and evaporation will be essential for successful development of water balance and hydrological prediction models for the African Great Lakes. The quality of hydrological monitoring and predictions of the likely future behaviour of the lakes will largely depend on these two components. The combined use of satellite and land-based rainfall data may improve the estimates of lake rainfall (WMO, 1981). The approach of satellite-based rain estimates combined with lakeshore rain gauge measurements is used to estimate summer lake rainfall over the Laurentian Great Lakes and could provide a useful measure of lake rainfall that may improve input to water balance models (Augustine *et al.*, 1994). Future modelling should account for factors that may influence the water balance components, such as land-use changes, changes in lake temperature, which may in turn change atmospheric circulation in the region, and changes in climate (Sene and Plinston, 1994). More precise estimations of the water balances and better forecasts of lake levels are important, since inhabitants of the African Great Lakes area are today economically more sensitive to lake-level changes.

5.4 STRATIFICATION AND WATER CIRCULATION

5.4.1 Stratification

Comparison of surface temperatures in East African lakes clearly shows a reduction in the amplitude of the temperature variations towards the equator, while the influence of the southeast trade winds is visible in the lakes of the southern hemisphere (Talling, 1969). The surface water temperatures of Lake Victoria vary between 24°C and 26°C, in Lake Tanganyika between 23.75°C and 27°C and, in Lake Malawi, located somewhat farther from the equator, between 23°C and 28°C (Talling, 1966; Coulter and Spigel, 1991; Eccles, 1974). Despite the small temperature differences, thermal stratification (see Box 5.4.1) occurs in all three lakes throughout most of the year. Only during the dry season between June and September, when air temperatures in the African Great Lakes region are lowest and the strongest winds blow, does a breakdown of stratification take place and is vertical mixing in all three lakes maximal. With a maximum depth of 80 m, Lake Victoria mixes from top to bottom (Talling, 1966), while its two sister lakes mix down to a depth of 250 m.

Lakes Tanganyika and Malawi are much deeper than Lake Victoria with maximum depths of 1,485 m and 700 m respectively. They are both permanently stratified and only mix down to a depth of 230–300 m. Lake Tanganyika has an epilimnion varying in depth from between 50 m and 80 m in the north basin and 150 m in the south basin (Coulter and Spigel, 1991), while the epilimnion of Lake Malawi is 50–125 m thick (Patterson and Kachinjika, 1995). In Lake Tanganyika, the metalimnion has its lower boundary at a depth of 300 m and in Lake Malawi at 230 m.

Solar radiation in the African Great Lakes region is relatively constant throughout the year with daily averages fluctuating between 400 cal.cm^{-1}.day^{-1} and 500 cal.cm^{-1}.day^{-1} in the Lake Victoria region and between 400 cal.cm^{-1}.day^{-1} and 600 cal.cm^{-1}.day^{-1} in the regions of Lakes Tanganyika and Malawi. In all three lakes, the breakdown in stratification is caused by a rise in evaporative cooling brought on by the strong southeast trade winds in the period June–August (Coulter and Spigel, 1991; Eccles, 1974; Newell, 1960). Evaporation is highest at night when air temperatures are lower than water temperature.

In the annual stratification cycle of the lakes, three phases can be distinguished: a warming phase in the period September–November/December, a phase of maximum stability from December to May and a cooling phase in May–August/September. Stratified conditions with a prominent thermocline fluctuating in depth are prevalent from September to May in all three lakes. Stratification may be reinforced by nocturnal sinking of cool surface water from the shallow lake margins to deeper parts in the lakes (Talling, 1963; 1966; Eccles, 1974). In all three lakes, a seasonal thermocline gradually develops during the warming phase, while additional temporary thermoclines may develop during calm, sunny periods. During the period between December and May, the thermocline in Lake Victoria descends, fluctuating between 30 m and 60 m in May. In Lake Malawi, it descends to a depth of 60 m in May. Lake Tanganyika has marked differences in stratification pattern between the north and south basins caused by different responses to wind action. Until December, the thermocline is more superficial in the north basin than in the south basin where it oscillates around a depth of 50 m. From December to May, the thermocline becomes well-established, fluctuating at a depth of about 50 m in both basins.

In the cooling phase between May and August, a breakdown in thermal stratification can be observed in all three lakes. Lake Victoria becomes completely isothermal and mixes from top to bottom, while, in Lakes Tanganyika and Malawi, a weak stratification persists. In Lake Tanganyika, free mixing occurs above a persisting thermocline at a depth of 50–80 m in the north basin, while mixing extends down to 150 m in the weakly stratified south basin (Coulter and Spigel, 1991). In Lake Malawi, mixing takes place down to 250 m and even below this depth, although the water column down to 250 m never becomes completely isothermal. Temperature difference between the surface and 250 m down shrink to less than 1°C during this period (Patterson and Kachinjika, 1995).

5.4.2 Vertical mixing

Vertical mixing (see Box 5.4.2) in the three lakes is influenced by the annual stratification cycle, during which a seasonal thermocline is formed and weakened, periods of calm, sunny weather alternate with strong winds creating and dissolving temporary thermoclines and internal seiches occur.

Vertical mixing in the three lakes reaches its maximum in the period July–August when the

Box 5.4.1 STRATIFICATION IN LAKES

Thermal stratification is the most important physical event in a lake's annual cycle. The sun heats the water near the surface and its density decreases. This results in a layer of less dense water overlying a denser, cool layer of water. In temperate lakes, three vertical layers can be distinguished: the epilimnion, the warmer less dense upper water layer, the hypolimnion, the cool denser lower water layer, and an intermediary layer of water inbetween, the metalimnion. These layers are very dynamic and fluctuate in size over the season. In addition, one or more thermoclines, which are regions where the temperature gradient is greatest, may be distinguished. The seasonal thermocline always lies within the metalimnion and smaller, temporary thermoclines may occur within the epilimnion or metalimnion. In temperate lakes, seasonal thermoclines occur with temperature differences up to 10–15°C, while in tropical lakes a much smaller difference of 1–3°C already creates a stable thermocline. This is caused by a greater decrease in density per degree rise in temperature at higher temperatures than at lower temperatures. A temperature difference in tropical lakes between surface and bottom as small as 1°C may still be sufficient for a stable stratification.

In temperate lakes, stratification is controlled by solar radiation and air temperature, while in the tropics the main factors controlling stratification are air temperature and wind. Tropical lakes deep enough to stratify and mix once a year are called monomictic. In temperate climates, only large lakes, such as the Laurentian Great Lakes (except for Lake Erie) and Lake Tahoe, which are never completely covered with ice and mix continuously during winter, are monomictic. The other temperate lakes with ice cover in winter mix twice a year, in autumn and spring and are dimictic. Shallow tropical lakes, such as Lake George in Uganda, stratify and destratify more than twice a year and are polymictic. Next to the above classification based on complete mixing some very deep tropical lakes, such as LakesTanganyika, Malawi and Kivu, do not completely mix and are called meromictic.

seasonal thermocline is weakened due to the lower air temperatures, increased evaporative cooling and the kinetic energy added by the stronger winds. Lake Victoria mixes completely in this period, during which a thermocline is absent (Talling, 1966). In the two other lakes, the thermocline only weakens and a temperature gradient persists. In Lake Tanganyika, free mixing takes place to a depth of 150 m in the south basin and to a depth of 80 m in the north basin, while slower mixing may cause vertical transfer down to 300 m, the level of permanent stratification (Coulter and Spigel, 1991). In Lake Malawi, mixing occurs down to a depth of 250 m (Eccles, 1974; Patterson and Kachinjika, 1995).

Owing to the strong southeast trade winds channelled along the length axis of the two rift lakes, a deeper sharper thermocline develops downwind in the northern part of the two lakes and a weak thermocline at the windward end of the lakes in the southern part, where upwelling of water from deeper layers and large-scale mixing occur (Coulter and Spigel, 1991; Patterson and Kachinjika, 1995). Based on a deflection of surface currents to the left by the Coriolis Force in lakes of the southern hemisphere, an east to west downward tilt of the thermocline and upwelling along the eastern shore may be expected (Coulter, 1968*a*), although recent research on Lake Malawi has revealed an upwelling along the eastern shore (Patterson and Kachinjika, 1995).

Owing to the relative shallowness of Lake Malawi's south basin, the deeper water consists of metalimnion water, while in Lake Tanganyika hypolimnion water also appears in the surface layers. This can be observed from fish kills and the appearance of deep water isotherms close to the surface (Coulter and Spigel, 1991). Kitaka (1972) described another event of upwelling by cyclonic circulation in the offshore waters of Lake Victoria. Stratification there may have been broken by a violent storm deepening the upper mixed layer.

BOX 5.4.2 THE IMPORTANCE OF VERTICAL MIXING

A thermocline acts as a barrier between the mixed layer in the upper part of the water column and the deeper water layers below it. Organic material, such as phytoplankton and detritus, can sink through it, but gases and nutrients in solution cannot. Decomposition of the accumulated organic material in the water layers below the thermocline results in deoxygenation of these layers as the oxygen used for the decomposition cannot be replaced. Loss of algae and organic material due to sinking also implies the loss of nutrients from the productive upper water layer. Therefore, the occurrence of a thermocline and the extent of vertical mixing is of crucial importance to a number of physical, chemical and biological processes in the lakes. The thickness of the upper mixed layer controls the distribution of oxygen and nutrients which determine the abundance and distribution of planktonic organisms. During stratified conditions, all or part of the epilimnion in tropical lakes is well-mixed by the wind and the depth to which vertical mixing extends will depend on the combined action of solar radiation and wind. During windy weather and storms, the upper mixed layer will thicken, while in calm and sunny periods, a thin mixed layer will be superimposed on the old mixed layer. In this way, multi-layer stratification may occur with temporary thermoclines in addition to the seasonal thermocline (Lewis, 1973; Horne and Goldman, 1994).

During stratified conditions in the remaining period of the year, vertical mixing is confined to the water layers above the thermocline. The thickness of the mixed layer will fluctuate in response to changes in weather conditions. During calm periods, temporary thermoclines reduce the incidence of vertical mixing, while windy periods or storms deepen the mixed layer again by dissolving the temporary thermocline. The occurrence of the temporary thermoclines, a common phenomenon in tropical lakes (see Box 5.4.2), has been observed in Lake Malawi during the warming phase between September and December (Degnbol and Mapila, 1981). Deepening of the mixed layer can be observed during the stratification period in Lake Victoria when strong winds tilt the thermocline downwards and surface water occasionally occupies the complete water column in the northern part of the lake (Fish, 1957; Talling, 1966).

5.4.3 Hypolimnion

The two rift lakes, Tanganyika and Malawi, have large, permanent and anoxic hypolimnia in contrast to the holomictic Lake Victoria. The hypolimnion of Lake Tanganyika is approximately homothermal at a temperature of 23.30°C ± 0.05°C (Coulter and Spigel, 1991). The lowest temperatures (23.25–23.28°C) were observed in the 500–800 m depth range by Capart (1952) and at 900 m (23.25°C) by Craig (1975), while temperatures near the bottom were slightly higher. The hypolimnion temperature in Lake Malawi was 22.68°C ± 0.01°C (Patterson and Kachinjika, 1995), which tallies with the values observed by Gonfiantini *et al.* (1979).

By contrast, stratification in shallow Lake Victoria is seasonal and broken down by southeast trade winds in the period from June to August. Only during the period of stable stratification between January and May may hypolimnion water become anoxic. Hypolimnion water ranging in temperature from between 22.85°C and 23.5°C, observed in 1927 (Graham, 1929) and in 1952–1953 (Fish, 1957), was not seen during recent studies in Uganda and Kenya when hypolimnion temperatures never fell below 23.8°C (Hecky *et al.*, 1994). These data may suggest a response by the lake to a possible trend towards climatic warming in East Africa since 1960 (Hecky, 1993).

In Lake Kivu, another deep East African lake with a maximum depth of 480 m, the conductivity of water increases rapidly below 70 m, the great density of the deeper water on account of its high salinity being responsible for permanent stratification, despite the remarkable increase in temperature (Damas, 1937). In Lake Tanganyika, the major ions (Na, K, Ca, Mg) show rather uniform profiles to the bottom (Degens *et al.*, 1971). Stratification in Lake Tanganyika appears to be determined by thermal gradients. The metalimnion/hypolimnion boundary in Lake Malawi is marked by a small increase in conductivity of 5–8 $\mu S.cm^{-1}$ at 230 m (Patterson and Kachinjika, 1995). The slight increase in conductivity in the deeper water layers of Lakes Malawi and Tanganyika can only contribute to a minor extent to their meromictic conditions.

Tritium isotope analysis used to estimate downward mixing in the water column and the transfer rates between density layers revealed that the mixing rate of hypolimnion and epilimnion water in Lake Tanganyika is extremely slow (Craig, 1975). The observed relatively high concentrations of the isotopes deuterium and oxygen-18 in deep water – which are much higher than those of the inflowing rivers – may indicate that the hypolimnion water is the product of a colder drier climate with higher evaporation (Craig, 1975). In Lake Malawi, tritium isotope analysis showed that, since 1943, annually 25% of the metalimnion water has been mixing with the hypolimnion water and some 20% of the metalimnion water with the epilimnion water (Gonfiantini *et al.*, 1979). Cooling of the deep water below 250 m during mid-1993 also suggests some mixing at the metalimnion/ hypolimnion boundary (Patterson and Kachinjika, 1995).

5.4.4 Currents

In all three lakes, surface currents (see Box 5.4.3) are dominated by the prevalent southeast trade winds. In Lake Victoria, the effect of the winds on the surface water seems to be a gradual displacement of surface water to the north. This northward surface current already observed by Graham (1929) was accompanied by a compensating flow of deeper water southwards resulting in a limited upwelling event in the southern part of the lake (Newell, 1960; Kitaka, 1972). In Lake Malawi, there appears to be a northerly drift of surface water on the western shore with a southerly return current on the eastern shore of about 0.5 km. hr^{-1} (Eccles, 1974). Currents along the shore to the northeast were observed in the bay at Chintheche with surface velocities of between 100 m. hr^{-1} and 300 m. hr^{-1} and occasionally up to 600 m. hr^{-1} (Ferro, 1977). In Lake Tanganyika, there also appears to be a clockwise current like that in Lake Malawi (Coulter and Spigel, 1991), as supported by observations of a generally north to south current along the east coast (Van Well and Chapman, 1976) and the westward swing of the Lufubu River as it enters the lake on its southwestern side (Coulter, 1968*a*).

Profile-bound density currents may play a role in all three lakes. Eccles (1974) and Patterson and Kachinjika (1995) presented evidence for these currents for Lake Malawi. Small oscillations of the thermocline involved large horizontal water displacements in the southeastern arm, generating currents along the bottom and resulting in greater mixing of epilimnion and metalimnion water. These currents were also observed in Lake Albert (Talling, 1963) and may occur in Lakes Tanganyika and Victoria caused by marginal cooling (Capart, 1952; Talling, 1966) and inflowing rivers (Coulter, 1968*b*).

Box 5.4.3 WATER MOVEMENTS

Forced by the transfer of wind energy to the water, water movements cause a number of oscillations of the water surface and deeper in the water column of a lake. The morphometry of the lake, the stratification structure and the lake's exposure to the wind will together determine the occurrence and nature of these water movements, in larger lakes modified by the earth's rotation ('coriolis force'). This force is zero at the equator and increases towards the poles. It will deflect currents and waves to the left in lakes of the southern hemisphere and to the right in lakes of the northern hemisphere.

There are two kinds of water movements which normally occur together: currents and waves. Currents consist of water flows, while waves consist of the rise and fall of water particles. Strong winds will produce currents and waves at the lake's surface and internal waves at the thermocline. Water currents at the surface are called surface drift. Surface waves are generated when winds blow over the water in one direction. Water is held at the lee shore by the wind until the wind drops and the water mass flows back under the influence of gravity. A surface wave develops, which moves backwards and forwards with a gradually decreasing amplitude. When water is blown by the wind to one end of the lake, it must eventually return; it usually flows back deeper down in the water column in the opposite direction of the prevailing wind. In stratified lakes, this often occurs just above the thermocline. After the wind stops, the water layers tilt back with the pull of gravity and an internal wave develops on the thermocline that may be detected as a periodic rise and fall of the thermocline. The internal wave will set the water layer near the thermocline in motion, resulting in an increased mixing of the upper and deeper water layers. In small lakes, the event of an internal wave can be described by a non-rotating model. In larger lakes, the coriolis force and the lake's morphometry take on greater importance, modifying the uninodal internal waves into two other types of internal waves: the Kelvin and Poincaré waves. Kelvin waves, whose frequency depends on the size of the lakes, have a pronounced effect on the nearshore waters where they may move the thermocline several metres; as for the Poincaré waves, whose frequency depends on the latitude, they have a pronounced effect on the hypolimnion in open waters (for more details, see Mortimer, 1974).

5.4.5 Internal waves

Internal waves (see Box 5.4.3) play an important role in Lakes Tanganyika and Malawi in the period after the cessation of the southeast trade winds. No internal waves have been observed in Lake Victoria, although surface waves normally inducing internal seiches are commonly observed in the lake (Newell, 1960). Theoretical calculations on the internal waves in Lakes Tanganyika and Malawi can be found in Coulter and Spigel (1991) and Patterson and Kachinjika (1995).

Temperature-depth observations in Lake Tanganyika revealed regular long-period internal wave oscillations with fundamental modes of 23–33 days and amplitudes of 30–40 m, as well as short-period internal waves with a mode of three days (Coulter, 1968*a*). The internal seiche appears to persist in Lake Tanganyika during the rainy season without major interruptions until the onset of the south wind in the following dry season (Coulter and Spigel, 1991). These two types of internal waves were also observed recently in the lake for several other physical and chemical parameters (Plisnier, 1994).

Internal waves in Lake Malawi were observed by Jackson *et al.* (1963) and Eccles (1974). Patterson and Kachinjika (1995) presented some evidence that seiching occurred in Lake Malawi during the period September– November in 1992 and 1993. Internal waves may even occur in the dry season. A plume of cold water observed by Patterson and Kachinjika (1995) in the northern part of Lake Malawi in July 1993 may have been caused by an internal seiche, while similar events were observed in Lake Tanganyika by Coulter (1968*ab*).

Large short-term vertical shifts of isotherms, such as those observed in the time–depth series of water temperature of earlier studies (Jackson *et al.*, 1963; Eccles, 1974; Degnbol and Mapila, 1982) were not observed in the time–depth series of water temperature for the offshore Nhkotakota station sampled in 1992–1993 by Patterson and Kachinjika (1995) .

5.4.6 Stratification in inshore waters

Differences between the stratification cycle in offshore and inshore waters exist in Lake Victoria. In addition to the offshore waters, the lake has a number of moderately shallow inshore channels and more or less isolated shallow gulfs and bays. Stratification in channels with depths of up to 30 m develops much earlier and breaks down earlier than in the offshore lake (Talling, 1966). The deeper parts of the gulfs, such as the entrance to the Mwanza Gulf with depths of 14 m, do not show prolonged stratification, except for short periods of calm weather in the main rainy season (Van Oijen *et al.*, 1981). The shallow inshore areas, such as the Nyanza Gulf and bays with depths of less than 10 m, only become stratified on a daily basis (Worthington, 1930; Fish, 1957; Talling, 1957; Akiyama *et al.*, 1977; Ochumba, 1983) and may be compared with shallow polymictic tropical lakes.

The shallower southern arms of Lake Malawi with depths of about 100 m have basically the same pattern of stratification as the first 100 m of the deeper northern part. The main difference between the two parts is that the water temperature on the lake bottom of the shallow southern arms often falls below the temperature of the deep water in the open lake in the cool season, owing to the cooling effect of the strong, dry southeast trade winds. The water chilled in the south is sinking and running along the bottom as a profile-bound density current (Eccles, 1974).

Owing to the upwelling at the southern end of Lake Tanganyika in the dry windy season, vertical mixing occurs to a depth of 150 m (Coulter, 1968*a*). Here, the thermocline disappears at the surface in May–June and becomes weak throughout the south basin; in August, the water column mixes freely to at least 150 m depth (Coulter, 1968*a*). Nutrient regeneration from the deeper water layers occurs under strong wind stress by upwelling of cooler water (Coulter, 1963).

5.5 WATER CHEMISTRY

5.5.1 Mineral composition

Lakes Victoria and Malawi both have a 'common' water type, while Lakes Tanganyika and Kivu have the sodium–potassium–magnesium bicarbonate water type (low chloride sub-type) (Kilham and Hecky, 1973). The chemistry of water draining the watershed of a lake is determined by the parent rock, the climate and by the topography and vegetation of the watershed (Horne and Goldman, 1994). The ionic composition of Lakes Victoria and Malawi is a product of deep weathering of granitic and metamorphic rocks of the African plateau and is hardly influenced by volcanic terrain (Kilham and Hecky, 1973). Lake Victoria is the most dilute of the three lakes with a conductivity of the surface water of 97 $\mu S.cm^{-1}$. The surface water of Lake Malawi has a conductivity of 285 $\mu S.cm^{-1}$, while that of Lake Tanganyika is the most concentrated with a conductivity of 610 $\mu S.cm^{-1}$. Factors responsible for the relatively high ionic concentrations of Lake Tanganyika are the mineral-rich water of Lake Kivu and the evaporative concentration within the lake itself. Lake Tanganyika and the inflowing Ruzizi River bear a striking resemblance in water chemistry (Degens *et al.*, 1971). After the Virunga volcanoes blocked the Nile drainage of Lake Kivu, the latter overflowed to the south into Lake Tanganyika via the Ruzizi River. The inorganic composition of the offshore waters of the three lakes is given in Table 5.5.1. Data for Lake Victoria are given for 1961 and 1988 to reflect the great changes in the lake's chemistry over the past 30 years.

Table 5.5.1 Chemistry of Lakes Victoria, Tanganyika and Malawi

	Lake Victoria		*Lake Tanganyika*		*Lake Malawi*	
	1961	*1988*	*Surface*	*400 m*	*Surface*	*400 m*
Na [1]	450	340	2,700	2,900	800	900
K	97	90	820	900	160	170
Ca	140	120	270	310	450	500
Mg	110	90	1,650	1,740	310	320
DIC [2]	–	920	5 880	6,720	2,360	2,510
Cl	110	93	750	780	130	140
SO_4	24	3	37	–	27	–
SRSi [3]	69.8	7.01	9.5	244	21.8	177.5
NO_3-N	0	0.2	0.3	0.0	>0.1	>0.1
NH^{4+}-N	0	0	0	150	0	
PO_4-P (SRP) [4]	0.42	0.23	0.15	5.73	0.13	1.25
Total P	1.52	1.13	–	–	0.53	3.23
Alkalinity ($me.l^{-1}$)	0.92	0.84	6.52	6.91	2.45	–
Conductivity ($\mu S.cm^{-1}$)	97	94	610	–	285	–

1. all concentrations in μM except when otherwise stated.
2. Dissolved Inorganic Carbon.
3. Modern analytical treatments present silicon data in terms of 'soluble reactive silicon' concentration (SRSi) or $Si(OH)_4$ concentration. In a large number of earlier studies (e.g. Talling, 1966) equivalent silica (SiO_2) concentrations are cited. Conversion of units may be derived from: 1 mg SiO_2/l = 0.47 mg Si (or SRSi)/l = 17mg-at Si/l = 17 mM $Si(OH)_4$.
4. SRP = Soluble Reactive Phosphorus.

Source: Hecky and Bugenyi, 1992, Table 2.

5.5.2 Dissolved oxygen

The surface waters of Lakes Victoria, Tanganyika and Malawi are generally well-oxygenated throughout the year. The drastic changes in limnology in Lake Victoria since the 1960s have affected the oxygen levels near the surface, which are now regularly supersaturated and as high as 13 $mg.l^{-1}$ during algal blooms (Ochumba and Kibaara, 1989).

In the three lakes, stratification and vertical mixing strongly affect the dissolved oxygen distribution below the surface layers. In the offshore waters of Lake Victoria, seasonal changes in dissolved oxygen closely reflect the three main phases of thermal stratification. In the warming phase, vertical gradients extend over most of the water column. During the phase of stable stratification, vertical gradients are centred upon the thermal discontinuity in the lake. In the 1960s, the deep offshore waters below 55 m registered only occasionally low oxygen concentrations (below 10% saturation) in the period of stable stratification, while in the early 1990s they contained less oxygen and anoxic conditions were encountered frequently (Hecky *et al.*, 1994). In the cooling phase, oxygen is uniformly distributed over the whole water column. Inshore areas in Lake Victoria are generally well-oxygenated from surface to lake-bottom. Low levels of oxygen have only been observed in the deeper inshore waters when a thermal discontinuity developed during a period of calm weather (Fish, 1957; Van Oijen *et al.*, 1981). In Lake Malawi, dissolved oxygen gradually decreases with depth until it is virtually absent at 250 m and a sharp oxycline is only rarely observed (Patterson and Kachinjika, 1995). During the stratification period, oxygen is generally present at levels of 7–8 mg $O_2.l^{-1}$ down to the thermocline. During the cooling period, vertical mixing increases oxygen levels in the water layers below a depth of 100 m. In Lake Tanganyika, oxygen also gradually decreases with depth, but the limit of dissolved oxygen lies at a lesser depth than in Lake Malawi at 100 m in the north basin and at 200 m in the south basin. The differences in stratification between the north and south basins are reflected in the dissolved oxygen distribution. Throughout the year, the depth limit of dissolved oxygen is lower in the north than in the south (Degens *et al.*, 1971; Hecky *et al.*, 1978). Oscillations in oxygen distribution in the water column closely follow those in temperature distribution (Coulter and Spigel, 1991). Upwelling events at the south ends of Lakes Tanganyika and Malawi also affect the oxygen distribution. In Lake Tanganyika, anoxic water from the hypolimnion may appear at the south end within 60 m of the surface in the period June–August and mixing of the water column may result in lower oxygen concentrations near the surface (Coulter and Spigel, 1991). The southern part of Lake Malawi has depths less than 200 m and upwelling there will only involve metalimnion water, which will not be anoxic as in Lake Tanganyika.

5.5.3 Nutrients

The principal elements required for plant production are carbon, phosphorus, nitrogen and silicon, this last element being important for diatoms as a major component of the cell wall. Nutrients may limit algal productivity in the tropics despite the high temperature there, allowing rapid nutrient recycling. Those nutrients most likely to be limiting in African lakes are nitrogen (Talling and Talling, 1965; Moss, 1969; Lehman and Branstrator, 1993; 1994) and phosphorus (Melack *et al.*, 1982; Kalff, 1983), while silicon may limit diatom growth (Hecky and Kilham, 1988). No single nutrient seems to continuously control algal growth in the African Great Lakes (Bootsma and Hecky, 1993).

Hecky *et al.* (1996) describe the nutrient cycles in the African Great Lakes, assuming that steady-state conditions (i.e. input of a nutrient) are equal to output and that concentrations and fluxes within the ecosystem are invariant. In general, nutrient input consists of atmospheric (wet and dry) deposition, riverine input, *in situ* nitrogen fixation and groundwater inflow. Nutrient losses include river outflow, groundwater outflow, gas exchange and sedimentation. No information is available on losses of nutrients to the sediments.

At present, Lake Malawi has the most complete data set of input and output of nutrients of all three lakes, assuming negligible groundwater inflow (Table 5.5.2). Nutrient retention is high for all four nutrients in Lake Malawi and this is also expected to be the case for Lakes Victoria and Tanganyika (Hecky *et al.*, 1996).

Atmospheric deposition constitutes an important source of nitrogen and phosphorus in all three lakes. Another important source of nitrogen is the fixation of atmospheric nitrogen by blue-green algae (e.g. *Anabaena*) and bacteria. In Lake Malawi, it is by far the most important source (Table 5.5.2) and the same is probably true for the other two lakes. The phytoplankton composition in Lake Victoria has evolved towards a dominance of nitrogen-fixing blue-green algae (Hecky, 1993). Since the 1960s, the atmospheric input of phosphorus has increased dramatically in Lake Victoria; that of nitrogen and sulphur appears to have changed little according to rainfall data for the northern part of Lake Victoria. The increase of phosphorus in rain may be associated with increased burning and soil erosion (Bootsma and Hecky, 1993). The main input of silicon stems from river inflow (Table 5.5.2).

In the almost closed basins of the African Great Lakes, downward and upward fluxes of nutrients between the upper water layers and deep water are of major importance to the nutrient concentrations in the mixed layer. Comparison of nutrient input and the supply of nutrients to the mixed layer from the deeper layers in Lakes Malawi and Tanganyika reveals the importance of vertical mixing for phosphorus and silicon (Bootsma and Hecky, 1993). Phosphorus input to the upper layers of Lake Malawi is dominated by vertical mixing and diffusion from below the oxic–anoxic boundary, which plays a very important role in phosphorus supply (Hecky *et al.*, 1996). Atmospheric deposition and river input account for only the remaining 10% of the estimated total phosphorus input. In Lake Victoria, dissolved phosphate is now always available in excess in the offshore surface waters, although it may become limiting in the lake's shallow inshore waters (Hecky, 1993). Denitrification around the oxic–anoxic interface means that there is no internal nitrogen loading from the deeper water in Lakes Malawi and Tanganyika. Denitrification is now also being observed in Lake Victoria, as the deep water layers become deoxygenated during the stratification period due to eutrophication (Hecky *et al.*, 1996). In the deep anoxic water layers of the hypolimnia of all three lakes, ammonia is the dominant form of inorganic nitrogen (Hecky *et al.*, 1996). The nitrogen demands in all three lakes must be met by input from rivers, wet and dry deposition and nitrogen fixation.

Silicon in Lake Victoria has been reduced by a factor of 10 since the 1960s. This is the result of the eutrophication in the lake in the last 30 years. Increased input of phosphorus has resulted in greater primary productivity. This has accelerated the sedimentation of silicon contained in diatom frustules, suggesting that silicon will eventually become a limiting factor for diatom growth (Hecky, 1993; Hecky *et al.*, 1996).

