Lake Malawi/Nyasa

Experience and Lessons Learned Brief

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1. Introduction

Lake Malawi/Nyasa (Figure 1) is the ninth largest, and third deepest, freshwater lake on Earth (Bootsma and Hecky 2003). In addition to its great size, it is distinguished by being home to a greater diversity of fish species than any other lake, the majority being endemic (Fryer and Iles 1972; Ribbink *et al.* 1983). As a result of these two qualities—its great size and biodiversity—the lake is recognized as part of the global heritage. At a time when both the quantity and quality of freshwater are becoming issues of concern in many parts of the world, the value of a lake that contains nearly 7% of the Earth's available surface freshwater is becoming increasingly obvious.

Within the Lake Malawi/Nyasa catchment, the lake's fisheries are seen as its primary asset. The fisheries are an important source of protein for riparian populations within Malawi, Tanzania and Mozambique, and make a significant contribution to the regional economy, especially within Malawi. Other benefits of the lake include water for irrigation, transportation and hydroelectric generation.

Formal management activities of one form or another have been carried out for Lake Malawi/Nyasa since the 1930s, although local management practices were probably implemented for centuries before then (Munthali 1994). Virtually all management activities, and much of the research, have focused on the lake's fisheries. Despite these management activities, total fish catches have declined, and the catch of some fish species has been dramatically reduced, especially in the southern part of the lake (Tweddle and Magasa 1989; Turner *et al.* 1995; Banda *et al.* 1996; Bland and Donda 1995). Thus, there remains a need to refine and better implement effective fisheries management strategies.

While fish species composition has been altered as a result of fishing pressure, Lake Malawi/Nyasa has not experienced a decline in species numbers, in contrast to some other African lakes (e.g., Lake Victoria). Nevertheless, continued increasing fishing pressures, along with changes in plankton community structure and water quality, may lead to a decreased biodiversity, and even losses of species, if preventive action is not taken. Sediment core data and historic phytoplankton data (Hecky *et al.* 1999) suggest that nutrient inputs to the lake may be increasing, and possibly causing changes in phytoplankton species composition.

Figure 1. The Lake Malawi/Nyasa Basin.

The current issues of primary concern for Lake Malawi/Nyasa, therefore, are fisheries management, biodiversity conservation, and water quality. This brief provides an overview of the historic and current management activities related to these issues, and, based on lessons learned from previous research and management activities, recommendations regarding management strategies for promoting sustainable fisheries management and conservation of biodiversity and water quality.

It should be noted that the lake is called "Malawi" in Malawi, "Niassa" in Mozambique and "Nyasa" in Tanzania. For simplicity, this brief refers to the lake as Lake Malawi/Nyasa, with no preference implicit in the order or exclusion of names; however, exceptions made for terms such as formal project or commission names.

2. Background

2.1 Biophysical Features

Lake Malawi ranks among the world's largest lakes, being the third deepest and ninth largest by surface area. Its geography reflects the fact that it is situated in a rift valley, the lake being long, relatively narrow, and deep. Its basin consists of a series of half-grabens (blocks of earth that have tilted and dropped during rifting). Some parts of the lakeshore are bordered by steep mountains, while the mountains that define the edges of the rift valley are separated from the lake by extensive lakeshore plains in other parts. As a result, nearshore topography varies between gently sloping beaches and steep, rocky coastline. The lake is underlain by more than 4 km of sediment in its deepest regions, reflecting its great age, estimated at several million years (Johnson and Ng'ang'a 1990; Owen *et al*. 1990).

Although some of the plateau regions around the lake contain thick colluvial soils, the drainage basin is dominated by metamorphic and igneous gneiss, schist and granite (Carter *et al*. 1973). The northern two-thirds of the watershed are predominantly a mixture of woodlands (evergreen, Brachystegia) and agriculture. The southern third is woodland on the Mozambique coast, but almost completely cultivated land within the Malawi portion of the watershed, with the exception of the steep hillsides on the western side of the rift valley, which are forest covered.

Table 1. Physical Characteristics of Lake Malawi/Nyasa.

Surface area (km^2)	29,500
Maximum depth (m)	700
Mean depth (m)	264
Volume (km^3)	7,775
Altitude (m asl)	474
Drainage area (km^2)	100,500
River inflow (km^3/yr)	29
River outflow (km^3/yr)	12
Rainfall (km^3/yr)	39
Evaporation (km^3/yr)	57
Residence time (years)	114

Source: Modified from Bootsma and Hecky (2003).

The largest part of the lake's watershed is within Malawi, followed by Tanzania and Mozambique (Figure 1). The watershed population density is greatest in the southern Malawian portion, although it is also relatively high at the northern end, in the Songwe and Kiwira River catchments. The watershed is more densely populated than that of Lake Tanganyika, but less than that of Lake Victoria.

Despite its large size, the lake does not have a high outflow water volume (Table 1). Of the approximately 68 km^3 of water that enters the lake annually, only about 16% flows out the Shire River, with the remainder being evaporated directly from the lake surface. Thus, the lake has a very long flushing time (Table 1). This distillation effect results in the lake water being more concentrated with regard to conservative ions than are its inflowing rivers. The long flushing time also has important water quality ramifications. Nutrients or other chemicals entering the lake essentially become trapped in the lake, and can only be removed by burial in the sediments, loss to the atmosphere (if the chemical has a gaseous phase), or the very slow process of water outflow through the Shire River.

The dominance of precipitation and evaporation in the lake's hydrologic cycle means that it also is very susceptible to changes in climate. A small increase in the precipitation: evaporation ratio can result in flooding, as occurred in 1979-80; in contrast, a small decrease in the ratio can result in the basin becoming closed with no outflow, as occurred between 1915 and 1937 (Kidd 1983). In recent years, the lake level has again been declining, and the lake nearly became closed at the end of 1997.

The lake is permanently stratified into three layers, separated by differences in water density (controlled primarily by temperature). The top, warm layer (epilimnion) varies in depth between 40-100 m, being deepest during the cool, windy season (May to September). Most algal growth occurs in this layer, supporting the lake's food web. The middle layer (metalimnion) is several degrees cooler than the surface layer, extending from the bottom of the epilimnion to about 220 m. Within this layer there are strong vertical gradients of dissolved nutrients and oxygen. The deepest layer (hypolimnion) extends from about 220 m to the lake bottom. This layer is the coolest (most dense), and contains high concentrations of dissolved nitrogen, phosphorus and silica. It is completely anoxic (no dissolved oxygen); thus, virtually no fish are found below 220 m.

Although the lake has never been known to completely mix vertically, there is a slow exchange of water between the three layers. The exchange rate varies with season and location. Generally, there is a greater upward flux of nutrientrich waters from the hypolimnion and metalimnion to the surface during the cool, windy season when the southeast trade winds blow (known locally as the *mwera*). In addition to vertical entrainment and mixing, upwelling can occur in parts of the lake during this season. Due to the lake's morphometry (shape), upwelling tends to be strongest in the lake's southeast arm. Thus, plankton production is usually greatest in the southeast arm during and shortly after the windy season (Bootsma 1993a; Patterson and Kachinjika 1995). Phytoplankton species composition also varies with season and location. Diatoms are usually dominant during the windy season, and can be dominant for much of the year at the lake's southern end (Hecky and Kling 1987; Bootsma 1993a; Patterson and Kachinjika 1995). Following the windy season, cyanobacteria (blue-green algae) often dominate during September to November, with surface blooms of filamentous blue-green algae (*Anabaena* spp.) often observed. Between December and April, the phytoplankton is often a mixture of small diatoms, blue-green algae, and green algae.

On a trophic scale (commonly used to classify lakes according to productivity), Lake Malawi can be classified as oligotrophic to mesotrophic (i.e., low to medium productivity). Chlorophyll-*a* concentrations (an index of algal abundance) are low—usually below 1 μg/L.

Pelagic (offshore) waters of the lake are very clear most of the year, due to low concentrations of dissolved organic compounds and suspended solids. However, large parts of the lake, particularly near shore, can become turbid during the rainy season, when rivers bring in large quantities of suspended solids.

Lake Malawi is the most species-rich lake in the world, containing an estimated 500 to 1000 species (Fryer and Iles 1972; Konings 1995). Eleven families of fish exist in the lake, but one family—the Cichlidae—makes up over 90% of all the lake's fish species, almost all of which are endemic. Diversity of the pelagic cichlids is high by any standards, but is greatest in the nearshore communities. In the rocky nearshore waters of Lake Malawi, more than 500 individuals and 22 species can be found in a 50-m^2 area (Ribbink *et al.* 1983). Not only are the cichlid species endemic to each lake, but within each lake local endemicity is common among the nearshore fishes, so that certain species or color forms are confined to specific islands or isolated rocky segments of the shoreline (Fryer and Iles 1972; Ribbink *et al.* 1983; Konings 1995).

The total fish catch is difficult to estimate, due to the large number of small-scale fishers and the government's limited capacity to collect sufficient catch data. Thompson (1995) estimated that the total annual catch is approximately 30,000 tonnes, while Lewis and Tweddle (1990) earlier estimated that the annual catch of one species alone, *Engraulicypris sardella* ("usipa"), may have exceeded 50,000 tonnes. The majority of the artisanal fishery yield is made up of *Copadichromis* spp. ("utaka"), *Engraulicypris sardella*, and *Lethrinops* spp. ("chisawasawa"). Yields of catfish and "chambo" (*Oreochromis* spp.) have decreased, currently making up less than 20% of the total catch (Irvine *et al.* 2002).

2.2 Political Features

Lake Malawi/Nyasa is shared by three countries—Malawi, Tanzania and Mozambique (Figure 1). The majority of the lake and its catchment lie within Malawi. The position of the Malawi-Tanzania border within the lake is contested; Malawi accepts the border running along the eastern shore of the lake, while Tanzania accepts it to run through the lake. Approximately 25% of the catchment is within Tanzania (Kidd 1983), although land use within Tanzania may have a disproportionate effect on the lake since the annual rainfall is greater at the northern end of the lake, with the river inputs therefore being greater. Approximately 20% of annual river inflow to the lake comes from the Ruhuhu River in Tanzania (Kidd 1983). About 7% of the catchment area is within Mozambique.