5.6 TROPHIC STRUCTURE AND DYNAMICS

The pelagic zone is the most important in Lakes Tanganyika and Malawi, while in shallow Lake Victoria, both the pelagic zone and the littoral zone play an important role. In this section, the main components of the trophic structure and biological processes, such as photosynthesis and respiration, are discussed, together with trophic dynamics in the pelagic ecosystems of the three lakes. Food-chain

Table 5.5.2 Annual nutrient input and the sulphur, nitrogen, phosphorus and silicon output of Lake Malawi

	Sulphur	*Nitrogen*	*Phosphorus*	*Silicon*
Input	1,440	15,200	143	6,720
• River inflow	1,330	740	80	6,720
• Wet and dry precipitation	100	2,650	63	trace
• Nitrogen fixation		11 810		
Output	140	120	4	240
• River outflow	140	120	4	240
Retention (= input – output)	1,290	15,080	139	6,480

Note: Concentrations of all elements are in megamoles.
Source: Hecky *et al.*, 1996; Table 2.

dynamics of Lakes Tanganyika and Malawi have been described recently (Hecky, 1991; Allison, 1995), but those of Lake Victoria are still poorly understood owing to the recent changes in the ecosystem.

5.6.1 The primary trophic level

5.6.1.1 Phytoplankton

Species composition

The phytoplankton of the African Great Lakes is characterized by a dominance of Cyanophyta and Chlorophyta, together with Diatomeae (Table 5.6.1). A special feature of the pelagic phytoplankton in Lake Tanganyika is the importance of Chrysophyceae. No other tropical lake has as great a number of species nor the biomass that the Chrysophyceae achieve in Lake Tanganyika (Hecky, 1991). These organisms are scarce in Lakes Victoria and Malawi.

One group of phytoplankton overlooked so far has been the picoplankton. A sample taken in 1987 revealed moderate numbers ($3.70 . 10^4$ cells. ml^{-1}) in the Nyanza Gulf (Kenya) of Lake Victoria (Hawley and Whitton, 1992).

In Lake Victoria, great changes have occurred in the phytoplankton composition since the early 1960s (Ochumba and Kibaara, 1989; Hecky, 1993; Mugidde, 1993; Gophen *et al.*, 1995). In the 1960s, the phytoplankton was made up largely of blue-green algae, diatoms and green algae (Talling, 1987). The phytoplankton of Lake Victoria is currently dominated by blue-green algae (Hecky, 1993; Gophen *et al.*, 1995). This shift towards blue-green algae dominance has probably been caused by changes in the ecosystem of the lake due to eutrophication, the introduction of Nile perch and possibly climatic changes in recent decades (Hecky, 1993). The dominance of blue-green algae may be explained by lower nitrogen/phosphorus ratios and declining silicon concentrations (Hecky, 1993).

In Lake Tanganyika, nanoplankton shares dominance with the blue-green *Anabaena* and the diatom *Nitzschia* at biomass maxima. At all other times, the nanoplankton is dominant in biomass (Hecky and Kling, 1981). Cryptophyceans are always present, but of secondary importance. Differences in species composition have been observed in the Cyanophyta of Lake Tanganyika: *Chroococcus* spp. are dominant in the northern waters and *Anabaena flos-aquae* fa. *aptekariana* in the southern waters. The distribution of nitrogen-fixing *Anabaena flos-aquae* may indicate the relative importance of biological nitrogen fixation (Hecky *et al.*, 1991).

In Lake Malawi, blue-green algae, green algae and diatoms dominate the phytoplankton, while chrysophytes and peridineans have always been rare (Hecky and Kling, 1987). The phytoplankton composition of Lake Malawi in 1992–1993 (Patterson and Kachinjika, 1995) closely resembled that of earlier years (Hecky and Kling, 1987; Haberyan and Mhone, 1991; Bootsma, 1993*ab*), although some differences in species composition have been observed between years.

Spatial and temporal distribution

Seasonal cycles of phytoplankton in the African Great Lakes correspond quite well to the stratification cycle. Stratified conditions in the lakes favour cyanophytes and chlorophytes, while periods of mixing favour diatoms and chrysophytes (Hecky and Kling, 1987; Talling 1987). In the rift lakes, the

Table 5.6.1 Phytoplankton composition in the African Great Lakes

	Dominant groups	*Most important species*
Lake Victoria		
1960	Diatomeae	*Aulacoseira (= Melosira) nyassensis* var. *victoriae, Stephanodiscus astrea, Cyclotella* spp., *Surirella* sp., *Cymatopleura spp*
	Cyanophyta	*Aphanocapsa spp., Anabaena flos-aquae, Anabaena spp., Microcystis spp., Anabaenopsis tanganyikae*
	Chlorophyta	*Staurastrum , Coelastrum*
1989–1990 (1986)	Cyanophyta	*Lyngbya bipunctata, Lyngbya* sp., *Cylindrospermopsis* sp., *Microsystis* sp. (1986)
	Diatomeae (of secondary importance)	*Synedra cunningtonii*
Lake Tanganyika	Cyanophyta–Chlorophyta	*Chroococcus* spp., *Anabaena flos-aquae*
1975	Chrysophyceae–Diatomeae	*Chrysochromulina parva, Chromulina* spp., *Spumella* sp., *Ochromonas* spp. *Nitzschia* spp., *Stephanodiscus* sp., *Cyclotella* sp., *Cyclostephanos* spp.
Lake Malawi	Cryptophyta (of secondary importance)	*Glenodinium* sp., *Peridinium* sp.
1980, 1990	Cyanophyta–Chlorophyta	*Lyngbya* spp., *Anabaena flos-aquae, Mougeotia* sp.
	Diatomeae	*Nitzschia* spp., *Stephanodiscus* sp.
	Cryptophyta (of secondary importance)	*Rhodomonas* sp., *Cryptomonas* sp.

Source: Lake Victoria 1960 (Talling, 1987); Lake Victoria 1989–1990 (Gophen *et al.*, 1995) Lake Victoria 1986 (Ochumba and Kibaara, 1989); Lake Tanganyika 1975 (Hecky and Kling, 1981; 1987); Lake Malawi 1980, 1990 (Hecky and Kling, 1987; Patterson and Kachinjika, 1995).

three phases of the stratification cycle each have a characteristic phytoplankton community. The cooling phase with its increased mixing (May–August) is characterized by the appearance of chrysophytes followed by diatoms. During the warming phase (September–December), almost all phytoplankton species show maximum biomass, while phytoplankton is dominated by Cyanophyta and Chlorophyta during stable stratification conditions (Hecky and Kling, 1987). In Lake Victoria, the diatoms were at a maximum biomass towards the end of the cooling phase in the 1960s, while Cyanophyta had their maximum abundance during the warming phase (Talling, 1987).

In addition to temporal fluctuations, phytoplankton of the African Great Lakes shows spatial variations in abundance, both horizontally and vertically. Horizontal large-scale patchiness occurs frequently in large lakes, reflecting the responses of phytoplankton populations to diffusivity (Reynolds, 1984). Horizontal variations have been observed in Lakes Victoria and Tanganyika and in some other large East African lakes (Talling, 1969; 1987; Coulter, 1963; Hecky and Kling, 1981; Hecky, 1991). In Lake Malawi, however, no great differences have been observed in the horizontal distribution of phytoplankton (Hecky and Kling, 1987; Bootsma, 1993*b*; Patterson and Kachinjika, 1995). Only in the relatively shallow southeast arm of the lake has a somewhat higher phytoplankton biomass been observed.

In Lake Victoria, differences in vertical distribution of phytoplankton observed during stratified conditions can be explained by different rates of sinking and differing degrees of resistance to the condition of the nearly deoxygenated lower layer. Blue-green algae showed maxima in the upper layers, desmids showing nearly uniform distribution and diatoms maxima in the lower water column (Talling, 1963).

In Lake Tanganyika, rather uniform vertical distributions of phytoplankton occur in the top 30 m with somewhat higher concentrations in the upper 20 m (Hecky *et al.*, 1978). Recent studies, however, have revealed a pronounced photo-inhibition of phytoplankton in the lake, which has major implications for the assessment of primary productivity in Lake Tanganyika (Salonen and Sarvala, 1994).

In Lake Malawi, blue-green algae tend to be shallower in the water column at the beginning of the year and concentrated near the surface at the end of the year. Sub-surface maxima of mainly diatoms near the thermocline were observed in the lake in 1993, probably reflecting a slower sinking rate caused by the greater water density (Patterson and Kachinjika, 1995).

Phytoplankton biomass and primary productivity

Algal biomass in the upper mixed layer of the African Great Lakes varies considerably during the year. Both direct estimates of biomass and of chlorophyll a are available for the three lakes.

In Lake Malawi, the phytoplankton biomass is relatively low compared to the other two lakes, fluctuating between 20 mg.m^{-3} and 200 mg.m^{-3} in the upper 50 m (Hecky and Kling, 1987; Bootsma, 1993*a*; Patterson and Kachinjika, 1995). In 1992–1993, maximum biomass was observed in the period

Table 5.6.2 Phytoplankton biomass, chlorophyll a and primary productivity in Lakes Victoria, Tanganyika and Malawi, other East African Lakes and the Laurentian Great Lakes

Lake	*Algal biomass (mg.m^{-3})*		*Chlorophyll a (mg.m^{-3})*		*Primary productivity (mg C.m^{-2}.day^{-1})*	
	Annual mean	*Maximum*	*Range*	*Mean*	*Range*	*Mean*
Victoria offshore (1960s)	–	1,600	1.2– 5.5	–	1,530 –3,550	2,310[1]
Victoria inshore (1960s)	–	–	10–15	12.5	–	–
Victoria offshore (1990s)	–	2,600	8.4–40	24.5	2,560–6,360	4,340[2]
Victoria in shore (1990s)	–	–	22.2–67.1	46.7	–	–
Tanganyika	150	1,600	0.1 –2.6	1.2	400 –3,100	800[3]
Malawi (1992)	85	200	0.1–7.2	0.68	150–3,800[1]	900[4]
Malawi (1993)	–	–	–	–	50–5,500	1,420
Kivu	1,100	2,100	–	–	600–1,000[3]	–
Albert	170	267	–	–	840–3,800[1]	–
Edward	1,000	2,000	–	–	4,300[4]	–
Superior	–	–	–	–	50–260	–
Huron	–	–	–	–	150–700	–
Michigan	–	–	–	–	70–1,030	–
Ontario	–	–	–	–	60–1,400	–
Erie	–	–	–	–	30–4,760	–

1. Paired bottle oxygen technique (Talling, 1965).
2. Estimated using the primary productivity model of Fee (1990).
3. Paired bottle ^{14}C method.
4. Only one ^{14}C measurement (in March) (Jannasch, 1975).

Sources: Hecky and Kling, 1981; 1987; Mugidde, 1993; Hecky and Fee, 1981; Patterson and Kachinjika, 1995; Vollenweider *et al.*, 1974 (Laurentian Great Lakes).

January–March with a secondary peak in June–August (Patterson and Kachinjika, 1995) in line with observations made in 1980 (Hecky and Kling, 1987). In the other rift lake, Lake Tanganyika, phytoplankton biomass may be higher, ranging from 25 $mg.m^{-3}$ to 1,570 $mg.m^{-3}$ in the upper 25 m with maximum biomass in October–November (Hecky and Kling, 1981). Recent research indicates that these measurements are most probably underestimated because of the effects of photo-inhibition (Salonen and Sarvala, 1994).

Primary productivity in water 20–60 m deep contributes significantly to the areal primary production in the lake and so far has not been included in any assessments.

At present, Lake Victoria has algal biomass ranging from between 140 $mg.m^{-3}$ and 2600 $mg.m^{-3}$ in the euphotic zone. The annual biomass maximum now occurs during stratification and mainly consists of heterocystous cyanophytes (Hecky, 1993). In the 1960s, algal biomass in the upper 30 m was of the same order, but the annual biomass maximum occurred at that time during the mixing period and consisted mainly of diatoms (Talling, 1966). In two other rift lakes, Lakes Kivu and Edward, algal biomass was observed in concentrations of up to 2000 $mg.m^{-3}$, while Lake Albert counted a lower maximum phytoplankton biomass of 267 $mg.m^{-3}$ (Hecky and Kling, 1987).

Chlorophyll a concentrations in offshore waters of Lake Victoria now range from between 8.4 $mg.m^{-3}$ and 40 $mg.m^{-3}$, which is considerably higher than the range of 1.2–5.5 $mg.m^{-3}$ in the 1960s; inshore waters show even higher concentrations in the range of 22.2–67.1 $mg.m^{-3}$ compared to a range of 10–15 $mg.m^{-3}$ in the 1960s (Mugidde, 1993). In 1985–1986 at offshore stations in the Kenyan waters of Lake Victoria, chlorophyll a oncentrations of up to 77.6 $mg.m^{-3}$ were observed (Ochumba and Kibaara, 1989). (For a list of chlorophyll a observations for Lake Victoria between 1960 and 1991, see Crul (1995, Table 8.1). Chorophyll a measurements are scant for Lake Malawi. Concentrations in 1980–1981 varied between 0.1 $mg.m^{-3}$ and 2.1 $mg.m^{-3}$ (with a mean value of 0.73 $mg.m^{-3}$ at 10 m and 0.65 $mg.m^{-3}$ at 50 m), the value being generally highest at 30–50 m. The highest values of between 1 $mg.m^{-3}$ and 2 $mg.m^{-3}$ were found from June to August and December to February (Degnbol and Mapila, 1982). The average Chorophyll a concentration of all samples taken in 1992 and 1993 was 0.68 $mg.m^{-3}$ (Patterson and Kachinjika, 1995).

Eutrophication has caused an increase in primary productivity in Lake Victoria from an average of 7.4 g $O_2.m^{-2}.day^{-1}$ in the 1960s (Talling, 1965) to an average of 13.9 g O_2 $m^{-2}.day^{-1}$ in the 1990s. There is evidence that the photosynthetic system is less efficient today than in the 1960s and that photosynthesis in the lake is light-limited (Mugidde, 1993). The mean annual rate of phytoplankton photosynthesis in Lake Tanganyika was estimated by Hecky and Fee (1981) at 800 mg $C.m^{-2}.day^{-1}$, assuming two seasons of equal duration. They also calculated a mean algal growth rate of 1.2 mg $C.m^{-2}.day^{-1}$ for Lake Tanganyika, which would appear to be very high as compared to other tropical lakes. These growth rates could easily generate the high biomass observed during blooms in October–November. Integrated primary production in Lake Malawi from March 1980 to February 1981 was 271 g $C.m^{-2}.yr^{-1}$, giving a daily average of 740 mg $C.m^{-2}$. Daily production was at its maximum in the period from June to September with levels of between 920 mg $C.m^{-2}$ and 1,140 mg $C.m^{-2}$; low levels were observed in December (380 mg $C.m^{-2}$) and in February (240 mg $C.m^{-2}$). Bootsma (personal communication) found an average photosynthetic rate of 656 mg $C.m^{-2}.day^{-1}$ for the whole lake and an average rate of 403 mg $C.m^{-2}.day^{-1}$ for a station sampled by Degnbol and Mapila (1982). Average photosynthetic rates for the Nkhotakota station in 1992 and 1993 were 329.4 g $C.m^{-2}.yr^{-1}$ and 518.3 g $C.m^{-2}.yr^{-1}$ respectively (Patterson and Kachinjika, 1995). The large difference in productivity between these two years can be explained by the more pronounced seiching pattern in the mixing season of 1993, resulting in greater amounts of nutrients in the epilimnion (Patterson and Kachinjika, 1995).

There is a pronounced differentiation between the plankton communities of inshore and offshore regions. In Lake Victoria, species abundant in inshore waters are *Merismopedia* spp., *Aulacoseira (Melosira) ambigua, Lyngbya circumcreta and Nitzschia acicularis.* Inshore bays typically support much higher phytoplankton densities and have a higher primary productivity, which appears to have increased from an average 10.6 g $O_2.m^{-2}.day^{-1}$ in the 1960s to 22.3 g $O_2.m^{-2}.day^{-1}$ nowadays (Mugidde, 1993).

Information on the primary production of periphyton in the African Great Lakes is scarce. In the deep rift lakes of Tanganyika and Malawi, the contribution of periphyton to overall production is limited to areas with a depth of less than 20 m and 50 m respectively. Here, it constitutes a major food resource of the diverse littoral fish communities (Fryer, 1957). The maximum potential benthic periphyton production in Lake Tanganyika has been approximated at 15% of the phytoplankton production by Hecky and Fee (1981), who used a maximum possible rate of 4 g $C.m^{-2}.day^{-1}$ and a littoral zone of 978 km^2. Periphyton photosynthesis in the southeast arm of Lake Malawi has been measured by Bootsma (personal communication). These measurements suggest a maximum of 1 g $C.m^{-2}.day^{-1}$ representing a significant proportion (19–38%) of total primary production. This also indicates that, with a littoral production rate of 1 g $C.m^{-2}$ $.day^{-1}$, the benthic algal production in both lakes makes only a relatively small contribution of approximately 5% to overall production. No data on periphyton production are available for Lake Victoria.

5.6.1.2 Macrophytes

In shallow Lake Victoria, macrophytes are far more important than in the two rift lakes. Along the coasts, especially in the northern and southern parts and on the island shores of Lake Victoria, fringing papyrus (*Cyperus papyrus*) swamps and floating papyrus islands are a common feature of the inshore waters. A main feature of a swamp is its buffering capacity, since it removes nutrients like phosphate from the water flowing through it (Beadle, 1932). The swamps bordering Lake Victoria provide a natural filtering of inflow. Reclamation of the remaining swamps would lead to a reduced buffering capacity and result in further eutrophication of the lake. This filtering capacity may also play a role in the purification of domestic wastewater in the future. Studies have indicated that these wetlands can be used in the treatment of sewage effluent (UNEP, 1989; van Bruggen *et al.*, 1995; Nalubega *et al.*, 1995), while this can be coupled with integrated fish farming (Denny, 1989).

The water hyacinth *Eichhornia crassipes* has become one of the main objects of research in Lake Victoria since it was first observed in the lake in 1989. It is now widespread in Lake Victoria (Thompson, 1991*a*; Twongo, 1992; Witte *et al.*, 1992*a*) and is a cause for much concern because of its negative environmental impact.

5.6.2 The second and higher trophic levels

5.6.2.1 Zooplankton

Species composition

The zooplankton in the pelagic zones of the three African Great Lakes is dominated by one (or two) calanoids and a few cyclopoids. Cladocera and Rotifera are rare and more or less restricted to inshore waters and littoral zones. Each of the three lakes boasts another organism in its zooplankton community: *Caridina nilotica* in Lake Victoria, *Chaoborus edulis* in Lake Malawi and *Limnocnida tanganyicae* in Lake Tanganyika. The most important zooplankton species of the three lakes are given in Table 5.6.3. Lake Tanganyika counts only three species that are regularly found in the pelagic plankton, while, in Lake Victoria, some 15 species may regularly be observed (Dumont, 1994). Lake Malawi falls in-between with eight species (Irvine and Waya, 1995). Zooplankton species composition and biomass in tropical lakes depends on predation and food limitation.

In the Kenyan waters of Lake Victoria, copepods contribute approximately 85% to the total zooplankton and the two most dominant species are *Thermocyclops neglectus* and *T. emini*. The inshore waters of the Nyanza Gulf have a richer zooplankton community; zooplankton densities gradually decrease from the shallow littoral zones in the Gulf to the offshore waters. Other planktonic organisms observed in the Gulf are Microturbellaria, Hydracarina, Ostracoda and larval stages of insects, especially Chaoboridae (Mavuti and Litterick, 1991). Dominant Cladocera in the Nyanza Gulf and the Mwanza Gulf are *Bosmina longirostris, Diaphanosoma excisum* and *Moina macrourus* (Mavuti and Litterick, 1991; Akiyama *et al.*, 1977). Rotifers are also widely distributed in these inshore waters and dominated by brachioniids (*Brachionus caudatus, B. calyciflorus).*

Owing to the changes in the ecosystem of Lake Victoria in the past three decades, a dominance of calanoid copepods (adults and copepodites) and cladocerans in the zooplankton before the increase in Nile perch has given way to a dominance of mainly nauplii and young copepodites of Cyclopoida and Calanoida. The large-bodied zooplankton probably declined in the face of an increase in predation by *Rastrineobola argentea*, which coincided with an increase in numbers of Nile perch (Gophen *et al.*, 1995).

The zooplankton community in Lake Tanganyika is dominated in biomass and numbers by crustacean copepods. Of the 68 known copepod species, the only important species in the pelagic zone are the calanoid copepod *Tropodiaptomus simplex* and two cyclopods, *Mesocyclops aequatorialis* and *Tropocyclops tenellus* (Coulter, 1991). Cyclopods contribute 61% to the total number of zooplankton and *Tropodiaptomus simplex* 39% (Kurki and Vuorinen, 1994). Special features of the pelagic zooplankton community of Lake Tanganyika are the prominence of Protozoa, the presence of *Limnocnida tanganyicae*, endemic Atyidae, fish larvae and endemic decapods, and the absence of Cladocera and Rotifera (Hecky, 1991). A small particle-feeding role has to fulfilled by Protozoa (Hecky, 1991). Of the sixteen Protozoan species, the ciliate *Strombidium* cf. *viride* was the most important in the 1970s (Hecky *et al.*, 1978).

The most important species of the pelagic zooplankton in Lake Malawi are the post-naupliar *Tropodiaptomus cunningtoni,* and the cyclopoid species *Mesocyclops aequatorialis aequatorialis* and *Thermocyclops neglectus.* Another calanoid copepod, *Thermodiaptomus mixtus,* is only found in the southern part of the lake. Cladocera are represented by *Diaphanosoma excisum,* but contribute little to the total zooplankton biomass and tended to be more abundant in the extreme south of the lake (Irvine, 1995*a*). Other elements of the zooplankton are larvae of *Chaoborus edulis* and the cyprinid *Engraulicypris sardella,* the larvae of which appear to be more abundant in the south (Thompson, 1995).

Temporal and spatial distribution

Recent studies on zooplankton in Lake Victoria reveal low densities throughout the year with an abundance of small-bodied zooplankters (Gophen *et al.*, 1995; Ndawula, 1994).

In Lake Malawi, the crustacean zooplankton has its maximum abundance between July and December, dropping to a minimum between February and May (Degnbol and Mapila, 1982; Twombly, 1983; Irvine, 1995*a*). *C. edulis* larvae showed maximum abundance

Table 5.6.3 Main zooplankton species in the African Great Lakes

	Calanoids	*Cyclopoids*	*Cladocera/Rotifera*	*Others*
L. Victoria	*Tropodiaptomus neumanii*	*Mesocyclops aequatorialis, M. major, M.* sp.	*Bosmina longirostris, Diaphanosoma excisum, Moina macourus*	*Chaoborus* sp. *Caridina nilotica*
	Thermodiaptomus galaeboides	*Thermocyclops neglectus, T. emini, T. oblogatus, T. crassus, T. incisus*	*Brachionus caudatus* *B. calyciflorus*	
L. Tanganyika	*Tropodiaptomus simplex*	*Mesocyclops aequatorialis* *Tropocyclops tenellus*	Both groups absent	*Limnocnida tanganyicae* *Limnocaridina* sp.
L. Malawi	*Tropodiaptomus cunningtoni*	*Mesocyclops aequatorialis aequatorialis* *Thermocyclops neglectus*	Cladocera and Rotifera only relatively abundant at south end of the lake	*Chaoborus edulis* *Engraulicypris sardella*

Sources: Mavuti and Litterick, 1991; Gophen *et al.*, 1995; Coulter, 1991*a*; Dumont, 1994; Irvine, 1995*ab*; Irvine and Waya, 1995.

in the latter part of the year (Irvine, 1995*b*). The larvae of *E. sardella* have well-defined seasonal patterns of abundance, being more abundant from August to October and low in number from December to March (Thompson, 1995). Twombly (1983) observed unseasonable short-term fluctuations in abundance in addition to seasonal fluctuations. Both seasonal and unseasonable fluctuations in abundance resulted in marked interannual variations in abundance.

The zooplankton community of Lake Tanganyika shows a higher abundance in the period July–October than in the period December–February (Rufli and Chapman, 1976; Rufli, 1976; Kurki and Vuorinen, 1994). The mean zooplankton biomass has been estimated at 480 mg.m^{-2} with a range of between 32 mg.m^{-2} and 1,245 mg.m^{-2} (Burgis, 1984). The ciliate *Strombidium* cf. *viride* is the dominant protozoan throughout the year with maximum densities occurring in the wet season. *Strombidium* always occurs with zoochlorellae in its cell in Lake Tanganyika (Hecky and Kling, 1981).

In addition to seasonal changes, spatial variations in both horizontal and vertical abundance are prominent in all three lakes. Distinct horizontal variations have been observed in abundance of the pelagic zooplankton in Lake Tanganyika (Rufli and Chapman, 1976; Rufli, 1976; Kurki and Vuorinen, 1994). with zooplankton densities being highest in the northern part of the lake. It is not known whether the low number and the locations of the sampling stations has contributed to this horizontal variation in abundance (Kurki and Vuorinen, 1994).

In Lake Malawi, the distribution of crustacean zooplankton biomass appears to be homogeneous over the lake (Irvine, 1995*a*). No clear horizontal variation in crustacean zooplankton abundance between inshore and offshore stations has been observed (Degnbol and Mapila, 1982). Other zooplankton organisms show horizontal variations in abundance: *Chaoborus edulis* larvae were generally lower in abundance in the extreme south, except for the latter part of 1993 (Irvine, 1995*b*) and average densities of *Engraulicypris sardella* larvae appear to be twice as high in the south as in the north (Thompson, 1995).

Diurnal vertical migration of zooplankton is a well-known phenomenon that has also been observed in the African Great Lakes. In the past sixty years, zooplankton in Lake Victoria have clearly shown well-marked diurnal migrations of all species, rising to the surface by or soon after sunset and descending at dawn (Worthington, 1931; Goldschmidt *et al.*, 1989). Van Meel (1954) observed migration of the crustacean zooplankton towards the surface in Lake Tanganyika at night. Zooplankton is found throughout the water column down to 200 m with an oxygen content of 0.16 mg.l^{-1}. Copepods concentrated in the upper 40 m water layer during the day and especially in the upper 20 m layer at night. A distinct secondary maximum in zooplankton distribution has been observed between 100 m and 175 m with an oxygen content of 0.2 mg.l^{-1}, indicating a migration to feed upon bacterial production near the oxic-anoxic layer or to avoid clupeids which avoid oxygen levels below 2 mg.l^{-1} (Hecky, 1991). An abundance of clupeids seems to be strongly coupled with zooplankton (Kurki and Vuorinen, 1994). Observed diurnal vertical migration of *Tropodiaptomus simplex* may also be linked to predator avoidance. The medusa *Limnocnida tanganyicae* medusae commonly occurs near the water surface, when the water is calm, and in the evening; there is some circumstantial evidence that these organisms migrate vertically (Coulter, 1991*c*).

Crustacean zooplankton inhabit the upper 60–80 m in Lake Malawi with maximum abundance at a greater depth during the day than at night (Irvine, 1995*a*). Upward migration at night is most obvious in *Tropodiaptomus cunningtoni.* Early larval instars of *Chaoborus edulis* show diurnal vertical migration of relatively low amplitude, probably in order to maintain themselves among their food supply, the crustacean zooplankton (Irvine, 1995*b*). The larger instars of *C. edulis* show the ability to inhabit low oxygenated water layers up to 200 m deep during the daytime, appearing near the surface at night. The reason for these large migrations is almost certainly to avoid the visually hunting planktivorous fish, which avoid low-oxygenated water (Irvine, 1995*b*). These vertical migrations of the zooplankton were also observed by Degnbol and Mapila (1982).

The only species of shrimp found in Lake Victoria, *Caridina nilotica*, has become an important element in the zooplankton. Before the increase in Nile perch, *Caridina* was often extremely abundant in littoral and sub-littoral regions over the hard bottom. This shrimp has been a common food item for several fish species (Corbet, 1961), including the shrimp-eating haplochromines of the *Haplochromis tridens* group (Witte and Van Oijen, 1990). *Caridina* itself is a detritus feeder. Following the increase in Nile perch in the 1980s, *Caridina* increased its biomass, becoming the nearly exclusive prey of juvenile Nile perch (Witte *et al.*, 1992*ab*). Increased densities of the shrimp have been reported in the littoral zone (Goldschmidt *et al.*, 1993). ROV observations have shown that *Caridina* is abundant and active near and below the point where oxygen levels decline towards zero (Kaufman, 1992). Observations of diurnal and nocturnal vertical distributions of *Caridina* at a sampling station in the Mwanza Gulf have revealed that during the daytime the complete population is concentrated in the lower part of the water column, migrating into the middle and upper parts at night (Goldschmidt *et al.*, 1993).

Zooplankton production

Estimates of zooplankton biomass and production available for Lake Malawi only indicate that total means of crustacean zooplankton standing biomass for Lake Malawi ranges between 886 ± 106 mg dry wt.m^{-2} and 2,424 ± 344 mg dry wt.m^{-2} with an overall mean of 1,608 ± 528 mg dry wt.m^{-2}.yr^{-1}. Average total copepod production amounts to 49.5 g dry wt.m^{-2} .yr^{-1} (Irvine, 1995*a*). Total mean standing biomass of *Chaoborus edulis* has been estimated for 1992 and 1993 at 72 ± 10 mg dry wt.m^{-2} and 201 ± 23 mg dry wt.m^{-2} and total production as 2.4 g dry wt.m^{-2} and 8.2 g dry wt.m^{-2} respectively (Irvine, 1995*b*). The average annual standing biomass of *E. sardella* larvae for 1992 and 1993 was 15.0 mg dry wt.m^{-2} and 34.8 mg dry wt.m^{-2} and an average production of 0.96 g dry wt.m^{-2}.yr^{-1} and 2.08 g dry wt m^{-2}.yr^{-1} respectively (Thompson, 1995).

5.6.2.2 Benthos and fish

The other main components in the grazing food chains of the lakes are benthic organisms and fish. Of the three lakes, shallow Lake Victoria has a prominent benthic fauna, while the benthos in the two rift lakes is restricted to the littoral zone.