As mentioned above, the population density is greatest in the southern part of the catchment within Malawi. According to the Malawi National Statistics Office, the population of Malawi was 9.9 million in 1998, with an annual growth rate of 2.0%. The northern and central regions of the country, which make up most of the Malawian portion of the lake catchment, contain 12% and 41% of the total population, respectively. However, the population growth rate in the northern region is higher than the national average, at 2.8% per year. Fourteen percent of the population lives in urban areas, with the urban population growth rate being about 4.7% per year. Within the portion of the population considered "economically active" (68%), 78% are subsistence farmers, while 13% are employees. In contrast to the Malawian portion of the catchment, the eastern and parts of the northwestern shores of the lake have relatively pristine vegetation, low population densities, and are lightly exploited. These areas are relatively remote from the centers of Tanzanian and Mozambican government and have been little developed. However, the two governments are making attempts to raise the economic standards of these regions through tourism and agricultural development.

Agriculture is the mainstay of Malawi's economy, accounting for almost half of the GDP, and for almost all export revenues. Agriculture also accounts for half of the GDP in Tanzania, and 35% of the GDP in Mozambique. Within Malawi, the fishing industry contributes between 2 and 4% to the GDP, employing almost 300,000 people either directly or indirectly. Over 80% of the total fish landings is from small-scale fishers. In the southern part of the lake, however, there is a commercial fishery (MALDECO) that targets fish stocks further offshore than do most artisanal fishers. Within Malawi, fish are estimated to provide about 70% of dietary animal protein (Bland and Donda 1995), with the majority of the fish coming from Lake Malawi/Nyasa.

In addition to fish and freshwater, other economic benefits gained from the lake include electricity, transportation, and an ornamental fish trade. The majority of electricity produced in Malawi comes from hydroelectric plants on the Shire River, which drains the lake. However, fluctuations in the river discharge, which is controlled by the lake level, make this power source precarious, particularly since the level of Lake Malawi/Nyasa is very sensitive to climatic changes. Between 1915 and 1935, the lake was completely closed, with no outflow. More recently, as a result of low lake levels in 1997, electrical power was being rationed in October and November, at the end of the dry season. There currently are plans to extend power lines from the Matambo power station in Mozambique's northwestern Tete province to the southern region of Malawi.

Large-scale transport on the lake is conducted almost exclusively by the government-owned Malawi Lake Services, which operates passenger and cargo vessels. The business is currently being operated under a 20-year concession to a private firm. Vessel operation is irregular, however, due to frequent breakdowns and concerns about low draught in some of the ports.

Lake Malawi/Nyasa's ornamental fish trade consists of two businesses, one based in Senga Bay and the other in Chipoka. While some exported species are directly from the lake, others are bred in tanks at Senga Bay. The ornamental fish trade in 1994 was valued at US$276,000 (Msiska 2001).

With a population of about ten million people, a growth rate of approximately 3% (Department of Research and Environmental Affairs 1999), and a resultant population density of about 106/km^2, Malawi is one of the most densely-populated countries in the sub-Saharan Africa. Associated impacts of the burgeoning human pressure include unsustainable agricultural and livestock grazing practices, shoreline occupancy for easy access to fish and water, and deforestation (Hecky 1993).

Malawi is one of the least developed countries in the world, with an estimated per capita income of about US$230. According to the World Bank, 43% of smallholders do not have sufficient income to acquire their most basic needs, while 30% do not have sufficient income even to meet their caloric needs. It is estimated that poverty is at a 60% level in rural areas, while it affects 65% of the urban dwellers. The main causes of poverty are low agricultural productivity, low non-farm income, low education, and poor health (UNDP/GOM 1993).

The implication of this low income is that farmers are unable to purchase inputs to improve their agronomic practices. Secondly, it means that, during the growing season, farmers have to work as casual laborers on commercial farms, at the expense of managing their own lands in an optimal manner.

Present experience in Tanzania shows that major sectoral water users (e.g., irrigated agriculture, hydropower generation) have independently been implementing parallel targeted development programs. A coordination mechanism of implementing projects is required. It has been further realized that the country's development programs have emphasized only water supply, and have not considered water resources management aspects as an integral component.

As part of the development of a water resources management capability, the country has been divided into nine basins, and new water resources management initiatives are being developed, using these basins for management units. A rapid appraisal was completed to rank the issues in order of importance for each basin. The basins within the Lake Malawi/Nyasa catchment are not currently prioritized. Further, the responsible government department currently is only able to provide resources for developing two of the basins, based on the presence of hydropower or irrigation infrastructure. Basin Water Offices are being established, and are envisioned to be self-financing.

Experience has shown that fragmented planning and management, lack of integrated sectoral approaches to development and conflicting sectoral policies are the main causes of water use conflicts in Tanzania. These conflicts highlight the need to manage the available water resources in a comprehensive manner, taking into consideration integrated plans in cross-sectoral uses of water, land-use, pollution control, environment and public health considerations on a basin-wide basis (World Bank 1996).

As part of a sector wide review, a comprehensive Rapid Water Resources Assessment (RWRA), based on existing information, was completed. The issues specifically identified for the Songwe and Ruhuhu basins include water pollution, impacts on fisheries, conservation of sensitive ecosystems (specifically wetlands on the Songwe River system), and intensive cattle grazing in the catchment.

The small portion of the lake's catchment that lies within Mozambique is in the province of Niassa. Although land in this province is very fertile, it is the country's most sparsely-populated province, with a total population of less than one million, despite attempts by the Mozambique Government to promote immigration to this province from other provinces. In an effort to promote development within this region, Mozambique and South Africa signed an agreement in 1996 to make land within Niassa province available to South African farmers.

Mozambique's economy has greatly improved since the end of the civil war. Between 1996 and 2000, the average annual inflation decreased from 47% to 2%, and GDP grew by almost 10% per year. In 2002, the economic growth was 12%—the best on the African continent. Although little of this development has extended to the Niassa Province, there has been a recent rapid expansion of tobacco growing and curing in this province. Ninety-five percent of the cultivated land comprises traditional, family-run farms, with an average size of 2 hectares.

3. Biophysical Environment

3.1 Temporal Trends: Past and Current Conditions

Because of its large volume and long hydraulic residence time (the annual river inflow to the lake is only 0.4% of the lake's total volume), Lake Malawi/Nyasa may respond very slowly to increased inputs of certain contaminants and, therefore, the detection of changes over time may be difficult if only the lake water is monitored. Although monitoring rivers and atmospheric inputs will provide a more sensitive analysis of temporal change, historic data on river water quality is very sparse, with the earliest measurements of atmospheric nutrient deposition made in 1990-91 (Bootsma *et al*. 1996). Nevertheless, historic limnological data suggest the lake may be responding to changes in land use within its catchment.

Because nutrient concentrations are low in Lake Malawi/Nyasa, phytoplankton concentrations also are low. The surface water concentrations of dissolved nitrogen and phosphorus typically are below 0.4 μmol/L and 0.1 μmol/L respectively, and the chlorophyll-*a* concentrations (used as an index of phytoplankton abundance) are below 1 μg/L. There is no evidence that current nutrient concentrations are greater than in earlier years. However, the nutrient concentration is a poor indicator of the rate at which nutrients are delivered to a lake, primarily because nutrients are rapidly assimilated by phytoplankton. Thus, their concentration may remain low even when nutrient delivery rates have increased. While there is insufficient historic data on nutrient inputs from rivers to determine if inputs to the lake have increased, analysis of sediments in the lake provides an alternative method of examining the lake's history. Recent sediment cores suggest that phosphorus inputs to the southern half of the lake have steadily increased over the past half century (Hecky *et al*. 1999). A similar trend is not apparent for the northern half of the lake, although there is some uncertainty as to whether the core data for this region adequately represents recent conditions.

Because phosphorus appears to be an important nutrient controlling phytoplankton production in the lake (Guildford *et al*. 2003), increased inputs of this nutrient might be expected to produce increased phytoplankton abundance. Although there is no strong evidence for this having occurred, a comparison of phytoplankton species composition in sediment cores, and among various studies conducted over the past several decades, suggests there has been a shift in species dominance. In the southern part of the lake, the previously-common *Planktolyngbya nyassensis* has been replaced by *Planktolyngbya tallingi*, a species more commonly seen under conditions of higher nutrient concentrations and lower light availability (Hecky *et al*. 1999). In addition, the potentially toxic species *Cylindrospermopsis raciborski* was recently reported. Understanding of the lower food web structure in the lake is insufficient to determine whether or not such changes may affect the zooplankton and fish production. In October 1999, however, a massive fish kill occurred along the entire western shore of the lake, with toxic algae being a possible cause for this kill.

The most likely cause of the apparent increase in phosphorus input to the lake appears to be land use changes. The majority of the Lake Malawi/Nyasa catchment is in Malawi, where the population has doubled in the past 25 years. Most of the population relies directly on subsistence agriculture for food, with the high population density resulting in the expansion of subsistence agriculture to marginal lands, including wetlands and steep hill slopes. Because application of fertilizers to agricultural land is minimal, it is unlikely that fertilizer application is causing in increased river loads of phosphorus. Rather, erosion of phosphorus-containing soils is the most likely cause of increased phosphorus loading to the lake. An indication of the extent of erosion in the lake catchment is provided by a comparison of dissolved organic carbon (DOC) and particulate organic carbon (POC) concentrations in tributary rivers. In undisturbed rivers, the DOC concentration is generally about 10 times the POC concentration. In contrast, in many Lake Malawi/Nyasa tributaries, the POC concentration is much higher than the DOC concentration (Ramlal *et al*. 2003), suggesting exceptionally high erosion rates within the catchment. Not only do these erosion rates result in accelerated nutrient inputs to the lake, the high suspended sediment loads in rivers increase the turbidity of nearshore waters. Data collected by Duponchelle *et al*. (2000) indicate that greater turbidity leads to decreased body condition in rock-dwelling cichlids in Lake Malawi/Nyasa, and the work of Seehausen *et al*. (1997) on Lake Victoria has shown that increased turbidity can lead to loss of biodiversity among cichlids.