Relatively little is known of benthic fauna in the African Great Lakes (Davies and Hart, 1981). Research on Lake Victoria originally focused on the taxonomy and ecology of lake fly larvae and molluscs, while in recent years it provided information on species composition, spatial and temporal distribution and biomass of benthic elements in inshore waters in Kenya and Uganda (Mothersill *et al.*, 1980; Okedi, 1990; Mbahinzireki, 1992). Recent research on Lake Tanganyika has focused on the endemic gastropodes (Mollusca) and ostracodes (Crustacea), providing excellent subject material for evolutionary studies (Michel *et al.*., 1992; Cohen, 1995). The molluscan fauna of Lake Malawi is much less diverse than that of Lake Tanganyika, but is still quite impressive (Livingstone and Melack, 1984).

The fish fauna of the African Great Lakes have been the subject of much research since the early 1900s (Crul, 1995; 1997; Crul *et al.*, 1995). Information on the fish communities of the lakes, especially the endemic cichlid flocks, and the main target species for fisheries, can be found in numerous scientific publications (Fryer and Iles, 1972; Greenwood, 1974; 1981; Beadle, 1981; Coulter *et al.*, 1986; Witte, 1987; Lowe-McConnell, 1987; Coulter, 1991 and in the bibliographies for the individual lakes: Tweddle and Mkoko, 1986; Tweddle, 1991; Coulter and Coulter, 1991*a*; Crul *et al.*, 1995).

5.6.3 Trophic dynamics

The trophic relationships in the pelagic zones of the two rift lakes are relatively simple. Those of Lake Victoria have become simpler since the increase in numbers of Nile perch and the drop in the endemic haplochromines. The relatively simple food webs in the pelagic zones contrast sharply with those of the inshore waters of the lakes with their extremely rich endemic cichlid species flocks (Lowe-McConnell, 1993; Hori *et al.*, 1993; Ribbink, 1991; Witte and Van Oijen, 1990). Information on the trophic dynamics in the pelagic zones of the three lakes is still far from complete.

Lake Victoria

The food web of Lake Victoria prior to the Nile perch explosion was dominated by the haplochromines (Ligtvoet and Witte, 1991). The ecological adaptation of the haplochromines is demonstrated by the existence of numerous trophic groups: detritus feeders, phytoplankton feeders, algae grazers, zooplankton feeders, insectivores, piscivores including egg-eaters and scale scrapers, mollusc feeders, crustacean eaters and parasite feeders (Witte and Van Oijen, 1990). The major trophic groups are the detritivores/planktivores and the zooplanktivores, making up 60% and 20% respectively of the total haplochromine biomass (Witte *et al.*, 1992*a*). The major food webs starting from detritus and phytoplankton run via the various trophic groups of haplochromines (Witte and Van Oijen, 1990) to the piscivores. A direct chain exists from phytoplankton to several tilapiine species (Ligtvoet and Witte, 1991). In the pre-Lates period, molluscs contributed significantly to the food web, as they constituted an important element in the food of many fishes.

In the 1980s, the Nile perch population exploded causing a dramatic decline in the haplochromines, as they were initially the favourite prey of the Nile perch. An estimated two-thirds of approximately 300 haplochromine cichlid fishes have become extinct. Only after the densities of the haplochromines had declined to near zero did the Nile perch switch to other prey, such as the prawn *Caridina nilotica* (Goldschmidt *et al.*, 1993), the cyprinid *Rastrineobola argentea* and its own juveniles (Witte *et al.*, 1992*ab*). In the present food web of Lake Victoria, the Nile perch is the top predator, replacing all original piscivores. The detritivorous/phytoplanktivorous haplochromines have been replaced by the atyid prawn *Caridina nilotica* and the zooplanktivorous haplochromines by the cyprinid *Rastrineobola argentea*. The indigenous tilapiine species have been replaced by the introduced *Oreochromis niloticus*. An important feature of the present system is the extensive cannibalism within the *Lates* population, which starts at very young stages. The bulk of the biomass within the fish community has shifted from primary consumers to the top predator *Lates*.

Both 'top-down' (the increase in the Nile perch) and 'bottom-up' (eutrophication) processes have far-reaching repercussions for the trophic dynamics of Lake Victoria and both are responsible for the massive changes in the lake's ecosystem (Witte *et al.*, 1992*a*; Hecky, 1993). Changes have occurred at all trophic levels (Witte *et al.*, 1995), including a shift in phytoplankton composition towards a dominance by blue-green algae (Hecky, 1993), and small-bodied zooplankters (Gophen *et al.*, 1995), an increase in the density of *Caridina nilotica* and oligochaetes (Witte *et al.*, 1992*b*; Goldschmidt *et al.*, 1993; Kaufman, 1992) and a decline in haplochromines (Witte et al, 1992*ab*). All these changes have disrupted the food webs in the lake's ecosystem and algal material has accumulated in the deeper layers, resulting in increased microbial processing leading to oxygen depletion in the deeper layers. During stratification, the water layers between 20 m and 50 m are deoxygenated (Hecky *et al.*, 1994). The tilapia species in Lake Victoria, which were phytoplanktivores before the introduction of the Nile perch, are presently mostly benthic feeders. They have been pushed out of the open water by the Nile perch into shallow water, where they now utilize the food available there, which is mainly bottom fauna and flora (Gophen *et al.*, 1995).

Lake Tanganyika

The lake has high annual fish yields consisting of two clupeids, *Stolothrissa tanganicae* and *Limnothrissa miodon*, and four centropomid predators *Lates stappersii*, *L. mariae*, *L. angustifrons* and *L. microlepis* (Coulter, 1991; Roest, 1992). Hecky *et al.* (1981) proposed two hypotheses to explain the high fish yields: either there is a highly efficient trophic structure or there are other sources of organic production in the lake recycling fixed carbon for the hypolimnion.

The high trophic efficiency of the lake may be explained by the trophic structure. Lake Tanganyika's pelagic food web is of a marine nature. The primary grazer is a calanoid copepod also commonly found in productive marine systems. The primary planktivores are clupeids, which are of marine origin, and the piscivores are all Centropomidae, a predominantly marine family (Hecky, 1991). In Lake Tanganyika, the most important cause of phytoplankton loss is probably grazing by zooplankton, as efficient grazing keeps algal biomass low, growth rates high and ensures that fixed carbon accumulates as fish biomass (Hecky, 1991). Several other sources of organic carbon, such as periphyton, macrophytes and allochthonous organic carbon, are probably not abundant enough in Lake Tanganyika (Hecky and Fee, 1981). The only remaining possible source of organic carbon is bacterial production. The enormous reservoir of reduced substances in the hypolimnion could sustain a significant bacterial production. Bacteria are reasonably abundant in the lake (Hecky and Kling, 1981). The density of the bacteria range between 140,000.ml^{-1} and 1,400,000.ml^{-1} and the mean density is 760,000.ml^{-1}. A trophic structure of Lake Tanganyika is given by Hecky (1984).

Lake Malawi

The trophic relationships in the pelagic zone of Lake Malawi are relatively simple (Degnbol and Mapila, 1982; Allison *et al.*, 1995). Five crustacean zooplankton species are quantitatively important to the pelagic ecosystem: one calanoid copepod, *Tropodiaptomus cunningtoni* and two cyclopoid copepods, *Mesocyclops aequatorialis aequatorialis* and *Thermocyclops neglectus*, two cladocerans, *Diaphanosoma excisum* and *Bosmina longirostris*, and larvae of *Chaoborus edulis* and *Engraulicypris sardella* and lastly only eight fish species or species groups: *Diplotaxodon* 'elongata', *Diplotaxodon* 'bigeye', *Synodontis njassae, Rhamphochromis longiceps, Rhamphochromis ferox, Engraulicypris sardella, Copadichromis quadrimaculatus and Opsaridium* spp.

The food web of the pelagic zone of Lake Malawi comprises five trophic levels: phytoplankton, herbivorous zooplankton (*T. cunningtoni, T. neglectus, D. excisum* and *B. longirostris*), predatory zooplankton (*M. aequatorialis aequatorialis, C. edulis* and *E. sardella* larvae), zooplanktivorous fish (*E. sardella, C. quadrimaculatus* and *D.* 'elongata' feeding on herbivorous zooplankton and *D.* 'elongata', *D.* 'bigeye', *S. njassae, R. longiceps* feeding on predatory zooplankton) and piscivorous fish (large *Rhamphochromis* spp. and *Opsaridium* spp. feeding on *E. sardella* and, to a lesser extent, on *R. longiceps, D.* 'bigeye' and *D.* 'elongata').

In the food web, the lakefly *C. edulis* appears to be a very important link between the herbivorous zooplankton and the fish. The diet of *C. edulis* larvae is estimated to consist of 72% herbivorous zooplankton, 10% *M. aequatorialis aequatorialis* and 8% algae. The larvae themselves form an important component of the diet of a number of fish species in the pelagic zone, although more than 50% of the *C. edulis* production does not pass to higher levels (Irvine, 1995*b*; Allison *et al.*, 1995). This is in contrast to previous studies by Turner (1982) and Degnbol (1990) which have implied that *C. edulis* is not heavily preyed upon by fish. Detritus does not seem to be a significant source of energy to the higher trophic levels, nor a significant source of organic carbon to organisms at the base of the food web (Allison *et al.*, 1995).

Allison *et al.* (1995) used estimates of biomass, production and consumption for the main trophic groups to summarize the trophic structure of the pelagic ecosystem using the steady-state ECOPATH model (for details on the ECOPATH model and the ICLARM software package of the ECOPATH model see Polovina (1984*a,b*) and Christensen and Pauly (1991) respectively). Based on the ECOPATH modelling and all other studies on the trophic groups, Allison *et al.* (1995) categorize the pelagic zone of Lake Malawi as a food-limited system without vacant niches. They conclude that, therefore, an introduced zooplanktivorous fish would probably not be successful and that an elimination of the lakefly *C. edulis* would probably have major implications for the pelagic ecosystem of the lake.

5.7 ANCIENT AND RECENT HISTORY OF THE AFRICAN GREAT LAKES

Lake sediments contain various organic and inorganic substances which may provide information on their ancient and recent history. Paleolimnology focuses on the dimension of time, together with related disciplines such as palaeoecology, paleontology and paleoclimatology. The progress made in the development of paleolimnological techniques and approaches over the last decade (Smol, 1992) can only facilitate the application of paleolimnological research to the African Great Lakes. Paleolimnological studies may provide information about long-term limnological and climatological trends in these lakes (Johnson, 1993).

Long-term data sets of basic physical and chemical parameters are not available for the African Great lakes. Sedimentation rates for these lakes are between 0.2 $mm.yr^{-1}$ and 5 $mm.yr^{-1}$ and the sediment records are therefore resolvable to decades or more (Johnson *et al.*, 1990). Lakes Tanganyika and Malawi especially, with their permanent anoxic conditions in the deep waters and seasonal pattern in autochtonous and allochthonous sedimentary components, are favourable to deposition and preservation of finely laminated sediments containing detailed information on seasonal, annual and longer-term environmental conditions.

In Lake Malawi, the sediments in the pelagic zone consist of laminated sequences of light–dark laminae couplets with an average thickness of 1 mm representing biannual sedimentation sequences. The light laminae are completely dominated by diatoms originating from algal blooms during the dry season, while the dark laminae consist of 50% diatoms and 50% terrestrial plant debris, mineral grains, clay and organic material sedimented in the rainy season (Pilskaln and Johnson, 1991). *Aulacoseira (Melosira)* appears to have been the dominant diatom in Lake Malawi sediments throughout the lake's 10,000-year depositional history (Owen *et al.*, 1990; Pilskaln and Johnson, 1991; Owen and Crossley, 1992), indicating the persistence of strong winds and resultant mixing and upwelling in the dry season.

Evidence of regional climatic change and fluctuations in lake level are also apparent in the sediment records. The laminated sequences indicating periods of high lake levels are frequently interrupted by diatom-rich, non-laminated layers reflecting fluctuations in local climate and lake level (Pilskaln and Johnson, 1991). Periods of low lake level are associated with a marked increase in littoral diatom species and coarse sand in the sediments and with an increase in allochthonous input (Johnson *et al.*, 1988). The surface of sandy lakeshore deposits has also been observed in the high-resolution seismic profiles made of the lake (Scholz and Rosendahl, 1988; Johnson and Davies, 1989).

Studies on sediment cores of Lake Tanganyika provide information on diatom succession: in the past 2,000 years, species of the genus *Nitzschia* appear to be the most common species, while prior to this date *Stephanodiscus* and *Aulacoseira* (*Melosira)* were the most important genera (Degens *et al.*, 1971). Evidence of regional climatic change and fluctuations in lake level is also apparent in the sediment records (Livingstone, 1965; Haberyan and Hecky, 1987). The surface of sandy lakeshore deposits observed in the high-resolution seismic profiles made of the lake indicate low water level stands (Scholz and Rosendahl, 1988).

In contrast to the mostly laminated offshore sediments of the two rift lakes, Lake Victoria has more homogeneous sediments. In its inshore waters, a semi-flocculent layer of soft mud (up to 3 m thick) with considerable plant debris may occur (Graham, 1929; Gee and Gilbert, 1968; Cordone and Kudhongania, 1971). Fine-grained Late-Pleistocene and Holocene sediments have a maximum thickness of about 8 m in the deepest parts in the northeastern corner of the lake. In the southern part of the lake, the sediments are less thick and in the western part even absent (Scholz *et al.*, 1990).

5.7.1 Ancient history

The study of the origin and history of the African Great Lakes goes back to the early part of this century, starting with the pioneer geological work by Wayland (1929) in the Lake Victoria basin (for more references, see Crul *et al.*, 1995), that by Dixey (1926) in the Lake Malawi basin and by Gregory (1921) in the Lake Tanganyika basin. Geological research in the African Great Lakes region intensified in the 1950s and 1960s. It was mainly focused on terrestrial environments and lasted until the early 1960s when the first sediment cores from a lake bed were obtained (Livingstone, 1965). In the past three decades, a great number of paleolimnological research programmes and studies have been undertaken in the three lakes (see Crul, 1995; 1997; Crul *et al.*, 1995 for key references).

In East Africa, upward earth movements and volcanic activity in Miocene times some 12–25 million years ago formed two great rift valleys in which tectonic activities created a series of lakes. Lakes Tanganyika and Malawi were the largest and deepest of these. Between the two rift valleys, the shallow basin of Lake Victoria was formed by gradual sagging of the area. There is some evidence that lakes also existed in the Lake Victoria region in the Early Miocene (Wayland, 1931). The present Lake Victoria is much younger, its origin probably going back to the Mid-Pleistocene some 500,000 years ago (Kendall, 1969). Despite being much younger than Lake Malawi and above all Lake Tanganyika, the oldest of the East African lakes, Lake Victoria remains one of the oldest lakes in the world. The hypothesis has been put forward of a gradual evolution of Lake Tanganyika in three stages – starting with a stage of meandering streams and swamps that changed into minor basins at the second stage and into deeper lake(s) as the result of tectonic activity and wetter climatic conditions at the third and last stage (Tiercelin and Mondeguer, 1991; Coulter, 1991*b*). Lake Malawi may be several million years old (Owen *et al.*, 1990). Geological evidence indicates that the lake originally occupied the northern part of its present basin and that it stood at a considerably higher elevation than today. Its present form and level were arrived at after complex tectonic activities (Fryer and Iles, 1972).

Until the Late Pleistocene, both tectonic activities and climatic changes contributed to the evolutionary development of the lakes on account of their impact on lake levels. Since that time, climate has become the major force in determining the water levels in the African Great Lakes (Livingstone, 1975; Street and Grove, 1976; Beadle, 1981), although single tectonic events may have contributed to the change in water level in a particular lake, e.g. the rise of the Virunga volcanoes in the Holocene resulted in higher lake levels in Lake Tanganyika owing to overflow from Lake Kivu via the Ruzizi River. In the past 25,000 years, major fluctuations in climate have occurred in Africa with great implications for lake levels (Beadle, 1981).

A major event in the history of Lake Victoria occurred around 14,730 B.P. when the lake level felt at least 75 m compared to contemporary levels (Kendall, 1969; Livingstone, 1976; Stager, 1984; Stager *et al.*, 1986). This was confirmed by the fact that in the lake's offshore waters, an acoustically transparent sediment only 8 m thick was observed, which would have been thicker when the lake was much older than 14,000 years (Scholz *et al.*, 1990). Recent research carried out on the lake by the IDEAL programme in March and April 1995 yielded seismic reflection profiles and sediment cores. Preliminary analysis of seismic profiles and cores suggests that the lake completely dried out during that event in the late Pleistocene (Johnson, 1995).

Paleolimnological studies provide information on the climatic history of the African Great Lakes over the past 42,000 years; a preliminary chronology of climatic changes in East Africa and lake-level fluctuations of the African Great Lakes is given in Table 5.7.1.

Lake levels in East Africa have changed considerably during the Late Quaternary (Street and Grove, 1979). Six main phases have been identified in the period from 30,000 B.P. to the present: a period of high lake levels from 30,000 B.P. to 26,000 B.P.; low lake levels from 26,000 to 21,000 B.P.; further drying of the lakes and low lake levels in the period 21,000–12,500 B.P.; a rise in lake levels between 12,500 B.P. and 10,000 B.P.; and in the period 10,000–4,500 B.P., a further rise in lake levels with a maximum increase in levels between 9000 B.P. and 7000 B.P. and, lastly, a fall in lake levels in the period from 4500 B.P. to the present

The climatic history of (East) Africa has been discussed by Nicholson (1981; 1996). Available records show that, in the past two centuries, several periods of wetter and dryer conditions have occurred in Africa, generally continental in scale. In the 1820s and 1830s, droughts affected most of the African continent. By the second half of the nineteenth century, most regions which had known droughts were experiencing humid conditions. The events of the early nineteenth century were repeated at the beginning of the twentieth century with severe droughts striking primarily in the 1910s. The above historical periods have modern analogues; for example, the 1950s are reminiscent of the period 1870–1895 characterized by low rainfall in tropical regions and greater rainfall in the subtropics, while the 1980s bear a resemblance to the 1910s and 1820–1830s. Historical climatic records clearly reveal two important characteristics of the African climate: firstly, the existence of more than one anomalous behaviour and, secondly, a spatial and temporal transition between anomalous dry and wet conditions that may be abrupt. This may result in either parallel or opposing trends in climatic conditions in neighbouring African regions.

5.7.2 Recent history

Until recently, most paleolimnological studies on the African Great Lakes were undertaken to interpret climatic change and describe the lakes' ancient history. The changes in the ecosystem of Lake Victoria also focused attention on this lake's recent history. A sediment core taken in offshore water provides evidence of the limnological changes in Lake Victoria since 1900 and of more profound

Table 5.7.1 Climatic history and lake levels of the African Great Lakes

Time period/lake levels in East Africa	*Lake Victoria*		*Lake Tanganyika*		*Lake Malawi*	
Pre-40,000 B.P.	Pre-42,000 B.P.	Similar climatic conditions as at present (Taylor, 1990)	Pre-40,000 B.P.	Lake levels 400–600 m below present level		
40,000–32,000 B.P.	42,000–32,000 B.P.	Considerably colder and dryer (Taylor, 1990)	40,000 B.P.	Lake at its present level due to a cool, humid climate		
30,000–26.000 B.P. HIGH LAKE LEVELS			35,000 B.P.	Lake levels 150 m below present level; *closed system*		
26,000–21,000 B.P. LOW LAKE LEVELS			35,000–22,000 B.P.	Lake levels 300 m below present level		
21,000–12,500 B.P. LOW LAKE LEVELS	21,000–12,000 B.P.	Considerably colder and dryer (Taylor, 1990, Stager *et al.*1986)	22,000–15,000 B.P.	Lake remained at this low level	Pre-25,000 B.P.	Lake level 250–500 m lower than at present due to a drier climate and possibly tectonic tilting (Scholz and Rosendahl, 1988)
	14,700–12,000 B.P.	Dry (Kendall, 1969)				
12,500–10,000 B.P. HIGH/INTERMEDIATE LAKE LEVELS	12,000–10,500 B.P.	Moderately wet (Kendall, 1969)	12000–8000 B.P.	Lake levels rising due to a more humid climate; with at around 9,500 B.P. the overflow of Lake Kivu into Lake Tanganyika due to blockage of Virunga volcanoes; *open system*	10,740 B.P.	A major low stand (Owen *et al.*, 1990)
10,000– 4500 B.P. HIGH LAKE LEVELS	10,500–9500 B.P.	Moderate dry (Kendall, 1969)				
4500 B.P. – present LOW LAKE LEVELS	9500 –6500 B.P.	Wet (Kendall, 1969)	3500 B.P.	Lake level 75 m lower than today due to cooler and drier climatic conditions; *closed system*		
	After 6500 B.P.	Slightly drier and/or more seasonal (Kendall ,1969)	2000 B.P.	Lake level 20 m below the present level		
			2000–1400 B.P.	The lake level 14 m higher		
			1400 B.P.–present	Lake Kivu became an open system again and together with the modern climate this resulted in a rise of the lake level of Tanganyika; *closed basin at least until* 1000 B.P.		
			1000 B.P.	The lake level 20 m below the present level. Possibly closed till modern times		
At present					950 A.D.	High lake levels (Crossley *et al.*, 1984)
					1150–1250 A.D.	Low lake levels (Owen *et al., 1990*)
					1390 A.D.	High lake levels (Crossley *et al.*, 1984)
					1780–1830 A.D.	Low lake levels (Owen *et al., 1990*)
					1870 A.D.	High lake levels (Owen *et al.*, 1990)
	1960 and 1980 A.D.	High lake levels	1878 A.D.	The lake overflowed; *open system*	1900–1930 A.D.	Lower lake levels (Owen *et al., 1990*)
			1960 A.D.	High lake levels	1980 A.D.	High lake levels

changes since 1960 indicating a eutrophication of the lake (Hecky, 1993).

Paleolimnological studies of the upper layer of the sediments may provide additional information on the limnological conditions in the lakes in recent decades and lakewide information on nutrient, phytoplankton and productivity dynamics.

6

Management and conservation of the African Great Lakes: the integrated approach

6.1 SUSTAINABLE DEVELOPMENT

The African Great Lakes serve as *renewable sources* of freshwater (Chapter 1) and fish, besides fulfilling other important economic functions in their riparian countries (Chapter 2). Economic development and rapid population growth in East Africa, however, are endangering the functioning of these lake ecosystems, a phenomenon also occurring in many other freshwater ecosystems around the world (Chapter 3). Water availability will most certainly be an environmental issue by the year 2025 in East Africa and perhaps the most important at that. The scarcity of water in several East African countries in the first half of the twenty-first century is sure to encourage migration to the urban centres located in the vicinity of the African Great Lakes. This development will further increase pressure on the lakes' water quality and fish production. Fish stocks in the lakes are already locally overexploited or under threat of overexploitation.

In addition to rapid population growth and migration to the region's urban centres, there is the acute problem of refugees, who are presently housed in large refugee camps in the vicinity of the Great Lakes. These camps, which are in fact large urban settlements bereft of any proper infrastructure, have a negative effect on the surrounding environment.

The African Great Lakes need to be managed and developed in a sustainable fashion. Otherwise, the ecosystems of the lakes will degrade to the point where they are unable to meet the demands of the present and future generations. In this century, lake ecosystems have degraded in developed countries in the temperate zone as a result of socio-economic processes, including clumsy technology (Björk, 1990) and restorative measures would require great cost. *Sustainable development* is defined by the World Commission on Environment and Development, 'the Brundtland Commission', as 'development which meets the needs of the present generation without compromising the ability of future generations to meet their own needs' (WCED, 1987).

Lakes, however, do not stand alone. Limnological research in the past century has clearly demonstrated that a lake responds sensitively to what is delivered to it from its watershed and airshed. Changes in the watershed and airshed through anthropogenic activities will affect the lake ecosystem. In recent decades, rapid population growth and the great changes in land use in the watersheds of the African Great Lakes have affected the ecosystems. As these lakes are large and nearly closed systems, changes in these ecosystems may only become apparent at a relatively late stage. Reversing such negative developments will be difficult, if not impossible, and extremely costly. Management and conservation of the African Great Lakes requires taking a *holistic view* of the ecosystems that includes both their watersheds and airsheds.

The African Great Lakes are *international* waters. This will complicate their sustainable development, management and conservation. Piecemeal efforts by individual countries to manage and conserve the lakes will not be successful and may be frustrated by activities in neighbouring countries. Co-ordinated

BOX 6.1 FISHERY ECONOMICS AND THE CONCEPT OF OVEREXPLOITATION

Overfishing and other fundamental concepts in fisheries, such as maximum sustainable yield, maximum economic yield and resource rent, as well as the effect of subsidies, can be illustrated with a simple theoretical fishery economics model like that shown in the graph below.

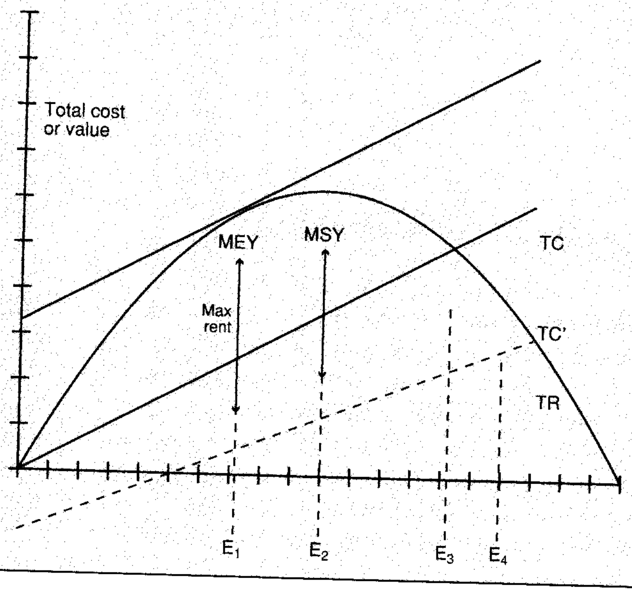
The horizontal axis represents the fishing effort, which may increase as the result of an increase in boats, fishermen, time fished, more efficient gear, etc. The vertical axis indicates the magnitude or the value of the cost associated with a particular level of effort.

The yield curve (TR) shows the change in value of the total catch ('Total Revenue') as the effort increases. The cost line (TC) shows the change in 'Total Costs' as the fishing effort changes and is based on a fixed sum per unit of fishing effort.

Starting from a non-exploited fish population, revenues initially increase rapidly as the fishing effort increases. After a while, a fishing effort is reached where the increase in value of the catch becomes zero: E_2 in the graph. If the fishing effort remains at this level and the fish population remains stable, then this catch can be harvested every year without overexploiting the fish stocks: the 'Maximum Sustainable Yield' (MSY). A further increase in fishing effort will result in a situation of overfishing and catches below the maximum level reached at E_2.

The total profit of fisheries ('Resource Rent') is the difference between the costs involved and the total yield, represented in the graph as the difference between the yield curve and the cost line. The yield at which the 'Resource Rent' is maximum, the 'Maximum Economic Yield' (MEY), is situated at fishing effort E_1. If there is a complete control over the fishing effort or the fishery is run taking into account economic factors only, fishing will probably take place at the level of MEY producing greatest profits. In an *open* fishing situation, access will continue until the fishing effort reaches a level at which the value of the total catch equals the total costs: E_3. At this point (the 'Zero Rent' Point or 'Open Access Equilibrium'), the fish stock is generally being overfished. Theoretically, a fisherman has at this point an income equal to what he could earn outside the fisheries sector ('opportunity income'). When he has no other opportunities than fishing, a fisherman will keep on fishing as long as he can pay his variable costs for fuel, gear and repairs, etc. Fishermen who own their boat and have no fuel costs will go on with fishing even when fish stocks are heavily overexploited.

Subsidies in the fisheries sector will lower the costs of fishing. In the graph, this will result in a lower Total Costs line (TC). In an open access situation, the Zero Rent point will be at a higher level of fishing effort (E_4). Thus, when governments subsidize fishing fleets, they encourage overfishing.



Source: DGIS, 1995.

action between all riparian countries, donor nations and international institutions is imperative to solve existing problems and prevent further degradation.

Environmental problems in the African Great Lakes ecosystems are primarily symptoms of more fundamental forces causing environmental degradation around the world: unequal distribution of the world's wealth, overpopulation, excessive consumption in industrialized countries and poverty in developing countries. In addition to these 'external' factors, there are several more specific obstacles to the process of sustainable development and management of these large international waters. These impediments also occur in other developing countries and even – sometimes to a lesser extent – in industrialized countries.

There is insufficient understanding of the lakes' ecosystems. Transfer of what information there is proves inadequate at all levels of the decision-making process. Information flows are often one-way. The exchange of information between institutions within a country is often limited and sometimes non-existent between different countries. Communication between scientists, decision-makers, (traditional) users and the general public is hampered by the fact that information is not presented in a form that can be understood by all. Public awareness is an essential factor in conserving lake ecosystems. Only when people understand why and how they should protect their lakes will measures to conserve lakes be effective.

There are gaps in the system of legal protection of international lakes in the riparian countries. Governments do not always appear to be effective in guarding the natural resources of these aquatic ecosystems and ensuring their sustainable use. Institutional capacity is often poorly developed and control and monitoring is mostly lacking or malfunctioning.

Traditional management systems that used to be able to conserve resources for centuries have been replaced by 'open access' management systems in recent decades. Indulging the short-term economic interests of individuals, groups or companies has resulted in overexploitation of resources (see Box 6.1) and pollution, shifting the cost to future generations. Governments, however, are often no better in managing natural resources than is the free market. Their policies may even be the cause of environmental degradation. For example, subsidies provided by governments encourage overuse of resources (see the example of overfishing given in Box 6.1) and make the economic activity appear artificially attractive.

It is the role of a government to decide whether an activity that may be economically rational for an individual or company is in the best interest of society at large. Often, governments fail to do so, both in developed and in developing countries. The failure of the current economic systems to properly value environmental resources contributes to this 'government failure'. Economic systems should account for non-market goods and services and the interests of future generations by becoming environmental economic systems.

Multilateral and bilateral donor agencies often used to ignore the environmental effects of their development projects on ecosystems. They have now begun to understand that development projects may have negative repercussions for the environment, to include environmental assessment in their projects and to fund projects with environmental goals.

Lastly, in the present economic systems, governments generally adopt the 'wait and see principle'. Only once an economic activity reveals itself to be harmful and there is hard evidence that damage is occurring are measures taken.

Conservation and sustainable management of the African Great Lakes requires an approach based on a holistic view of lake ecosystems. Management decisions regarding (development) activities affecting the watershed and airshed of the lakes have to take into account the consequences for the lake ecosystems. This *'integrated ecosystem approach'* in which the lake basin becomes the management unit must also consider the international character of the lakes, which means the sharing of the waters and associated renewable and non-renewable resources and the necessity for regional co-operation between riparian countries.

6.2 INSTRUMENTS FOR MANAGEMENT AND CONSERVATION OF LAKE BASINS

Several instruments may assist in promoting conservation and sustainable management of lakes. These instruments, such as planning and economic tools, regulations and restoration measures, can be used by decision-makers in government, industry and funding agencies, and some of them also by non-governmental organizations (NGOs), conservation organizations and even individuals.

Key factors in the process of conservation and sustainable management of the African Great Lakes are the *creation of public awareness* and the *existence of a knowledge base.*

Protection of the environment depends on the active involvement of well-informed citizens. Only once they are well-informed can citizens bring pressure to bear on governments to take appropriate decisions in favour of the environment, since in democratic countries – and even in the most authoritarian ones – government officials and industrial managers ultimately respond to public pressure. More and more citizens and NGOs have become active partners with governmental officials in forming new policies, formulating legislation and regulations, and implementing environmental programmes and projects.

Effective management and conservation of the African Great Lakes depend on the availability of accurate, up-to-date information. Scientific inventory, research and monitoring play an essential role in gathering the necessary information on which decision-makers and the public depend. This information has to be compiled, translated into a digestible form and transferred to decision-makers and the public. Understanding the processes involved in the functioning of large lakes is crucial. A 1991 workshop on the importance of external perturbations for short-term and long-term changes in large lake ecosystems, sponsored by UNESCO's Man and Biosphere Programme, attempted to assess current understanding of the most important processes involved in the functioning of large lakes. The workshop identified key areas for research and suggested objectives for future research (Tilzer and Bossard, 1992) (see Appendix I).

6.2.1 Planning tools

The *Environmental Impact Assessment* (EIA) is one of the planning processes for achieving more sustainable development. Various project EIA systems have been established throughout the world, firstly in industrialized countries in the 1970s and later also in the developing countries. The EIA has been gradually evolving from a defensive tool of environmental protection in the early years into a constantly changing process that seeks to establish a harmonious relationship between the environment and development. International development and funding agencies, such as the World Bank, European Union and the United Nations Environment Programme (UNEP), have set EIA guidelines for their funding approval process.

The *Strategic Environmental Assessment* (SEA) expands EIA from projects to policies, plans and programmes. SEA is defined as a formalized, systematic and comprehensive process of evaluating the environmental impacts of a policy, plan or programme and its alternatives, including the preparation of a report on the findings of the evaluation and the use of the findings in decision-making (Therivel *et al.*, 1992). It applies EIA at earlier, more strategic stages of development. Two SEA systems can broadly be distinguished. The first one, the 'incremental' SEA system, is expanding the system of project EIA to include higher levels of plans and programmes in an attempt to move towards more sustainable practices and is now commonplace in most developed countries. The second SEA system, the 'trickle-down' system, is likely to become a key method for implementing sustainable development.

The 'trickle-down' SEA system involves a number of steps:

- making a commitment to the objective of sustainable development;
- determining the parameters within which sustainable development is to be achieved;
- determining the carrying capacity within these parameters;
- making a SEA of all relevant policies, plan and programmes using alternative development scenarios;
- selecting one development scenario that optimizes socio-economic factors;
- making an EIA of individual projects within the limits set by the SEA; and
- the launching of a monitoring programme that would give feedback to enable all the above-mentioned steps to be adjusted as appropriate (Therivel *et al.*, 1992).

Another powerful planning concept is the *'integrated ecosystem approach'*. This approach offers governments a holistic way of dealing with threats to large international waters, like that to the African Great Lakes. It takes the lake basin as a management unit. In this way, the traditional sector-by-sector response of governments resulting in piecemeal solutions can be replaced by an approach that applies management policies across sectors. This approach has gradually been accepted in the management of the Laurentian Great Lakes (Box 6.2).

Action plans may be powerful planning instruments for the promotion and co-ordination of activities for sustainable management and conservation of the African Great Lakes. Action plans can assist in raising funds and political support by focusing attention to the most urgent problems and by clearly presenting priorities for action. The plans should be formulated in close collaboration with the organisations who will have to implement the proposed actions and be supported by a broad-based group of government officials, resource managers and scientists.

Box 6.2 An integrated ecosystem approach to managing the Laurentian Great Lakes

Within the framework of water quality agreements for the Laurentian Great Lakes, the integrated ecosystem approach has been the most recent development in the management of natural resources. It evolved under the auspices of the International Joint Commission (IJC) from earlier approaches to managing the Great Lakes, namely the piecemeal and environmental approaches.

The concept of the integrated ecosystem approach is that an ecosystem has three essential segments: the environment, the economy and the society. No segment can be sacrificed without this having a negative impact on human interests. The system is open, making any exchange of energy, matter or information possible with other neighbouring areas and between segments. The central principle of an integrated ecosystem approach is that it relates people to the ecosystems that contain them, rather than to the environments with which they interact. The idea behind the approach is to try to manage ourselves instead of managing the environment.

A set of measures forms an ecosystem approach when a number of criteria are met: a focus on integrated knowledge; a perspective that relates systems at different levels of integration; and measures that are ecological, anticipatory and ethical in respect to nature.

Remedial action plan programmes for 42 degraded areas ('areas of concern') in the Laurentian Great Lakes Basin Ecosystem were developed and implemented following a recommendation by the IJC Great Lakes Water Quality Board in 1985. In many of the areas of concern, progress has been made. Three remedial action plan programmes for the Rouge River, Hamilton harbour and Fox River/Southern Green Bay have been successful in implementing integrated ecosystem approaches to restore these degraded areas. Implementation of the integrated ecosystem approach requires the establishment of a basin committee in which all 'stakeholders' – from international governments to the concerned citizen – work co-operatively as equal members to accomplish the common goal of restoring a degraded area. In parallel with these reactive remedial action plans, proactive plans should be developed in order to prevent the old problems from occurring again or new ones emerging. The cost of these action plans is immense (thousands of millions of United States dollars), bearing in mind the short-term economic gains over recent decades, which caused the degradation of the areas in the first place. (Hartig and Vallentyne, 1989; Regier, 1992).

6.2.2 Economic tools

Several economic tools can be used to protect large lakes like the African Great Lakes. Firstly, the establishment of *usage rights systems* covering both stationary and fleeting resources. Examples of fishery management tools are the individual fishing quota system and the territorial user-right fisheries (TURFs). Secondly, the *valuation of renewable resources* by using recently developed techniques, such as 'travel cost', 'hedonic pricing' and 'contingent valuation' methods (Turner *et al.*, 1993). Lastly, the application of *market forces* by providing incentives for the sustainable management of resources and disincentives in case of pollution or overexploitation. These instruments seek to modify human behaviour through the price mechanism and have the advantage of fitting neatly into the cost-benefit approach.

6.2.3 Regulations

Regulations are a tool used by governments both at the national and international levels. International regulations originate from treaties between two or more countries and from customary international law (McCaffrey, 1993). The effectiveness of regulations depends on public awareness, control and enforcement.

All kinds of regulations can be used for the management and conservation of large lakes. A wide range of regulations, including international fishery treaties, is used to control exploitation of fish stocks, for example, the recently proposed Draft Code of Conduct For Responsible Fisheries (FAO, 1995). Almost all fishery regulations in past decades have attempted to control fish stocks by limiting the fishing effort or controlling the quantity of fish caught. This approach has not been very successful (McGoodwin, 1990). Influenced by the theory of 'common property' resources, new management techniques still attempting to limit the effort are being developed, such as 'individual transferable quotas' (McGoodwin, 1990; Wilson *et al.*, 1994). The new techniques being developed all use the concept of active participation by the fishing communities in the management of their fisheries (*co-management* or *folk management*) (Dyer and McGoodwin, 1994).

Controls on the introduction of alien species may take the form of regulations on imports of non-native species for aquaculture or regulations to prevent accidental introductions. Pollution by land-based sources and accidents involving ships or dumping by ships are controlled by national and international regulations on pollution, transport and shipping safety. A new, potentially powerful form of regulation is the use of trade and tax controls, for example in order to create incentives for 'clean production' and to promote waste prevention.

Several international agreements contain provisions affecting international waters, including the Ramsar (Wetlands) Convention, World Heritage Convention and the Convention on Biological Diversity (for more information, see WCMC, 1992).

Most international agreements governing the protection of natural habitats also contain an obligation to establish protected areas. Protected areas play a vital role in the conservation of habitats and ecosystems. The initial purpose of many such areas was the protection of spectacular scenery, but in recent years this concept has developed more and more into the protection of endangered species and ecosystems rich in biodiversity. The importance of the current protected area concept to the African Great Lakes with their extremely valuable faunal diversity is evident. Protected areas may range from a small, highly protected reserve to a large UNESCO biosphere reserve with the establishment of buffer zones (WCMC, 1992). The key to successful protection of a specific area is, once again, public understanding, participation and support. It is essential to integrate existing usage rights, needs and ownership of the resident population into the design of protected areas and the fixing of objectives for these.

6.2.4 Restoration of lake ecosystems and populations

Degraded ecosystems and depleted populations may be restored anthropogenically. There are many examples of successful lake restoration in industrialized countries, such as the restoration of Lakes Washington and Shagawa and the measures to halt the eutrophication of Lake Tahoe in the USA (Horne and Goldman, 1994). The restoration of deleted populations may be possible by manipulating and enhancing existing populations using such methods as the introduction of species and stocking. All methods of recovering populations require extensive knowledge of the species and lake ecosystem concerned. Introducing a species in particular may have far-reaching repercussions for the ecosystem of the lake.

Lake restoration in recent decades mainly concerned activities in the lake itself, in order to adjust the structure and function of the ecosystem. The number of half-measures in the name of ecosystem restoration and the lack of a holistic view, combined with the concept of spreading and diluting, have bred problems elsewhere, for example in coastal waters (Björk, 1990).

Lake and population restoration activities should be seen as a last resort. Priority measures should be placed on maintaining existing ecosystems and populations by removing the original problem(s).

6.3 EXISTING NATIONAL AND INTERNATIONAL INSTITUTIONS

In the countries of the African Great Lakes, a wide range of governmental departments, research institutes and NGOs have taken the lead in the conservation of the lakes and their watersheds.

As the fisheries resources of the African Great Lakes are of major economic importance, both the Department of Fisheries and the national research institutes in the different countries are working on appropriate management and development schemes, providing research programmes for their national fisheries and generating regional activities for the management of the shared fish resources. The Lake Victoria Fisheries Organization has recently been established by the Governments of Kenya, Uganda and the United Republic of Tanzania.

Environmental protection and conservation activities are mostly the mandate of special commissions or departments within ministries, such as the National

Environment Secretariat of the Ministry of Environment and Natural Resources in Kenya, the National Environmental Management Council and the Environment Directorate within the Ministry of Environment, Natural Resources and Tourism in the United Republic of Tanzania and the Ministry of Environmental Protection in Uganda, although other ministries and departments in these countries are also responsible for certain environmental issues. Other governmental institutions may also be involved in the management of the lake basin, such as the Lake Basin Development Authority (LBDA) in Kenya with a mandate in the Lake Victoria basin area.

In addition, a great number of NGOs have been established in the African Great Lakes region in the past decade: in the Lake Victoria basin, OSIENALA ('Friends of Lake Victoria' in the Luo language), KAME (Kisumu Anti-Malarian and Environmental Group) and recently, 'The Lake Victoria Wetlands Team' in Kenya (Howard, 1994).

National governments and local NGOs in East Africa are assisted by several institutions at the international level in their efforts to achieve more sustainable management and conservation of the international waters of Lakes Victoria, Tanganyika and Malawi.

6.3.1 International assistance programmes and governmental organizations

Bilateral and multilateral donor agencies fund international assistance programmes and (inter) national governmental institutions implementing projects related to the African Great Lakes. A list of the most important current and recent projects related to the management and conservation of the resources of the African Great Lakes is given in Appendix V.

The Global Environment Facility (GEF) is an international World Bank programme established to assist in the protection of the global environment and to promote environmentally sound and sustainable economic development. Three agencies, the World Bank, UNEP and the United Nations Development Programme (UNDP) are responsible for the administration, strategic planning and implementation of the projects respectively. The GEF consists of a 'core' trust fund (GET), together with various co-financing arrangements. The participation of regional multilateral banks like the African development Bank and United Nations agencies, such as the Food and Agriculture Organization (FAO) and World Metereological Organization (WMO) is provided for in the GEF. The GEF's Scientific and Technical Panel (STAP) has established working groups covering global warming, biodiversity and international waters. Three GEF projects have recently become operational on the African Great Lakes: one biodiversity project on Lake Malawi and two international waters projects on Lakes Tanganyika and Victoria. In addition, GEF has implemented several other projects on biodiversity in the African Great Lakes region (see Appendix V).

The European Development Fund (EDF) is the financial instrument of the European Union for assistance to countries in Africa, the Caribbean area and the Pacific, with whom the EU has concluded the Lomé Agreement. There is currently one major EDF project on the African Great Lakes: the Lake Victoria Regional Fisheries Research Project, which entered into its second phase in 1996.

There are further European Union funds of potential importance to the management and conservation of the African Great Lakes: with INCO (International Cooperation) of the European Union Research and Technology Fund promoting scientific and technological co-operation with the developing countries (co-ordinated by Directorate General XII) and LIFE (L'instrument financier pour l'environnement), the European Union's environment programme allocates 5% of its total budget to projects outside the European Union.

Several multilateral governmental organizations assist in the management and conservation of the African Great Lakes basins. The Department of Fisheries of the FAO is currently carrying out a number of fisheries management and research projects on the three lakes (see Appendix V) and the Committee for Inland Fisheries of Africa (CIFA), with its sub-committees for the Development and Management of the Fisheries of Lake Victoria and Lake Tanganyika and the Working Group on Environment, promotes research programmes on the lakes for a rational utilization of the fishery resources and is assisting in establishing a scientific basis for regulatory measures.

UNEP funds projects on wetland management and conservation in East Africa. Together with UNDP, it is a participating agency in the GEF projects on the African Great Lakes. Recently, UNDP and FAO implemented a special 'Chambo' fishery research project on Lake Malawi (FAO, 1992). UNESCO's International Hydrological Programme is contributing through the project 'Comprehensive and Comparative Study of Great lakes' to a broader knowledge base of the African Great Lakes ecosystems. UNESCO is also involved in the conservation of natural resources and biodiversity in the African Great Lakes basins through its Man and Biosphere (MAB) Programme.

The World Conservation Union (IUCN), formerly the International Union for Conservation of Nature and Natural Resources, boasts a membership of both governmental and non-governmental organizations and is one of the world's leading forces for the conservation and sustainable management of the African Great Lakes.

6.3.2 International lake and river basin organizations

In the African Great Lakes region, several river basin organizations (RBOs) dealing with international water resources already exist (Rangely *et al.*, 1994):

- Kagera Basin Organisation (Burundi, Rwanda, Uganda and United Republic of Tanzania) with the aim of strengthening economic co-operation in the Kagera River basin;
- Énergie des grands lacs (EGL) (Burundi, Democratic Republic of the Congo and Rwanda), a regional energy planning organization of the Communauté économique des pays des grands lacs (CEPGL) dealing with the hydro-electric power development on the Ruzizi River;
- the Zambezi River Authority (Zambia, Zimbabwe) focusing on the Kariba Dam on the Zambezi River.

As indicated in Chapter 2, the river systems of the Nile, Congo and Zambezi Rivers, of which the three Great Lakes form a part, are international rivers each shared by more than six countries, while the lakes themselves are shared by at least three countries. The role of these RBOs is in general to promote studies and activities for sustainable development of the water resources of the river basins concerned. To date, there are no lake basin organisations for the African Great Lakes. Outside the region, there is one lake in Africa which has an international basin commission, Lake Chad, which is shared by Cameroon, Chad, Niger and Nigeria.

The Nile Basin countries already have experience in working together through co-operation in the Hydromet Survey Project (1967–1992). Recently, a new initiative was taken by the basin states. Ministers responsible for water affairs from six Nile Basin countries (Democratic Republic of the Congo, Egypt, Rwanda, Sudan, Uganda and the United Republic of Tanzania) agreed to co-operate on water resource matters. In January 1993, the Technical Co-operation Committee for the Promotion of the Development and Environmental Protection of the Nile Basin (TECCONILE) was created as a temporary successor to the Hydromet Survey Project. With assistance provided by the Canadian International Development Agency (CIDA), TECCONILE prepared a Nile River Basin Action Plan (TECCONILE, 1995*b*). The Action Plan contains 22 projects with five main components: integrated water resources planning and management, capacity building, training, regional co-operation and environmental protection and enhancement.

6.3.3 International non-governmental organizations (NGOs)

One international NGO that has contributed to the management and conservation of the African Great Lakes, their associated wetlands and watersheds is the World Wide Fund for Nature (WWF). It has been involved in the establishing an education centre in the Lake Malawi National Park (Bootsma, 1992). Other international NGOs which may play a role in the future are *the* International Lake Environment Committee (ILEC) and the UNEP International Environmental Technology Centre (IETC) with its Shiga (Japan) Office focusing on freshwater lake/reservoir basins.

6.3.4 International research organizations

A number of international research organizations and networks have carried out research or been involved in activities to disseminate information on the African Great Lakes basins: the African Great Lakes Group of the International Limnological Society (SIL), An International Decade for the East African Lakes (IDEAL), the Scientific Committee on Problems of the Environment (SCOPE) of the International Council of Scientific Unions (ICSU) and International Center for Living Aquatic Resources Management (ICLARM).

The African Great Lakes Working Group of SIL initiated in 1989 the process of information exchange by organizing the International Symposium on Resource Use and Conservation of the African Great Lakes in Burundi (Lowe-McConnell *et al.*, 1992; see Appendix II). Since then, the Group has continued to disseminate information through publications on the African Great Lakes to co-ordinate research, collaborating with other international organizations that include FAO, UNEP, UNDP, UNESCO, the European Union and the World Bank. The SIL Symposium in Burundi was followed by several other large meetings all attended by members of the Group: among others, the International Conference on the Conservation and Biodiversity of Lake Tanganyika, in Burundi (1991), the Symposium on the Limnology and Fisheries of Lake Tanganyika, in Finland (1991), the Symposium on the Impact of Species Changes on African Lakes, in London (1992), the FAO/IFIP Workshop on Small Pelagic Fish in African Great Lakes, in Burundi (1992), the IDEAL Symposium on the Limnology, Climatology and Paleoclimatology of the East African Lakes, in Uganda (1993), the SIAL Workshop on Speciation in Ancient Lakes, in Belgium (1993), the UK/Southern African Development Community (SADC) Pelagic Fish Resource Assessment Seminar, in Malawi (1994) and the Symposium on the Fisheries of Lake Tanganyika, in Finland (1995). The Group has collaborated with UNESCO on implementing the project 'Comprehensive and Comparative Study of Great Lakes' (IHP IV M-5.1), of which the present report is one of the results.

IDEAL is a research initiative by the international paleoscience community (Johnson, 1993). The project focuses its research on the paleoclimatic record of the East African lake system, which is one of the oldest in the world. Therefore, it intends to address a number of scientific issues to arrive at a better understanding of the paleoclimatic record and to increase knowledge on lake ecosystem processes (Johnson and Odada, 1996) (see also Appendix III).

Together with UNEP and several international donor agencies, SCOPE has organized a workshop on nutrient cycles in terrestrial and aquatic ecosystems in Africa (Tiessen and Frossard, 1991), focusing on the interrelation between lakes and watersheds.

ICLARM has been entrusted with responsibility for fisheries research within the Consultative Group on International Agricultural Research (CGIAR) system. It was involved in a Fisheries Resources Study Project on Lake Victoria in Uganda and will be involved in new fisheries research and management initiatives of the Special Programme for African Agricultural Research (SPAAR).

One new initiative is that launched by the European Union, the EU–ACP Fisheries Research Initiative (FRI). In the context of EU–ACP co-operation, the EU–ACP Joint Assembly made fisheries the focus of one of its working groups The FRI aims to ensure sustainable use of fishery resources for the benefit of sector stakeholders and in order to conserve aquatic ecosystems. Research will have an important role to play by providing approaches and solutions. FRI is co-ordinated by DG VIII and DG XII of the Commission of European Countries.

6.4 TOWARDS CONSERVATION AND SUSTAINABLE MANAGEMENT OF THE AFRICAN GREAT LAKES

The governments and populations of the East African countries are responsible for the sustainable management and conservation of the African Great Lakes and their watersheds. The water and natural resources of the lakes are of vital importance to their economies. The welfare and societal well-being of present and future populations will depend on how well these renewable resources are protected and managed. By protecting the natural ecosystems sustaining these resources, people will ensure the availability of resources and avoid the negative consequences of neglect (e.g. depleted resources, pollution, public health hazards and the significant economic cost of lost benefits and restoration measures(.

Water does not respect borders. The African Great Lakes being shared water bodies, co-operation and goodwill among countries sharing the resources are required. Therefore, it is essential for the riparian countries to collaborate formally in joint commissions in order to exchange information and develop programmes that are of joint interest and benefit. As the lakes are inextricably linked with their watersheds and airsheds, there is a need for comprehensive management taking the lake basin as a management unit.

Before sustainable management and conservation of these lake basins can be achieved, the national development objectives and main water-related and aquatic resources-related policies of the countries concerned need to be integrated into environmental considerations. Most East African countries have recently elaborated and implemented National Environmental Action Plans (NEAPs) or equivalent documents (World Bank, 1994). These NEAPs describe the major environmental concerns and problems, and formulate policies and actions to address those problems identified. Strategic plans for integrated environmental management of the lake basins can be formulated in order to guide plans and actions to protect the lakes' ecosystems and manage their natural resources.

Each country has its own set of unique environmental, economic and societal conditions that influence its policies for sustainable management of the lake basin. The integration of conservation into management requires a strong commitment on the part of government, the participation of stakeholders and a multisectoral approach. Lake-basin management will need institutional arrangements at all levels:

- at the international level – establishment of lake basin commissions and other supra-national institutions;
- at the national and sub-national levels – improved inter-ministerial co-operation and consultation of experts from within and outside the government and, last but not least;
- at local level – active participation by local communities, NGOs and the private sector in decision-making.

Extensive limnological and hydrological research and reviews on the lakes' ecosystems, as well as special studies on the main environmental problems, will be necessary to inform all parties involved from decision-makers to stakeholders. With this information in hand, decision-makers and stakeholders will be able to formulate rational strategies and action plans for an integrated environmental management of the lakes' basins.

Consensus on the hydrological and limnological description of these international water systems will facilitate agreement between the riparian countries on the use, planning, management and conservation of the lakes.

On the basis of the information brought together in the three monographs (Crul, 1995; Crul, 1997; Crul et al. 1995) and in the present report, a Workshop on the Water Balance of the African Great Lakes, held in Entebbe (Uganda) in December 1995, identified gaps in understanding of the lakes' ecosystems and formulated priority areas for limnological and hydrological research. A report on the above Workshop has been published by UNESCO.

References

Ackermann, W. C.; White, G. F.; Worthington, E. B. (eds.). 1973. *Man-made Lakes: their Problems and Environmental Effects*. Geophysical Monograph 17. Washington D.C., American Geophysical Union, 847 p.

Akiyama, T.; Kajumulo, A. A.; Olsen, S. 1977. Seasonal variations of plankton and physicochemical condition in Mwanza Gulf, Lake Victoria. *Bull. Freshw. Fish. Res. Lab.* 27:49–61.

Allison, E. H.; Patterson, G.; Irvine, K.; Thompson, A. B.; Menz, A. 1995. The pelagic ecosystem. In: A. Menz (ed.), *The Fishery Potential and Productivity of the Pelagic Zone of Lake Malawi/Niassa*. Chatham, Natural Resources Institute, pp. 351–67

Augustine, J. A.; Woodley, W. L.; Scott, R. W; Changnon, S. A. 1994. Using geosynchronous satellite imagery to estimate summer-season rainfall over the Great Lakes. *Jl Great Lakes Res.* 20(4):683–700.

Baker, J. M. 1992. Oil and African Great Lakes. In: R. H. Lowe-McConnell, R. C. M. Crul and F. C. Roest (eds.), Symposium on Resource Use and Conservation of the African Great Lakes, Bujumbura 1989. *SIL Mitteilungen* 23:71–8.

Barica, J. 1990. Long-term trends in Great Lakes nutrient concentrations: A summary. Verh. Internat. *Verein. Limnol.* 24:369–70.

Baxter, R. M. 1977. Environmental effects of dams and impoundments. *Ann. Rev. Syst.* 8:255–83.

Beadle, L. C. 1932. Scientific results of the Cambridge Expedition to the East African Lakes 1930–1931, vol. 3. Observations on the bionomics of some East Africa swamps. *Jl Linn. Soc. (Zool.)* 38:135–55.

——. 1974. *The Inland Waters of Tropical Africa: an Introduction to Tropical Limnology*. London, Longman, 365 p.

——. 1981. *The Inland Waters of Tropical Africa*. 2nd edition. London, Longman, 475 p.

Beauchamp, R. S. A. 1939. Hydrology of Lake Tanganyika. *Int. Revue ges. Oceanogr.* 10:510–20.

——. S. A. 1940. Chemistry and hydrography of Lakes Tanganyika and Nyasa. *Nature* 146:253–6.

——. 1946. Lake Tanganyika. *Nature* 157:183–4.

——. 1953. Hydrological data from Lake Nyasa. *Jl Ecol.* 41:226–39.

Beer, M. de. 1989. Light measurements in Lake Victoria, Tanzania. *Ann. Mus. Roy. Afr. Centr. Soc. Zool.* 257:57–60.

Belt, D. 1992. The World's Great Lake. *Nat Geogr.* 181(6):2–39.

Berner, E. K.; Berner, R. A. 1987. *The Global Water Cycle: Geochemistry and Environment.* New Jersey, Prentice Hall, Englewood Cliffs.

Björk, S. 1990. Governing ecosystems for sustainable function. *Verh. Internat. Verein. Limnol.* 24:55–60.

Bootsma, H. A. 1992. Lake Malawi National Park. In: R. H. Lowe-McConnell, R. C. M. Crul and F. C. Roest (eds.), Symposium on Resource Use and Conservation of the African Great Lakes, Bujumbura 1989. *SIL Mitteilungen* 23:125–8.

——. 1993*a*. *Algal Dynamics in an African Great Lake and their Relation to Hydrographic and Meteorological Conditions*. Ph.D. thesis. Canada, University of Manitoba.

——. 1993*b*. Spatio-temporal variation of phytoplankton biomass in Lake Malawi, Central Africa. *Verh. Internat. Verein. Limnol.* 25:882–6.

BOOTSMA, H. A.; HECKY, R. E. 1993. Conservation of the African Great Lakes: a limnological perspective. *Conservation Biology* 7(3):644–56.

BOS, A. R. 1995. *A limnological Survey on Lake Mweru, Zambia*. Nchelenge, Dept of Fisheries, 31 p. (mimeo).

BUGENYI, F. B.; BALIRWA, J. S. 1989. Human intervention in natural processes of the Lake Victoria ecosystem – The problem. In: J. Salanki and S. Herodek (eds.), *Conservation and Management of Lakes. Symposium Biol. Hungary* 38. Budapest, Akademial Kiado, pp. 311–40.

BURGIS, M. J. 1984. An estimate of zooplankton biomass for Lake Tanganyika. *Verh. Internat. Verein. Limnol.* 22:1199–203.

CALJON, A. G. 1992. Water quality in the Bay of Bujumbura (Lake Tanganyika) and its influence on phytoplankton composition. In: R. H. Lowe-McConnell, R. C. M. Crul and F. C. Roest (eds.), Symposium on Resource Use and Conservation of the African Great Lakes, Bujumbura 1989. *SIL Mitteilungen* 23:55–66.

CAPART, A. 1949. Sondages et carte bathymétrique du lac Tanganika. Résultats scientifiques de l'exploration hydrobiologique du lac Tanganika (1946–1947). *Inst. Roy. Soc. Nat. Belgique* 2(2):1–16.

——. 1952. Le milieu géographique et géophysique. Résultats scientifiques de l'exploration hydrobiologique du lac Tanganika (1946–1947). *Inst. Roy. Soc. Nat. Belgique* 1:3–27.

CHRISTENSEN, V.; PAULY, D. 1991. *A guide to ECOPATH II Software System (Version 2.0)*. ICLARM Software 6, 71 p.

COBB, C. E. 1987. The Great Lakes' troubled waters. *Nat. Geogr.* 172(1):2–31.

COHEN, A. S. 1991. Report on the first International Conference on the Conservation and Biodiversity of Lake Tanganyika, Bujumbura, Burundi, 11–13 March, 1991. Compte rendu de la première conférence internationale sur la conservation et la biodiversité du lac Tanganika, Bujumbura, Burundi, 11–13 mars, 1991, 128 p.

——. 1995. Paleoecological approaches to the conservation biology of benthos in ancient lakes: a case study from Lake Tanganyika. *Jl N. Am. Benthol. Soc.* 14(4):654–68.

COHEN, A. S.; BILLS, R.; COCQUYT, C. Z.; CALJON, A. G. 1993. The impact of sediment pollution on biodiversity in Lake Tanganyika. *Conserv. Biol.* 7(3):667–77.

COHEN, A. S.; KAUFMAN, L.; OGUTU-OHWAYO, R. 1996. Anthropogenic threats, impacts and conservation startegies in the African Great Lakes – a review. In: T. C. Johnson and E. O. Odada (eds.), *The Limnology, Climatology and Paleoclimatology of the East African Lakes*. New Jersey, Gordon & Breach Publ.

CORBET, P. S. 1961. The food of non-cichlid fishes in the Lake Victoria basin, with remarks on their evolution and adaptation to lacustrine conditions. *Proc. Zool. Soc. London* 136(1):1–101.

CORDONE, A. J.; KUDHONGANIA, A. W. 1971. *Identification of 'Organisms' in Lake Victoria Responsible for Echosounder Traces*. EAFFRO Annual Report, 1970, pp. 28–41.