In addition to catchment erosion, a large proportion of the nitrogen and phosphorus entering the lake originates from the atmosphere. There are no historic data for comparing recent measurements, but a global comparison indicates that atmospheric deposition rates of nitrogen and phosphorus in the Lake Malawi/Nyasa region (Bootsma *et al*. 1996, 1999) are among the highest in the published literature. There are several possible causes of these high deposition rates, including the large extent of biomass burning that occurs in this part of Africa (Andreae 1993), and increased exposure of soil to wind erosion, promoted by burning, deforestation and over-grazing of land. Because measurements of atmospheric deposition are usually made over land, it is difficult to determine how accurately these measurements reflect deposition rates on the lake. Based on sampling location relative to wind direction, Bootsma *et al*. (1996, 1999) argue that the rates measured near Monkey Bay and Senga Bay are probably applicable to the lake surface. While further measurements at different locations directly over the lake will result in a better understanding of the magnitude of these inputs and their potential sources, they are unlikely to alter the conclusion that the atmosphere is a major source of nitrogen and phosphorus for the lake.

Changes in land use not only affect erosion and nutrient inputs to the lake, they also appear to have had a significant effect on the hydrology within the catchment. A review of historic lake levels, rainfall records, and land use changes by Calder *et al*. (1995) indicates that between 1967 and 1990, forest cover in the lake catchment decreased from 64% to 51%, resulting in an increased water input to the lake, due to a decrease in terrestrial evapotranspiration rates. As a result, early-1990s lake levels were approximately 1 m higher than they would have been in the absence of this deforestation. While this may appear to be a benefit to the lake, the implications are probably negative for terrestrial systems and for streams and rivers, since stream flow tends to be less stable in deforested catchments.

Lake Malawi/Nyasa has not experienced exotic fish species introductions, such as those that have drastically altered the fish communities of Lake Victoria. However, water hyacinth (*Eichornia crassipes*) was first introduced to Malawi in the 1960s, and is now present in the lake and many of its tributaries. Although the plant is not abundant within the lake, probably due to the low nutrient concentrations, there is potential for water hyacinth to become a problem in the lake if nutrient inputs increase. This may have serious implications for biodiversity, since the lake's richest fish communities are found in the nearshore zone. Most of the water hyacinth currently found in the lake originates in its tributaries, and dies out in the lake. However, within the tributaries, and in the out-flowing Shire River, water hyacinth is abundant, having resulted in problems at the Liwonde barrage and at the Shire River hydro-electricity generating plants. The Malawi government initiated a biological control program in 1995, using the weevil *Neochetina* spp., which appears to have some success (Phiri *et al*. 2001), although water hyacinth remains a problem.

Because there are few large cities in the immediate vicinity of Lake Malawi/Nyasa, industrial and urban influences on the lake appear to have been moderate to date. PCB and DDT levels in the lake are similar to, or slightly lower than, those measured in the Laurentian Great Lakes of North America (Kidd *et al*. 1999). However, measured concentrations of some organochlorines, lindane and dieldrin in air and water indicate that their concentrations will continue to rise in the lake, since they are not yet at equilibrium with the atmosphere. Further, although concentrations of pesticides, PCBs and mercury in most fish from Lake Malawi are low, mercury levels in some larger fish species, such as mpasa (*Opsaridium microlepis*) and ncheni (*Rhamphochromis* spp.) are sufficiently high to be of potential concern to pregnant women and children (Kidd *et al*. 1999).

Even though it has been given little attention to date, climate change has occurred within the Lake Malawi/Nyasa region over the past century, and it will likely be more dramatic over the next century. Vollmer (2002) has meticulously reconstructed historic deep water temperatures for the lake, showing that the hypolimnion has warmed from 22.02°C to 22.74°C between 1939 to 1999. While this increase appears small, it is significant when one considers that the lake is very weakly stratified during the cold, windy season. The implications for lake nutrient cycles, plankton production and fish production depend on whether the surface waters have warmed more or less than the deep waters. If the surface has warmed more than the deep water, vertical mixing will be reduced, resulting in less nutrient supply and lower plankton production. While the current effect of climate warming on the lake is uncertain, air temperatures in this part of Africa are predicted to increase by approximately 4°C over the next century, and will likely alter lake levels, lake hydrodynamics and biogeochemical cycles.

While fishery catches have remained relatively stable in Lake Malawi/Nyasa, the catches of a number of larger, more economically-valuable species have declined dramatically, especially in the lake's southern arms of the lake where fish catches have historically been the greatest. These include catfish (*Bagrus* and *Bathyclarias* species), mpasa (*Opsaridium microlepis*), nchila (*Labeo mesops* and *L. cylindricus*), and chambo (*Oreochromis* species) (FAO 1993; Turner 1994, 1995; Irvine *et al*. 2002). The reduction in numbers of catfish and chambo is due to overfishing, while the decline of potamodromous fishes (mpasa and nchila) is likely due to a combination of overfishing and river and nearshore habitat degradation. The persistence of relatively constant catch rates, despite the declines in several species, is due to increasing fishing pressure and a reduction in net mesh sizes. As a result, the catch per unit effort has declined, as has per capita income (Bulirani 2003). Fish consumption has declined from 14 kg/person/year in the 1970s to less than 6 kg/person/year (Malawi State of the Environment Report, 2002).

To identify potential new fisheries, an ODA/SADC project, Fishery Potential and Productivity of the Pelagic Zone of Lake Malawi/Niassa, was implemented between 1987 and 1994 (field work commenced in 1992). This project identified untouched, deepwater pelagic fish stocks, consisting primarily of *Diplotaxodon* spp. and *Rhamphochromis* spp. (Menz 1995). These stocks have not yet been targeted, however, due to the logistic difficulties associated with the development of a pelagic, deepwater fishery.

Lake Malawi/Nyasa supports an ornamental fish trade, which targets nearshore cichlids, primarily in rocky habitats. This trade provides foreign exchange for Malawi, although its economic significance is probably very minor, relative to the artisanal fishery. There are few data to determine the impacts of this trade on the abundance and diversity of nearshore fish. As a result of escapes and dumping, however, some species have been introduced to parts of the lake in which they were not indigenous, resulting in disruptions of the structure of local fish communities (Ribbink *et al*. 1983).

Based on historic trends of fisheries, water quality, and hydrology, and recent data on river water quality, the main threats to the Lake Malawi/Nyasa ecosystem are:

- overfishing in some areas (nearshore, especially southern end of lake);

- increased nutrient inputs and changes in phytoplankton composition;
- sediment loading;
- loss of biodiversity due to fishing and nearshore water quality impacts; and,
- water levels (re: electricity).

The ultimate causes of these threats, in addition to overfishing, are:

- deforestation;
- sub-optimal agricultural practices;
- biomass burning; and,
- climate change.

3.2 Lake and Drainage Basin Resource Conflicts

Almost all resource conflicts within the Lake Malawi/Nyasa basin fall within four categories: (a) overfishing; (b) poor agricultural practices; (c) deforestation; (d) biomass burning.

Overfishing. As outlined above, overfishing is the result of increased fishing activity and use of illegal gear to catch smaller fish. This is primarily an issue in the southern part of the lake, as well as in Lake Malombe downstream from Lake Malawi. The problem is largely confined to Malawi, with overfishing not being a major concern in Tanzania or Mozambique. Within some parts of Malawi, the Fisheries Department is unable to collect sufficient data to allow estimates of maximum sustainable yield, or to develop management strategies (e.g., see Sipawe *et al*. 2001). Within the southern part of the lake, moderately good data on catch statistics are collected through trawl surveys and beach monitoring programs. Although these data are used to develop legislation and management strategies for the fishery, the government does not have the necessary financial resources to enforce fisheries regulations. Based on current patterns, the nearshore fisheries of Lake Malawi/Nyasa will continue to deteriorate.

Although the lake is shared among three countries, there presently is minimal conflict related to fish catches within the lake. The Mozambican coast has a low population density and, therefore, fishing pressure is low in this region. The dispute over the border location between Malawi and Tanzania at the northern end of the lake is primarily a political one, resulting in minimal conflicts between fishers of the two countries. This is because the fisheries are confined to nearshore regions, and few Malawians have access to the east side of the lake. However, if efforts are made to exploit the recently-identified pelagic fish stocks, the potential for conflicts will increase. This may become an even more contentious issue with the development of the Mtwara corridor, the goal being to promote transportation between Tanzania's Indian Ocean port in Mtwara and the northeast lakeshore region (southwest Tanzania), and to expand industrial activities (including natural resource extraction) within this region.

Poor Agriculture Practices. The vast majority of people (80%) living within the Lake Malawi/Nyasa catchment rely directly on agriculture for subsistence. As a result of increasing population density, as well as land tenure reform allocating land to large estates and conservation areas, the amount of land available to rural populations has been decreasing, forcing people to cultivate in marginal areas (wetlands, steep hill slopes, poor soils, etc.) that were previously untouched, with negative social, economic and environmental consequences that will become more severe over time. The governments of the riparian countries will inevitably need to promote economic diversification in order to lessen the direct dependence on land access, although current emphasis is on maximizing agricultural production. A significant proportion of the land in Malawi occupied by tobacco estates remains wooded because the land is being held by owners for future use. Because of the great need for land by smallholders, mechanisms to promote the agricultural utilization of this land are being considered. However, while this may promote agricultural production in the short term, it will have negative consequences with regard to soil erosion, water quality, and fuel wood supply.