COULTER, G. W. 1963. Hydrobiological changes in relation to biological production in southern Lake Tanganyika. *Limnol. and Oceanogr.* 8:463–77.

——. 1968*a*. *Hydrological processes and primary production in Lake Tanganyika*. Proc. 11th Conf. Great Lakes Res., pp. 609–26.

——. 1968*b*. Thermal stratification in the deep hypolimnion of Lake Tanganyika. *Limnol. and Oceanogr.* 13(2):385–7.

——. (ed.). 1991*a*. *Lake Tanganyika and its Life*. British Museum (Natural History)/Oxford Univ. Press, 354 p.

——. 1991*b*. Zoogeography, affinities and evolution with special regard to the fish. In: G. W. Coulter (ed.), *Lake Tanganyika and its Life*. British Museum (Natural History)/Oxford University Press, pp. 275–305.

——. 1991*c*. Composition of the flora and fauna. In: G. W. Coulter (ed.), *Lake Tanganyika and its Life*. British Museum (Natural History)/Oxford University Press, pp. 200–74.

——. 1994. Lake Tanganyika. *Arch. Hydrobiol. Beih. Ergebn. Limnol.* 44:13–18.

COULTER, M. R.; COULTER, G. W. 1991. A comprehensive bibliography of Lake Tanganyika. In: G. W. Coulter (ed.), *Lake Tanganyika and its Life*. British Museum (Natural History)/Oxford University Press, pp. 306–36.

COULTER, G. W.; SPIGEL, R. H. 1991. Hydrodynamics. In: G. W. Coulter (ed.), *Lake Tanganyika and its Life*. British Museum (Natural History)/Oxford University Press, pp. 49–75

COULTER, G. W.; MUBAMBA, R. 1993. Proposal for designing reserve management plans for Sumbu National Park, Lake Tanganyika. *Conservation Biology* 7:678–85.

COULTER, G. W.; ALLANSON, B. R; BRUTON, M. N.; GREENWOOD, P. H.; HART, R. C.; JACKSON, P. B. N.; RIBBIN, A. J. 1986. Unique qualities and special problems of the African Great Lakes. *Environmental Biology of Fishes* 17:161–183.

CRAIG, H. 1975. Lake Tanganyika geochemical and hydrographic study: 1973 expedition. *Publ. Scripps Inst. of Oceanogr. Series*, 75–5:1–83.

CRAIG, J. F. 1992. Human-induced changes in the composition of fish communities in the African Great lakes. *Reviews in Fish Biology and Fisheries* 2:93–124.

CROSSLEY, R.; DAVISON-HIRSCHMANN, S.; OWEN, R. B.; SHAW, P. 1984. Lake level fluctuations during the last 2,000 years in Malawi. In: J. C. Vogel, *Cainozoic Palaeoclimates of the Southern Hemisphere.* Rotterdam, A. A. Balkema, pp. 305–16

CRUL, R. C. M. 1995. *Limnology and Hydrology of Lake Victoria.* Studies and Reports in Hydrology 53. Paris, UNESCO.

——. 1997. *Limnology and Hydrology of Lakes Tanganyika and Malawi.* Studies and Reports in Hydrology 54. Paris, UNESCO.

CRUL, R. C. M.; SILVESTRE, G. T.; POSTMA, D. J.; VAN OIJEN, M. J. P.; ACERE, T. O.; BONGERS, G. 1995. *A Bibliography of Lake Victoria.* Technical Documents in Hydrology SC-95/WS/16. Paris, UNESCO.

DAMAS, H. 1937. Recherches hydrobiologiques dans les lacs Kivu, Edouard et Ndalaga (Congo Belge). *Verh. Inter. Ver. Limnol.* 8:51–68.

DAVIES, B. R.; HART, R. C. 1981. Invertebrates. In: J. J. Symoens, M. Burgis and J. J. Gaudet (eds.), *The Ecology and Utilization of African Inland Waters.* UNEP Reports and Proceedings Series 1. Nairobi, UNEP, pp. 51–68.

DEGENS, E. T., VON HERZEN, R. P.; WONG, H.-K. 1971. Lake Tanganyika: water chemistry, sediments, geological structure. *Naturwissenschaften* (New York) 58(5):229–41.

DEGNBOL, P. 1990. *The Pelagic Zone of Central Lake Malawi – a Trophic Box Model.* ICES CM 90 /L:30, 7 p. (mimeo).

DEGNBOL, P.; MAPILA, S. 1982. Limnological observations on the pelagic zone of Lake Malawi from 1970 to 1981. In: FAO, *Biological Studies on the Pelagic Ecosystem of Lake Malawi.* FI:DP/MLW/75/019 Technical Report 1. Rome, FAO, pp. 5–47.

DEJOUX, C. 1988. *La pollution des eaux continentales africaines. Expérience acquise, situation actuelle et perspectives.* Collection Travaux et Documents 213. Paris, ORSTOM.

DENNY, P. 1989. Pilot Project on Papyrus Swamp Management for Sustainable Renewable Resource Development at Butaleja Pilot Village. *Strategic Resources Planning in Uganda.* Wetlands, vol. IX. Nairobi, UNEP, pp. 59–63.

DEVROEY, E. 1949. A propos de la stabilisation du niveau du lac Tanganika et de l'amélioration de la navigabilité du fleuve Congo. *Mém. Inst. r. Col. Belge* 5(3):1–135.

DGIS, 1995. *Fisheries in developing countries. Towards sustainable use of aquatic resources.* Sectoral policy document of Development Cooperation, 9. The Hague, Ministry of Foreign Affairs, xi + 96 p.

DIXEY, F. 1926. The Nyasaland section of the Great Rift Valley. *Geogr. Jl,* 68:117–40.

DUMONT, H. 1994. Ancient lakes have simplified pelagic food webs. *Arch. Hydrobiol. Beih. Ergebn. Limnol.* 44:203–22.

DYER, C. L.; MCGOODWIN, J. R. (eds.). 1994. *Folk Management in the World's Fisheries.* Niwot, University of Colorado Press, 347 p.

ECCLES, D. H. 1974. An outline of the physical limnology of Lake Malawi (Lake Nyasa). *Limnol. and Oceanogr.* 19(5):730–42.

——. 1984. On the recent high levels of Lake Malawi. *Sth. Afr. Jl Sci.* 80:461–8.

——. 1988. A Quarter Century of Great Lakes Research in Africa. *Jl Limnol. Soc. Sth. Afr.* 14(1):41–8.

ECCLES, D. H.; TREWAVAS, E. 1989. Malawian Cichlid Fishes. *The Classification of some Haplochromine Genera.* Herten, Lake Fish Movies, 334 p.

EDMOND, J. M., STALLARD, R. F.; CRAIG, H.; CRAIG, V.; WEISS, R. F.; COULTER, G. W. 1993. Nutrient chemistry of the water column of Lake Tanganyika. *Limnol. and Oceanogr.* 38(4):725–38.

EDMONDSON, W. T. 1972. The present conditions of Lake Washington. *Verh. Internat. Verein. Limnol.* 18:284–91.

ELLIS, W. S. 1990. The Aral: a Soviet sea lies dying. *Nat. Geogr.* 177(2):72–92.

FALKENMARK, M. 1989. The massive water scarcity now threatening Africa – Why isn't it being addressed? *Ambio* 18(2):112–18.

FAO. 1978. *Systematic Index of International Water Resources Treaties, Declarations, Acts and Cases by Basin.* Legislative Study 15. FAO, Rome.

——. 1992. Fisheries management in the south-east arm of Lake Malawi, the Upper Shire river and Lake Malombe with special reference to the fisheries on chambo (*Oreochromis* spp.) Report on the Workshop held at Mangochi, 8–11 July, 1992. FI:DP/MLW/86/013, Technical Paper 1, 106 p.

——. 1995. *Draft Code of Conduct of Responsible Fisheries.* FAO, Rome.

FEE, E. J. 1990. Computer programs for calculating in situ phytoplankton photosynthesis. *Can. Tech. Rep. Fish Aquat. Sci.* 1740. v + 27 p.

FERRO, W. 1977. *A Limnological Baseline Survey of the Chintheche Area of Lake Malawi.* FAO FI:MLW/71/516/13. Rome, FAO, 23 p.

FISH, G. R. 1957. A seiche movement and its effect on the hydrology of Lake Victoria. *Fish. Publ.* 10:1–68.

FLOWER, R. J. 1994. A review of current biological and recent environmental research on Lake Baikal from a British perspective. Lake Baikal. *Freshwater Forum* 4(1):8–21.

FRYER, G. 1959. The trophic interrelationship and ecology of some littoral communities of Lake Nyasa with special reference to the fishes, and a discussion of the evolution of a group of rock-frequenting Cichlidae. *Proc. Zool. Soc. Lond.* 132(2):153–281.

FRYER, G.; ILES, T. D. 1972. *The Cichlid Fishes of the Great Lakes of Africa.* Edinburgh, Oliver & Boyd, 642 p.

FRYER, G.; TALLING, J. F. 1986. Africa: the FBA connection. *Rep. Freshwat. Biol. Ass.* 54:97–122.

GEE, J. M.; GILBERT, M. P. 1968. The establishment of a commercial fishery for *Haplochromis* in the Uganda waters of Lake Victoria – Part II. Jinja, Uganda. EAFFRO Occasional Paper 8.

GILLMAN, C. 1933. The hydrology of Lake Tanganyika. *Bull. Geol. Surv.* (Tanganyika Territory, Dar es Salaam) 5:1–25.

GLEICK, P. H. (ed.). 1993*a*. *Water in Crisis. A Guide to the World's Fresh Water Resources.* New York/Oxford, Oxford University Press, 473 p.

——. 1993*b*. Water and energy. In: P. H. Gleick (ed.), *Water in Crisis. A Guide to the World's Fresh Water Resources.* New York/Oxford, Oxford University Press, pp 67–79.

——. 1993*c*. Water in the 21st century. In: P. H. Gleick (ed.), *Water in Crisis. A Guide to the World's Fresh Water Resources.* New York/Oxford, Oxford University Press, pp 105–13.

GOLDMAN, C. R. 1988. Primary productivity, nutrients and transparency during the early onset of eutrophication in ultra-oligotrophic Lake Tahoe, California-Nevada. *Limnol. and Oceanogr.* 33:1321–33.

GOLDMAN, C. R.; JASSBY, A. D.; AMEZAGA, E. de. 1990. Forest fires, atmospheric deposition, and primary productivity at Lake Tahoe, California-Nevada. *Ver. Int. Ver. Limnol.* 24:499–503.

GOLDSCHMIDT, T.; WITTE, F.; VISSER, J. DE. 1989. Ecological segregation of zooplanktivorous haplochromines (Pisces, Cichlidae) from Lake Victoria. In: T. Goldschmidt (ed.), *An Ecological and Morphological Field Study on the Haplochromine Cichlid Fishes (Pisces, Cichlidae) of Lake Victoria.* Ph.D. Thesis. Leiden, State University of Leiden, pp. 23–50.

GOLDSCHMIDT, T.; WITTE, F.; WANINK, J. H. 1993. Cascading effects of the introduced Nile perch on the detritivorous/phytoplanktivorous species in the sub-littoral areas of Lake Victoria. *Conservation Biology* 7(3):686–700.

GONFIANTINI, R.; ZUPPI, G. M.; ECCLES, D. H.; FERRO, W. 1979. Isotope investigation of Lake Malawi. In: *IAEA, Proceedings on the Application of Nuclear Techniques to the Study of Lake Dynamics, Vienna, 29 August–2 September 1977.* Vienna, IAEA, pp. 195–205.

GOPHEN, M.; OCHUMBA, P. O. B;. KAUFMAN, L. S. 1995. Some aspects of perturbation in the structure and biodiversity of the ecosystem of Lake Victoria (East Africa). *Aquat. Living Res.* 8:27–41.

GRAHAM, M. 1929. *The Victoria Nyanza and its Fisheries.* A report on the fishing survey of Lake Victoria 1927–1928 and Appendices. London, Crown Agents for the Colonies, 255 p.

GRÉBOVAL, D.; FRYD, M. 1993. *Inland Fisheries of Eastern/Central/Southern Africa: Basic Fisheries Statistics.* UNDP/FAO RAF/87/099-TD/52/93. UNDP/FAO Regional Project for Inland Fisheries Planning, 98 p.

GREENWOOD, P. H. 1974. The cichlid fishes of Lake Victoria, East Africa: The biology and evolution of a species flock. *Bulletin of the British Museum Natural History (Zool) Suppl.* 6:1–134.

——. H. 1981. *The Haplochromine Fishes of the East African Lakes.* Collected papers on their taxonomy, biology and evolution with an introduction and species index. New York, Cornell University Press, 839 p.

——. 1994. Lake Victoria. *Arch. Hydrobiol. Beih. Ergebn. Limnol.* 44:19–26

GREGORY, J. W. 1921. *The Rift Valleys and the Geology of East Africa.* Seeley Service & Company, London.

HABERYAN, K. A.; HECKY, R. E. 1987. The late Pleistocene and Holocene stratigraphy and paleolimnology of the Lakes Kivu and Tanganyika. *Palaeogeogr. Palaeoclim. Palaeoecol.* 61:169–97.

HABERYAN, K. A.; MHONE, O. K. 1991. Algal communities near Cape Maclear, southern Lake Malawi, Africa. *Hydrobiologia* 215:175–88.

HANEK, G.; COENEN , E. J. (eds.). 1994. *Report of the Third Joint Meeting of the LTR'S Co-ordination and International Scientific Committees. December 1994.* FAO/FINNIDA Project Research for the Management of the Fisheries on Lake Tanganyika GCP/RAF/271/FIN-TD/27 (E), 181 p.

HARRISON, K. P.; LORUM, L. E.; MATTICK, A. K. 1976. *A Water Resources Assessment of Lake Malawi.* WMO/UNDP project report MLW/71/518, 167 p.

HARTIG, J. H.; VALLENTYNE, J. R. 1989. Use of an ecosystem approach to restore degraded areas of the Great Lakes. *Ambio* 18(8):423–8.

HAWLEY, G. R. W.; WHITTON, B. A. 1991. Survey of algal picoplankton. *Verh. Internat. Verein. Limnol.* 24:1220–2.

HECKY, R. E. 1984. African lakes and their trophic efficiencies: a temporal perspective. In: D. G. Meyers and J. R. Strickler (eds.), *Trophic Interactions within Aquatic Ecosystems. 1981* AAAS Symposium 85. Boulder, Westview Press, pp. 405–48.

——. 1991. The pelagic ecosystem. In: G. Coulter (ed.), *Lake Tanganyika and its Life.* British Museum (Natural History)/Oxford University Press, pp. 90–110.

——. 1993. The eutrophication of Lake Victoria. Kilham Memorial Lecture, 25th Congress of SIL. *Verh. Internat. Verein. Limnol.* 25:39–48.

HECKY, R. E.; BUGENYI, F. W. B. 1992. Hydrology and chemistry of the African Great Lakes and water quality issues: Problems and solutions. In: R. H. Lowe-McConnell, R. C. M. Crul and F. C. Roest (eds.), Symposium on Resource Use and Conservation of the African Great Lakes, Bujumbura 1989. *SIL Mitteilungen* 23, pp. 45–54.

Hecky, R. E., Bootsma, H. A.; Mugidde, R.; Bugenyi, F. W. B. 1996. Phosphorus pumps, nitrogen sinks and silicon drains: plumbing nutrients in the African Great Lakes. In: T. C. Johnson and E. O. Odada (eds.), *The Limnology, Climatology and Paleoclimatology of the East African Lakes*. New Jersey, Gordon & Breach Publ.

Hecky, R. E.; Bugenyi, F. W. B.; Ochumba, P. O. B.; Talling, J. F.; Mugidde, R.; Gophen, M.; Kaufman, L. 1994. Deoxygenation of the deep water of Lake Victoria, East Africa. *Limnol. and Oceanogr.* 39(6):1476–81.

Hecky, R. E.; Fee, E. J. 1981. Primary production and rates of algal growth in Lake Tanganyika. *Limnol. and Oceanogr.* 26:532–47.

Hecky, R. E., Fee, E. J; Kling, H. J.; Rudd, J. W. 1978. *Studies on the Planktonic Ecology of Lake Tanganyika.* Can. Dept of Fish and Environment. Fisheries and Marine Service Technical Paper 816:1–51.

——.; ——.; ——.; ——. 1981. Relationship between primary production and fish production in Lake Tanganyika. Trans. *Am. Fish. Soc.* 110:336–45.

Hecky, R. E.; Kilham, P. 1988. Nutrient limitation of phytoplankton in freshwater and marine environments. *Limnol. and Oceanogr.* 33:796–832.

——.; ——. 1981. Phytoplankton ecology and zooplankton of the euphotic zone of Lake Tanganyika: species composition, biomass, chlorophyll content, and spatio-temporal distribution. *Limnol. and Oceanogr.* 26:548–64.

Hecky, R. E.; Kling, H. J. 1987. Phytoplankton ecology of the great lakes in the rift valleys of Central Africa. *Arch. Hydrobiol. Beih.* 25:197–228.

Hecky, R. E.; Spigel, R. H.; Coulter, G. W. 1991. The nutrient regime. In: G. W. Coulter (ed.), *Lake Tanganyika and its Life.* British Museum (Natural History)/Oxford University Press, pp. 76–89.

Hori, M.; Gashagaza, M. M.; Nsombo, M.; Kawanabe, H. 1993. Littoral fish communities in Lake Tanganyika: irreplaceable diversity supported by intricate interactions among species. *Conserv. Biol.* 7(3):657–66.

Horne, A. J.; Goldman, C. R. 1994. *Limnology*. 2nd edition. New York, McGraw-Hill Inc., 576 pp.

Howard, G. 1994. A new wetland NGO for Kenya. *IUCN Wetlands Programme Newsletter* 9:5.

Hulme, M. 1992. Rainfall changes in Africa: 1931–1960 to 1961–1990. *Int. Jl Climatol.* 12:685–99.

Hurst, H. E. 1952. *The Nile: a General Account of the River and the Utilization of its Waters*. London, Constable, 326 p.

Irvine, K. 1995*a*. Standing biomasses, production and spatio-temporal distributions of the crustacean zooplankton. In: A. Menz (ed.), *The Fishery Potential and Productivity of the Pelagic Zone of Lake Malawi/Niassa.* Chatham, Natural Resources Institute, pp. 85–108.

Irvine, K. 1995*b*. Ecology of the lakefly, *Chaoborus edulis*. In: A. Menz (ed.), *The Fishery Potential and Productivity of the Pelagic Zone of Lake Malawi/Niassa*. Chatham, Natural Resources Institute, pp. 109–40

Irvine, K.; Waya, R. 1995. The zooplankton: general sampling methods and estimation of biomass and development rates. In: A. Menz (ed.), *The Fishery Potential and Productivity of the Pelagic Zone of Lake Malawi/Niassa*. Chatham, Natural Resources Institute, pp. 69–83.

Jackson, P. B. N.; Iles, T. D.; Harding, D.; Fryer, G. 1963. *Report on the Survey of Northern Lake Nyasa 1954–55*. Zomba, Government Printer, 171 p.

Jannasch, H. W. 1975. Methane oxidation in Lake Kivu (Central Africa). *Limnol. and Oceanogr.* 20:860–4.

JFRO (Joint Fisheries Research Organisation). 1960. *Annual Report 9, 1959*. Lusaka, Government Printer.

JFRO (Joint Fisheries Research Organisation). 1962. *Annual Report 10, 1960*. Lusaka, Government Printer.

JFRO. 1964. *Joint Fisheries Research Organisation Annual Report 11, 1962.* Lusaka, Government Printer.

Johnson, T. C. (ed.). 1993. IDEAL – an International Decade for the East African Lakes. Science and Implementation Plan. Past Global Changes (PAGES) Workshop Report, Series 93-2. PAGFES Project, Bern, 43 p.

——. 1995. Paleoclimatic studies suggest that Lake Victoria was dry. *IDEAL Bulletin*, Autumn 1995:1.

Johnson, T. C.; Davies, T. W. 1989. High resolution seismic profiles from Lake Malawi, East Africa. *African Earth Sci.* 8:383–92.

Johnson, T. C.; Odada, E. O. (eds.). 1996. The limnology, climatology and paleoclimatology of the east African Lakes. IDEAL Symposium, Jinja, Uganda, February 1993. Newark, New Jersey, Gordon & Breach Publ.

Johnson, T. C.; Halfman, B. M.; Vaughan, N. D. 1988. *Sediment Core Descriptions: Malawi '86: Lake Malawi, East Africa.* Duke University Mar. Lab. Project. PROBE Technical Report.

Johnson, T. C.; Talbot, M. R.; Kelts, K.; Cohen, A. S.; Lehman, J. T.; Livingstone, D. A.; Odada, E. O.; Tambala, A. F.; McGill, J.; Arquit, A.; Tiercelin, J.-J. 1990. *An International Decade for the East African Lakes. Workshop Report 1 on the Paleoclimatology of African Rift lakes, Bern, Switzerland, March 29–31, 1990.* Duke University Marine Lab. Technical Paper. Beaufort, Duke University, 37 p.

Kalff, J. 1983. Phosphorus limitation in some tropical African lakes. *Hydrobiologia* 100:101–112.

Kaufman, L. 1992. Catastrophic change in species-rich freshwater ecosystems. The lessons of Lake Victoria. *BioScience* 42(11):846–58.

Kaufman, L.; Cohen, A. S. 1993. The Great Lakes of Africa. *Conserv. Biol.* 632–3.

Kendall, R. L. 1969. An ecological history of the Lake Victoria Basin. *Ecol. Monogr.* 39:121–76.

Kidd, C. H. R. 1983. *A Water Resources Evaluation of Lake Malawi and the Shire River*. UNDP project report MLW/77/012, 135 p.

Kilham, P.; Hecky, R. E. 1973. Fluoride: geochemical and ecological significance in East African waters and sediments. *Limnol. and Oceanogr.* 18:932–45.

Kilham, P.; Kilham, S. S. 1990. Endless summer: internal loading processes dominate nutrient cycling in tropical lakes. *Freshw. Biol.* 23:379–89.

Kilham, S. S.; Kilham, P. 1990. Tropical limnology: Do African lakes violate the first law of limnology? *Verh. Internat. Verein. Limnol.* 24:68–72.

Kitaka, G. E. B. 1972. An instance of cyclonic upwelling in the southern offshore waters of Lake Victoria. *Afr. Jl Trop. Hydrobiol. Fish.* 2(1):85–92

Kite, G. W. 1981. Recent changes in level of Lake Victoria. *Hydrol. Sci. Bull.* 26(3):233–43

——. 1982. Analysis of Lake Victoria levels. *Hydrol. Sci. Jl* 27(2):99–110.

——. 1984. Regulation of the White Nile. *Hydrol. Sci. Jl* 29(2):191–201.

Krishnamurthy, K. V.; Ibrahim, A. M. 1973. Hydrometeorological studies of Lakes Victoria, Kioga and Albert. In: W. C. Ackermann, G. F. White and E. B. Worthington (eds.), *Man-made Lakes: Their problems and Environmental Effects.* Geophysical Monograph 17. Washington D.C., American Geophysical Union, pp. 272–7.

Kurki, H.; Vuorinen, I. 1994. Zooplankton biology. Presentation of SSP results. In: G. Hanek and E. J. Coenen (eds.), *Report of the Third Joint Meeting of the LTR'S Co-ordination and International Scientific Committees. December 1994.* FAO/FINNIDA Project Research for the Management of the Fisheries on Lake Tanganyika. GCP/RAF/271/FIN-TD/27 (E), pp. 52–71.

Kutzbach, J. E.; Street-Perrot, F. A. 1985. Milankovitch forcing of fluctuations in the level of tropical lakes from 18 to 0 kyr BP. *Nature* 317:130–4.

Lehman, J. T.; Branstrator, D. K. 1993. Effects of nutrients and grazing on phytoplankton of Lake Victoria. *Verh. Internat. Verein. Limnol.* 25:850–5.

Lehman, J. T.; Branstrator, D. K. 1994. Nutrient dynamics and turnover rates of phosphate and sulfate in Lake Victoria. *Limnol. and Oceanogr.* 39(2):227–53.

Leloup, E. 1949. Une mission hydrobiologique belge au lac Tanganika (1946–1947). *Les naturalistes belges*, 30(1):2–9 and 30(2):22–7.

Lema, A. J. 1990. East African climate: 1880–1980. *Water Resources Development* 6:270–7.

Lewis, W. M. 1973. The thermal regime of Lake Lanao (Philippines) and its theoretical implications for tropical lakes. *Limnol. and Oceanogr.* 18:200–17.

——. 1987. Tropical limnology. *Ann. Rev. Ecol. Syst.*, 18:159–84.

Ligtvoet, W.; Witte, F. 1991. Perturbation through predator introduction: effects on the food web and fish yields in Lake Victoria (East Africa). In: O. Ravera (ed.), *Terrestrial and Aquatic Ecosytems; Perturbation and Recovery.* Chichester, Elliss Horwood Ltd, pp. 263–8.

Lindqvist, O. V.; Mikkola, H. 1989. *Lake Tanganyika: Review of Limnology, Fisheries, Stock Assessment, Biology of Fishes and Fisheries.* FAO Report, CGP/RAF/229/FIN, 51 p.

Livingstone, D. A. 1965. Sedimentation and the history of water level change in Lake Tanganyika. *Limnol. and Oceanogr.*, 10(4):607–10.

——. 1975. Late Quaternary climate change in Africa. *Ann. Rev. Ecol. Syst.* 6:249–80.

——. 1976. The Nile – Palaeolimnology of headwaters. In: J. Rzóska (ed.), *The Nile. Biology of an ancient River.* The Hague, Junk Publ., pp. 21–30.

Livingstone, D. A.; Melack, J. M. 1984. Some lakes of Sub-Saharan Africa. In: F. B. Taub (ed.), *Lakes and Reservoirs Ecosystems of the World.* Amsterdam, Elsevier Publ., pp. 467–97

Loeb, S. L. 1993. Impact of aquatic biological analyses on policy decisions. *Verh. Internat. Verein. Limnol.* 25:383–6.

Lowe, R. H. 1952. *Report on the Tilapia and Other Fish and Fisheries of Lake Nyasa 1945–47.* Part 2. London, Fish. Publ. Colon. Off. 1(2):126 p.

Lowe-McConnell, R. H. 1987. *Ecological Studies in Tropical Fish Communities.* Cambridge, Cambridge University Press. 382 p.

——. 1993. Fish faunas of the African Great Lakes: origins, diversity and vulnerability. *Conserv. Biol.* 7(3):634–43.

Lowe-McConnell, R. H.; Crul, R. C. M.; Roest, F. C. (eds.). 1992. Symposium on Resource Use and Conservation of the African Great Lakes, Bujumbura 1989. With 46 figures and 18 tables in the text . *SIL Mitteilungen* 23, 128 p.

Lowe-McConnell, R. H.; Roest, F.C.; Ntakimazi, G.; Risch, L. 1994. The African Great Lakes. In: Teugels *et al.*, Biological Diversity in African Fresh- and Brackish Water Fishes. Geographical overviews. Symposium PARADI. *Ann. Mus.r. Afr. Zool.* 275:87–94.

Martens, K.; Goddeeris, B.; Coulter, G. (eds.). 1994. Speciation in Ancient Lakes. *Erg. Limnol.* 44:1–508.

Martin, P. 1994 Lake Baikal. In: K. Martens, B. Goddeeris and G. Coulter (eds.), Speciation in Ancient Lakes. *Erg. Limnol.* 44:3–11.

Mavuti, K. M.; Litterick M. R. 1991. Composition, distribution and ecological role of zooplankton community in Lake Victoria, Kenya waters. *Verh. Internat. Verein. Limnol.* 24:1117–22.

Mbahinzireki, G. B. 1992. Observations on the benthic communities of northern Lake Victoria, Uganda. (Abstract) p. 15. In: Anonymous, *Workshop 'Biodiversity, Fisheries and the Future of Lake Victoria', Jinja, Uganda, August 17–20, 1992.* Workshop program and list of Abstracts. Jinja, UFFRO.

McCaffrey, S. C. 1993. Water, Politics and International Law. In: P. H. Gleick (ed.), *Water in Crisis. A guide to the World's Fresh Water Resources.* New York/Oxford, Oxford University Press, pp. 92–104.

McGoodwin, J. R. 1990. *Crisis in the World's Fisheries. People, Problems, and Policies.* Stanford, Stanford University Press, 235 p.

Meaden, G. J.; Kapetsky, J. M. 1991. *Geographical Information Systems and Remote Sensing in Inland Fisheries and Aquaculture.* FAO Fish. Tech. Paper 318. Rome, FAO, 262 p.

Melack, J. M.; Kilham, P.; Fischer, T. R. 1982. Responses of phytoplankton to experimental fertilization with ammonium and phosphate in an African soda lake. *Oecologia* 52:321–6.

Menocal, P. B. de; Ruddiman, W. F.; Pokras, E. M. 1993. Influences of high- and low-latitude processes on African terrestrial climate: Pleistocene eolian records from equatorial Atlantic Ocean Drilling Program, Site 663. *Paleoceanog.* 8:209–42.

Menz, A. (ed.) 1995. *The Fishery Potential and Productivity of the Pelagic Zone of Lake Malawi/Niassa.* Chatham, Natural Resources Institute, 386 p.

Michel, A. E.; Cohen, A. S.; West, K.; Johnston, M. R.; Kat, P. W. 1992. Large African Lakes as natural laboratories for evolution: Examples from the endemic gastropod fauna of Lake Tanganyika. In: R. H. Lowe-McConnell, R. C. M. Crul and F. C. Roest (eds.), Symposium on Resource Use and Conservation of the African Great Lakes, Bujumbura 1989. *SIL Mitteilungen* 23:85–99.

Micklin, P. P. 1988. Dessication of the Aral Sea: a water management disaster in the Soviet Union. *Science* 241:1170–6.

Mölsä, H. 1995. *Symposium on Lake Tanganyika Research, 11–15 September 1995.* Abstracts. C. Natural and Environmental Sciences 34. Kuopio, Kuopio University Publications, 117 p.