In most developed countries, conflicts arise between agriculture and water management sectors because the excessive application of pesticides and fertilizers has negative impacts on the water quality and ecology of rivers and lakes. In the Lake Malawi/Nyasa catchment, soil erosion is the primary means through which agricultural activities affect the rivers and the lake. The impacts of fertilizers and pesticides are relatively small on a whole lake basis, although there is potential for localized impacts, particularly in cotton-growing regions and near large sugar plantations. Because soil erosion is detrimental to both water quality and crop production, there is no inherent conflict between the agricultural water management sectors, and improved soil and water conservation will benefit both sectors. The current challenge is to identify areas within the catchment where soil erosion is the greatest, and to implement feasible strategies to reduce erosion in those areas. Significant progress in this area has been made within the Lake Victoria catchment as a result of extension work conducted through the Lake Victoria Environmental Management Project (LVEMP), and lessons from that project would likely benefit managers within the Lake Malawi/Nyasa catchment.

Deforestation. As in the fisheries sector, the governments of the three countries have been unable to enforce forest management regulations, or to adequately monitor and inventory forest resources. Consequently, much of the forest and woodland resources are openly accessible to the public. The great reliance on wood as a fuel source and building material, combined with high population densities, is causing a rapid net loss of forests. While some of this loss is due to slash and burn activities associated with clearance of new land for agriculture, recent analysis of time-series satellite imagery reveals that much of the loss is via gradual attrition (2 to 3% per year) within forest reserves, conservation areas and national parks (Eastman and Toledano 1996). Some efforts have been made to promote forest and wildlife conservation in these areas through education and sustainable utilization (e.g., beekeeping and honey production). As with agriculture, however, the heavy, direct reliance on natural resources for sustenance and income, along with high population density, makes it impossible to both preserve woodlands and ensure the basic needs of people are met. This is perhaps most evident in Lake Malawi National Park, which includes five enclave villages almost completely dependent on trees within the park as a source of fuel and building materials. Regarding lake management, there is a huge disconnect between forest management and water quality management. Although water conservation is recognized by managers as a benefit of forests, catchment hydrology, water quality and fisheries production are not used to measure the success of forest management programs. Indeed, to forest managers, the ecosystem is the forest, not the larger catchment.

Biomass Burning. The final resource conflict, biomass burning, is one whose impacts on Lake Malawi/Nyasa have been under-appreciated. Although extensive measurements have not been made in many parts of East Africa, as previously noted, several studies (Bootsma *et al*. 1996, 1999; Langenberg *et al*. 2003) indicate a large portion of nitrogen and phosphorus entering the African Great Lakes originates from the atmosphere, with atmospheric nutrient deposition rates being greater in this region than in many other parts of the world. There is strong evidence that these high atmospheric nutrient loads are due directly and indirectly to burning (Bootsma *et al*. 1996). In fact, the region surrounding Lake Malawi/Nyasa is among the most frequently-burned regions of Africa. Although not well documented, there are probably multiple reasons for the burning, including the preparation of fields for cultivation, burning of woodlands to open up agricultural areas, promotion of early growth of grass for grazing animals, hunting, accidental fires, and traditions. Although it is evident that burning results in increased nutrient inputs to the lake, the impacts on lake nutrient cycles and plankton production requires further study. If this input is considered undesirable, reducing the atmospheric inputs to the lake will be an even greater challenge than reducing river inputs, because the former originate from a much larger area than the lake catchment, and their management will require a large effort to address the causes of biomass burning on a large, regional scale. Such an effort will only be successful if implemented from an agricultural perspective, since farmers and rural populations responsible for much of the burning have little incentive to change their practices for the betterment of the lake.

4. Management Environment

4.1 Government Management

Within each of the three riparian countries, lake research and management activities carried out by government institutions have been limited almost exclusively to fisheries, with the focus being on catch per unit effort (CPUE) data to set fishing restrictions. This work is carried out by the Fisheries Department and the Institute for Fisheries Research (Instituto de Investegação Pesqueira), respectively, in Malawi and Mozambique. In Tanzania, the Tanzania Fisheries Research Institute (TAFIRI) is responsible for fisheries research, with results being provided to the Fisheries Department. While some of these departments have recruited staff with training in areas such as water chemistry and plankton ecology, the relationship between fisheries and water quality, plankton ecology, and land use is given very little attention. Although the importance of biodiversity is recognized, the only management action to address biodiversity conservation has been the establishment of Lake Malawi National Park.

Within the larger catchment, management of natural resources is done on a sector basis. Government institutions directly involved with management of the lake and its resources are listed in Table 2. With the exception of Lake Malawi National Park, all lake management activities are focused exclusively on fisheries.

In addition to being strongly sectoral, natural resource management in the three countries is characterized by top-down management models, with minimal stakeholder involvement. While recent development programs have attempted to foster greater stakeholder input, ironically the lack of stakeholder involvement may be due to the large role that development organizations have played in managing natural resources within the region. Although management activities in the lake have been heavily supported by external development agencies, these agencies also have had a strong hand in directing of management activities as well, with the input of government agencies sometimes being post factum. Similarly, these donor initiatives may actually inhibit inter-

Table 2. Government Departments in Tanzania, Malawi and Mozambique Directly Involved in Managing Lake Malawi/Nyasa and Its Resources.

Tanzania	Malawi	Mozambique
Tanzania Fisheries Research Institute (TAFIRI)	Department of Fisheries	Institute of Fisheries Research
Tanzania Department of Fisheries	Department of National Parks and Wildlife (Lake Malawi National Park)	Institute for Development of Small Scale Fisheries
		National Directorate for Fisheries

sectoral collaboration because they are often developed with predetermined objectives and agendas dealing with specific sectoral problems but ignoring larger, ecosystem-scale issues. In addition, externally-funded programs may demand a great deal of time from senior government staff, detracting from longer-term initiatives that the government is pursuing independently (Bulirani 2003).

Although there currently is little integrated management of natural resources within the catchment and the lake, each government has structures in place to facilitate a transition to ecosystem-based management. In Malawi, a National Environmental Policy was approved by the Cabinet in 1996, being implemented through the Environment Management Act. It establishes a National Council for the Environment, with powers to mediate conflicts, and gives the Environmental Affairs Department responsibility for coordinating environmental monitoring, investments in natural resource sectors, and environmental education. Collaboration within Malawi and, to some degree, among Malawi and the other two countries, also has been promoted by the National Aquatic Resource Management Programme (NARMAP), implemented through the Department of Fisheries, funded by GTZ (Germany), and completed in 2003. While this program does not consider the terrestrial part of the ecosystem, it does attempt to promote collaboration and information sharing among various government and non-government agencies working on the lake, and a research approach that goes beyond the conventional focus on fisheries.

In Tanzania, the National Environmental Management Council (NEMC) has proposed a National Conservation Strategy for Sustainable Development (NCSDD), which includes an Environmental Action Plan that prioritizes natural resource problems, recommends actions, and identifies lead agencies for the actions. The environmental legislation to support this strategy is expected to be completed in 2004. As part of its National Environmental Action Plan, Tanzania has identified six priority environmental concerns, including land degradation, deforestation, water supply and water quality, pollution, deterioration of aquatic systems, loss of wildlife habitat and biodiversity. Overall coordination of natural resource management policy within Tanzania is the responsibility of the Department of Environment, within the Vice President's Office.

Within Mozambique, oversight of natural resource management is the responsibility of the Ministry for the Coordination of Environmental Affairs (MICOA). Management is guided by a number of sectoral policies, those most relevant to the lake being the National Policy on Environment (1995), the National Water Policy (1995), and the National Policy on Fisheries (1996). These policies were developed within sectors, with drafts being circulated among sectors for comment before submission to the Cabinet. In 2003, Mozambique completed the development of a National Environmental Management Programme (NEMP), which defines Mozambique's environmental policy, establishes the legal framework for this policy, and defines the institutional structures to implement the policy and enforce the laws.

The efficacy of these agencies has been limited to date. Although NEMC has had some success in getting various sectoral agencies within Tanzania to adopt a more collaborative, holistic approach to environmental management, little progress has been made in Malawi and Mozambique. There is not only a need to improve communication among departments, but also to have a central body responsible for the overall gathering, processing, and dissemination of environmental information at the ecosystem level, this lesson being emphasized in the final report of the Malawi Environmental Monitoring Program. In each country, significant progress recently has been made in defining long-term environmental management strategies. It is now imperative that these strategies be used to ensure that externally-funded development programs address the identified priority issues, that they mesh with government programs and agendas, and that they are coordinated with each other.

Until recently, there was virtually no coordination among the three countries regarding research and management in the lake and its catchment. In recognition of the need for such coordination, however, the three countries, with support from FAO, have recently (in 2003) developed a draft convention on the sustainable development of the lake and its basin. This draft convention proposes the establishment of a Lake Malawi/Niassa/Nyasa Basin Commission, which would be made up of a Council of Ministers, a Steering Committee, a Permanent Secretary, and a number of Standing Committees dealing with fisheries management, water resources management, and catchment management. Each country also is to establish a National Committee made up of representatives of various natural resource management institutions, academic institutions, private sector, and local community representatives. The Commission's proposed mandate would include data dissemination, promotion of training, public education and research related to the lake and to water resources, monitoring of environmental conditions in the lake basin, and enhancement of cooperation among various governmental and non-governmental agencies involved in activities related to natural resource management in the lake basin.

4.2 Development Programs

Due to extremely limited financial resources for research and management within each of the three countries, activities supported directly by the governments have been confined almost exclusively to monitoring fish catches, and the use of catch data to develop fisheries regulations. Even these activities are limited, however, due to lack of adequate research vessels and frequent breakdowns of available vessels. As a result, most of the research carried out on the lake over the past four decades has been implemented through donor agencies, usually in collaboration with regional fisheries departments. A list of some of the major projects is given in Table 3. Although this list is not exhaustive, it provides a large enough basis from which an assessment of the benefits of such projects can be made.