Mori, S.; Ikusima, I. 1980. *Proceedings of the First Workshop on the Promotion of Limnology in Developing Countries.* Kyoto, SIL, 172 p.

Mortimer, C. H. 1974. Lake Hydrodynamics. *Mitt. Int. Ver. Limnol.* 20:124–97.

Moss, B. 1969. Limitation of algal growth in some central African waters. *Limnol. and Oceanogr.* 14: 591–601.

Mothersill, J. S.; Freitag, R.; Barnes, B. 1980. Benthic macro-invertebrates of northwestern Lake Victoria, East Africa: abundance, distribution, intraphyletic relationships between taxa and selected concentrations in the lake-bottom sediments. *Hydrobiologia,* 74:215–24.

Mugidde, R. 1993. The increase in phytoplankton primary productivity and biomass in Lake Victoria (Uganda). *Verh. Internat. Verein. Limnol.* 25:846–9.

Nalubega, M. F.; Kansime, L.; Lijklema, J. J. A.; Van Bruggen, R. H.; Aalderink, G. J.; Alaerts F. R.; Bugenyi, F. W. B. 1995. An introduction to studies on mass transport and nutrient retention in a tropical freshwater wetland receiving secondary effluent. In: *Proceedings of the Fourth International Conference on Wetland Systems for water Pollution Control, 6–10 November 1994, Guangzhou, China.*

Nakayama, M. 1994. Application of satellite remote sensing to estimate lake water quality. In: D. Dudgeon and P. K. S. Lam (eds.), Inland waters of tropical Asia and Australia: Conservation and Management. *Mitt. Internat. Verein. Limnol.* 24:345–7.

Nash, L. 1993. Water quality and health. In: P. H. Gleick (ed.), *Water in Crisis. A Guide to the World's Fresh Water Resources.* New York/Oxford, Oxford University Press, pp 25–39.

Ndawula, L. M. 1994. Changes in relative abundance of zooplankton in northern Lake Victoria, East Africa. *Hydrobiologia* 272:259–64.

Newell, B. S. 1960. The hydrology of Lake Victoria. *Hydrobiologia* 15:363–83.

Nicholson, S. E. 1980. Saharan climates in historic times. In: M. A. J. Williams and H. Faure (eds.), *The Sahara and the Nile.* Rotterdam, Balkema, pp. 173–200.

——. 1981. The historical climatology of Africa. In: T. M. L Wigley, M. J. Ingram and G. Farmer (eds.), *Climate and History.* Cambridge, pp. 249–70.

——. 1993. Climate and climate variability in East Africa. In: IDEAL *Symposium on the Limnology, Climatology and Paleoclimatology of the East African Lakes. IDEAL, Jinja, Uganda, 18–23 February 1993.* Programme with abstracts, p. 21.

——. 1996. Environmental change within the historical period. In: T. C. Johnson and E. O. Odada (eds.), *The Limnology, Climatology and Paleoclimatology of the East African Lakes.* New Jersey, Gordon & Breach Publ.

Nicholson, S. E.; Flohn, H. 1980. African environmental and climatic changes and the general atmospheric circulation in late Pleistocene and Holocene. *Climatic Change* 2:313–48.

Ochumba, P. B. O. 1983. *A Review of the Limnological Features of Lake Victoria and the Fishery Management Options, with Emphasis on the Winam Gulf of Kenya.* KMFRI Technical Paper, Kisumu, Kenya, 28 p.

Ochumba, P. B. O.; Kibaara, D. I. 1989. Observations on blue-green algal blooms in the open waters of Lake Victoria, Kenya. *Afr. Jl Ecol.* 27:23–34.

Ogutu-Ohwayo, R. 1992. The purpose, costs and benefits of fish introductions, with specific reference to the Great Lakes of Africa. In: R. H. Lowe-McConnell, R. C. M. Crul and F. C. Roest (eds.), Symposium on Resource Use and Conservation of the African Great Lakes, Bujumbura 1989. *SIL Mitteilungen* 23, pp. 37–44.

Okedi, J. Y. 1990. Observations on the benthos of Murchison Bay, Lake Victoria, East Africa. *Afr. Jl Ecol.* 28:111–22.

Owen, R. B.; Crossley, R. 1992. Spatial and temporal distribution of diatoms in sediments of Lake Malawi. *Jl of Paleolimnology* 7:55–71.

Owen, R. B.; Crossley, R.; Johnson, T. C.; Tweddle, D.; Kornfield, I.; Davison, S.; Eccles, D. H.; Engstrom, D. E. 1990. *Major low levels of Lake Malawi and their implications for speciation rates in cichlid fishes.* Proceedings Royal Society of London 240:519–53.

Parkkinen, J.; Tuomainen, V.; Mölsä, H.; Lindqvist, O. V.; Patomäki, L. 1995. Remote Sensing in Lake Tanganyika Research Project. Abstract. In: H. Mölsä, Symposium on Lake Tanganyika Research, 11–15 September 1995. Abstracts. C. Natural and Environmental Sciences 34. Kuopio, Kuopio University Publications, 117 p.

Patterson, G.; Kachinjika, O. 1995. Limnology and Phytoplankton Ecology. Chapter 1. In: A. Menz (ed.), *The Fishery Potential and Productivity of the Pelagic Zone of Lake Malawi/Niassa.* Chatham, Natural Resources Institute, pp. 1–67.

Patterson, G.; Wooster, M. J.; Sear, C. B. 1995. *Real-time Monitoring of African Aquatic Resources using Remote Sensing, with Special Reference to Lake Malawi.* Chatham, Natural Resources Institute, 21 p.

Payne, A. I. 1986. *The Ecology of Tropical Lakes and Rivers.* Chichester, John Wiley & Sons, 301 p.

Petr, T. 1978. Tropical man-made lakes – their ecological impact. *Arch. Hydrobiologia* 81(3):368–85.

Pilskaln, C. H.; Johnson, T. C. 1991. Seasonal signals in Lake Malawi sediments. *Limnol. and Oceanogr.* 36(3):544–57.

Piper, B. S.; Plinston, D. T.; Sutcliffe, J. V. 1986. The water balance of Lake Victoria. *Hydrological Sciences Jl* 31(1):25–38.

Polovina, J. J. 1984*a*. Models of coral reefs ecosystems. I. The ECOPATH model and its application to French Frigate shoal. *Coral Reefs* 3:1–11.

——. 1984*b*. An overview of the ECOPATH model. *Fishbyte,* 2:5–7.

Postel, S. 1993. Water and agriculture. In: P. H. Gleick (ed.), *Water in Crisis. A Guide to the World's Fresh Water Resources.* New York/Oxford, Oxford University Press, pp. 56–66.

Rangeley, R.; Thiam,, B. M.; Andersen, R. A.; Lyle, C. A. 1994. *International River Basin Organizations in Sub-Saharan Africa.* World Bank Tech. Paper 250:70 p.

Rashid, M. M. 1995 Some additional information on the limnology and the fisheries of Lakes Nasser (Egypt) and Nubia (Sudan). In: R. C. M. Crul and F. C. Roest (eds.), *Current Status of the Fisheries and the Stocks of the Four Largest African Reservoirs: Kainji, Kariba, Nasser/Nubia and Volta.* CIFA Technical Paper 30. Rome, FAO, pp 81–110.

Regier, H. A. 1992. Ecosystem integrity in the Great Lakes Basin: an historical sketch of ideas and actions. *Jl of Aquatic Ecosystem Health* 1:25–37.

Reinthal, P. 1993. Evaluating biodiversity and conserving Lake Malawi's cichlid fish fauna. *Conserv. Biol.* 7(3):712–17.

Reynolds, C. S. 1984. *The Ecology of Freshwater Phytoplankton.* Cambridge, Cambridge University Press, 384 p.

Ribbink, A. J. 1991. Distribution and ecology of the cichlids of the African Great Lakes. In: M. H. A. Keenleyside (ed.), *Cichlid Fishes: Behaviour, Ecology and Evolution.* London, Chapman & Hall, pp. 36–59.

——. J. 1994. Lake Malawi. *Arch. Hydrobiol. Beih. Ergebn. Limnol.* 44:27–33.

Ricardo-Bertram, C. K.; Borley, H. J. H.; Trewavas, E. 1942. *Report on the Fish and Fisheries of Lake Nyasa.* London, Crown Agents, 181 p.

Roest, F. C. 1992. The pelagic fisheries resources of Lake Tanganyika. In: R. H. Lowe-McConnell, R. C. M. Crul and F. C. Roest (eds.), Symposium on Resource Use and Conservation of the African Great Lakes, Bujumbura 1989. *SIL Mitteilungen* 23, pp. 11–15.

Rzóska, J. 1976. Lake Victoria, physical features, general remarks on chemistry and biology. In: J. Rzóska (ed.), *The Nile, Biology of an Ancient River.* Monographiae Biologiae 20. The Hague, Junk Publ.

Rufli, H. 1976. *Preliminary Analysis on Zooplankton Sampling in Lake Tanganyika in May 1976.* FAO Report FI:DP/URT/71/012/44. 10 p.

Rufli, H.; Chapman, D. W. 1976. *Preliminary Analysis on Zooplankton Sampling and Estimates of Fish Abundance in Lake Tanganyika in October 1975.* FAO Report FI:DP/URT/71/012/31. 14 p.

Salonen, K.; Sarvala, J. 1994. Carbon-energy budget. Presentation of SSP results. pp. 46–51. In: G. Hanek and E. J. Coenen (eds.), *Report of the Third Joint Meeting of the LTR'S Co-ordination and International Scientific Committees.* December 1994. FAO/FINNIDA Project Research for the Management of the Fisheries on Lake Tanganyika. GCP/RAF/271/FIN-TD/27 (E).

Scheren, P. 1995. *A Systematic Approach to Lake Water Pollution Assessment. Water Pollution in Lake Victoria, East Africa.* Eindhoven, Eindhoven University of Technology, 79 p.

Scheren, P. A. G. M.; Bosboom, J. C.; Njau, K. N. 1994. *Rapid Assessment: Water pollution in the Catchment of Lake Victoria, Tanzania.* Centre for International Cooperation Activities. Eindhoven, Eindhoven University of Technology, 45 p.

Scholz C. A.; Rosendahl, B. R. 1988. Low stands on Lakes Malawi and Tanganyika, delineated with multifold seismic data. *Science* 240:1645–8.

Scholz, C. A.; Rosendahl B. R; Versfelt, J. W; Rach, N. 1990. Results of high-resolution echo-sounding of Lake Victoria. *Jl Afr. Earth Sci.* 11(1/2):25–32.

SCUDDER, T. 1989. Conservation *versus* development: River basin projects in Africa. *Environment* 31:4–9, 27–31.

SENE, K. J.; PLINSTON, D. T. 1994. A review and update of the hydrology of Lake Victoria in East Africa. *Hydrol. Sci.* 39(1):47–63.

SHILOMANOV, I. A. 1993. World fresh water resources. In: P. H. Gleick (ed.), *Water in Crisis. A Guide to the World's Fresh Water Resources.* New York/Oxford, Oxford University Press, pp. 13–24.

SMOL, J. P. 1992. Paleolimnology: an important tool for effective ecosystem management. *Jl Aquatic Ecosystem Health* 1:49–58.

STAGER, J. C. 1984. The diatom record of Lake Victoria (East Africa): the last 17,000 years. In: D. G. Mann (ed.), *Proceedings of the Seventh International Diatom Symposium. Philadelphia, August 22–27.* Koelz, Koenigstein, pp. 455–76.

STAGER, J. C.; REINTHAL, P. N.; LIVINGSTONE, D. A. 1986. A 25,000 year history for Lake Victoria East Africa, and some comments on its significance for the evolution of cichlid fishes. *Freshwater Biology* 16:15–19.

STANLEY, N. F.; ALPERS, M. P. (eds.). 1975. *Man-made Lakes and Human Health.* Academic Press, 495 p.

STREET, F. A.; GROVE, A. T. 1976. Environmental and climatological implications of Late Quaternary lake level fluctuations in Africa. *Nature* 261:385–90.

SYMOENS, J. J. 1956. Le lac Tanganika. *Bulletin des Naturalistes Belges* 37(11–12):288–316.

TALLING, J. F. 1957. Diurnal changes of stratification and photosynthesis in some tropical African waters. London, Proceedings Royal Society of London B147:57–83.

——. 1963. The origin of stratification in an African rift lake. *Limnol. and Oceanogr.* 8:68–78.

——. 1965. The photosynthetic activity of phytoplankton in East African lakes. *Int. Rev. ges. Hydrobiologia* 50:1–32.

——. 1966. The annual cycle of stratification and phytoplankton growth in Lake Victoria (East Africa). *Int. Revue ges. Hydrobiologia* 51:545–621.

——. 1969. The incident of vertical mixing, and some biological and chemical consequences in tropical African Lakes. *Verh. Int. Ver. Limnol.* 17:998–1012.

——. 1987. The phytoplankton of Lake Victoria (East Africa). In: M. Munawar (ed.), *Phycology of Large Lakes of the World.* Arch. Hydrobiol. Beih. Ergebn. Limnol. 25:229–56. .

—— 1992. Environmental regulation in African shallow lakes and wetlands. *Rev. hydrobiol. trop.* 25(2):87–144.

TALLING, J. F.; TALLING, I. B. 1965. The chemical composition of African lake waters. *Int. Rev. ges. Limnol.* 25:229–56.

TAYLOR, D. M. 1990. Late Quaternary pollen records from two Ugandan mires: evidence for environmental change in the Rukiga Highlands of southwest Uganda. *Palaeogeogr., Palaeoclimatol., Palaeoecol.* 80:283–300.

TAYLOR, K. C.; LAMOREY, G. W.; DOYLE, G. A.; ALLEY, R. B.; GROOTES, P. M.; MAYEWSKI, P. A.; WHITE, J. W. C.; BARLOW, L. K. 1993. The 'flickering switch' of Late Pleistocene climate change. *Nature* 361:432–5.

TECCONILE. 1995*a*. *Water resources Atlas of the River Nile Basin.* Entebbe, TECCONILE, 42 p.

TECCONILE. 1995*b*. *The Nile River Basin Action Plan.* Entebbe, TECCONILE, 34 p. + 2 Annexes.

TEMPLE, P. H. 1964. Evidence of lake-level changes from the northern shoreline of Lake Victoria, Uganda. In: R. W. Prothero and R. M. Prothero (eds.), *Geographers and the Tropics: Liverpool Essays.* London, Longmans, pp. 31–56.

THERIVEL, R.; WILSON, E.; THOMPSON, S.; HAENEY, D.; PRITCHARD, D. 1992. *Strategic Environmental Assessment* London, RSPB/Earthscan.

THOMPSON, A. B. 1995. Eggs and larvae of *Engraulicypris sardella.* In: A. Menz (ed.), *The Fishery Potential and Productivity of the Pelagic Zone of Lake Malawi/Niassa.* Chatham, Natural Resources Institute, pp. 179–99.

THOMPSON, K. (ed.). 1991. *The Water Hyacinth in Uganda. Ecology, Distribution, Problems and Strategies for Control.* Proceedings of a National Workshop, 22–23 October 1991, Kampala, Uganda. Uganda, UN/FAO Kampala, 162 p.

THOMPSON, L. G.; MOSLEY-THOMPSON, E.; DANSGAARD, W.; GROOTES, P. M. 1986. The little ice age in the stratigraphy of the tropical Quelcaya ice cap. *Science* 234:361–4.

TIERCELIN, J.-J.; MONDEGUER, A. 1991. The geology of the Tanganyika trough. In: G. Coulter (ed.), *Lake Tanganyika and its Life.* British Museum (Natural History)/Oxford University Press, pp. 7–48.

TIESSEN, H.; FROSSARD, E. (eds.). 1991. *Phosporus Cycles in Terrestrial and Aquatic Ecosystems.* Regional Workshop 4: Africa. Proceedings of a workshop arranged by SCOPE and UNEP at UNEP, Nairobi, Kenya, March 18–22, 1991. Saskatoon, Saskatchewan Institute of Pedology.

TILZER, M. M.; BOSSARD, P. 1992. Large lakes and their sustainable development. *Aquatic Sciences* 54(2):91–103.

TURNER, J. L. 1982. Lake flies, water fleas and sardines. *Biological Studies on the Pelagic Ecosystem of Lake Malawi.* FI:DP/MLW/75/019, Technical Report 1. Rome, FAO, pp. 165–173.

TURNER, R. K.; PEARCE, D.; BATEMAN, I. 1993. *Environmental Economics. An Elementary Introduction.* New York, Harvester Wheatsheaf, 328 p.

TWEDDLE, D. 1991. *A Limnological Bibliography of Malawi.* FAO/CIFA Occasional Paper 13, Supplement 1. Rome, FAO, 18 p.

——. 1992. Conservation and threats to the resources of lake Malawi. In: R. H. Lowe-McConnell, R. C. M. Crul and F. C. Roest (eds.), Symposium on Resource Use and Conservation of the African Great Lakes, Bujumbura 1989. *SIL Mitteilungen* 23:17–24.

TWEDDLE, D.; MKOKO, B. J. 1986. *A Limnological Bibliography of Malawi.* CIFA Occ. Paper 13, 75 p.

TWOMBLY, S. 1983. Seasonal and short term fluctuations in zooplankton abundance in tropical Lake Malawi. *Limnol. and Oceanogr.* 28(6):1214–24.

TWONGO, T. 1992. Management issues, options and strategies for Lake Victoria fisheries. In: Ssentongo and F. L. Orach-Meza (eds.), *Report of National Seminar on the Development and Management of the Ugandan Fisheries of Lake Victoria, Jinja, Uganda 6–8 August 1991.* RAF/87/099-TD/31/92 (E). Bujumbura, UNDP/FAO Regional Project IFIP.

UNEP. 1989. *Strategic Resources Planning in Uganda. Wetlands.* Vol. IX. Nairobi, UNEP, 101 p.

VAN BRUGGEN, J. J. A.; OKIA, O. T.; KASIIME, F. 1995. Wastewater purification by the tropical macrophyte *Cyperus papyrus* in a segmented channel in the greenhouse. In: *Proceedings of the Fourth International Conference on Wetland Systems for Water Pollution Control, 6–10 November 1994, Guangzhou, China.*

VAN MEEL, L. 1954. Le phytoplancton. Résultats scientifiques de l'exploration hydrobiologique du lac Tanganika (1946–1947). *Inst. Roy. Soc. Nat. Belgique* 4 (1)A:1–681.

VAN OIJEN, M. J. P.; WITTE, F.; WITTE-MAAS, E. L. M. 1981. An introduction to ecological and taxonomic investigations on the haplochromine cichlids from the Mwanza Gulf of Lake Victoria. *Neth. Jl Zool.* 31:149–74.

VAN WELL, P.; CHAPMAN, D. W. 1976. *Summary of Limnological Observations in Lake Tanganyika near Kigoma, 1974–1975.* FAO Report FI:/DP/URT/71/012/39, 24 p.

VANDEN BOSSCHE, J.-P.; BERNACSEK, G. M. 1990*a*. *Source Book for the Inland Fisheries Resources of Africa: 1.* CIFA Technical Paper 18.1. Rome, FAO, 411 p.

——.; ——. 1990*b*. *Source Book for the Inland Fisheries Resources of Africa: 2.* CIFA Technical Paper 18.2. Rome, FAO, 240 p.

——.; ——. 1991. *Source Book for the Inland Fisheries Resources of Africa: 3.* CIFA Technical Paper 18.3. Rome, FAO, 219 p.

VOLLENWEIDER, R. A.; MUNAWAR, M.; STADELMANN, P. 1974. A comparative review of phytoplankton and primary production in the Laurentian Great Lakes. *Jl Fish. Res. Bd. Canada* 31:739–62.

WAYLAND, E. J. 1929. *Rift Valley and Lake Victoria.* Compte Rendu de la XV^{e} Session. International Geological Congress (Pretoria) Section VI:323–53.

——. 1931. The Rift Valley and Uganda waterways. In: *Summary of Progress of the Geological Survey of Uganda (1919 to 1929).* Entebbe, Goverment Printer, pp. 40–4.

WCED. 1987. *Our Common Future.* World Commission on Environment and Development (Brundtland Commission). Oxford, Oxford University Press, 400 p.

WCMC. 1992. *Global Biodiversity. Status of the Earth's Living Resources.* World Conservation Monitoring Centre. London, Chapman & Hall, xx + 594 p.

WETZEL, R. G.; LIKENS, G. E. 1991. *Limnological Analyses.* 2nd edition. New York, Springer Verlag, 391 p.

WHITE, G. F. 1988. The environmental effects of the high dam at Aswan. *Environment* 30(7):4–40.

WILLIAMS. W. D. 1988. Limnological imbalances: the antipodean viewpoint. *Freshwater Biology* 20:407–20.

WILLIAMS, W. D. 1994. Constraints to the conservation and management of tropical inland waters. In: D. Dudgeon and P. S. Lam (eds.), Inland Waters of Tropical Asia and Australia: conservation and Management. *SIL Mitteilungen* 24:357–63.

WILSON, J. A., ACHESON, J. M.; METCALFE, M.; KLEBAN, P. 1994. Chaos, complexity and community management of fisheries. *Marine Policy* 18(4):291–305.

WITTE, F. 1987. From form to fishery. *An Ecological and Taxonomical Contribution to Morphology and Fishery of Lake Victoria Cichlids.* PhD-thesis. Leiden, State University of Leiden, 154 p.

WITTE, F.;. GOLDSCHMIDT, T.; WANINK, J. H.; VAN OIJEN, M. J. P.; GOUDSWAARD, P. C.; WITTE-MAAS, E. L. M.; BOUTON, N. 1992*a*. The destruction of an endemic species flock: quantitative data on the decline of the haplochromine cichlids of Lake Victoria. *Env. Biol. Fish.* 34:1–28.

WITTE, F.; GOLDSCHMIDT, T.; GOUDSWAARD, P. C.; LIGTVOET, M. J. P.; VAN OIJEN, M. J. P.; WANINK, J. H. 1992*b*. Species extinction and concomitant ecological changes in Lake Victoria. *Neth. Jl Zool.* 42:214–32.

WITTE, F.; GOLDSCHMIDT, T; WANINK, J. H. 1995. Dynamics of the haplochromine cichlid fauna and other ecological changes in the Mwanza Gulf of Lake Victoria. In: T. Pitcher and P. J. B. Hart (eds.), *The Impact of Species Changes in African Lakes.* London, Chapman & Hall, pp. 83–110.

WITTE, F.; VAN OIJEN, M. J. P. 1990. Taxonomy, ecology and fishery of haplochromine trophic groups. *Zool. Verh. Leiden* 262:1–47.

WMO. 1974. *Hydrometeorological Survey of the Catchments of Lakes Victoria, Kyoga and Albert* (Vols 1–3). Geneva, WMO.

WMO. 1981. *Hydrometeorological Survey of the Catchments of Lakes Victoria, Kyoga and Mobutu Sese Seko.* Vol. 1. Geneva, WMO.

WORLD BANK. 1992. *Tanzania. Preliminary Assessment of Environmental Issues.* Draft report based on findings of a World Bank mission. Washington D.C.,World Bank, 67 p.

——. 1994. *The World Bank Annual Report 1994.* Washington D.C., The World Bank, 254 p.

WORLD RESOURCES INSTITUTE. 1988. *World Resources 1988–89*. World Resources Institute and the International Institute for Environment and Development in collaboration with the United Nations Environment Programme. New York, Basic Books.

WORTHINGTON, E. B. 1930. Observations on the temperature, hydrogen-ion concentration, and other physical conditions of the Victoria and Albert Nyanzas. *Int. Rev. ges. Hydrobiol. Hydrogr.* 24:328–57.

——. 1931. Vertical movements of freshwater macroplankton. *Int. Rev. Hydrobiol.* 25:394–436.

WORTHINGTON, E. B.; LOWE-MCCONNELL, R. H. 1994. African Lakes Reviewed: creation and Destruction of Biodiversity. *Environmental Conserv.* 21(3):199–213.

WOUBE, M. 1994. Environmental degradation along the blue Nile river basin. *Ambio* 23(8):519–20.

Appendices

APPENDIX I

Key areas of research and objectives of particular importance for the understanding of large lakes (Tilzer and Bossard, 1992)

Key area of research	Objectives of research
1. Land-water interactions	a. Initiate continuous measurements and develop models of lake hydrology, lake levels and water supplies. b. Characterize the composition and distribution of dissolved and suspended material in the principal tributary rivers. c. Establish sites for monitoring meteorological conditions of large lakes and their catchments, and for sampling atmospherically derived material.
2. Physical processes	a. Develop the database needed to identify quickly modern changes and to allow the interpretation of paleolimno-logical information. b. Measure annual thermal dynamics of lakes, together with their effects on the circulation of water, including advective and diffusive processes. c. Develop hydrodynamic models for lakes which differ in latitude, size and morphometry. d. Initiate comparative studies of large lakes that include the mechanisms and dynamics of deep-water renewal, in order to understand the processes responsible for vertical exchange and biogeochemical fluxes.
3. Biogeochemistry and nutrient relations	a. Evaluate the biogeochemical cycles of nutrients for biological production. b. Determine the role of biotic composition in controlling the quantity and elemental composition of material exported to the trophogenic zone. c. Construct mass balance models of biologically and geochemically important constituents, particularly nutrients. d. Determine mechanisms and rates of transfer of nutrients, tracers and other constituents between water and biotic and abiotic particles.

	e. Evaluate rates of physical transport and transformation of particulate and dissolved matter in the water column.
	f. Determine the role of bottom deposits and resident organisms on mixing, burial and exchange of constituents with overlying water.
4. Food webs	a. Investigate the structures of true autochthonous pelagic food webs in large lakes and their variations over short and long time scales.
	b. Study community structures, including size spectra and species composition. Consider sestonic particle distribution and sedimentation properties. Apply new techniques (flow cytometry, HPLC analysis, immunofluorescence, RNA/DNA sequencing) to characterize the major picoplankton populations.
	c. Assess biomass and production of heterotrophic bacteria, phototrophic picoplankton, and protozoa in relation to the larger phytoplankton and zooplankton. Measure the major fluxes between phytoplankton, respectively settling seston, and bacteria, and determine the efficiency of carbon transfer through the microbial and the classic food web. Develop a mechanistic framework for bacteria – organic matter interactions which explains and predicts specific fluxes into and from free-living and attached bacteria.
	d. Measure body size relationships between consumers and their prey organisms. Observe the threshold food concentrations above which new consumers appear during the season or in long-term studies. Look for organisms with unusual trophic roles (mixotrophy, symbiosis, etc.). Assess trophic interactions with consideration of the relative importance of bottom-up and top-down controls in overall community dynamics.
	e. Establish inventories and biodiversity archive collections of endemic species and assess their role in nature. Monitor biodiversity and identify ecological niches occupied by introduced alien species.
	f. Identify and quantify the uses of littoral resources by pelagic components in large lakes. Evaluate the significance of long-term and short-term changes in the availability of littoral resources on food web interactions. Evaluate the importance of the littoral zone in large lakes as an interface between land and water ecotones.
5. Remote sensing	a. Implement long-term remote sensing of large lakes and their ecosystems
	b. Conduct appropriate calibration studies for the verification of remotely sensed data, and use these data to improve physical and biological models.
6. Long-term monitoring	a. Assess natural long-term cycles of major physical and programmes chemical components, with particular reference to mass balances of nutrients and pollutants
	b. Assess long-term trends in phytoplankton, zooplankton and benthic succession, to identify shifts in species composition. This will also allow early detection of foreign species invasions and a timely assessment of their ecological impacts.
	c. Determine pathways of contaminant transfer within the food web, with special attention to biomagnification through top predators such as fishes, birds and mammals.
	d. Initiate a programme of sediment trap collection, and of lake bottom sediment studies, in order to provide information of fate and storage of accumulated material, as well as to reconstruct and interpret recent lake history.
	e. Ensure easy access and exchange of both meteorological and limnological data from various monitoring programmes.

APPENDIX II

Recommendations of the International Limnological Society (SIL) symposium on resource use and conservation and of the African Great Lakes in Bujumbura, 29 November–2 December 1989 (Lowe-McConnell et al., 1992).

In view of the exceptional value of the African Great Lakes to the welfare of the riparian population and to mankind as a whole,

a. as a major source of protein, particularly in the form of fish;
b. as a major supply of fresh water close to semi-arid areas, and as avenues of transportation;
c. on account of the great geological age of some of these lakes;
d. on account of their unique faunas containing many (often hundreds) of species not found in any other lake and showing great genetic diversity;
e. on account of their special value for scientific work including evolutionary studies;
f. for their landscape value which has a high tourism potential.

In view of the present lack of knowledge on many aspects of the functioning of these lakes.

In view of the vulnerability of these lakes to changes brought about by man's activities, both within and outside the lakes,

a. on account of the extremely long water retention time (e.g. Lake Tanganyika is virtually a closed basin);
b. on account of the low chemical buffering of the lake waters;
c. on account of the limited distribution of many of the fish and invertebrate species within one lake (often limited to about 500 m of shoreline).

In view, often, of the lack of co-ordination at national and international level of activities both of exploitation and research within the lakes.

In view of the fact that many introductions of non-endemic species of fish have been made to lakes without due regard to the possible deleterious effects on indigenous species and the likely consequences of invasion of other parts of the drainage system.

In view of the great dangers from potential developments, such as oil exploitation, to the lake ecosystems.

In view of the impacts from the use of agrochemicals which are already showing on the natural resources of the Great Lakes.

In view of the financial and technical constraints in the region of the African Great Lakes.

The symposium recommends that

1. the lacustrine states take all the measures for the conservation of the African Great Lakes which are compatible with their long-term exploitation, and recommends that the international community provides technical and financial support.
2. comprehensive programmes of scientific research be undertaken on the African Great Lakes, which should be co-ordinated on a regional and interregional scale, and be supported by international organisations and agencies of co-operation.
3. in order to conserve the great natural heritage of the African Great Lakes, the lacustrine states:
   a. carefully manage the lake resources, and their catchments;
   b. safeguard and monitor the water quality;
   c. establish lacustrine National Parks or Reserves, including their landward catchments, in areas particularly rich in characteristic diverse faunas and habitats;
   d. introduce by legislation measures for the protection of endangered species and biotopes;
4. national and regional fisheries institutions be strengthened and regional meetings facilitated.
5. resource surveys and stock assessment methods be standardized, as well as fishery data collecting systems.
6. strong efforts be made to inform the human populations on the economic and scientific values of the lake resources:
   a. by sensitising Government decision-makers to the economic values and social benefits of fisheries and of fishery management institutions;
   b. through extension courses for fishermen;
   c. through courses at schools to inform the younger generation.