The general objective of many of these projects has been to assess the status of various fisheries in Lake Malawi/ Nyasa, and promote better management of these fisheries. Exceptions are the Malawi Environmental Monitoring Program, which focused more specifically on monitoring of terrestrial resources within the lake catchment, and the SADC/GEF Lake Malawi/Nyasa Biodiversity Conservation Project, which focused on biodiversity conservation (one of the six focus areas of the GEF) and, like the MEMP program, took a broad ecosystem approach.

The working strategy of most development projects has been: (a) to carry out some form of research or survey to obtain data; (b) to use these data to better understand the various aspects of the Lake Malawi/Nyasa ecosystem, including social and economic conditions; and (c) to apply this understanding to the development of management strategies to maintain or improve the status of the system with regard to natural resource (especially fish) production, water quality/quantity management, biodiversity conservation, and economic welfare of the riparian populations. Most projects also included training components and outreach components. Most projects have been reasonably successful in regard to points (a) and (b). Much more is know about the Lake Malawi/Nyasa basin ecosystem today than 30 years ago, primarily because of the work carried out by the projects above listed in Table 3, as well as work carried out within various government departments.

Table 3. Selected Development Projects on Lake Malawi/Nyasa between 1970 and 2003.

Project Title	Dates	Organization	Objective
Fishery Expansion Project	1977-1981	UNDP/FAO; Malawi government	Quantify potential yield of pelagic fish stocks in Lake Malawi/Nyasa.
Chambo Project	1988-1992	UNDP/FAO; Malawi government	Develop management plan for Chambo (Oreochromis spp.) in southeast arm of Lake Malawi, upper Shire River, and Lake Malombe.
UK/SADC Fisheries Project	1987-1994	UK DfID/SADC, governments of Malawi, Tanzania, Mozambique	Assess offshore fishery potential of Lake Malawi/Nyasa.
Lake Malawi Fisheries Development Project	1991-2000	World Bank	Facilitate access to offshore fishery through privatization of boat construction industry, construction of plank boats, and establishment of credit facilities for fishers.
Malawi Environmental Monitoring Program	1993-1999	USAID; University of Arizona; Clark University, Malawi government	Assess current environmental status and rates of change, and improve capacity to assess environmental impact of specific policies.
SADC/GEF Lake Malawi/ Nyasa Biodiversity Conservation Project	1995-1999	SADC; GEF (implemented by World Bank), CIDA; UNDP; UK DfID, DANIDA, FAO	Map diversity and identify threats to lake's biodiversity; propose conservation management strategies; educate public with regard to conservations need; assess environmental legislation and recommend revisions with regard to biodiversity conservation.
Ncheni Project	1996-2001	University of Hull; UK DfID, governments of Malawi and Tanzania	Determine diversity of pelagic cichlids and provide advice on sustainable exploitation.
Comprehensive Study on Lake Malawi Ecology for Sustainable Utilization	1998-2001	JICA; Chancellor College (Malawi)	Develop research facilities at Chancellor College; conduct research on fish genetics.
Preparation of a Preliminary Physical Processes and Water Quality Model for Lake Malawi/Nyasa	1999-2000	World Bank; University of Waterloo; Delft Hydraulics; UNU/INWEH	Develop initial hydrodynamic, water quality, and catchment models for Lake Malawi/ Nyasa, and provide training in model use.
National Aquatic Resource Management Programme (NARMAP)	1997-2003	GTZ (Germany)	Develop inland fisheries and aquaculture; conceptualization of participatory community fisheries management.
Lake Malawi Artisanal Fisheries Development Project	2003-2008	African Development Bank	Enhance management and utilization of fisheries resources, and protect tributary watersheds.

The information and understanding resulting from this work is absolutely essential to managing the ecosystem and its resources. This lesson has been learned repeatedly in various parts of the world, an example being the North American Great Lakes, which offer valuable lessons regarding the need for high-quality scientific data for effectively managing large aquatic ecosystems. Only after research indicated which nutrients were responsible for eutrophication, and where these nutrients were coming from, was it possible to develop and implement management strategies to reduce the impacts of eutrophication on the North American Great Lakes. In like manner, fisheries cannot be managed without adequate data on catch trends, fishing effort, and fish ecology. Biodiversity cannot be conserved in the face of intensive resource exploitation without understanding the mechanisms by which human activities may threaten it. Conservation of water quality and quantity, critical for fish production, biodiversity conservation, electric power generation, and human consumption, also requires a thorough understanding of hydrology at the ecosystem scale, and the biogeochemical processes influencing water quality. Research on the Lake Malawi/Nyasa ecosystem, including its drainage basin, has been a critical prerequisite to effective management, and will continue to be essential.

In regard to point (c) on the implementation of management strategies based on data and understanding, most development projects have had limited success. Despite the fact that our understanding of the lake ecosystem is better today than it was 30 years ago, total fish catches in Lake Malawi/Nyasa have declined by approximately 25% (Malawi 2002 State of the Environment Report), with the catch of some species, such as Chambo (*Oreochromis* spp.) declining even more. Although there are no reported species extinctions in the lake, the diversity of fish catches has greatly declined in some areas, some evidence that land use may be having a deleterious effect on water quality (Bootsma and Hecky 1999). There is clearly a need to more effectively translate the results of research into effective management strategies. This implementation is inhibited partly by economic constraints. In the case of fisheries management, strategies require enforcement, but the governments of the riparian countries do not have the financial resources to enforce regulations. One potential solution to this problem is increased involvement of the community in fisheries management, an approach currently being tested in parts of Lake Malawi/Nyasa, and that has achieved some success for Lake Victoria through the Lake Victoria Environmental Management Project, as discussed further below.

4.3 Community-Based Natural Resource Management

All three countries are currently implementing government "decentralization". In Tanzania, decentralization policy is enacted through the Regional Administration Act (1997). A 1999 revision of the Local Government Act states that local authorities are to provide for protection and proper utilization of the environment for sustainable development. In Malawi, decentralization was promoted through the 1998 Local Government Act. In Mozambique, the process of decentralization was initiated in the late 1980s, and has gone through a number of phases in the past 25 years. Mozambique conducted its first local government elections in 1998. In all three countries, the actual implementation of decentralization has been very slow and, although accepted in principle by many citizens, it is not always welcome by officials at regional or district levels, who may be unwilling or unable to assume increased responsibilities caused by decentralization. In Malawi, the process of decentralization, along with a series of frequent changes in government budgeting and accounting systems, has created confusion with the public service (Bulirani 2003).

One of the objectives of decentralization is to give communities greater control over managing local resources. While this has not been done with regard to terrestrial resources in the lake catchment, a large number of Beach Village Committees (BVCs) have been established in Malawi, both on Lake Malawi/Nyasa and on Lake Malombe, with the objective of promoting local management of artisanal fisheries. This was first initiated through the GTZ-funded National Aquatic Resources Management Program, with the initiative formally recognized by the government with the enactment of the Fisheries Conservation and Management Act in 1997. The success of these committees has been equivocal to date. Problems include internal conflict within BVCs, corruption, inadequate education of committee members, disparities between regulations for artisanal versus commercial fishers, and the apparent unwillingness of the Fisheries Department to transfer authority to the local level (Dobson and Lynch 2003).

5. Lessons Learned

5.1 The Need for an Ecosystem Approach

Although the fisheries departments in the three countries recognize that fish production and biodiversity conservation are linked to plankton ecology, nutrient cycling, physical limnology, and land-lake interaction, financial constraints restrict their activities to the most pressing concerns of fish production and fish catches. This approach has sufficed in the past, when external impacts on the lake were minimal, and fishing was the primary impact humans had on the lake. But as the population density has increased, so has the variety of ways in which human activities are affecting the lake, with signs that fish production and biodiversity in the African Great Lakes are now being influenced by factors other than fishing pressure, including the atmospheric deposition of nutrients (Bootsma *et al.* 1996), increased inputs of nutrients and sediments from the catchment basin (Hecky *et al.* 2003), changes in plankton community composition (Bootsma and Hecky 1999), climate change (Verburg *et al.* 2003) and alteration of habitat, including siltation and altered hydrology of rivers and streams (Calder *et al.* 1995). Thus, effective lake management will require an expansion, from the focus on fishing activities, to an ecosystem approach accounting for the relationship between fish, water quality, and hydrology, and the ways in which human activities are affecting them.

There is currently no government agency in any of the three countries responsible for monitoring or managing water quality in Lake Malawi/Nyasa. Although there are departments in each country responsible for overseeing water supply, these agencies deal primarily with domestic water supply, and do very little monitoring of water quality in the lake. The fact that no agencies are responsible for monitoring or managing water quality in the lake reflects the narrow focus of each of the natural resource management agencies.

As a natural resource, water is much more mobile than most. It is a medium that connects almost all natural resource management sectors, including forestry, agriculture, water supply, national parks and fisheries, with the lake and the fisheries being at the bottom (i.e., receiving end) of the hydraulic gradient. Until recently (i.e., the beginning of the last century), the impacts of various types of land use on hydrology and water quality in the Lake Malawi/Nyasa catchment were not great. When population densities were low, and urban/industrial development minimal, human activities in the terrestrial part of the catchment had little impact on water quality, biodiversity and fish production in the lake. However, it became apparent several decades ago that habitat degradation might be responsible for the declining riverine cyprinid fisheries, especially *Labeo* species (Alimoso *et al.* 1990), suggesting that the rivers and lake could not be managed in isolation. Due to its mobility, and its potential to be altered between the location of rainfall and the point of entry to the lake, water quality cannot be managed within a sector, or within geographic boundaries that ignore hydrologic boundaries. Thus, water quality/quantity problems in Lake Malawi/Nyasa cannot be managed within the lake; rather, they must be addressed upstream, in the forests, farmland, parks, and cities. Water quality management (and lake management) requires an ecosystem approach. Unfortunately, this approach is currently very weak in all three riparian countries.

Because there was not a great need for an ecosystem approach until relatively recently, it would be incorrect to state that recognition of the need for this approach is the result of a "lesson learned" in the Lake Malawi/Nyasa ecosystem. However, this lesson has been learned in other systems, including Lake Victoria and the North American Great Lakes. Thus, the Lake Malawi/Nyasa community of stakeholders has the opportunity to learn from these other systems, and develop an integrated management strategy that will prevent ecosystem alteration from becoming as extreme as it has in other large lakes around the world.

The need for a catchment-wide, international organization, such as the proposed Lake Basin Commission mentioned in section 4.1, is primarily a result of the need for an ecosystem approach. Until recently, there was not a strong need for coordination among the three countries in regard to lake management. Although fishing was the main activity affecting the lake, the impact of Mozambique on the fishery has been negligible, and there have been no significant disputes between Malawi and Tanzania regarding the fisheries at the northern end of the lake. Unlike Lake Victoria, where three countries each have had a significant stake in, and impact on, the lake's fisheries, Lake Malawi has experienced no real need for a fisheries management organization. But, as population density and land use intensity continue to increase in the Tanzanian and Mozambican portions of the catchment, and as exploitation of pelagic fish stocks in the northern part of the lake becomes more feasible (e.g., through development of the Mtwara corridor), the need for a coordinated ecosystem management approach also continues to increase. While this need was acknowledged in two recent projects on the lake (UK/SADC Fisheries Project; SADC/GEF Biodiversity Project), these projects had limited success in promoting collaboration among the three countries. As pointed out

Table 4. National Agencies in the Lake Malawi/Nyasa Catchment That May Potentially Play a Role in Development of an Ecosystem Management Strategy (Note: This list is not exhaustive).

Malawi	Tanzania	Mozambique
Land Resources and Conservation Department	Ministry of Water, Water Resources Department	Institute of Fisheries Research
Department of Forestry	Department of Forestry	Institute for Development of Small Scale Fisheries
Department of Agriculture	Department of Wildlife	National Directorate for Fisheries
Department of National Parks and Wildlife	Department of Fisheries	National Directorate for Water
Fisheries Department	Tanzania Fisheries Research Institute	Ministry for the Coordination of Environmental Affairs (MICOA)
Department of Environmental Affairs (DEA)	National Environment Management Council (NEMC)	Ministry of Agriculture and Rural Development
National Research Council	University of Dar Es Salaam	National Directorate of Forestry and Wildlife
University of Malawi		Niassa Provincial Deptartment of Water and Sanitation

in the Implementation Completion Report for the second project, creating an organization in which equitable treatment is maintained, while at the same time ensuring the benefits and responsibilities of each country are proportional to their impacts on the ecosystem, is a sensitive task. This is especially the case for Lake Malawi/Nyasa, which is impacted largely by activities within the country of Malawi, and minimally by Mozambique. Based on experiences in the above two projects, it will be critical during development of any tri-national lake basin organization to be very specific from the outset about the relative roles and responsibilities of each country within the organization. Agreement on the initial definition of these roles may be a challenge, since there is potential for conflict between political agendas, and the realities of management priorities within the basin. But an agreement that is specific, with regard to details of organizational structure, membership, funding, management and country obligations, will help to secure the long-term viability of this approach.

By definition, the ecosystem approach is multidisciplinary, requiring involvement of a number of different environmental sectors, including fisheries, hydrology, agriculture and forestry. Various government agencies that might be involved in an ecosystem management approach for Lake Malawi/Nyasa are listed in Table 4.

At a Lake Malawi/Nyasa modeling workshop held in Lilongwe, Malawi in 2000, representatives from a number of these agencies discussed the need for an ecosystem approach for natural resource management in the Lake Malawi/Nyasa catchment. There was unanimous agreement on the need for such an approach (the workshop results are presented as an appendix in the Final Report: Preparation of a Preliminary Physical Processes and Water Quality Model for Lake Malawi/Nyasa, available at http://www.uwm.edu/People/hbootsma/Lake%20Malawi/Model%20Report/Mdlind.htm).

It also was recognized that changes may be necessary in the approach that the various agencies take to natural resource management. In particular, it was pointed out that implementation of an ecosystem approach requires improved communication among the various sectors, and among the three countries. Agriculture and Forestry managers need to hear from Fisheries managers/researchers about how deforestation, soil erosion, chemical use, and biomass burning affect the lake and its biota. Fisheries managers need to know which parts of the catchment are most impacted by deforestation and poor agricultural practices. Based on this communication, these agencies, ideally under the umbrella of an overseeing environmental agency, need to identify and prioritize problems and develop coordinated management strategies. It was recommended that this could be facilitated partly by regional workshops focusing on the theme of water quality conservation, by development of a Lake Malawi/Nyasa internet site, and by a "mini monograph" on Lake Malawi and its catchment, providing all relevant agencies with an overview of current management issues within the lake and its surrounding terrestrial catchment. However, the most urgent need is for establishment of a regional organization devoted to the harmonization of management strategies within the Lake Malawi/Nyasa catchment. As pointed out above, this process recently was initiated through the proposal of a Lake Malawi/Niassa/Nyasa Basin Commission. Establishment of a lake basin commission, with sufficient clout to promote better communication and collaboration within and between countries, will be a major step forward in managing the Lake Malawi/Nyasa ecosystem.

One potential pitfall of the ecosystem approach is that it is so large scale that objectives may seem out of reach. In many cases, although problems are identified and management strategies designed, and even though general objectives are defined (e.g., improved water quality or reduced soil erosion), these objectives are not well quantified and timelines not set. In implementing management strategies, it is critical that quantitative, realistic goals are defined, and target dates for achieving these goals are set. This has rarely been done in natural resource management plans within the Lake Malawi/Nyasa ecosystem. Examples of quantitative goals include the specification of suspended solids loads in key rivers, specification of nutrient concentrations in rivers, or a targeted catch for a given fish species. These goals and schedules must be agreed to by all relevant management agencies in each riparian country. By setting specific goals and timelines, it becomes possible to determine the degree of success. Without some quantification of success, the management strategies become an end in themselves, with a loss of interest and motivation over time. Critical to this process is the monitoring of environmental conditions, since data collected through monitoring is the yardstick by which success is measured.

5.2 The Need for Integration of Research Findings into Management Strategies

In addition to the need for more inter-sectoral collaboration, a number of agencies stated a need for better communication between researchers and managers/policymakers within departments, between departments (e.g., TAFIRI and the Fisheries Department in Tanzania), and among countries. There appear to be two causes of this problem. In some cases, researchers are not proactive about providing their results to managers and policymakers and, therefore, thereby hindering an effective decision-making process. This can be solved by setting schedules for regular dissemination of research reports, and organizing regular workshops. Further, it appears that researchers often assume their results will be understood and applied by managers, and they typically do not follow through to determine how the results of their work are used.

This problem also is common in development projects, which tend to last long enough to gather and analyze information, but not long enough to follow through with the implementation of results. This is partly because implementation is usually viewed as the responsibility of governments. As mentioned above, however, many projects do not produce highly trained researchers and managers capable of independently continuing research initiated by a project, or determining how the research results should be applied to management strategies. As a result, projects often end with the convening of a final workshop, at which final reports are provided, but little momentum is carried forward. This problem can be exacerbated by the lack of interest or political will by government agencies to follow through on project recommendations. Only government agencies, and the individuals within those agencies that have heavily invested in the design and implementation of a project will be committed to following through with the application of the project results.

Recognizing the need for better communication, a recent NARMAP workshop was held in Malawi, with the objective of defining the structure for a network for fisheries and aquatic research (with the proposed acronym of NETFISHAR). The objective is to promote communication and dissemination of information among network members, and provision of information to the general public. While some progress has been made in defining the structure and membership of this network, the mechanisms for communication and information dissemination are still not well defined.

5.3 The Potential for Community-Based Management

A community-based management approach seems very appealing, because it places more power in the hands of resource users, and offers a potential solution to the problem of governments' inability to enforce regulations. As pointed out above, however, efforts to promote community-based management of fisheries by establishing Beach Village Committees on Lake Malombe and Lake Malawi/Nyasa have met with limited success (Dobson and Lynch 2003).

A number of recommendations were made in a recent workshop (NARMAP 2001) to improve the success rate of this approach, including:

- The "community" must be well-defined;
- There is a need to distinguish between land-based and lake-based communities;
- A community-based management approach must build on existing management systems in communities (e.g., traditional authorities);
- There is a need to assess the commitment of migrant fishers to this approach;
- There is no single model that can be applied to all communities, with different fisheries perhaps needing different management models;
- There is a need to better define the role of the Department of Fisheries in this new paradigm; and,
- Research results must be better disseminated and explained to communities.

In addition to these recommendations, the workshop concluded there was insufficient information on fish marketing at local and regional levels, and that the economic links between fishing and local non-fishing communities are not well-understood. In a survey of fishers, for example, Donda and Bell (1993) found that, while fishers are open to measures that will improve fishery income, they often are often reluctant to adopt such measures if they involve short-term sacrifices and social disruption.

Although co-management may resolve some fisheries management problems, it will not solve two basic problems: (a) the demands for natural resources exceeds the supply, and (b) continued access to fisheries as a "commons" will always result in over-exploitation (Brox 1992). Real relief will only come when the economic base of rural communities is diversified, with a decreased direct reliance on natural resources for sustenance and income (Hara 2001).

5.4 The Need for Knowledge and Education

Most development projects related to Lake Malawi/Nyasa have included some type of educational component (usually referred to as "capacity building"). In many cases, the capacity building takes the form of counterpart positions, in which one or more national trainees are assigned to work with an expert during the course of a project. In some cases, training also has included provision of formal education at the Master's or Ph.D. level. This education is generally obtained at a foreign institution, usually in Europe or North America, but is occasionally facilitated through a university in Malawi or another African country.