7. if any further introduction of any organism into the Great Lakes systems is contemplated, it be proceeded by intensive scientific research into the ecology of the species and the ecology of the system into which it is proposed to introduce it.
8. clear guidelines, specific for African inland waters, be prepared on how a proposed new introduction can be thoroughly appraised. The symposium welcomes the fact that such guidelines are to be discussed at the eight session of CIFA in October 1990 and urges that every effort should be made to implement this initiative.
9. every effort be made to prevent any introduction of fish or other organisms into the deep Rift Valley lakes Tanganyika and Malawi and their drainage systems, to protect their endemic faunas.
10. at the international level, aquariums at Zoological gardens be used to mobilize public opinion to support measures to ameliorate specific problems (such as the fish populations of Lake Victoria) and to raise funds to be used to study the situation and investigate methods of restoration.
11. now that pollution threats have been recognized and it is realized that information on pollution is far from sufficient, that a 'state of the lake' environmental audit be carried out for each of the Great Lakes. This would collate and interpret existing information and identify gaps in our knowledge as a guide to future research and action.
12. bearing in mind recommendation [1] and recognizing a trend towards increasing population pressure and industrial development, information about the circulation and the fate of pollutants in lakes and the toxicity of pollutants to key species be obtained.
13. new developments around the Great Lakes and their catchment areas be preceded by an Environmental Impact Assessment. The onus is on the proposer of the development to finance the Environmental Impact Assessment. Examples of such development are:
    a. oil exploration,
    b. sewage plants
    c. road construction,
    d. construction of dams for irrigation, water supply and hydroelectricity,
    e. industrial development.
14. the lakes be protected from potential damage from agrochemicals. This should involve the establishment of an effective control system for identifying which agrochemicals should be allowed for particular uses.
15. account be taken of the fact that the some current land use practices e.g. forest burning, intensive agriculture on steep slopes, and destruction of wetlands, which act as a buffer to reduce pollutants entering the lakes, are contributing to the degradation of water quality in the Great Lakes.
16. where riparian countries are asked in the interests of the international community not to carry out particular measures, that means be investigated whereby the international community could compensate them.
17. a permanent system for mutual consultations and co-ordination of action between the states be set up. The best method of doing this needs investigation, but it might take the form of a Commission which would ensure regular meetings of scientists and administrators and ensure a flow of information on Great Lakes activities. The Commission should incorporate all interests in the natural resources of the lakes and help to set priorities.

APPENDIX III

IDEAL - an International Decade for the East African Lakes (Johnson, 1993)

The scientific issues to be addressed by IDEAL focus on five topical areas given below for which research questions have been formulated at the IDEAL Symposium on the Limnology, Climatology and Paleoclimatology of the East African Lakes, in Jinja, Uganda, 18–22 February 1993.

Climatology

Research questions:

1. What are the regional mean values of major climatic elements: rainfall, temperature, wind, evaporation, and relative humidity, and how do they differ immediately over and adjacent to each lake? How can conditions over the lake be established? For example are satellite estimates of lake rainfall required or practicable?
2. What are the temporal and spatial variability of key parameters, particularly rainfall, temperature, and wind?
3. What are the large-scale forcing of the region's climate and prevailing weather patterns in the catchment area? How is this impacted by interaction with the lakes and their surrounding topographies?
4. Are there vastly different but stable climatic regimes during recent times that can be identified?
5. What are the hydrological and energy budgets of the lake? To what extent does the groundwater exchange impact on the hydrological budget? What are the characteristics of river discharge: flow rate, temperature, major ion and nutrient composition? What are the histories of lake level fluctuations?

Physical limnology

Research questions:

1. What are the temporal and spatial variability of the vertical and horizontal fluxes of heat, mass dissolved and suspended material and momentum in the lakes? How do the time and length scales of transport and mixing vary seasonally within each lake and between lakes as a result of their climatic setting, morphometry and latitude?
2. Based on the results of question 1, above, what is the impact of circulation and stratification on primary production, planktotophic interactions, resource populations, introduced pollutants and sediment dynamics during different seasons, at different locations, and in different lakes?
3. How does the stability of the water column vary seasonally? How do the vertical exchange rates and depth-dependent residence times vary? To hat extent is stability controlled by thermal or salinity structure? Does the deep thermal structure coincide with the adiabatic gradient and is it near equilibrium with the present climatic conditions?
4. What is the dominant momentum balance? How do along-shore and cross-shore momentum balance compare? How do they vary with water depth and distance from shore? How do they vary from lake to lake as a function of local climate, morphology and latitude?
5. What controls the exchange between the coastal and pelagic regions of the lake? Is exchange primarily due to a vertical circulation, like upwelling , or is it due to a horizontal circulation, e.g. an active meso-scale eddy filed? is this circulation dominated by local wind forcing, by basin seiches, by through flow or by buoyancy forcing? How is it likely to change with changes in climate and societal impact?
6. What is the transparency of the surface waters and how does this affect light transmission and the vertical distribution of solar energy absorption?

Geochemistry

Research questions:

1. What are the distributions of naturally occurring constituents that are chemically and biologically active in the epilimnetic and hypolimnetic water columns, and how are dothey vary seasonally and interannually? Primary concern will be on the cycles and isotopes of carbon, oxygen, nitrogen, phosphorous, silicon and sulfur.
2. To what extent can time-dependent chemical and isotopic tracers, such as tritium/helium-3, dissolved atmospheric chlorofluorocarbons (CFC's), argon-39 and radiocarbon be used to determine the rates of mixing and chemical and biolagical recycling within the lake?
3. What are the external influences on lake geochemistry i.e. what are the atmospheric, riverine and sediment sources and sinks of various constituents?
   a. How important are the atmospheric sources of fixed nitrogen and phosphorous, gaseous loss of ammonia in upwelling areas, exchanges of tritium and the stable isotopes of water, and exchanges of oxygen, carbon dioxide and other gases?
   b. What are he fluvial influxes of dissolved constituents? How do the riverine sources of certain constituents such as fixed nitrogen and phosphorous compare with the atmospheric source?

   c. How important are the sediments as sources of nutrients, trace elements and other species which are released through diagenetic processes and transported by diffusion in pore waters or advection of ground water? Of special interest are sedimentary organic components, their origins, behaviour in diagenesis, and roles as 'bio-indicators' of changing lake conditions.
4. Given the the presence of an anoxic hypolimnion in many of the lakes, how significant is the redox process in the chemical balance of the lakes? How important is methane production and oxidation? What is the relative importance of denitrification and nitrification, ammonification and ammonia volatilization in the nitrogen cycle? To what extent are the budgets of sulfur, phosphorous, iron and other trace elements influenced by redox processes? By microbial systems? Do these processes leave their signature in the sedimentary record?

Biological processes

Research questions:

1. What are the driving mechanisms behind speciation in the great lakes of east Africa? How have the historical factors of climatic and geological change molded patterns of biodiverslty we observe in the lakes today? Can comparative studies of species flocks between lakes and co-speciation provide us with a general understanding of intrinsic factors regulating rates of speciation?
2. What are the extinction processes in these great lakes and what is driving them? Have the forces and their responses been constant in time? To what extent are the rates of speciation and extinction linked phenomena
3. What mechanisms dominate biological production and species composition across trophic levels? How do these vary between tropical great lakes with different environmental conditions? To what extent are these mechanisms controlled by biological feedbacks in these lakes, and what are the relative contributions of external forces and internal dynamics?
4. What are the dynamics of ecological communities in these lakes? How do the communities respond to different kinds of perturbations, and how faithfully are the known historical perturbations recorded in the modern sediments?

Paleoclimatology

Research questions:

1. What is the tropical record of past climate change?
2. How is the record linked to global climate on carious time sclaes?
3. What is the response and sensitivity of the African Great Lakes to climatic change?
4. Given the importance of the tropics to the global heat budget, do changes in east African climate lead or lag other elements of the global climate system?

Time intervals of focus

a. The last millennium

1. In what ways does the sediment record of the last century reflect historical records of lake levels (e.g., the 1961 highstand event), ENSO variation, drought recurrence and intensity, rhythmic rainfall intensity and patterns, and seasonal variation?
2. Were the lakes affected by the climatic excursions responsible for the Little Ice Age or the Medieval Warm Interval?
3. Are there climatic links to the known human migrations?
4. Do the lakes record the spread of exotic foods in Africa, the history of landuse and burning, and the history of human changes in the catchment region?

b. The last glacial maximum through Holocene

1. What was the nature of the climate transition from the last glacial maximum? The fine scale climatic structure of the African tropics appears complex (e.g.Kendall, 1969). Is there a coherent Younger Dryas signal?
2. Does tropical African climate show evidence of centennial-scale oscillations such as occur in ice cores (e.g., Thompson *et al.*, 1986)? What is the direction and magnitude of change over the tropical belt?
3. Do the lake sediments show coherent records of rapid change events (thresholds)? Do they indicate multi-modal states of climates? What are the rates of change across transitions? Can precursor signals be identified that are useful in forecasting events?
4. What is the evidence for climate stress as a factor in the development of prehistoric societies?

c. Multiple glacial/inter-glacial cycles

1. Is the fine structure of the last termination of a glacial cycle repeated in earlier terminations?
2. Is there evidence for periods of a bi-modal, 'flickering switch' behavior of tropical climate comparable to what has been observed in ice cores (e.g., Taylor*et al.*, 1993)

3. What are the interactions of tectonic forcing and mesoclimates in tropical Africa?
4. What is the record of volcanic eruptions linked with environmental dynamics and, perhaps, human evolution?
5. What are the leads and lags in the behavior of lake systems in terms of their relationship to Milankovitch Cycles suggested by studies such as Kutzbach and Street-Perrott (1985) and deMenocal*et al.*, 1993)?
6. What are the origin and coherence of seismic sequence boundaries in the great lakes, and what is their relationship to high altitude glacial/interglacial cycles?

d. The Tertiary

1. What is the coincidence of hominid evolution, culture and environmental history?
2. Are the origins of the east African great lakes coupled with the onset of intensification of the monsoon system?
3. Do we see evidence of relative shifts in importance of the different orbital cycles?

APPENDIX IV

Resolutions of the Workshop of People, Fisheries, Biodiversity and the Future of Lake Victoria, held in Jinja (Uganda), 17–20 August 1992 (Kaufman, 1992)

After careful consideration of available evidence based on research results, we conclude that the environment of Lake Victoria is changing rapidly and the fishery is unsustainable at its present composition and yield. Due to overfishing and a development of an export market, the amount of fish protein now available for local consumption is inadequate. The changing condition of the fishery will affect the social and economic welfare of millions of people in the Lake Victoria basin. Prospects for the future are cause for grave concern and reason for immediate action designed to resolve key unknows and establish research and management policies that can be developed and applied expeditiously. The resolution presented below outline the urgent need to understand current changes in limnology and the environment, to understand how fish biology affects the sustainability and management of the fishery, and to understand and mitigate the social and economic impacts of anticipated changes and varied management options.

General recommendation

It is necessary to form a Lake Victoria Fisheries Commission to harmonize research and management strategies for the Lake Victoria basin. An important scientific function of the commission should be to foster close international co-operation, standardisation of research and manegement methods, cross-calibration of scientific instruments , and continuity of monitoring.

Limnology and environment

- There is need to develop a general ecosystems model of Lake Victoria that includes the physical, chemical, biological, and human factors required to understand and predict lake productivity.
- Due to increased oxygen depletion, loss of fish habitat and fish kills are extensive. There is urgent need to understand the controls on oxygen distribution and levels in Lake Victoria, including the influence of low levels on fish stocks.
- Tremendous alterations in the food web have occurred in the last 30 years. Understanding the effects of these changes on water quality and lake productivity requires determination of the flows of nitrogen, phosphorus, sulphur, silicon, oxygen, and carbon into the lake ecosystem.
- There is need to determine the energy flow through the two major trophic pathways (grazing and detritus) that couple fish productivity with primary production.
- A research and management programme for the wetland and forest habitat in the riparian zone of the lake and its waterways should be undertaken, with special attention to the water hyacinth.

Fish biology

- We must quantify interactions among food-web structures, water quality, and life-history characteristics of fishes in order to understand the relationship between fish production and the causes of eutrophication and anoxia in Lake Victoria.
- There is continuing need for stock assessment such as that now underway with the support from the European Community. Such assessments are necessary to guide ecosystems modelers, policy makers, fisheries investors, and fisheries managers.
- Refuge areas (fish parks) should be established to protect the diversity of the native fish species and maintain spawning stocks of commercially important species.
- The possible contribution of aquaculture and management of alternative fisheries to the fishery industry should be fully explored, including their potential for restoring and rehabilitating indigenous stocks.
- Proposals for the introduction of exotic flora and fauna to the Lake Victoria ecosystem should be submitted to the Lake Victoria Commission for evaluation. Such proposals must be treated with great caution and rigorously evaluated with respect to biological, economic, and social impacts. Introductions must meet with approval of all three riparian nations. Management of species already introduced is essential to the welfare of exiting fisheries.

Policy, management and economics

- The quality of runoff water from the land is deteriorating and may affect fish habitat. Fishery scientists should define water quality requirements of the fishery and work closely with limnologists in drafting overall guidelines for the water quality of Lake Victoria.
- Proposals for fisheries planning and development should be submitted to the Lake Victoria Commission for detailed social and environmental impact assessment before implementation. All proposals must cognizant of the changing patterns of ownership and the control of harvesting and processing facilities. They should also analyze the differential incomes received by the various participants in the fishery.

- The fisheries planning process needs to be integrated with development of information systems encompassing regional, social, economic, and biological data. Programs should be developed to assist those groups most likely to suffer the effects of predicted declines in the current fishery.
- Research should identify the factors that facilitate or impede local participation in fisheries management, and fisheries officials should be familiarized with programmes in other countries that involve local fishers and fisheries management.
- The supply of fish within the lake basin available to local populations is insufficient to meet their needs. Studies should be conducted to determine if the expansion of the Nile perch fishery and export marketing have contributed to reduced dietary protein and malnutrition in local people.
- The feasibility of levying a tax on fish exported from the basin to support the research, management and monitoring of the fisheries should be determined. Proceeds should be directed initially toward the effective implementation of regulations on fishing gear, methods and allowable catch.

APPENDIX V

Information on current and recent projects on the African Great Lakes ecosystems and the management and conservation of their natural resources

In this appendix information is given on projects related to the management, development, conservation and research of the African Great Lakes ecosystems and resources. In addition some projects in East and Southern Africa which may be of importance to the management and conservation of the African Great Lakes are included. More detailed information on projects can be obtained from SIS Focal Point, the implementing agencies and participating national institutions. No attempt is made to provide a complete overview of ongoing and recent projects.
A large number of projects are implemented on agricultural practices, soil erosion, soil and forestry research, agro-forestry, land management in the catchment areas of the African Great Lakes. These projects may directly or indirectly contribute to the conservation of the African Great Lakes. Information on these projects may be found in the Special Programme for African Agricultural Research (SPAAR) Information System.

Information sources

[1] Global Environment Facility (GEF) – Quarterly Operational Report – April 1995
[2] Special Programme for African Agricultural Research (SPAAR) Information System (SIS) November 1995
The World Bank. Washington DC, USA
SIS Focal Point – International Agricultural Centre, Mr. F. Neuman/Ms K. Vermooten, P.O. Box 88. 6700 AB Wageningen, The Netherlands
[3] Fisheries Project Information System (FIPIS) – 1995, Fisheries Department, FAO Rome
Mr. D. Insull, FIPIS, Fisheries Department, FAO, Via delle Terme di Caracalla, 00100 Rome, Italy
[4] Individual project documents.

Project information

Project title: **Comparative and Comprehensive Study of Great Lakes**
Implementing agency: UNESCO
Executing agency: International Limnological Society (SIL) African Great Lakes Group
Project identifier: IHP IV M-5.1
Start date: 1992 End date: 1995
Country/countries: Regional; African Great Lakes countries
Activities: desk studies, workshops
Statement of objectives/abstract: *see Foreword to this report*

Project title: **GEF – Lake Victoria Basin and Ecosytem Management – Pilot Phase**
Implementing agency: UNDP
Executing agencies: National Working groups of Kenya, Uganda and the United Republic of Tanzania
Start date: 1994 End date: 1996
Country/countries: Kenya, Uganda and the United Republic of Tanzania
Total project cost: US$1,800,000
Statement of objectives/abstract: *National Working Groups of the three countries are now in the process of formulating programmes activities for the Regional Task forces on Fisheries and Water hyacinth, and Water quality and Wetlands Conservation.*

Project title: **GEF – SADC Lake Malawi/Nyasa Biodiversity Conservation**
Implementing agency: World Bank
Executing agency: Malawi Fisheries Dept/Southern African Development Community (SADC) Fisheries Unit
Associated participation: Malawi Wildlife Society, World Wildlife Fund (WWF)
Project identifier: 3MALGE001
Start date: 1995 End date: 1999 (4 years)
Country/countries: Malawi, Mozambique and United Republic of Tanzania
Total project cost: US$5,000,000
Statement of objectives/abstract: *Lake Malawi has a unique freshwater ecosystem, home of over 500 endemic fish species. The project will conduct faunal surveys, identify biodiversity hotspots, prepare a conservation and management plan for the lake, recommend revisions to national environmental legislation, and fund environmental training and education activities.*

A parallel Canadian project (C$4.2m) will finance research capacity-building through twinning with a Canadian institution in limnology and water quality monitoring, laboratory equipment and public education.

Project title: **GEF – Pollution Control and Other Measures to Protect Biodiversity in Lake Tanganyika**
Implementing agency: UNDP
Executing agencies: National Resources Institute (NRI)/Marine Resources Assessment Group (MRAG)/IFE (UK)
Associated participation: National and international scientific and technical organizations; academic institutions, NGOs
Project identifier: RAF/92/G32
Start date: 1995 End date: 2000 (5 years)
Country/countries: Burundi, Democratic Republic of the Congo, United Republic of Tanzania, Zambia
Total project cost: US$10,000,000
Statement of objectives/abstract: *Development of a strategic plan for long-term management of the Lake and its unique biological resources. The project fosters a better understanding of the ecosystem, establishes and harmonizes regional efforts, implements pollution monitoring programme and conservation plans, and trains relevant individuals through on-the-job education, support to universities and fellowships.*

Project title: **GEF – Institutional Support to Protect East African Biodiversity**
Implementing agency: UNDP
Executing agency: FAO
Associated participation: African Wildlife Fund (AWF), East African Wildlife Society (EAWS), IRA, IUSC, Southern African Development Community (SADC), WCI, World Conservation Monitoring Centre (WCMC, UK), WCST, World Wildlife Fund (WWF)
Project identifier: RAF/92/G31
Start date: 1993 End date: 1997 (4 years; Phase II proposed)
Country/countries: Kenya, Uganda, United Republic of Tanzania
Total project cost: US$10,000,000
Statement of objectives/abstract: *Strengthening of indigenous capacities to conserve biological diversity though support of education, in-service training, awareness enhancement and conservation activity to put training into practice. The project seeks to improve co-ordination in establishment or support of biodiversity units within government lead agencies and to enhance regional collaboration.*

Project title: **GEF – Conservation of the Bwindi Impenetrable National Park and the Mgahinga Gorilla National Park**
Implementing agency: World Bank
Executing agency: Ministry of Tourism, Wildlife and Antiquities
Associated participation: World Wildlife Fund (WWF), African Wildlife Fund (AWF), Wildlife Clubs of Uganda, CARE-Uganda, Inst. of Trop. Forest Conservation
Project identifier: 3UANGE001
Start date: 1991 End date: 1995 (5 years)
Country/countries: Uganda
Total project cost: US$4,800,000 (Co-fin. USAID)
Statement of objectives/abstract: *The project will establish a trust fund, the income from which will provide a sustainable source of funds for the management of the Bwindi Impenetrable Forest and Mgahinga Gorilla National Parks and the conservation of their biodiversity. A Trust Management Board, representative of the local communities, NGOs and the government will allocate the Fund's net income to selected park management, research and community development projects.*

Project title: **GEF – Transfrontier Conservation areas and Institutional Strengthening – Pilot Phase**
Implementing agency: World Bank
Executing agency: Nat. Direct. of Forestry, Wildlife; Ministry of Agriculture
Associated participation: Southern African Nature Foundation, World Wildlife Fund (WWF)
Project identifier: 3MOZGE001
Start date: September 1995 End date: —
Country/countries: Mozambique
Total project cost: US$7,500,000 (US$2m being sought)

Statement of objectives/abstract: *This project will prepare and implement management plans of several wildlife-rich border areas that are contiguous with national parks in neighbouring Zimbabwe and South Africa. A major objective of the project is to protect migration corridors for big game populations that cross transnational borders.*

Project title: **GEF – Biodiversity Conservation in Southeast Zimbabwe**
Implementing agency: World Bank
Executing agency: Govt Dept of National Parks and Wildlife Management, Ministry of Environment and Tourism
Associated participation: World Wildlife Fund (WWF), Limpopo Save Development Committee
Project identifier: 3ZIMGE002
Start date: 1995 End date: 2000 (5 years)
Country/countries: Zimbabwe
Total project cost: US$55,000,000 (GEF contribution US$4.8m)
Statement of objectives/abstract: *With the involvement of local communities, the project will design and implement a natural resource management programme for Gonarhezu National Park on the Mozambique and South African border, complementing the Mozambique Transborder Areas Project. It will rehabilitate the infrastructure of Gonarhezu to stimulate eco-tourism, develop community wildlife management and sustainable use programmes and strengthen park management capacity.*
Associated World Bank Project: Wildlife Management and Environmental Conservation Project
This project attempts to strengthen all aspects of the Department of National Parks, to strengthen the management and infrastructure of four other national parks, and eventually to support integrated community-based conservation and development programmes similar to those in Gonarhezu Park in these four parks.

Project title: **GEF – Conservation of the Tana River National Primate Reserve**
Implementing agency: World Bank
Executing agency: Kenya Wildlife Service
Associated participation: CARE-Kenya, YMCA, World Conservation Union (IUCN), National Museums of Kenya, East African Wildlife Society
Project identifier: KENGE001
Start date: 1995 End date: —
Country/countries: Kenya
Total project cost: US$6,200,000
Statement of objectives/abstract: *Development and implementation of a management plan for the Tana River National Primate Reserve, which contains the last remaining contiguous area of indigenous riverine forest along the Tana River. The Tana River Reserve protects two endangered primate species, the Red Colobus and Crested Mangabey monkeys.*

Project title: **Research for the Management of the Fisheries on Lake Tanganyika**
Implementing agency: FAO
Project identifier: GCP/RAF/271
Start date: 1994 End date: 1998
Country/countries: Regional; Burundi, Democratic Republic of the Congo, United Republic of Tanzania, Zambia
Total project cost: US$5,835,425
Statement of objectives/abstract: *The overall development objective is the provision of a rational basis for the maximum exploitation of the fishery resources of Lake Tanganyika, in order to increase the supply of high-protein food to the riparian States in line with national development goals.*
Intermediate objectives are:
(1) the establishment of an agreed ongoing lake-wide modern scientific fisheries research programme with the continuing exchange and utilization of the research results and experiences at Lake Tanganyika among all four participating States;
(2) ensuring the four national research centres each have the capacity (human and logistical) to continue, wihout duplication of effort, the agreed fisheries research programme independent of major external assistance inputs;
(3) ensuring the four national research centres are able to provide their Governments with the scientific data and advice required for the further detailed planning of their national development programmes, aimed at the optimum exploitation of their fishery resources at Lake Tanganyika;
(4) the establishment and implementation by the Government of the four riparian States of a mechanism to co-ordinate their management and exploitation of the pelagic fishery resources of the whole of Lake Tanganyika;
(5) the national research centres each able to provide scientific data and advice to their Government regarding the overall use of Lake Tanganyika's resources, including also the management of water supplies for the lakeside communities, the combat against pollution, the conservation of the biological and other lacustrine natural resources.

Project title: **Lake Malawi Chambo Fisheries Research Project**
Implementing agency: FAO
Project identifier: MLW 86/13
Start date: 1988 End date: 1991
Country/countries: Malawi
Statement of objectives/abstract: *To carry out biological, stock assessment and socio-economic research relevant to the formulation of a management plan for the Chambo fisheries of the South East Arm of Lake Malawi and of Lake Malombe.*

Project title: **Information Systems for Water Resources, Monitoring and Planning in the Lake Victoria Region**
Implementing agency: FAO
Project identifier: GCP/RAF/.... /JAP
Start date: 1994 End date: 1999 (5 years)
Country/countries: Kenya, Uganda, United Republic of Tanzania
Total project cost: US$2,500,000
Statement of objectives/abstract: *The project is designed to fully use and, in the process, strengthen existing institutional capacity and resources in the public and private sectors of the participating countries through special agreements, service contracts and local recruitment. To support this process and the management activity, the project will use innovative approaches made possible by technological developments in satellite remote sensing, environmental telemetry and geographically referenced data banks.*

Recent and ongoing regional Lake Victoria basin and River Nile basin (water) resources projects

TCP/RAF/8969	Monitoring, Forecasting and Simulation of the River Nile basin (1990–1991)
CCPS/RAF/256/ITA	IGADD Early Warning & Food Information System (1990–1993)
GCP/RAF/231/JPN and GCP/RAF/232/JPN	Remote Sensing for an Early Warning System in Eastern and Southern Africa
GCP/INT/439/BEL	Strengthening of the Agro-meteorological Component of the Global Information, Early Warming and Locust Control System (–1993)
TCP/RAF/2371	Water Hyacinth Control in East Africa (1993–1998)
TCP/RAF/2365(A)	Water Resources Management Policy and Institutions in the Lake Victoria Region (1993–1996)
TCP/RAF/2373 (A)	Assistance to the Establishment of the Lake Victoria Fisheries Commission (1993–)
GCP/EGY/18/USA	Monitoring, Forecasting and Simulation of the River Nile in Egypt' Phase II (1993–1995)
RAF/87/030	Sub-Saharan Africa Hydrological Assessment (1987–1993)

Ongoing or pipeline projects in the Lake Tanganyika basin.
Information on project title, donor agency and/or executing agency, countries involved

Source: GEF Lake Tanganyika project document 1995.

Role of Ecotones in Lake Tanganyika	UNESCO/DANIDA	Burundi
Bujumbura Municipal Water Quality	GTZ (Germany), BWW	Burundi
Biodiversity Support Project (INECN)	USAID/Peace Corps B	Burundi
Ntahangwa River Basic Project	FAC (France) / Institut des sciences agronomiques du Burundi (ISABU)	Burundi
Project Memwere & Muhuta	Swiss Aid, Travaux Publics	Burundi
Projet d'Aménagement de Haute Terre	Italian Foreign Aid (watershed management)	Burundi
Sewage treatment facility for Bujumbura	Kreditanstalt für Wiederaufbau (KFW, Germany), SETIBU	Burundi
Administrative Management Design (ADMADE) project for national parks and wildlife services	World Wildlife Fund (WWF) & USAID	Zambia
Zambian Environment Educational Programme (ZEEP)	World Wildlife Fund (WWF)	Zambia
Fisheries Loan & Capital Equipment	IBR	Zambia
FAO Lake Tanganyika (United Republic of Tanzania) Fisheries Project	FAO/Netherlands	Tanzanian Government

Ornamental Fish Export Production	Centre for the Promotion of Imports from Developing Countries (CBI), Netherlands	United Republic of Tanzania
Land Degradation in Western Tanzania	DANIDA	Tanzanian Government
Integrated Regional Development	Norwegian Agency for International Development (NORAD) Tanzanian Government	
Hydrothermal Activity in Lake Tanganyika (TANHYDRO)	French and German National Science Foundations	Burundi, Democratic Republic of the Congo, United Republic of Tanzania

Programme: **Commission of the European Communities (CEC) – African, Caribbean and Pacific (ACP group) Fisheries Research Initiative**
Implementing agency: CEC DG XII
Start date: 1996 End date: —
Country/countries: Global with regional initiatives
Statement of objectives/abstract: *The European Union (EU)/ACP Joint Assembly made fisheries in the context of ACP–EU co-operation the focus of one of its working groups. The Initiative aims at the sustainable use of fishery resources for the benefits of sector stake holders and the conservation of the aquatic ecosystems. Research would have to play an important role in providing approaches and solutions. The research initiative is co-ordinated by DG VIII and XII of the Commission of European Countries.*

Project title: **Lake Victoria Fisheries Research Project – Phase II**
Implementing agency: Commission of European Communities (CEC)
Start date: 1996 End date: 2001 (5 years)
Country/countries: Kenya, Uganda, United Republic of Tanzania
Total project cost: ECU 8,000,000
Statement of objectives/abstract: *The project will assist in the creation and initial functioning of a viable management framework for the fisheries of Lake Victoria. It will create and develop the knowledge base required for the rational management of the fisheries of Lake Victoria.*

Project title: **UK/SADC Pelagic Fish Resource Assessment Project (Lake Malawi/Niassa)**
Implementing agency: Overseas Development Agency (ODA)
Project identifier: 062/522/001
Start date: 1992 End date: 1995
Country/countries: Malawi, Mozambique, United Republic of Tanzania
Total project cost: £3,730,000
Statement of objectives/abstract: *The project undertook a hydro-acoustic and limnological assessment of pelagic fish resources and associated trophic factors in Lake Malawi (Niassa). The project deployed a 15 m catamaran research vessel and a multidisciplinary team of scientists from UK, Malawi, United Republic of Tanzania and Mozambique in a series of synoptic surveys from a base at Senga Bay in Malawi where a laboratory and accommodation were provided. For results see Menz (1995).*

Project title: **Belgium/Communauté économique des pays des grands lacs (CEPGL) Hydrobiological Project**
Implementing agency: Belgium/CEPCL
Executing agencies: University of Leuven, University of Ghent, University of Burundi, Centre national de recherche scientifique (CNRS, France) Uvira
Start date: 1992 End date: 1997
Country/countries: Burundi, Democratic Republic of the Congo, Rwanda
Statement of objectives/abstract: *A newly established regional centre for hydrobiological research ('Centre régional de recherches en hydrobiologie appliquée' (CRRHA) in the CEPGL region (Burundi, Democratic Republic of the Congo, Rwanda) focuses its research on the coastal area of Lake Tanganyika and the major northern affluents.*

Project title: **Lake Victoria Research Project/ HEST Research Project**
Implementing agency: DGIS, The Netherlands
Executing agencies: HEST, Leiden, and TAFIRI, United Republic of Tanzania
Start date: 1979 End date: 1995
Country/countries: United Republic of Tanzania
Statement of objectives/abstract: *From 1979 to 1989 the HEST project focused on research into the taxonomy and*

ecology of the haplochromine cichlids in Lake Victoria. From 1989 onwards the project focused on the Nile perch fisheries and the impact of the Nile perch introduction on the endemic fish fauna in Lake Victoria.
Currently a small research survey is held every year to sample the HEST transect in the Mwanza Gulf.