Training and education of qualified professionals are primary prerequisites for effective lake basin management. For example, educated scientists must monitor water quality and the health of fish stocks, and determine the processes that affect these properties. Educated managers must determine the strategic actions necessary to maintain high water quality and fishery yields. Both scientists and managers must advise policy-makers on appropriate strategies to facilitate conservation of water quality, fish production, and biodiversity. Indeed, the education of highly qualified researchers and managers is probably the single most important contribution that development projects can make to the sustained management of the Lake Malawi/Nyasa basin, and the economic welfare of the region as a whole. Osita Ogbu of the African Technology Policy Studies Network has pointed out that, "With knowledge you create your own wealth, with aid you create dependency." Nevertheless, the numerous development projects conducted in the Lake Malawi/Nyasa basin over the past four decades have met with limited success in this regard, due primarily to four major impediments that currently limit the effectiveness of training within development projects:

The lack of proper training in the aquatic sciences at the undergraduate level. The goal of most development projects with regard to education is to produce professionals capable of working independently in doing scientific research, ecosystem management, and environmental policy-making. Professionals with this capacity generally require a Ph.D. or, at least a Master's degree, in their respective field. Completion of these degrees usually requires two to five years, which is similar to or longer than the lifespan of most development projects. Thus, these projects require recruits adequately trained at the undergraduate level, and ready to enter directly into a Master's or Ph.D. program in aquatic sciences. Identifying such recruits within East Africa is difficult, particularly within Malawi, this problem being specifically highlighted in both the SADC/GEF Lake Malawi/Nyasa Biodiversity Conservation Project, and the USAID-funded Malawi Environmental Monitoring Program. As a result, there is stiff competition among natural resource management development projects for education counterpart staff with adequate undergraduate training. Many projects end up recruiting under-qualified counterparts. Although valuable training is still received, it is typically at the technical, rather than senior level. As a result, these projects fail to produce national leaders in the areas of research and management.

There are two possible solutions to this problem in the Lake Malawi/Nyasa region. The first is to have development programs include more training at the undergraduate level. However, there are two impediments to this approach: (a) the required educational programs are often not available in regional universities, making it necessary to send trainees out of the country, and (b) the requirement for a 6-10 year training program, if the goal is to ultimately produce professionals at the Master's and Ph.D. level, which is beyond the lifespan of most development projects.

The second solution is to work with regional post-secondary educational institutions to develop undergraduate programs that more directly address aquatic sciences. Areas in which educational capacity can be strengthened include natural resource management, limnology (aquatic chemistry, hydrology, hydrodynamics, plankton ecology), and fish biology/ecology.

The lack of a suitable post-project environment in which trained professionals can apply their skills toward research and management. In many cases, although trainees conduct their work in a highly goal-oriented and logistically well-supported project environment, this direction and support are quickly lost upon completion of a project. Although this lesson has been learned repeatedly over four decades of development projects, many projects are still designed with the assumption that trainees will ensure continued research and implementation of results after formal project completion. This generally does not happen, however, for several reasons. Lack of funds prevents continued work in many cases, including funds for equipment operation (including boats and ships), equipment maintenance, and expendable supplies and on-going expenses associated with research and management implementation. Departmental motivation/political will also is an impediment; unless department heads are seriously committed to the objectives of a development program, logistic support for achieving them will disappear soon after external support ceases.

Logistic and intellectual support also will help maintain motivation in trained scientists and managers, which can be facilitated to a large degree through regional and international collaboration. For example, the development of long-term relationships between research institutions in the Lake Malawi/Nyasa region and those in developed countries and in other parts of Africa will allow regional scientists and managers to conduct their work in a more global context, thereby allowing them to more easily stay abreast of current knowledge, and to be part of a larger community that fosters intellectual excellence.

The loss of highly trained professionals to other countries. A relatively large number of professionals trained through development projects eventually leave their home countries. Some do not return after receiving their degrees, while others may return, but eventually find positions in other countries. Although this problem is ultimately the result of economic conditions in the home country, there are actions that development projects, along with national governments, can take to improve the retention of trained professionals, including: (a) The working environment must be improved so that good work is rewarded. In many government positions, promotion is based more on length of service (seniority) than on performance; thus, there is little motivation for professionals to perform to standards of excellence, as well as frustration for those who do; (b) Trained professionals must have continued financial and intellectual support following the termination of a project. This can take the form of a commitment by their government department or institution for a minimal amount of support, or a commitment by the funding agency for a continued, moderate amount of financial support following the end of a project's main initial phases. Some efforts have been made to provide continued funding sources for African scientists on a competitive basis (e.g., the Wildlife Conservation Society's Africa Program; the Environmental Change Program of START (System for Analysis, Research and Training)), and increased support through such programs will likely increase the probability of retaining professionals in their home countries.

The high turnover rate of government positions. In all three Lake Malawi/Nyasa riparian countries (Malawi, Tanzania, Mozambique), government positions tend to be transient, with government employees frequently re-located within, and occasionally between, departments. Thus, many staff receiving specialized training in the context of a development project find themselves in positions where there is no need or motivation to apply the training they received. For example, staff in the Malawi Department of National Parks and Wildlife, who work in Lake Malawi National Park, will require specialized training in fish identification, SCUBA diving, and aquatic ecology. If these staff are re-located to a terrestrial park, however, they have little opportunity to apply their specialized skills, with the staff that replace them perhaps not having the required special training to carry out research and management in an aquatic park. An assessment of staff at the various fisheries research stations in the three countries around the lake would likely reveal that there is very little overlap between the current staff, and the staff that occupied these stations 10 years ago. Thus, insufficient time is allowed for many to develop a thorough expertise in one area.

In addition to training professionals, public education often is seen as critical for successful natural resource management programs. It is critical for compliance with management programs, and also prerequisite to the development of any community-based management programs, which have become more popular in the past decade. The approach of many projects to public education has been somewhat naïve, however, in that it often is assumed that, if the public is educated about the need for management, they will simply comply. There are several reasons, though, why compliance is uncommon. First, a mentality has been established in which local communities have come to rely on donor-funded initiatives to solve local problems. Indeed, the effectiveness of local communities in managing their resources has decreased in some cases as a result of donor and government intervention, mainly because the interventions fostered an attitude among the local community that it should be rewarded for its involvement in management activities. Second, political displacement of local authorities has left local communities with a sense of helplessness, and a loss of natural resource ownership. Returning a sense of confidence and self-control to communities requires a concerted effort by government agencies. In Malawi, this has been initiated through the process of government decentralization, put into place in 1998. To date, however, local communities have seen few benefits from this process.

Within some development projects and government extension programs, it is assumed that education in itself will lead to better natural resource management (i.e., if people know that their actions are harming the environment and leading to long-term negative impacts, they will change their behavior). However, the behavior of individuals is generally determined by the magnitude of the benefits derived by the individual, not the benefit to the overall community. Farmers told that soil erosion is bad for fish are unlikely to be concerned about soil erosion. In contrast, farmers told that soil erosion is bad for crop production will be concerned. Further, in some cases, management strategies beneficial for the ecosystem as a whole may not be beneficial locally (e.g., forest conservation on potential agricultural land). Thus, an ecosystem management approach cannot completely rely on education and community-based management. Rather, some level of government intervention is still required to prevent the "Tragedy of the Commons" (Hardin 1968).

5.5 Summary of Lessons Learned and Recommendations

- There is a need for a regional (tri-national) plan for management of the lake and its catchment;
- Management of the lake and catchment must be carried out with an ecosystem perspective, rather than the current fractured sectoral approach;
- Internationally-funded development programs must use national and regional plans as guides for developing agendas and priorities for externally funded projects; better dovetailing of these projects with national and regional agendas will promote collaboration, and minimize disruptions of on-going government programs and the excessive work loads on government staff;
- An ecosystem approach will require better collaboration and communication among sectors within and between countries. Government infrastructure within each country already exists to facilitate this goal. The nascent Lake Malawi/Niassa/Nyasa Basin Commission may be the best mechanism to promote regional collaboration;
- Goals and timelines, with specific targets, are required to guide the ecosystem approach and assess its success over time;
- Although internationally-funded development programs have greatly improved our understanding of the Lake Malawi/Nyasa ecosystem, implementation of recommendations arising from this understanding have not been well implemented. Lessons-learned include: (a) National and local governments must be more involved in the design of development programs; (b) Communication between researchers and managers/policy makers must be improved; (c) Governments are often unable to carry out implementation of recommendations because of both financial and human capacity limitations. While there is a continuing need for research and monitoring, the leap from research findings to applied management cannot be made by governments alone. Rather, development projects must also assist with the implementation of natural resource management programs; (d) There is lack of coordination among numerous related development programs. Thus, one of the main tasks of a lake basin organization should be to define research and management priorities, which can then be used as the basis for new development programs;
- Although there is potential for community-based management, it is not a panacea, and the relative roles of communities and government institutions must be defined;
- Fishers and other stakeholders must be better informed of research findings and implications, and must have more say in developing management plans;

- There is an immediate need for better enforcement of fishery regulations in the southern part of the lake;

- Although research in previous projects has improved understanding of fisheries, fish ecology, biodiversity, hydrology, hydrodynamics and nutrient cycles in the lake and its catchment, there remains a need for monitoring fisheries and water quality, and further research into current pressing issues, including the causes and consequences of atmospheric nutrient deposition, linkages between water quality and fish production/ biodiversity, mechanisms to ensure biodiversity conservation, impacts of continuing climate change, and prioritization of management areas both within the lake and drainage basin;

- Ultimate relaxation of fisheries pressure and land use pressure will require diversification of the economic base;

- There is a great need for longer-term investment in the education of scientists and managers in the field of aquatic natural resources. This will require an increase in the capacity of regional universities to provide education in aquatic sciences at the undergraduate level; and,

- Regional and international collaborative relationships must be strengthened to provide intellectual and, when possible, logistic support for national scientists and managers within the three riparian countries.

6. References

Alimoso, S., J. Magasa, and N. van Zalinge. 1990. "Exploitation and management of fish resources in Lake Malawi." In: *Fisheries of the African Great Lakes*. International Agricultural Centre, Wageningen, Netherlands. Occasional Paper 3. pp. 251-265.

Andreae, M.O. 1993. "Global distribution of fires seen from space." *EOS* 74: 129-135.

Banda, M.C., T. Tómasson, and D. Tweddle. 1996. "Assessment of the deep water trawl fisheries of the South East Arm of Lake Malawi using exploratory surveys and commercial catch data." In Cowx, I.G. (ed.), *Stock Assessment in Inland Fisheries*, Fishing New Books, Oxford. pp. 53-75

Bland, S.J.R., and S.J. Donda. 1995. "Common property and poverty: Fisheries co-management in Malawi." *Fisheries Bulletin* No. 30: 1-16.

Bootsma, H.A., M.J. Bootsma, and R.E. Hecky. 1996. "The chemical composition of precipitation and its significance to the nutrient budget of Lake Malawi." In: Johnson, T.C., and E.O. Odada (eds.), *The Limnology, Climatology and Paleoclimatology of the East African Lakes*, Gordon and Breach, Toronto. pp. 251-265.

Bootsma, H.A., J. Mwita, B. Mwichande, R.E. Hecky, J. Kihedu, and J. Mwambungu. 1999. "The atmospheric deposition of nutrients on Lake Malawi/Nyasa". In Bootsma, H.A., and R.E. Hecky (eds.), *Water Quality Report, Lake Malawi/Nyasa Biodiversity Conservation Project*, SADC/GEF. pp. 85-111.

Brox, O. 1990. "The common property theory: Epistemological status and analytical utility." *Human Organisation* 49(3).

Bulirani, A.E. 2003. "The challenges of developing an integrated approach to the management of Lake Malawi/ Niassa and its catchment resources." In Wright, A. and J. Chafota (eds.), *Lake Malawi/Niassa/Nyasa Ecoregion, Report on Donors and Partners Meeting*, Annex C, WWF Ecoregion Conservation Programme.

Calder, I.R., Hall, R.L., Bastable, H.G., Gunston, H.M., Shela, O., Chirwa, A., and Kafundu, R. 1995. "The impact of land use change on water resources in sub-Saharan Africa: a modeling study of Lake Malawi." *J. Hydrol*. 170: 123-135.

Carter, G.S., H.W. Haslam, and S.H. Smith. 1973. *Regional geochemical reconnaissance of Malawi*. Malawi Government Printer, Zomba.

Dobson, T.A., and K.D. Lynch. 2003. "As nearshore stocks drop, Malawi begins a return to local fisheries management." *J. Great Lakes Res*. 29 (Suppl. 2): 232-242.

Donda, S.J., and R. Bell. 1993. *Community Participation Consultancy Report, Vol. I*. Fisheries Department, Lilongwe, Malawi.

Duponchelle, F., A.J. Ribbink, A. Msukwa, J. Mafuka, and D. Mandere. 2000. "The potential influence of fluvial sediments on rock-dwelling fish communities." In: Duponchelle, F. and A.J. Ribbink (eds.), *Fish Ecology Report, Lake Malawi/Nyasa/Niassa Biodiversity Conservation Project*. SADC/GEF. pp. 111-132.

Eastman, J. R., and J. Toledano, 1996. "Forest Monitoring in Malawi Using Long Time Series Vegetation Data." *Earth Observation Magazine* 5(9): 28-31.

FAO. 1993. *Fisheries management in the WE arm of Lake Malawi, the Upper Shire River and Lake Malombe, with particular reference to the fisheries on Chambo (Oreochromis spp.)*. FAO, CIFA Technical Paper No. 21, Rome.

Hara, M. 2000. "Fisheries co-management; what and whose agenda." First WARFSA/SaterNet Symposium: Sustaniable Use of Water Resources, Maputo, 1-2 November 2000. http: //www.iwsd.co.zw/Papers%5CHara.pdf

Hecky, R.E., H.J. Kling, T.C. Johnson, H.A. Bootsma, and P. Wilkinson. 1999. "Algal and sedimentary evidence for recent changes in the water quality and limnology of Lake Malawi/ Nyasa." In: Bootsma, H.A., and R.E. Hecky (eds.), *Water Quality Report, Lake Malawi/Nyasa Biodiversity Conservation Project*, SADC/GEF. pp. 191-214.

Irvine, K., K. Martens, S.A. Mapila, J. Snoeks, G. Carvalho, E. Allison, G. Turner, A. Aggrey, and P.O.J. Bwathondi. 2002. *The trophic ecology of the demersal fish community of Lake Malawi/Niassa, Central Africa*. INCO-DC (International Cooperation with Developing Countries), Final Report to European Commission, Contract No. ERBIC18CT970195.

Johnson, T.C., and P. Ng'ang'a. 1990. "Reflections on a rift lake." Amer. Assoc. Petrol. Geol. Memoir 50. In: B.J. Katz (ed.), *Lacustrine Basin Exploration: Case Studies and Modern Analogs*, AAPG, Tulsa. pp. 113-135.

Kidd, C.H.R. 1983. *A water resources evaluation of Lake Malawi and the Shire River*. UNDP Project MLW/77/012, World Meteorological Organization, Geneva. 132 pp.

Kidd, K.A., W.L. Lockhart, P. Wilkinson, and D.C.G. Muir. 1999. "Metals, pesticides and other persistent contaminants in water, sediments and biota from Lake Malawi." In: Bootsma, H.A., and R.E. Hecky (eds.), *Water Quality Report, Lake Malawi/Nyasa Biodiversity Conservation Project*, SADC/GEF. pp. 243-276.

Langenberg, V.T., S. Nyamushahu, R. Roijackers, and A.A. Koelmans. 2003. "External nutrient sources for Lake Tanganyika." *J. Great Lakes Res*. 29 (Suppl. 2):169-180.

Lewis, D.S.C., and D. Tweddle. 1990. "The yield of usipa (*Engraulicypris sardella*) from the Nankumba Peninsula, Lake Malawi (1985-1986)." *Coll. Rep. Fish. Res. Malawi*: Occ. Pap. 1: 57-66, ODA, United Kingdom.

Milliman, J.D., and J.P.M. Syvitski. 1992. "Geomorphic/tectonic control of sediment discharge to the ocean: the importance of small mountainous rivers." *J. Geol*. 100: 525-544.

Msiska, O.V. 2001. "A review of the limnology of Malawi." In: Wetzel, R.G., and B. Gopal (eds.), *Limnology in Developing Countries 3*. Societas Internationalis Limnologiae. pp. 121-189.

Munthali, S.M. 1994. *Protected Areas and People: Sustaining Lake Malawi's Ecology*. Report to the Department of National Parks and Wildlife, Malawi. pp. 1-36.

NARMAP (National Aquatic Resource Management Program). 2001. Lake Malawi Fisheries Management Symposium. Lilongwe, 5th-9th June, 2001. Malawi Department of Fisheries, and GTZ (Deutsche Gessellschaft für Technische Zusammenarbeit.

Owen, R.B., R. Crossley, T.C. Johnson, D. Twedle, I. Kornfield, S. Davison, D.H. Eccles, and D.E. Engstrom. 1990. "Major low levels of Lake Malawi and their implications for speciation rates in cichlid fishes." *Proc. R. Soc. Lond*. 240: 519-553.

Phiri, P.M., R.K. Day, S. Chimatiro, M.P. Hill, M.J.W. Cock, M.G. Hill, and E. Nyando. 2001. "Progress with biological control of water hyacinth in Malawi." In: Julien, M.H., M.P. Hill, T.D. Center, and D. Jianqing (eds.), *Biological and Integrated Control of Water Hyacinth, Eichornia crassipes*, ACIAR Proceedings 102. pp. 47-52.

Ramlal, P.S., R.E. Hecky, H.A. Bootsma, S.L. Schiff, and M.J. Kingdon. 2003. "Sources and fluxes of organic carbon in Lake Malawi/Nyasa." *J. Great Lakes Res*. 29 (Suppl. 2): 107-120.

Ribbink, A.J., B.A. Marsh, A.C. Marsh, A.C. Ribbink, and B.J. Sharp. 1983. "A preliminary survey of the cichlid fishes of rocky habitats in Lake Malawi." *S. Afr. J. Zool*. 18: 147-310.

Seehausen, O., J.J.M. Van Alphen, and F. Witte. 1997. "Cichlid fish diversity threatened by eutrophication that curbs sexual selection." *Science* 277: 1808-1811.

Sipawe, R.D., W. Namoto, and O.C. Mponda. 2001. "Analysis of catch and effort data for the fisheries of Nkhotakota 1976-1999." *Fisheries Bulletin* No. 50, Department of Fisheries, Lilongwe.

Turner, G. "Fishing and the conservation of endemic fishes of Lake Malawi." *Archiv fur Hydrobiologie* 44: 481-494.

Turner, G. 1995. "Management, conservation and species changes of exploited fish stocks in Lake Malawi." In: Pitcher, T.J., and P.J.B. Hart (eds.), *The impact of Species Changes in African lakes*, Chapman & Hall, London. pp. 365-396.

Turner, G.F., D. Tweddle, and R.D. Makwinja. 1995. "Changes in demersal cichlid communities as a result of trawling in southern Lake Malawi." In: Pitcher, T.J., and P.J.B. Hart (eds.), *The Impact of Species Changes in African lakes*. Chapman and Hall. pp. 397-412.

Tweddle, D., and J.H. Magasa. 1989. "Assessment of multispecies cichlid fisheries of the Southeast Arm of Lake Malawi, Africa." *J. cons. Int. Explor. Mer*. 45: 209-222.

Vollmer, M.K. 2002. *Studies of deep-water renewal in Lakes Malawi/Nyasa and Issyk-Kul using sulfur hexafluoride and chlorofluorocarbons as time-dependent tracers*. Ph.D. Thesis, University of California, San Diego.

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