Project title: **UNDP/WMO – Hydro-meteorological Survey Projects Upper Nile Basin**
Implementing agency: UNDP/WMO
Start date: 1960 End date: —
Country/countries: All countries bordering the Nile River
Statement of objectives/abstract: *Since the 1960s and 1970s a network has been established for the collection of basic data needed for the analysis and planning of development and conservation of the water resources of the Upper Nile in order to provide the groundwork for intergovernmental co-operation for storage, regulation and use of the Nile. A mathematical model of the Upper Nile basin was established for simulation of the River Nile and its headwaters to a point 20 km north of Lake Albert with a catchment area of 410,00 km^2.*
In January 1993, TECCONILE, the Technical Co-operation Committee for the Promotion of the Development and Environmental Protection of the Nile basin, was created as a temporary successor organization to the Hydro-meteorological Survey. With financial assistance provided by the Canadian International Development Agency (CIDA) a Nile River Basin Action Plan (NRBAP) has been developed.

Project title: **Sub-Saharan Africa Hydrological Assessment**
SIS Record number (MFN): 01108
Implementing agency: World Bank
Project identifier: RAF/87/030/C/01/42 (UNDP)
Start date: 1987 End date: 1991
Country/countries: Sub-Saharan Africa
Total project cost: US$4,527,000
Statement of objectives/abstract: *The project will evaluate the status of existing hydrological data (precipitation, surface and groundwater), networks and collection systems and make recommendations for the filling of important gaps. upgrading of quality of data collection and enhancement of the capability to measure, retrieve, process and publish hydrological data and information in sub-Saharan countries. Recently, Algeria was added to the countries specified in the original project under a separate UNDP-funded project (ALG/88/021). The ultimate aim is to assist countries in the improvement of hydrometric work for planning and evaluating water resource development programmes and projects.*

Project title: **Agricultural Research and Training (Uganda Agricultural Technology and Training Project, AGTECH)**
SIS Record number (MFN): 01209
Start date: 24 June 1993 End date: 31 December 2000
Implementing agency: World Bank
Country: Uganda
Total project cost: US$28,870,000
Statement of objectives/abstract: *The objective of the project is to facilitate accelerated growth in agricultural production to fuel economy-wide development and to improve overall food security and export potential through the generation of sustainable farming systems that conserve the resource base and improve environmental quality. In pursuit of these overall objectives, the project would aim to increase production and income of small farmers through: (1) re-organization and strengthening of the institutional framework for planning and carrying out agricultural research and extension efficiently and effectively; (2) the development and dissemination of improved production and resource conservation technology for the dominant crop-livestock, crop-fisheries, and agro-forestry production systems; and (3) manpower training. The project is expected to be supported by several donors and would comprise assistance for: (i) the setting up of an organizational structure for resource allocation and coordination of the national research programme including possibly construction of a headquarters building; (ii) provision of services by this national structure in the areas of research planning and management, budgeting, biometrics and information systems; (iii) making key national crop, livestock, forestry, fisheries, factor and disciplinary research programmes more effective through the rehabilitation of main research centers and training; (iv) reinforcing adaptive research to generate the required location-specific, farmer-tailored technology for increased production; (v) the introduction of an effective and professional extension service, first in the high potential areas; (vi) the establishment of close research/extension linkages to facilitate technology transfer and feedback to researchers from extension workers and farmers; and (vii) the reinforcement of Makerere University to supply appropriately trained manpower. Research and extension services would be designed to operate effectively within the country's severe budgetary constraints.*
Financing provided by IDA would fund primarily: (a) establishment costs of a national agricultural research entity; (b) construction, rehabilitation, transport and equipment for research centers; (c) civil works, vehicles, training and communications equipment for extension; (d) civil works, equipment and transport for Makerere University; (e)

operating costs; and (f) training and technical assistance in collaboration with other donors. Effective donor co-ordination would be essential to the project's viability.

Project title:	**Bio-monitoring of Insecticide Applications in Zimbabwe, Malawi, Zambia and Mozambique**
SIS Record number (MFN):	01604
Implementing agency:	Commission of the European Communities
Start date: May 1986	End date: May 1988
Country/countries:	Africa; Malawi; Mozambique; Zambia; Zimbabwe;
Total project cost:	DM1,500,000

Statement of objectives/abstract: *Aerial dispersion of insecticides over thousands of square kilometres in Africa is potentially hazardous to man and his environment. The EEC's activity involves biomonitoring the effects of endosulfan on non-target organisms and ecosystems using synecology, experimental biomonitoring, and residual analysis. The objective is to make insecticide application by the sequential aerosol spraying technique environmentally acceptable.*

Project title:	**Nile Perch (Uganda)**
SIS Record number (MFN):	02436
Implementing agency:	International Development Research Centre (Canada)
Project identifier:	86-0137
Start date: 12 November 1986	End date: 12 November 1989
Country/countries:	Uganda
Total project cost:	C$519,850

Statement of objectives/abstract: *Nile perch (*Lates niloticus*), a large predatory fish, was introduced to several East African lakes in the 1950s and 1960s in the hope that it would eat commercially undesirable fishes. Nile perch now constitute up to 50 % of the small fisheries catch in Uganda. Species composition of the catch has changed dramatically, and reduced total yields are feared if the predator totally dominates native species. This project studies the population dynamics and ecological (particularly predator-prey) relationships of Nile perch in Lake Albert, to which it is indigenous, and Lakes Kyoga and Victoria, to which it has been introduced. The impact of the introduction will be assessed, and guidelines for management of small fisheries disseminated.*

Project title:	**Nile Perch (United Republic of Tanzania)**
SIS Record number (MFN):	02463
Implementing agency:	International Development Research Centre (Canada)
Project identifier:	87-0128
Start date: 5 January 1988	End date: 5 January 1991
Country/countries:	United Republic of Tanzania
Total project cost:	C$239,800

Statement of objectives/abstract: *Total numbers and composition of fish caught in the artisanal fisheries of Southern Lake Victoria have changed dramatically following spread of the predator Nile perch from the northern part of the lake. Research is required to achieve maximum yields from the rapidly changing stocks. The Tanzania Fisheries Research Institute will assess catch and abundance trends, and compare the effectiveness of different types of fishing gear, determine the impact of Nile perch predation on fisheries; and advise fishermen and development agencies on appropriate fishing techniques and management actions. Links with a similar project in Ugandan waters of Lake Victoria and with other fishery scientists in the region, will be strengthened.*

Project title:	**Lake Productivity (Canadian Freshwater Institute (FWI)/Uganda)**
SIS Record number (MFN):	02515
Implementing agency:	International Development Research Centre (Canada)
Project identifier:	88-1036
Start date: 27 February 1989	End date: 29 February 1992
Total project cost:	C$139,910

Statement of objectives/abstract: *Introduction of the predator Nile perch into Lakes Victoria and Kyogain Uganda has been followed by changes in traditional small-scale fisheries. Lake productivity mechanisms, which determine long-term fishery production, may be changing as a result of increased predator abundance or nutrient runoff from surrounding lands. This project will complement the ongoing Nile Perch (Uganda) project (3-P-86-0137) by researching changes in lake productivity under the changed ecological conditions of the past two decades. Researchers will investigate primary productivity in relation to fish production; examine the abundance of invertebrate food in relation to Nile perch; compare water quality to the pre-perch period; and strengthen the limnological research capacity of the Uganda Freshwater Fisheries Research Organization (UFFRO) through cooperative research and training.*

Project title: **Inshore Stock Assessment: an Evaluation of the Role of Permanently Protected Areas**
SIS Record number (MFN): 03396
Implementing agency: International Foundation for Science
Project identifier: G/1512-1
Start date: June 1989 End date: —
Country/countries: Zimbabwe
Total project cost: SEK72,000
Statement of objectives/abstract: *The Kariba artisanal fishery supports about 600 fishermen with roughly 5,000 direct dependents. These fishermen operate along 310 km of shoreline. Some 290 km of this shoreline has been closed to fishing, with the intention that this part would serve as a fish recruitment area for those parts of the shoreline where fishing is allowed. Mr Machena will test the validity of this fishery management hypothesis by studying the distribution of fish biomass and species between the protected and fished areas in Lake Kariba. The results of this study will influence the design of the future inshore fishery policy.*

Project title: **Fisheries Development Project**
SIS Record number (MFN): 03431
Implementing agency: World Bank; Malawi
Project identifier: 3MALPA072; Cr. 2225; Report No. 9086-MAI
Start date: 4 September 1991 End date: 30 June 1999
Statement of objectives/abstract: *The main objective of the project is to assist Malawi to realize more fully the potential contribution of the fisheries sub-sector to the economy, while ensuring that off-take does not exceed sustainable yields, through: (a) increasing fish production to improve nutrition and protein supply for the population; (b) generating additional off-farm employment and income to reduce poverty among the rural population particularly women; (c) conserving the natural resource base of Malawi's water bodies and preventing environmental degradation; and (d) improving institutional capacity for fisheries sub-sector policy formulation research, planning, monitoring and control. The project would consist of the following components: (i) institution building for strengthening the Fisheries Department (FD) to enable it to concentrate on regulatory functions, staff training, and technical assistance; (ii) research for strengthening FD's research capacity and focusing research activities on assessment of fish stocks (exploratory surveys of the demersal fish stock assessment, formulation of plans to monitor and manage commercial fisheries in Malawi water bodies, assessment of the effect of bottom trawling and beach seining on the lake's ecosystem, development of techniques for managing coastal fisheries, and co-ordination of research activities financed by other donors), pilot lake resource conservation and management programmes, and development of pilot fish farming models designed to integrate aquaculture into farming systems in different ecological zones with appropriate agricultural technologies; (iii) production for rehabilitating and developing existing capture fisheries by supporting the traditional/artisanal fishermen, semi-commercial and commercial fishing activities, and processing and marketing; and (iv) infrastructure for rehabilitating, upgrading and building access roads, jetties for fish landing, and shore-based facilities.*

Project title: **Fisheries Development Project**
SIS Record number (MFN): 03593
Implementing agency: World Bank
Project identifier: C15290; Cr. 1529-ZA; Report No. 5012-ZA
Start date: 16 August 1985 End date: 30 June 1990
Country/countries: Zambia
Statement of objectives/abstract: *The project would represent the first stage of a long-term programme to develop the fisheries sub-sector in Zambia. It would support Government of the Republic of Zambia's efforts in the expansion of fish production, marketing and distribution systems through extension of credit to private fish producers and marketing entities by Zambia Agricultural Development Bank (ZADB). Further support to these objectives would be provided through provision of foreign exchange for importing raw materials and machinery spares required to manufacture fishing nets, technical assistance to ZADB and Department of Fisheries (DOF), and monitoring and evaluation. The project components are: (1) institutionalized credit services to artisanal fishermen and for commercial fisheries on Lake Kariba, collection and marketing facilities and ice-making plant at Kafue; (2) foreign exchange assistance for net manufacturing; (3) improved management of fish resources–rehabilitation of existing water transport equipment, and provision of land transport and research and communication equipment. Under this component, the project would strengthen the role of DOF in providing training and extension services to artisanal fishermen, in carrying out research and studies to determine fish stocks and maximum sustainable yields of fishing areas covered by the project, and in experimenting with and advising on new fishing gear and methods. An experienced fisherman would be employed to work with the research and extension staff of DOF to develop, demonstrate then train local fishermen in lift-net fishing technique for Kapenta. Technical assistance would also be provided to the DOF in fisheries research and extension; and (4) co-ordination and monitoring and evaluation.*

Project title: **Support to SADC Co-ordination of Fisheries, Forestry and Wildlife**
SIS Record number (MFN): 04036
Implementing agency: Southern African Development Community (SADC)
Project identifier: Project 4.0.3
Total project cost: US$400,000
Statement of objectives/abstract: *The project aims to provide technical assistance to the Ministry of Forestry and Natural Resources in Malawi, in order to enable it to discharge its regional coordination responsibility effectively. The project would cover costs of technical assistance experts, consultancies, workshops and procurement of equipment.*

Project title: **Regional Fisheries Training Programme**
SIS Record number (MFN): 04037
Implementing agency: Southern African Development Community (SADC)
Project identifier: Project 4.0.5
Start date: February 1990 End date: 1997
Total project cost: US$5,950,000 (financing gap: US$5,750,000)
Statement of objectives/abstract: *The lack of adequate training opportunities is a major constraint on fisheries development. The project aims to ensure that training facilities, in the region are adequate to meet this need. To achieve this objective, the project would strengthen selected national institutions to provide for both national and regional needs. The specific objectives of the project are to: (a) strengthen the national institutions to be included in the programme; (b) utilize, in consultation with the Regional Training Council (RTC), the SADC fellowship programme to enable SADC students to attend courses for which they been selected; and (c) establish links with institutions outside the region for the exchange of information on fisheries training. The institutions identified are: Eduardo Mondlane University, Maputo, Mozambique, for research training in marine fisheries; University of Zimbabwe for research training in freshwater and aquaculture; Bunda College, Malawi, for diploma level training for development, technical and extension officers; Fisheries Training Centre, Mbegani, United Republic of Tanzania, for training in specialist subjects, such as capture electronics and refrigeration; and Natural Resource Training Centre, Mpwepwe, for training of fisheries assistants, extension workers and scouts.*

Project title: **Support to SADC Fisheries Co-ordination Unit**
SIS Record number (MFN): 04043
Implementing agency: Southern African Development Community (SADC)
Project identifier: Project 4.0.10
Total project cost: US$150,000
Statement of objectives/abstract: *The project would support the planning and administrative work of the SADC Fisheries Coordination Unit.*

Project title: **Joint Research of Pelagic Fisheries Resources of Lake Malawi/Nyasa**
SIS Record number (MFN): 04047
Implementing agency: Southern African Development Community (SADC)
Project identifier: Project 4.4.1
Total project cost: US$2,510,000
Statement of objectives/abstract: *The project aims to carry out research on offshore fish stocks of Lake Malawi/Nyasa as a basis for their improved sustainable exploitation. A feasibility study has been carried out and letters of agreement for the implementation of the project have been signed by the three Member States involved. The research work would start in August/September, 1990 when the research vessel is expected to arrive.*

Project title: **Lake Kariba Fisheries Research and Development**
SIS Record number (MFN): 04053
Implementing agency: Southern African Development Community (SADC)
Project identifier: Project 4.9.1
Start date: April 1988 End date: 1994
Total project cost: US$8,340,000
Statement of objectives/abstract: *The project aims to carry out multidisciplinary research on various aspects of fisheries on Lake Kariba, with a view to recommending the most appropriate management of the fishery resource for sustainable utilization. Research work is in progress and a new research vessel is under construction.*

Project title: **Regional Development of Community-based Management and Utilization of Wildlife Resources in Rural Areas**
SIS Record number (MFN): 04091
Implementing agency: Southern African Development Community (SADC)
Project identifier: Project 6.0.16
Total project cost: US$19,000,000

Statement of objectives/abstract: *The objective of the project is to find long-term solutions to the problems of wildlife management and utilization in rural areas, by transferring to target communal areas the necessary skills designed and implemented under different management models. The project, which covers Botswana, Malawi, Zambia and Zimbabwe, would include infrastructure development in communal areas and procurement of equipment, vehicles and the design of management models.*

Project title: **Economics of Conservation**
SIS Record number (MFN): 04103
Implementing agency: Southern African Development Community (SADC)
Project identifier: Project 7.0.1(5)
Statement of objectives/abstract: *A third workshop on the Economics of Conservation was held in Francistown, Botswana, in 1989, as part of a workshop series on a cost–benefit analysis of projects in which conservation is an essential component.*

Project title: **Regional Hydrological Assessment Project**
SIS Record number (MFN): 04110
Implementing agency: Southern African Development Community (SADC)/World Bank
Project identifier: Project 7.0.2
Start date: November 1988- End date: 1990
Total project cost: US$1,000,000
Statement of objectives/abstract: *The main objective of the project is to evaluate the status of existing hydrological data networks and collection systems, and to make recommendations for the filling of important gaps, up-grading of the quality of data collection and the general enhancement of the ability to measure, retrieve, process and publicize hydrological data and information in the SADC region. The project is being implemented by the World Bank with funding from UNDP.*

Project title: **Development of Environmental Impact Assessment (EIA) – Phase I**
SIS Record number (MFN): 04120
Implementing agency: Southern African Development Community (SADC)
Project identifier: Project 7.0.6
Start date: 1990 End date: 1994
Total project cost: US$1,100,000 (financing gap: US$720,000)
Statement of objectives/abstract: *The objective of this Phase I project is to develop appropriate regional and national institutional frameworks and to strengthen the capacity of specialized SADC and national bodies to apply Environmental Impact Assessment (EIA), including the training of personnel at the required levels and in the appropriate skills. The project activities would involve: (a) regional workshop on EIA; (b) formulation of principles, guidelines and techniques for EIA application in the SADC region; (c) regional consultation on application of EIA; (d) review and development of proposed methodologies; (e) regional training course on EIA; and (f) a seminar on incorporation of EIA in project and programme design and development planning in SADC member States.*

Project title: **Ecology of Lake Kariba**
SIS Record number (MFN): 04131
Implementing agency: Swedish Agency for Rural Co-operation with Developing Countries
Project identifier: BI-ZIM-02
Start date: 1 July 1982 End date: —
Funding by donor agency: SEK9,456,000
Statement of objectives/abstract: *The objectives of the project are to: (a) provide basic data for the proper utilization and management of the diverse lake resources; (b) start to analyse the possibilities to increase the useful production from the lake; (c) train postgraduate students from the University of Zimbabwe for a PhD in biology; and (d) start the limnological laboratory of Lake Kariba Research Station. The project has now produced one PhD graduate with three more close to completion. Their destination after completion are: National Parks & Wildlife (1), National Museums (1), University of Zimbabwe – Lake Kariba Research Station (1), Private sector (1). The facilities developed at the Station have enabled it to run a regional training course in limnology.*

Project title: **Small-scale Fish Systems (Kenya)**
SIS Record number (MFN): 04216
Implementing agency: International Development Research Centre
Project identifier: 89-0166
Start date: 30 May 1990 End date: 31 March 1993
Total project cost: C$232,410
Statement of objectives/abstract: *The fisheries situation on Kenya's portion of Lake Victoria has changed dramatically in the last ten to fifteen years. One result has been the increased marginalization of women who engage*

*in artisanal (small-scale) processing/trading of fish. The fish species of interest are Nile perch (*Lates niloticus*) and omena (Engraulicypris). The Development Program of the Diocese of Maseno South of the Church of the Province of Kenya has completed a two-year project with the help of the UK-based Intermediate Technology Development Group, and intends to introduce technological improvements to groups of women at two landing beaches in South Nyanza District. This project will improve the earnings of rural women fish processor/traders through their reintroduction into the mainstream of the Nile perch producing, handling, processing, and marketing system, and through improved omena processing methods.*

Project title: **Artisanal Fisheries (Kenya) – Phase II**
SIS Record number (MFN): 04255
Implementing agency: International Development Research Centre
Project identifier: 88-0332
Start date: 3 May 1989 End date: 11 April 1992
Total project cost: C$116,000
Statement of objectives/abstract: *Phase I of this project sought to establish a profile of artisanal (small-scale) fishermen on Lake Victoria in Kenya, and to identify obstacles and opportunities in their industry that policy intervention might address. One of its findings was that the future of artisanal fishery on Lake Victoria is seriously in doubt, owing to growing competition from commercial fishery, which has the advantages of more capital, superior technologies and more lucrative markets. This project will deal with this and other questions, revealed but not pursued by the earlier project. In particular, it will attempt a deeper analysis of the policy options. In so doing, it will study artisanal fishery and commercial fishery in Kenya as parallel activities, and will seek arrangements that would encourage their growth as complementary systems. Its results will be published. A post-project seminar is planned as a further attempt to disseminate results.*

Project title: **Local Applications of Remote Sensing Techniques (LARST) for Local Management of Lake Resources**
SIS Record number (MFN): 04683
Implementing agency: Overseas Development Administration (Natural Resources and Environment Department, NRED)
Project identifier: 793-625-102-YK
Start date: 1 April 1992 End date: 31 March 1994
Country/countries: Malawi, Namibia, UK, United Republic of Tanzania,
Total project cost: £75,300
Statement of objectives/abstract: *The wider objectives of the project are to: improve local facilities for monitoring lacustrine environments; increase relevance and speed of production of satellite-based remotely sensed data products to environmental monitoring and resource management; and provide application-specific `tools' for the management of lake fish resources in Africa and elsewhere. The immediate objectives are to: support local management of lacustrine resources by integrating locally received satellite data with other inputs; provide tools to resource managers and specialists to help them obtain and process relevant satellite data in near real-time, so as to generate outputs that are immediately useful; and develop alogorithms for estimating physical and bio-physical parameters as indicators of the state of the lacustrine environment and fisheries.*

Project title: **Local Applications of Remote Sensing Techniques (LARST) for Monitoring of Wildlife and National Parks**
SIS Record number (MFN): 04685
Implementing agency: Overseas Development Administration (Natural Resources and Environment Department, NRED)
Project identifier: 793-625-104-YK
Start date: 1 April 1992 End date: 1 March 1995
Country/countries: Botswana, Namibia, UK, Zimbabwe
Total project cost: £120,200
Statement of objectives/abstract: *The wider objective of the project is to improve local management of wildlife, in and outside wildlife and other parks and to develop strategies for more effective management of national parks. The immediate objectives are: to develop application software (modules) to be used locally; develop and prototype applications modules relevant to wildlife and park management; develop with collaborators a system capable of tracking wildlife, using the ARGOS service available on NOAA satellite; and report on remote sensing opportunities in wildlife management.*

Project title: **Quantification of Fish Losses**
SIS Record number (MFN): 04778
Implementing agency: Overseas Development Administration (Natural Resources and Environment Department, NRED)
Project identifier: 793-624-102-YK
Start date: 1 April 1992 End date: 31 March 1995
Country/countries: UK, United Republic of Tanzania
Total project cost: £250,268
Statement of objectives/abstract: *The wider objectives of this project are to: enhance the income of families involved in the production, processing and marketing of fisheries products; and develop a package of loss assessment methodologies applicable elsewhere. The immediate objectives are to: develop an appropriate and efficient package of loss assessment methodologies applicable in the United Republic of Tanzania; develop a project research structure responsive to the process development approach: quantify fish losses in terms of value; quantify other fish losses, i.e volume; and identify where losses occur and whom they affect.*

Project title: **International Center for Living Aquatic Resources Management (ICLARM)**
Record number (MFN): 05363
Implementing agency: International Center for Living Aquatic Resources Management
Project identifier: S-C NETWORK
Start date: 1977 End date: —
Country/countries: Global; Malawi; Bangladesh; Indonesia; Peru; Philippines; Solomon Islands; Zambia
Total project cost: US$2,230,000 (1986 budget)
Statement of objectives/abstract: *Improving productivity of coastal and inland fisheries as well as aquaculture. ICLARM conducts and stimulates research on critical problems related to the exploitation, management, and utilization of living aquatic resources. The multidisciplinary approach is broad, ranging from basic biology to socio-economics. ICLARM programme areas are Resource Assessment and Management, Aquaculture, Education and Training, and Information. Some specific ICLARM activities include: (a) fisheries stock assessment and management modules in Indonesia, Peru, the Philippines, and Zambia; (b) development and wide dissemination of calculator and microcomputer programmes and manuals for fisheries stock assessment and management; (c) evaluation of small-scale fisheries management options in Asia and the Pacific; (d) research and planning for integrated coastal resources management in ASEAN member states of Southeast Asia; (e) genetics of major cultured freshwater species, especially tilapias, to develop improved strains and better broodstock and seed management practices; (f) the integration of aquaculture systems into existing agriculture systems in a manner which encourages broad participation by small-scale farmers; and (g) analysis of economic and policy issues to identify means to accelerating technology transfer and its application.*
Type of funding: jointly financed (Joint financers: AIDAB; Ford Foundation; GTZ;NORAD; Rockefeller Foundation; UNDP; USAID; DANIDA; FAO; ADB; IDRC; Kuwait Institute for Scientific Research; New Zealand; Planters Products, Inc.; San Miguel Corporation; Skaggs Foundation; ODA; United National University; World Bank).
General notes: Technically, ICLARM is an international center. ICLARM has no research laboratory of its own and few staff members. ICLARM operates very much like a network by relying mostly on facilities and personnel of state/national, regional, international centres.

Project title: **Microbiology in Relation to Agricultural and Environmental Issues**
SIS Record number (MFN): 05678
Implementing agency: University of Nijmegen, Department of Microbiology and Evolutionary Biology, Faculty of Science
Start date: 1 January 1993 End date: 1 June 1997
Total project cost: NLG4,000,000
Statement of objectives/abstract: *The objective of the project is to establish an applied microbiology unit at the university of Dar es Salaam well equipped to perform research and carry out consultancies at microbiological problems related to agricultural and environmental issues. Project activities are the following: (1) to set up an education programme in applied microbiology at the University of Dar es Salaam at the BSc, MSc and PhD levels; (2) training of staff members of the University of Dar es Salaam in a sandwich structure up to the PhD level. The experimental work during this phase is done at the University of Nijmegen; and (3) carry out microbiological research by the unit of applied microbiology at the University of Dar es Salaam. Part of this research is done in co-operation with the Dept of Microbiology and Evolutionary Biology, Faculty of Science, University of Nijmegen, the Netherlands. The project activities were funded up to the end of 1992 by DGIS (Directorate General International Co-operation) and for 1993–1997 via Nuffic within the MHO programme. On the Dutch side the Dept of Microbiology and Evolutionary Biology, Faculty of Science, University of Nijmegen is involved. The Unit of Applied Microbiology is located within the Dept of Botany at the University of Dar es Salaam.*

Project title: **United Republic of Tanzania: Quantification of Post-harvest Losses of Fish**
SIS Record number (MFN): 05740
Implementing agency: Overseas Development Administration (Natural Resources and Environment Department, NRED)
Project identifier: 793–624–107–YK
Start date: 1 January 1993 End date: 31 March 1995
Country/countries: UK, United Republic of Tanzania
Total project cost: £42,400
Statement of objectives/abstract: *The objectives of the project are to: develop a package of loss assessment methodologies applicable in the United Republic of Tanzania and elsewhere; quantify fish losses in terms of value; and identify where losses occur and whom they affect.*

Project title: **Adaptation of an Improved Fish Smoking Kiln (developed by National Resources Institute (NRI) to meet the needs of artisanal fishing communities in Uganda)**
SIS Record number (MFN): 05764
Implementing agency: Overseas Development Administration (Natural Resources and Environment Department, NRED)
Project identifier: 793–624–105–YK
Start date: October 1992 End date: 31 March 1994
Country/countries: Uganda, UK
Total project cost: £40,500
Statement of objectives/abstract: *The wider objectives of this project are to: improve the quality and quantity of food products from the fisheries sector in IDCS; and improve living standards of fisherman and fish traders and processors. The immediate objectives are to: assess the effect of bacteriological contamination of pond water on the quality of farmed fish; and establish bacteriological contamination levels compatible with acceptable quality of two aquaculture species.*

Project title: **Zambia Environmental Assessment and Planning Support Programme (NEAPP)**
SIS Record number (MFN): 06389
Implementing agency: World Conservation Union (IUCN)
Project identifier: ZM006702
Start date: 1 April 1994 End date: 1 April 1997
Country/countries: Zambia
Total project cost: NLG4,360,147
Statement of objectives/abstract: *This project will support operationalization of the concept of environmental protection and control by institutional support and training. Objectives: Long term objective: to develop a practice-oriented environmental assessment / planning programme by strengthening capacity of the NEC, MENR and other key Ministries at the central and provincial Government levels. Short term objectives: 1. Strengthening the Environmental Assessment and Planning Capacity of NEC. 2. Development of an Environmental Economics Capacity Institutional setting. The World Conservation Union (IUCN), through its Zambia Country Office and with backstopping from the IUCN-Regional Office for Southern Africa in Harare and IUCN's Global Conservation Strategy Services, acts as the contracting agency and is responsible for planning, managing and administration of the programme.*

Project title: **Specific Studies on Limnology and Hydrology of the Great East African Lakes. A Case Study of Nutrient and Pollutant Loading into the Northern region of Lake Victoria**
Implementing agency: *UNESCO-ROSTA (Nairobi)/ Makerere University Kampala, Uganda*
Start date: December 1994 End date: December 1995
Country/countries: Uganda
Total project cost: US$15,000
Statement of objectives/abstract: *This project aims to assess the current nutrient and pollution sources and loads into the northern part of Lake Victoria. Studies relate pollutant loading into the lake to the observed ecological changes including the infestation of the lake by the water hyacinth. The studies cover the towns of Kampala, Jinja and Entebbe, which discharge their effluent through wetlands fringing the lake.*

For projects implemented by universities and research institutes see Crul, 1995; 1997; Crul *et al.*, 1995:

- CNRS/Japan Coop. Study Ecology Lake Tanganyika
- IDEAL
- PROBE
- CASIMIR/SIAL
- University of Burundi/ University of Arizona
- University of Burundi/ University of Ghent
- KMFRI Kenya / University Oklahoma
- LBDA Kenya / University Milan
- KMFRI / LVRCP
- Makerere University Uganda / Harvard University /New England Aquarium
- FIRI Uganda/ NSF Switzerland